Validation of simulated dynamic behavior of sprayer boom in Solidworks through actual field experiments

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Abstract: Dynamic behavior of agricultural implements has always been a challenging topic for researchers. In precision farming, precise control of the agricultural implements is a very important task. To study the dynamics of agricultural implements, Researchers conduct field experiments as well as laboratory tests. These methods are very costly and the measurements are usually associated with some errors. Providing well-controlled experimental conditions in practice is very difficult, if not impossible. In this article, the capability of the SolidWorks in simulation and predicting the dynamic behavior of a conventional sprayer boom is discussed. To validate the results, field tests were conducted using a conventional sprayer boom. The results showed that there was no significant difference at 95% confidence level between results from computer simulation and those obtained from the field test of conventional sprayer boom.

Keywords: simulation, boom sprayers, solidworks, dynamic behavior

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1 Introduction

Precision agriculture today is practiced by many farmers in developed countries. Ever increasing shortages of resources and environmental issues highlight the need for extending precision farming techniques to more areas of the agricultural industry. Researchers are struggling to improve agricultural efficiency by fixing problems with agricultural machinery. One of the agricultural operations that causes the highest costs and environmental pollution is spraying pesticides by either tractor mounted or self-propelled sprayers.

Experiments show that the boom vibrations have a significant effect on the spray pattern, so reducing the vibrations of sprayer's boom is necessary to solve the problem of non-uniformity in the pattern of chemicals spray(O'Sullivan, 1986). The movement of the sprayer is the main source of variation in the spray pattern(Iyer and Wills, 1978).

Damping the vibrations of the boom when crossing the dips and bumps have always been a serious challenge faced by researchers involved with precision spraying. Therefore, the study of the dynamic behavior of spray booms has received the most emphasis by scientists and researchers and helped them to design more effective damping systems for maintaining the desired uniformity of spray pattern. Researchers have introduced various methods for studying the dynamic behavior of the spray booms either in a laboratory or in a field. All of the method used, have their own advantages and disadvantages.

One of the first spray boom suspension systems was built by Nation (1980) that had twin universal links. He measured the boom vibration through accelerometer mounted at the right end of the boom and found that variations in spray deposit are proportional to the amount of boom movement(Nation, 1982).

Sinfort et al. (1994) used an electrohydraulic

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simulator to test sprayer under controlled, laboratory conditions. They concluded that boom dynamics may increase the spray deposit coefficient of variation (CV), by 44%. Sinfort and Herbst (1996) examined a boom motion and spray pattern evaluation under practical conditions. Spray boom motions were investigated on a motion simulator equipped with seven hydraulic servo jacks which used hydraulic power to simulate the vibrations caused by the boom's movement in the field. In their studies, they found that the chemicals distribution quality, in addition to the environmental conditions and the static factors of the boom structure, depended on the dynamic factors including the boom motion. They did report the accuracy of their method compared to the field test method.

Lebeau and Destain (1998) conducted the field test using a LIDAR (light detection and ranging) system to measure the spray boom movements. In their proposed method, the sensor was mounted on the boom, having its beam directed towards a special reflective target fixed rigidly at the front of the tractor and oriented perpendicular to the light beam. The main drawback of this method was the positioning of the target. To overcome the limitations of the accelerometer method, a semi-automated method was used by Sinfort et al. (1998) to monitor boom motions. A video camera positioned at the headland recorded the tip movements of the boom traveling along a test-track. They concluded that online implementation of this method would not be feasible.

Unsteady boom movement has been recognized as a potential limitation to the precision application. Pochi and Vannucci (2001) designed a low-cost laboratory boom movement measurement system and compared it with the reference system. A potentiometer and angular transducer were used to sense vertical and longitudinal boom movements respectively. Results indicated that a difference of less than 10 mm exists between the low-cost system and the reference system.

Engelen et al. (2006) constructed a finite element model representing the dynamic behavior of a spray boom. In their model, they used the experimental vibration data obtained from field measurements.

Herbst et al. (2015) successfully developed a test bench to evaluate the performance of boom height control system on the stationary sprayer.

Laboratory, as well as field experiments, are both costly. To avoid these costs, computer simulation can be considered as an alternative method. Finding the right software for simulation of dynamic systems is not always an easy task. Therefore, validation of the software for simulation is an essential step in choosing appropriate software. The purpose of this article is to investigate the capability of the SolidWorks software in simulating the dynamic behaviors of a spray boom.

2 Materials and methods

SolidWorks 2017 was used for simulation. It enables the user to study the effects of external loads on structures and mechanisms such as stress, displacement, natural frequency, etc. through finite element analysis (FEA). It also provides motion analysis, which is used for accurate simulation and analysis of moving assemblies (effects of forces, springs, dampers, and friction)(Glodov, 2014). It is important to point out that utilization of this program leads to results which are precise and accurate in the case of the numerical solution of the equations in the whole magnitude referring to the motion of mechanism while the given results are obtained in the graphic form(Vavro et al., 2017). Based on Langenakens et al. (1999) experiment to validate the results of the simulation, a field test was conducted with a conventional 8 meters' sprayer boom. Tests were carried out according to manufacturer's instructions at three speed levels of 3 (low), 5 (medium) and 8 km h^{-1} (high), with three bumps heights of 10, 15 and 20 centimeters (Figure 1) with three replications.

Similar experiments were carried out in the SOLIDWORK environment with the same variables. For this purpose, a similar sprayer with the existing field sprayer was designed in SolidWorks software that its specification was exactly the same in terms of dimensions and mass (Figure 2).

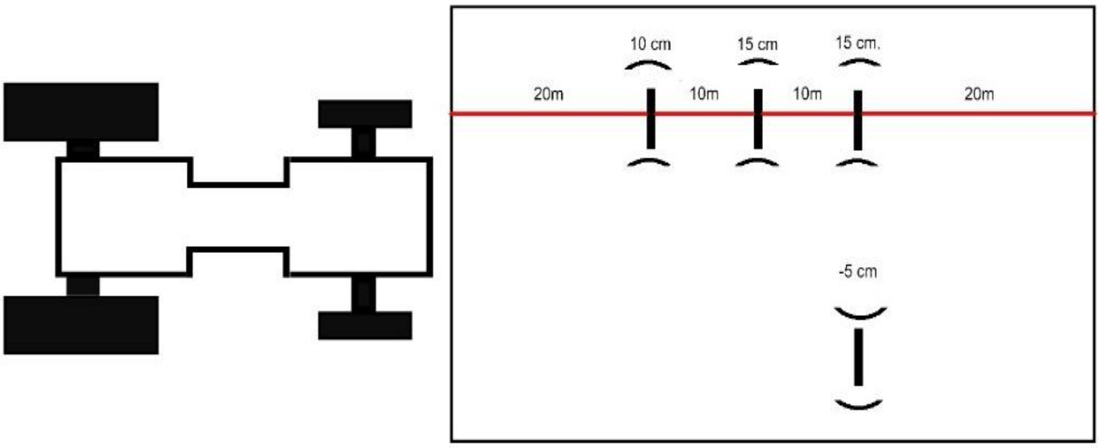

Figure 1 Layout of experiments based on Langenakens's tests

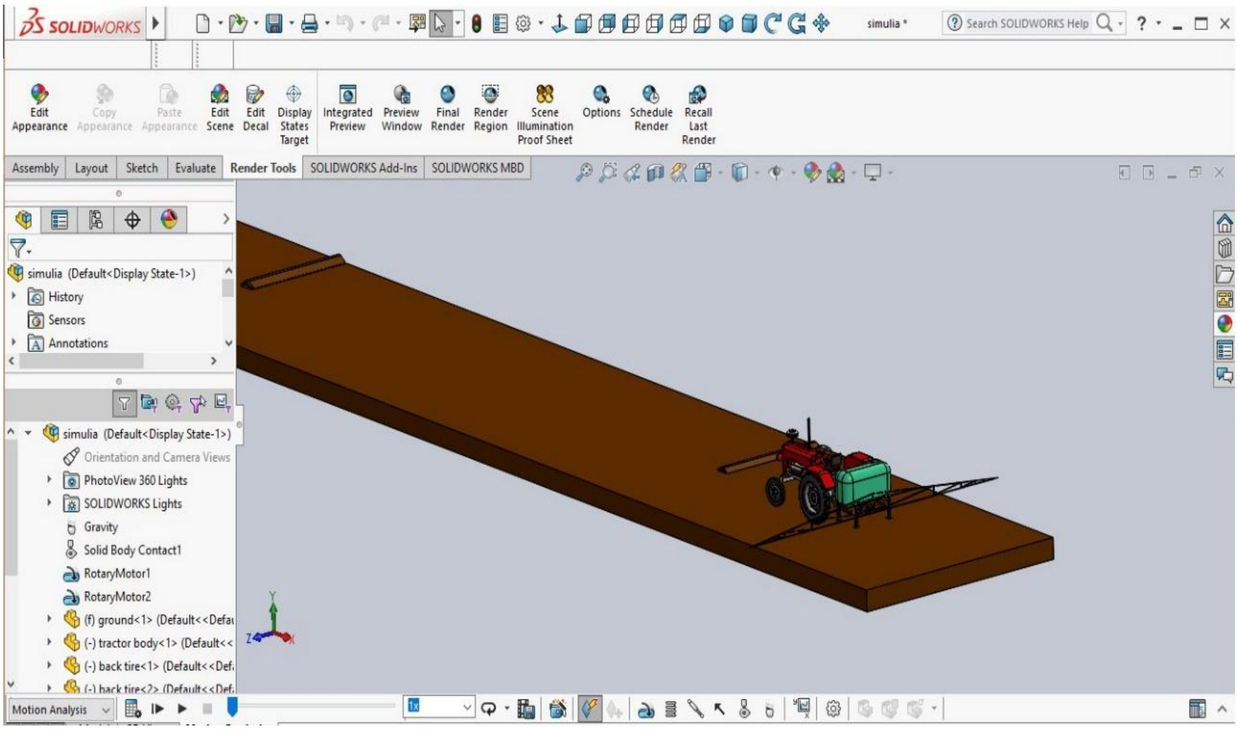

Figure 2 Simulation for tractor mounted sprayer in the SOLISWORKS software environment

For acquisition of vertical acceleration as well as axial rotation data in the conventional sprayer, data logger with accelerometer and gyroscope was used. The data logging rate and the accuracy of the accelerometer and gyroscope measurement were set to 50 Hz, 0.1 m s^{-2} and 0.1°, respectively. In simulated sprayer, Result's and Plot tools were used for data extraction in the SOLIDWORKS environment.

Table 1 indicates the maximum vertical acceleration in meters per second squared for actual and simulated sprayers.

3 Results and discussion

Figure 3 depicts the distribution of acceleration data for an actual and simulated sprayer at different speeds and bump heights with three replications.

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Table 1 Maximum vertical acceleration (m s^{-2}) for the actual and simulated sprayers at different speeds and bump heights

speed	low			medium			high		
Bump heights (cm)	10	15	20	10	15	20	10	15	20
Actual sprayer	6.28	4.90	7.50	5.71	7.24	8.51	6.59	7.36	6.36
Simulated sprayer	5.39	4.93	7.76	5.51	7.93	7.98	7.05	7.48	8.13

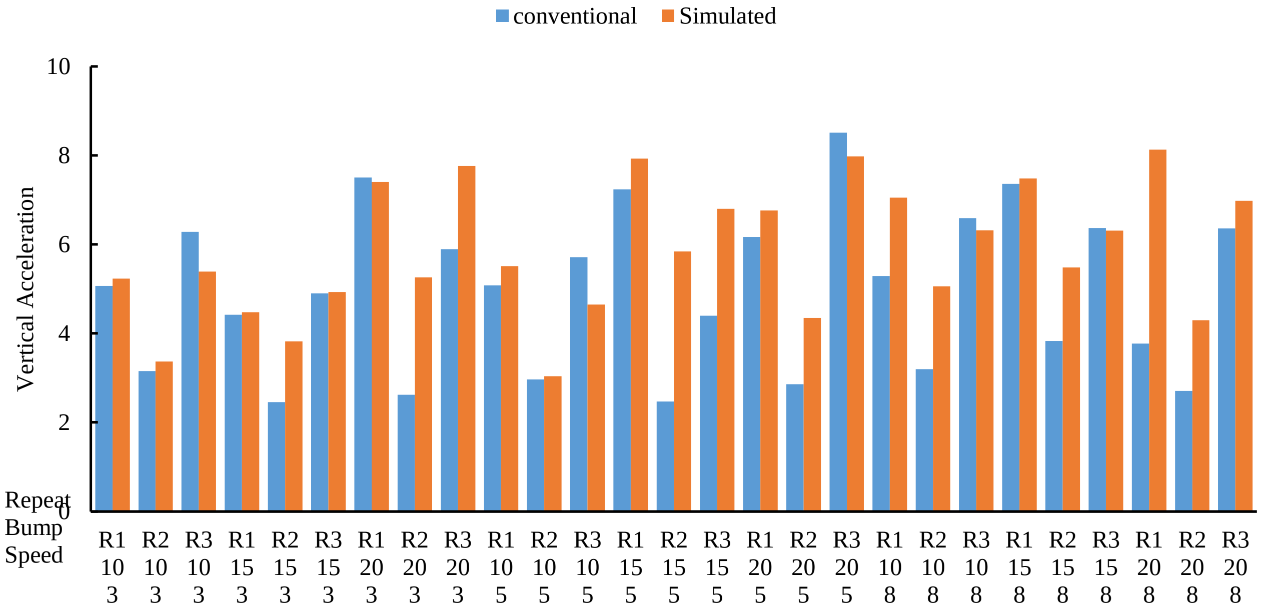

Figure 3 Vertical acceleration in ms^{-1} for actual and simulated sprayers at different speeds and bump heights with three replications

To compare the behavior of the actual and the simulated spray booms in terms of vibrations, the multivariate analysis was used. As shown in Table 2, there was no significant difference between the performances of two sprayers at 10% probability level.

Table 2 Multivariate analysis of variance on vibration levels of the sprayers

Dependent Variable: data

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	23.079[a]	5	4.616	1.746	0.142
Intercept	1566.120	1	1566.120	592.386	0.000
sprayer	11.034	1	11.034	4.174	0.047
speed	4.586	2	2.293	0.867	0.427
bump	7.458	2	3.729	1.411	0.254
Error	126.900	48	2.644		
Total	1716.098	54			
Corrected Total	149.979	53			

Note: a. R Squared = 0.154 (Adjusted R Squared = 0.066)

But there was a significant difference between the behaviors of two sprayers at 5% probability level with the Sig. number of 0.047. Also, there was no significant difference between results obtained for different speeds and bumps. One of the main reasons that caused the difference at the probability level of 5% between actual and simulated sprayers was that the simulated uniformity and homogeneity of the path of movement with the software were not the same as actual field conditions. Also, the actual tractor's tires pressure, as well as their mechanical behavior, can have a significant impact on the results. To obtain the best results from the simulation, the stiffness values for tractor's rear and front tires were set on 200 and 300 kN m^{-1} respectively, and the penetration value was set on 0.01 cm. Sharon (1975) showed that inflation pressure and tire volume (size) greatly affect the stiffness of agricultural tires. Stiffness increases almost linearly with inflation pressure. Typical values for stiffness are 250 kN m^{-1} and 450 kN m^{-1} at inflation pressures of 80 Kilopascal and 200 Kilopascal, respectively. Within the normal range of tire loads, driving speeds, ply ratings, rim widths, and lug heights characteristics influence tire stiffness only slightly. Despite the great dependence on inflation pressure, tire stiffness can vary widely, because many other parameters are active. At an inflation pressure of 100 Kilopascal, the stiffness values for tractor’s rear tires can range from 200 to 300 kN m^{-1}

Table 3 shows the Maximum axial rotation for the actual and simulated sprayer. Figure 4 illustrates the distribution of axial rotation data for an actual and

These differences are mainly the result of tire volume (size).

simulated sprayer at different speeds and bump heights with three replications.

Table 3 Maximum Axial rotation for the actual and simulated sprayers at different speeds and bump heights

speed	low			medium			high		
Bump heights (cm)	10	15	20	10	15	20	10	15	20
Actual sprayer	4.19	4.70	8.81	3.22	4.34	9.87	4.61	6.47	9.48
Simulated sprayer	3.16	5.11	9.68	3.61	5.29	9.82	3.19	5.44	9.47

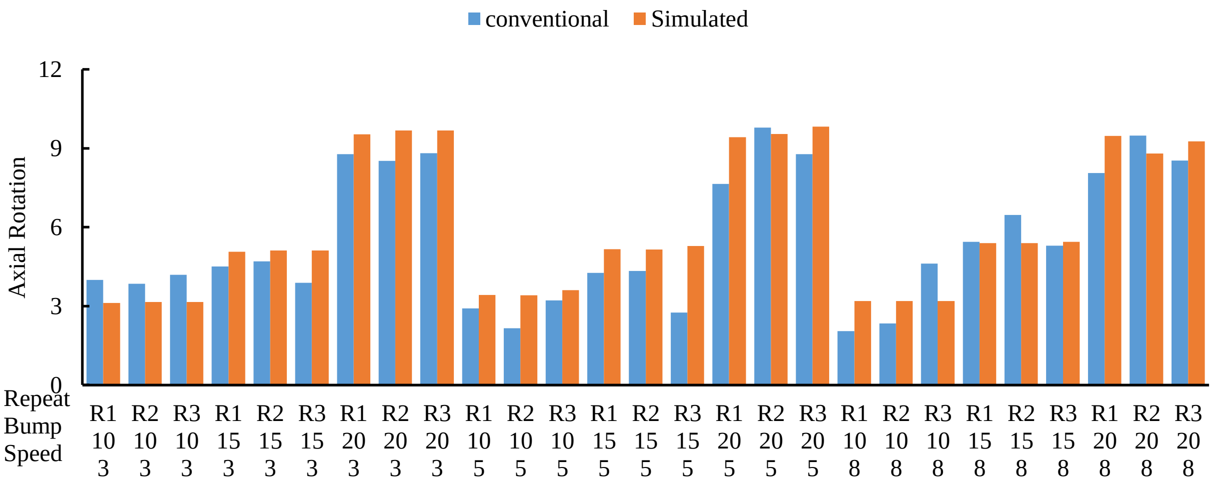

Figure 4 Axial rotation in degree for actual and simulated sprayers at different speeds and bump heights with three replications

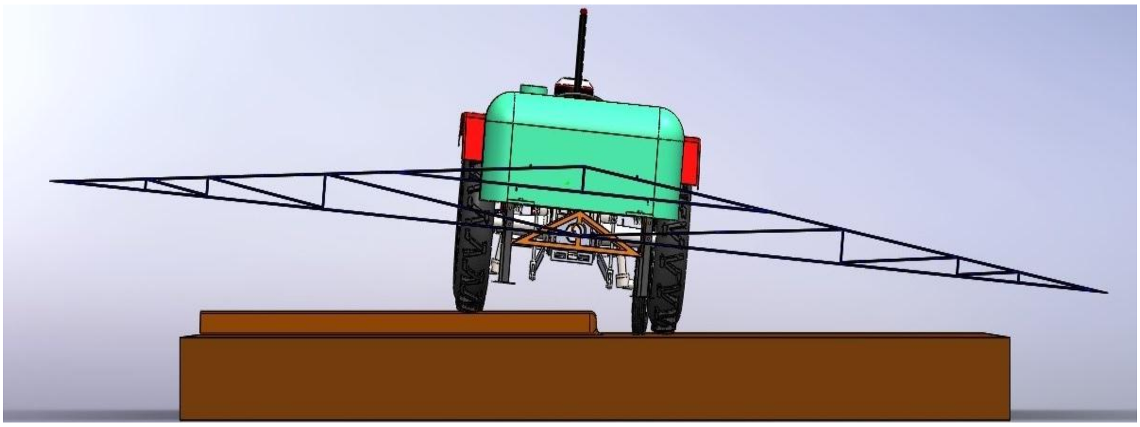

Figure 5 Simulated sprayer behavior on 15 cm height bump

Figure 6 actual sprayer behavior on 15 cm height bump

Figure 5 and Figure 6 show the movement of the actual and simulated sprayer on a 15 cm bump.

To compare the behavior of the actual and the simulated spray booms in terms of axial rotation, the univariate analysis was used. As shown in Table 4, there was no significant difference between the performances of two sprayers at 5% probability level with the Sig. number of 0.516.

Table 4 Univariate analysis of variance on axial rotation of the sprayers

Dependent Variable: data					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2.843[a]	1	2.843	0.428	0.516
Intercept	1792.166	1	1792.166	269.714	0.000
sprayer	2.843	1	2.843	0.428	0.516
Error	345.524	52	6.645		
Total	2140.533	54			
Corrected Total	348.367	53			

Note: a. R Squared = 0.008 (Adjusted R Squared = -0.011)

4 Conclusion

According to the results obtained from the simulation and field experiments, it can be concluded the simulation results from the SolidWorks can be used to study the dynamic behavior of the sprayers with a fairly good accuracy and costly laboratory as well as field experiments can be avoided.

There was a significant difference between the vertical accelerations of the actual and simulated sprayers at 5% probability level, but given the fact that the Sig. value was very close to 0.05, and the difference was not significant at the 10% probability level. Therefore, simulation results can be accepted with a good approximation for the vibration levels. And also for the axial rotation, because of no significant difference at the 5% probability level, the results of the SolidWorks can be accepted strongly.

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