Comparison of Boom Design Parameters of Three Different Tractor Mounted Domestically Manufactured Field Crop Sprayer Booms

Medet İTMEÇ, Ali BAYAT

Cukurova University, The Faculty of Agriculture, Department of Agricultural Machinery and Technologies
Engineering, Adana
Corresponding author: mitmec@cu.edu.tr

Abstract: In spraying operations, design of boom and material used on the boom are very important for spray distributions and boom life. Especially during the spraying operation, vibrations of the spray-boom movement of field crop sprayers affect liquid distribution in a negative way. Rigidity of the sprayer boom construction is a must, to restrain the vibrations. Beside the rigidity, construction materials are desired to be ductile and not to permit sudden failure. In this study, three domestically manufactured tractor mounted sprayer booms which have same boom widths but different weights and designs, were evaluated in view of Design for Manufacturing and Assembly (DFMA) which are used to minimize product cost through design and process improvements. Welded parts (weld beads), machined parts, were counted. According to labor cost and raw material data, steel construction expenditure of all these sprayers were compared with each other. To do these, all of these tractor mounted sprayers were drawn and assembled in Autodesk Inventor Professional 2017 Educational. According to these booms weight and construction design, strength of these tractor mounted sprayers were also compared by the aid of Autodesk Inventor Static Analysis Module under 900N load. At the end of the study static analysis results of this tractor mounted-sprayers were monitored. Based on the results of static stresses, design evaluation and suggestions are also made at the end of results for decreasing labor cost, used raw materials etc.

Key words: Sprayer boom design, static analysis module of Autodesk Inventor, manufacturing
costs

Traktöre Monte Edilen Yerli Yapım, Üç Farklı Tarla Pülverizatörünün Kollarının Tasarım Parametrelerinin Karşılaştırılması

Özet: İlaçlama operasyonlarında;ilaçlama kanadının tasarımı ve kullanılan malzeme, ilaç dağılımı ile kol ömrü açısından çok önemlidir. Özellikle ilaçlama operasyonlarındaki ilaçlama kanadının tarla içerisindeki titreşimleri sıvı dağılımını olumsuz şekilde etkilemektedir. İlaçlama operasyonu esnasında,titreşimleri dizginleyebilmek için ilaçlama kanadının konstrüksiyonunun rijitliği bir gerekliliktir. Rijitliğin yanı sıra, konstrüksiyonun malzemelerinin sünek ve ani kopmalara müsade etmemesi arzu edilir. Bu çalışmada üç adet yerli yapım traktöre monte edilen aynı ilaçlama kolu genişliğine sahip ancak farklı ağırlık ve tasarımlardaki pülverizatörler; amacı imalat maliyetlerini düşürmek ve proses iyileştirmesi olan İmalat ve Montaj için Tasarım (DFMA) bakış açısıyla değerlendirilmiştir. Kaynak adetleri, işlenmiş parça adetleri sayılmıştır. İşçilik ve hammade maliyetlerine, çelik konstrüksiyon maliyetlerine göre bu üç pülverizatör karşılaştırılmıştır. Üç adet traktöre monte edilen pülverizatör Autodesk Inventor Professional 2017 Educational programında çizilmiş ve montaj edilmiştir. İlaçlama kolu konstrüksiyon tasarımına ve ağırlığına göre traktöre monte edilen bu üç adet tarla pülverizatörünün mukavimliği Autodesk Inventor Static Analysis Module sayesinde 900 N yük altında karşılaştırılmıştır. Çalışmanın sonucunda statik analizin sonuçları paylaşılmıştır. Bu analiz sonuçlarına göre işçilik maliyetleri kullanılan hammade vb. açısından tasarım değerlendirmesi önerileri yapılmıştır.

Anahtar kelimeler: İlaçlama kolu tasarımı, Autodesk Inventor'ün static analiz modülü, imalat
maliyetleri

INTRODUCTION

A standard field crop sprayer consists of a liquid tank, pump, pressure control unit, distribution valves, chassis, boom, spray nozzles, filters and many hoses. Of course, each of these components is important in

spraying operations. For example, the nozzles are perhaps the cheapest parts on the sprayer, but they do have a big impact on the effectiveness of the pesticide. On the other hand, when spraying in the field, the boom is always expected parallel to remain on the field surface and to work without vibration. A well-designed boom must not incline in the open position relative to the point of attachment to the chassis. Otherwise, the nozzles in the end of the boom become closer to the field surface and as a result, the wetting area of the nozzles in that area narrows and the nozzle spray patterns do not overlap, resulting in unsprayed spaces. Since agricultural enterprises in Turkey have an average of 5-6 hectares of arable land, tractor mounted type sprayers with a tank capacity of 400-600 liters are generally preferred in pesticide applications. This type of sprayers is usually manufactured domestically and the sales competitiveness of the manufacturers is at a low price. Because of this, the boom, which has a significant share in manufacturing cost, is not manufactured in conformity with standards and in construction. Generally, several models of boom are produced by copying between manufacturers. There are 338.625 pto driven sprayers which are used in 2016 according to the Turkish Statistical Institute (TUİK) in Turkey. Of course, not all of them are mounted type sprayers, but it can be said that a significant part is mounted type field sprayers.

By the aid of the developing technologies, in pesticide application, which is one of the most important parameters of the agricultural production, is started to carry out pesticides to the targets. Especially; proper nozzle selection, pesticides with low surface tension, using of air assisted spraying etc. helps the pesticide to meet with plant successfully (Bayat 2006). By means of these developments, precision in pesticide application is increased, not effectively used pesticides are started to decreased. As are worldwide, developments in Turkey also start. However, applying these new technologies to the sprayers increases the production costs. and eventually the expensive agricultural sprayers. leaves the farmers in the lurch. Designs of tractor-mounted sprayers are different from each other's, therefore investment costs and economic life also differs.

In Turkey, when we looked at the sprayer market, most of designs and manufacturing of tractor–mounted field sprayer booms are not done by using engineering calculations and standards. These field sprayer booms are cheap but reliability and economic life of these sprayers are not good enough. Especially when working in the field conditions, because of the vibrations field sprayer booms' arms can be broken from weld core regions. In this situation pesticide application is delayed depending upon the maintenance. Studies show that whether well designed tractor-mounted field crop sprayer booms work in 5-11 km/h range, field sprayers also have 1500 hours estimated life. Because of the seasonal nature of farm work, farm machinery is used during relatively short periods of the year. With growth in average farm size machines of high capacity are required to accomplish their task during these short periods (Srivastava, 2006). Nations (1982) states, for better stability booms should be constructed as stiff beams and attached through suspensions which isolate them as much as possible from the rolling motions. In the same study of Nations, experiments showed that measured vertical movement of boom tips with 2,4 m/s tractor velocity, with full tank was approximately 0,25 m. It also effects spray pattern and overlap. The vertical tip movement of a vibrating boom has been related to distribution and it has been shown that relative horizontal movement or whip can also have an appreciable effect on the uniformity of the spray distribution pattern (Mahalinga, 1978). Homogenous spray distribution in field crop protection is required to achieve an optimal treatment efficiency. Many technical developments on crop sprayers are designed to improve the spray coverage homogeneity: pressure regulation based on forward speed, boom suspension, automatic slope correction, low drift nozzles, air assistance etc. (Lebeau, 2002) Unwanted horizontal and vertical movements of the sprayer boom, caused by soil unevenness, create local under- and over-doses of spray liquid, which results in spots where the desired effect is not obtained and spots where chemical residues remain in the crop and the soil. Owing to vertical translations and rolling of the boom, the distance between the nozzles and the ground is different from the desired (or optimal) distance. The overlap of the spray cones of the

nozzles is disturbed and a redistribution of the spray liquid along the boom takes place. (Kennes, 1998)

According to Nation (1982) for a better boom performance:

(i) A boom should be a single stiff structure with tight joints and positive location in the break back mechanism;

(ii) The use of wire or chains for supporting extended parts should be avoided and

(iii) A form of flexibility should be provided between the sprayer and boom which will reduce the transmission to the boom of the rapid Rolling movements of the sprayer.

Today, to catch best designs, engineering calculations are applied with a method called Finite Element Analysis (FEA). The finite element analysis is fast becoming the most engineering design tool. All major farm equipment manufacturers make finite element programs available to their engineers. (Krutz, 1984). In design and manufacturing steps beside FEA high quality workmanship is also very important. FEA evaluate only the problem physically, and it senses as if there were no defects on raw material and no workmanship fault. Because of manufacturing defects part can failure suddenly, at that time predicting the failure is not easy. Therefore, manufacturing is also as important as design.

In this study, three domestically manufactured tractor mounted sprayer booms which have same boom widths but different weights and designs, were drawn in Autodesk İnventor Professional 2017 Educational and these sprayer booms were evaluated in view of Design for Manufacturing and Assembly

(DFMA) which are used to minimize product cost through design and process improvements. Welded parts (weld beads), machined parts, fasteners, assembly processes were counted. According to labor cost and raw material data, steel construction expenditure of all these sprayers were compared with each other.

MATERIALS and METHODS

In this research, three traditionally manufactured tractor mounted sprayers which have a nominal tank capacity of 400l were used and sprayers/booms were named as A_1, A_2, A_3. All the sprayers were assembled and manufactured by individual companies. These field sprayers were drawn one by one; each part of the sprayer booms were detailed according to their manufacturing process. In Table 1, some design and calculated parameters of sprayer used are given.

These data are taken into account when discussing the results. Assembling the parts were carried out with weld beads and fasteners which were called from Autodesk Inventor Library as Standards. booms steel constructions were evaluated by Autodesk Inventor Professional 2017 Static Analysis Module. To use this computer program, first of all, the Static Analysis, surface match was chosen as automatic, fixed point are selected as height adjustment parts which were connected to tank constructions. In FEA, the assemblies of constructions were covered with meshes and matrices were existed. These meshes were used to analysis of stress and calculated by the Autodesk Inventor Professional 2017. In Static Analysis there is color scale which is reference to the stress that exists on construction.

Table1. Some design and calculated parameters of sprayers used in the research

Sprayers	Boom Weight [3] (kg)	Sprayer Weight [*] (kg)	Boom Width (m)	Boom Material Sizes (mm)	Boom Material	Number of Boom Sections	Ratio (BW[3]/SW[*])	Boom Hook System to Base Chasis
A_1	38.956	120	7,5	a, b, c	St 37	2	0.32	bolted
A_2	34.618	140	7,5	a, b	St 37	3	0.25	bolted
A_3	52.168	190	7,5	b, d, e	St 37	3	0.27	Bolted plus lanyard

a:25*25*2 mm square profile mild steel

b:40*40*2.5 mm rectangular profile steel mild steel

c:6*20 mm rectangular sheet metal mild steel

d:60*40*3 mm rectangular profile steel mild steel

e:80*60*3 mm rectangular profile steel mild steel

*BW/SW: Boom weight to Sprayer Weight (dimensionless)

In stress analysis color scales red to blue. Red color means stresses maximum; blue color shows the minimum stresses. Of course these sprayer booms do not carry heavy loads, aim of these booms only carrying the nozzles. and own weights. But in field dynamically unexpected loads can be applied on these booms. For this reason, testing the resistances of booms against to the loads is very important. To show stress difference and to become clear stress difference on color scale, 900 N force and constructions' gravity forces was applied on all field sprayer boom. Thus resistance of all sprayer booms were evaluated with sameload.900 N load of each field sprayers were distributed as 250 N per arms and 400 N for main boom. According to the Von Mises Theory, Autodesk Inventor Professional 2017 calculated the stress over the constructions. So as a failure criterion, whether Von Mises stress induced in the material exceeds yield strength (for ductile material) of the material.

For all field sprayer booms displacements were calculated as cantilever beam with external moment and force. When deflections were calculated, color scales red to blue. Red color means maximum deflections blue color shows the minimum deflections.

Counted manufacturing data such as number of weld beads and machined parts are given in Table 2. These data were helpful for DFMA. According to these data expenditure of constructions was calculated. In view of Design for Manufacturing and Assembly (DFMA) costs of field sprayers were also compared with each other. As shown in Table 2, boom A_3 had less weld beads and machine parts on it than the boom A_1 and A_2.

**Table 2. Manufacturing data of three different tractor mounted sprayers**

Properties	Sprayers		
	A_1	A_2	A_3
Weld Beads	112	88	54
Machined Parts(laser cut,sheet metal bending, turning, etc.)	42	52	29

To compare manufacturing cost of all three booms, an average costs which were taken from local manufactures of Adana city of Turkey. were used. In the region steel construction machining costs were 1.7 $/kg and raw material costs were nearly 0.6 $/kg.
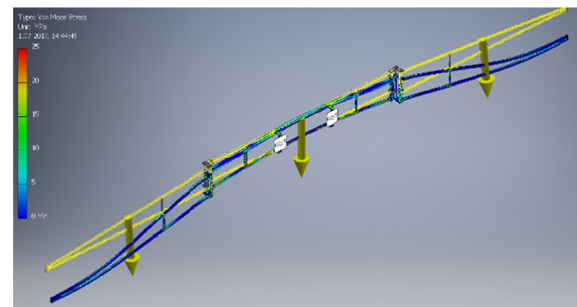
RESULTS and DISCUSSIONS
Resistance Comparisons

A_1 field sprayer boom was drawn as shown in Figure 1, 900N load with field sprayer booms' weight was applied Figure 2. In Figure 3 Maximum stress in construction was 69 MPa. As shown Figure 4 in maximum deflection was 4.68 mm.
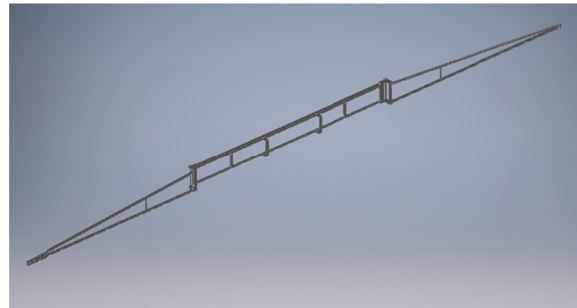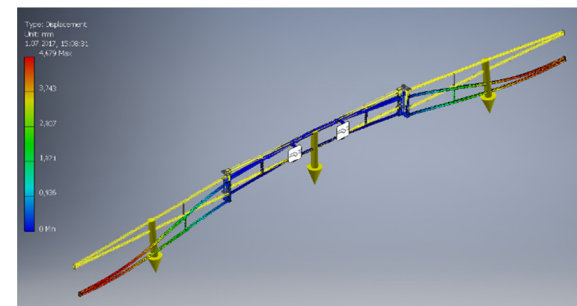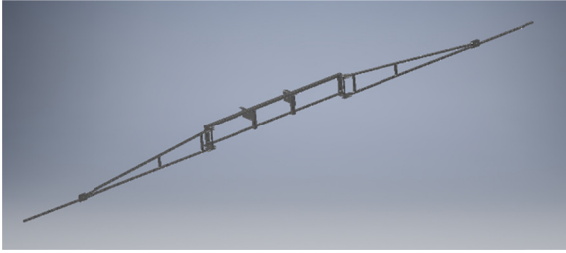

Figure 1. A_1 field sprayer boom construction

Figure 2. Behavior of A_1 field sprayer boom under 900N
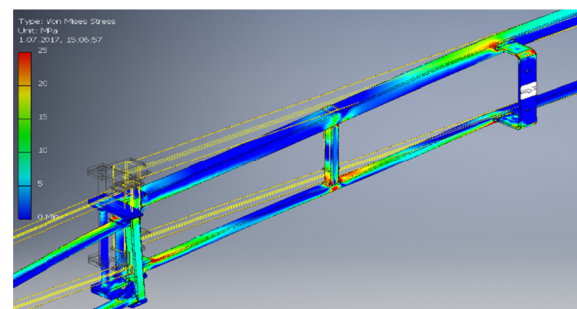
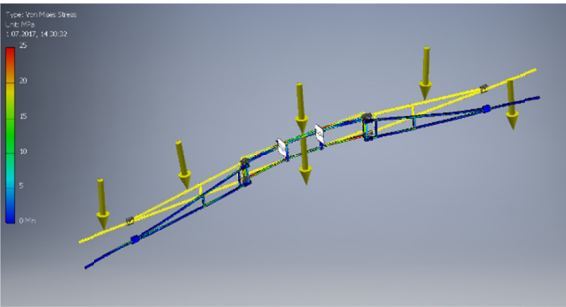**Figure 3. Critical regions of A_1 field sprayer booms**

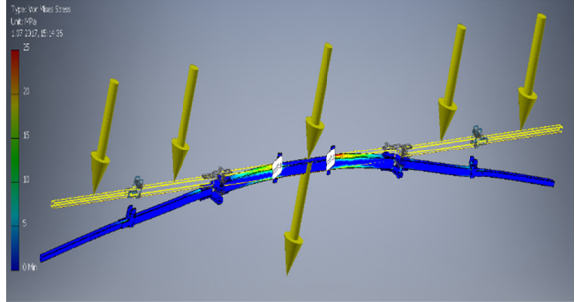**Figure 4. Deflection of A_1 field sprayer boom under 900 N**

Figure 5. A₂ field sprayer boom construction
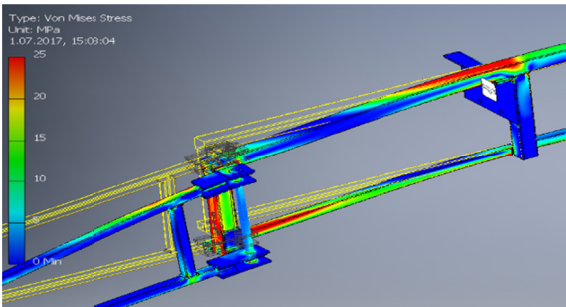

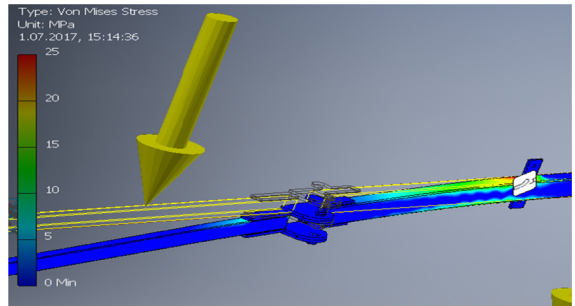
Figure 6. Behavior of A₂ field sprayer boom under 900N

Figure 5, 900N load with field sprayer booms' weight was applied in Figure 6. In Figure 7 stresses can be seen better. Maximum stress in construction was 82 MPa .Furthermore as shown Figure 8 in maximum deflection was 6.59 mm.
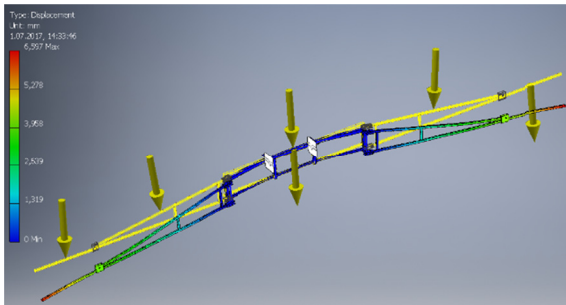

Figure 7. Critical regions of A₂ field sprayer booms

Figure 8. Deflection of A₂ field sprayer boom under 900 N

Figure 9. A₃ field sprayer boom construction

Figure 10. Behavior of A₃ field sprayer boom under 900N

A₃ field sprayer boom was drawn as shown in Figure 9, 900N load with field sprayer booms' weight was applied Figure 10. In Figure 11 Maximum stress in construction was 31.6 MPa. Furthermore as shown Figure 12 max. deflection was 5.39 mm.
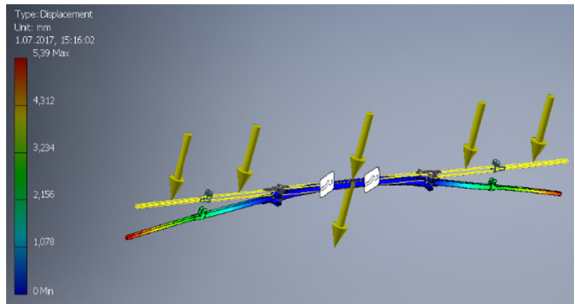

Figure 11. Critical regions of A₃ field sprayer booms

Figure 12. Deflection of A₂ field sprayer boom under 900N

As shown in results minimum stresses were occurred at A_3 Field sprayer booms. But at A_1 field sprayer boom's construction had minimum deflection.

Boom Manufacturing Cost Comparisons

Assuming raw material costs as 0.6 \$/kg and manufacturing costs as 1.7 \$/kg, each boom cost was calculated and given in Table 3. Firstly, according to results data in Table 3, boom A_1 was lightest field sprayer totally. It has two boom sections which was important for easily manufacturing, there is no extra boom hook system such as a lanyard, self-carrying system, and ratio of BW/SW was largest. For manufacturing boom A_1 there were three different profile types. Unused and scrap material of each profiles increases manufacturing costs.

Table 3. Manufacturing costs of each field sprayers according to datas

Properties	A_1	A_2	A_3
Weight (kg)	38.96	34.62	52.17
Number of Weld Beads	112	88	54
Number of Machined Parts (laser cutting, bending sheet metal, turning, profile cutting)	42	52	29
Expenditure of steel constructions \$/kg	7.32	7.48	3.30

Number of profiles must be less for easily manufacturing and assembling. Number of weld beads were also highest and number of machined parts were medium. There were too many assembly positions. Therefore, to manufacture the boom A_1, for better product and weld quality fixtures are needed to fix steel construction because of too many weld beads. Manufacturing the fixtures are also costs, to decrease assemble costs fixtures must be minimum as possible. At first sight, it seemed as easily manufactured and assembled however number of welds and machined parts and profiles too much. In this design both manufacturing and assembly costs are high for per kilograms. Maximum stress under 900 N static load was 69 MPa at weld core region and deflection was 4,68mm as the smallest. Of course less deflection means better sprayer pattern but at elevated stresses.

Boom A_2 was lightest in boom weight, it has three boom sections. When boom section increases, manufacturing will be more complex than before. There is no boom hook system self-carrying system and BW/SW is lowest which means tank carrying structure is unnecessarily heavy, according to other constructions but lightest boom weight is an advantage. In this design two different types profiles were used for decreasing scrap and unused materials. This parameter is desired to decrease manufacturing costs. Number of weld beads were average but number of machined parts were largest. Increasing machined parts also increases manufacturing costs. In this design both manufacturing and assembly costs are highest for per kilograms because of machined parts.

Maximum stress under 900 N static load was 82 MPa as highest at weld core region and deflection was 6,59 mm as highest. When deflection increases sprayer pattern disrupts. As can be seen 82 MPa means low resistance to forces.

Lastly, boom A_3 was heaviest in both totally boom and field sprayer. It has three boom sections. When boom section increases manufacturing will be more complex than before. Boom hook system as lanyard. .BW/SW is average but total weight and boom weights are heavy. In this design 3 heavy profiles have been used, Unused and scrap material of each profiles increases manufacturing costs. Number of profiles must be less for easily manufacturing and assembling. Number of welds and machined parts were least and plain. This means easily manufacturing and assembly. As can be seen in Table 3. Expenditure of steel construction is minimum. Maximum stress under 900 N static load was 31,6 MPa and lowest at weld core region and deflection was 5,39 mm as modest. By the aid of the positive contribution of lanyard, deflection effect disappears As can be seen 31,6 MPa means high resistance to forces.

CONCLUSION

According to the results obtained the following findings can be drawn:

(1) A boom must be light both in chassis and boom. As possible, number of boom section must be least. It must carry both dynamic loads and own weights. Kind of profiles which are used for manufacturing the booms must be least as possible. Also weld beads, machined parts must

be least as possible. When weld beads and machined parts increased both manufacturing costs increased also workmanship mistakes.

(2) When these three field sprayers are evaluated in DFMA and Static Analysis, boom A_3 is obtained as best design of all these parameters beside it's weight and deflection. By the aid of cable (lanyard)that used, deflection can be better.

(3) For reliable, durable and cheap field sprayer boom there is no need complexity. Simplicity of a field sprayer boom provides ease of assembly and manufacturing. Simplicity of field sprayer boom decreases manufacturing costs it also increases economic life of field sprayer boom.

REFERENCES

Bayat, A., Öztekin, S., Bereket Barut Z., Bozdoğan, A., Özcan, T.M., Güzel E., İnce A., Yıldız Y., 2006.Tarım Makinaları 2, Adana: Nobel

Mahalinga, I., ve Wills, B.M.D., 1978.Factors Determining the Design of Tractor-mounted Sprayer Booms-Sprayer Nozzle Characteristics J.agric.Engng Res.

Nation, H.J., 1982.The Dynamic Behavior of Field Sprayer Booms J.agric.Engng Res.

Krutz, G., Thompson., L, Claar, P., 1984. Design of Agricultural Machinery, Canada:John Wiley & Sons, Inc.

Srivastava A., K., Goering., C,E., Rohrbach, R.,P., Buckmaster, D.R. 2006.Engineering Principles of Agriculturel Machines, USA: American Society of Agriculturel and Biological Engineers.

Lebeau, F., Bouchat,X., Ruter, R., Destain, M.F., 2002.Spray Pattern Model for Standardisation of Boom Behaviour Tests.Aspects of Applied Biology

Kennes, P., Ramon, H., Baerdemaeker, J., 1998.Modelling the Effect of Passive Vertical Dynamic Behaviour of Sprayer Booms J Agric Engng Res

2016.http://www.tuik.gov.tr/