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MODELLING OF A MULTI-CROP THRESHER: FINITE ELEMENT ANALYSIS OF THE THRESHING DRUM.

By

***Adelere Olusegun William[1], Ajav Emmanuel A[2], Sunmonu Segun Emmanuel[1], Jimoh Raheem Olatunji[1], Hassan Muhammed Olalekan[1].**

[1]Department of Engineering and Scientific Services, National Centre for Agricultural Mechanization, (NCAM), Nigeria.
[2]Department of Agriculture and Environmental Engineering, University of Ibadan, Oyo State, Nigeria.

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Abstract

CAD software are tools which have been developed to aid engineers in design and design optimization process. Series of multi-crop threshers have been modelled and developed using different CAD software but many of those research works do not perform Finite Element Analysis of the components of the thresher in order to determine the deformations in those components as a result of the operating condition of the machine. A multi-crop thresher was modelled using Autodesk Inventor (a CAD software) and Finite Element Analysis (FEA) was performed on the threshing drum of the machine in this write-up. The various component parts of the machine were modelled in the parts environment of the software, assembled in the assembly environment and exploded in the presentation environment after which drawings of the machine (isometric, autographic and parts) were extracted from the drawing environment of the software. For the FEA of the threshing drum, the operating conditions of the drum were determined such as bearing load, threshing torque and the force exerted by the feed material on the bars attached to the threshing drum which were applied on the drum. The drum was discretized into finite elements and FEA was carried out in the analysis environment of the software. It was discovered that under the operating conditions to which the threshing drum was subjected to for the FEA, there was no failure of the drum though little deformation was recorded. The maximum Von mises stress of 2.246 MPa which is the working stress of the threshing drum was less than the yield strength of stainless steel (the material make-up of the drum) of 250 Mpa. The maximum first and third principal stress of 2.10896 MPa and 0.2639 MPa respectively are less than the yield strength of the material while the maximum first and third principal strain of 0.0000099 and 0.000000102 shows infinitesimal deformation. The overall maximum displacement of 0,0360034 mm and the maximum displacement in the x, y and z axis of 0.036 mm, 0.0155 mm and 0.001587 mm shows little deformation in the threshing drum under the operating conditions it was subjected to. The factor of safety obtained was also very high indicating a safe design. After modelling the multi-crop thresher and analyzing the FEA result of the threshing drum, it can be concluded that the design is a safe one since it passed all the tested criteria.

Keywords: *Multi-crop thresher, Autodesk Inventor, Finite Element Analysis, Computer Aided Design, Modelling.*

1.0 INTRODUCTION

Computer Aided Design (CAD) is the use of computers to aid in the creation, modification, analysis, or optimization of a design (Narayan, 2008). It is a program which helps users to create Stereolithographic (STL) files (Gamal and Mazel, 2019). CAD software increases the productivity of a designer, improves the quality of design, improves communication between a designer and the reader of the design through documentation and dimensioning, and creates a database for manufacturing. It helps in designing, analyzing and optimizing 3D models. This software helps to design ideas and visualize concepts through realistic renderings by giving form to the ideas and to also imitate the showing of the design in the real world. Its use in designing electronic systems is known as electronic design automation (EDA). In mechanical

*Corresponding Author: Adelere Olusegun William

design it is known as mechanical design automation (MDA) or computer-aided drafting (CAD), which includes the process of creating a technical drawing with the use of computer software (Madsen, 2012). Designs made through CAD software are helpful in protecting products and inventions when used in patent applications. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations.

Autodesk Inventor is one of the CAD software and is used for 3D mechanical design, simulation, visualization, and documentation. It was developed by Jacob San and was first released in 1999. It allows 2D and 3D data integration in a single environment, creating a virtual representation of the final product that enables users to validate the form, fit, and function of the product before it is ever built. Autodesk Inventor includes parametric, direct edit and freeform modeling tools as well as multi-CAD translation capabilities in their standard DWG drawings. Inventor uses Shape Manager, Autodesk's proprietary geometric modeling kernel. Autodesk Inventor competes directly with SolidWorks, Solid Edge, and Creo. Autodesk Inventor have been used by engineers in the design and modelling of various mechanical and agricultural equipment.

Wen (2012) used the software in the design of automatic transplanting robot where he utilized the rapid modelling characteristics of inventor to create the mechanical model, analyzed the movement mechanism and calibrated mechanical properties with the features of intuition, interactive operation, simulated the behavior of trans-planter and then calculated the various properties of the work piece.

Łukaszewicz (2017) used Autodesk Inventor in the virtual prototyping of two models of a three wheeled vehicle where he modeled the vehicles to test their suspension system. His work was divided into two phases, in which the first phase includes creating the digital models of the two vehicles while the second phase consisted of conducting a simulation of the models' behavior in the dynamic simulation environment of the Autodesk Inventor software. The created models were analyzed in order to determine the forces at individual connection nodes of the suspension while driving on a curved section of a road. The obtained data in the form of force values over time and displacements at individual suspension nodes of the vehicles can then be used to conduct a more detailed endurance analysis of individual construction elements of the models. Trestianu and Baroiu (2017) used the software to model a type T1 differential torsen while Lande *et al.* (2021) used the software to design and model an automatic drainage cleaning machine. Also Bostan *et al.* (2006) developed processional drives using the Autodesk Inventor platform. Threshing is the process of loosening, removing or separating grain from the ear heads. It consists of sequence of operations that are designed to detach the desired product from the mass of the harvested crop material and to separate it from the mixed mass (Pandey and Stephens, 2016). Threshing is one of the important post-harvest operations which is usually performed on grain or cereal crops and it requires attainment of sets of processing condition that must be attained for effective threshing action to be accomplished in a manual or mechanical operation (Olaoye *et al.*, 2011). Threshing can be done either manually or mechanically. The earliest known method of threshing is a manual one which is to beat the grain out from their sheaves with the help of a stick or other hard objects which is a time-consuming, labour intensive and low output process, also high losses were recorded (Enaburekhan, 1994). This brought about the development of machines which can be used for threshing operations to overcome these difficulties which paved way for the development of multi crop threshers. The multi-crop threshers which were developed are used to handle a number of crops and are highly successful for threshing cereal crops and pulses. The advantage of multi crop threshers is that with minor adjustments it can be used to thresh different crops, whereas other threshers can thresh a particular crop only. (Pandey and Stephens, 2016). The ideal threshing unit (processor) is the one that produces a perfect threshing of maximum crop through put with optimum grain separation, while it preserves the natural shape and quality of the grain and minimize grain loss (Miu, 1995).

Pandey and Stephens (2016) conducted the performance evaluation of a high capacity multi crop thresher on 'gram' crop at three different speeds of 550 rpm, 600 rpm and 650 rpm at corresponding feed rate of 16 q/h, 18 q/h, 20 q/h. The evaluation was carried out with respect to threshing efficiency, cleaning efficiency, grain loss, grain breakage and the output capacity and it was discovered that in threshing gram with the aid of the multi crop thresher, the maximum threshing efficiency was found to be 98.98 per cent at cylinder speed of 600 rpm and feed rate 20 q/h. Similarly, the cleaning efficiency was found to be 97.30 per cent at cylinder speed of 600 rpm and feed rate 20 q/h while the maximum total grain loss was found to be 3.3 per cent at cylinder speed 550 rpm and maximum feed rate 20 q/h. The grain breakage was found to be 1.70 per cent at cylinder speed of 650 rpm and feed rate 20 q/h. The output capacity was found to be 9.62 q/h at cylinder speed of 600 rpm and feed rate 20 q/h and the net saving with multi crop thresher in threshing cost compared to traditional threshing method was found to be 31 per cent for gram crop.

Olaoye *et al.* (2012) used computer applications to select operating parameters in a stationary grain crop thresher, in which various operating parameter influencing performance of a stationary grain crop thresher were established. These parameters were deduced from the established analytical models describing the underlying principles for the crop characteristics and machine variables as factors influencing the overall machine performance of a stationary multi-crop thresher by Olaoye (2004). The results obtained from the study showed that graphs of data from measured thresher performance indices against the predicted data for all the established models indicated high correlation between the models and the measured data at $p \leq 5$ % significance level.The aim of this research work is to model a multi crop threshing machine and conduct a finite element analysis (FEA) of the threshing drum of the machine. The specific

*Corresponding Author: Adelere Olusegun William

objectives are: Parts modeling of the various components of the multi crop threshing machine, assembly of the modeled parts to form the multi crop threshing machine and finite element analysis of the threshing drum of the machine. The scope of this research work is to model the components parts of a multi crop thresher using the parts drawing interphase of the Autodesk Inventor, assemble the component parts to form the machine in the assembly interphase and analyse the stress and reactions in the threshing drum using the stress analysis interphase by conducting a Finite Element Analysis (FEA) on the threshing drum.

2.0 MATERIALS AND METHODS

The threshing machine was already fabricated by the National Center for Agricultural Mechanization (NCAM), Ilorin, Nigeria. This report makes use of the Autodesk Inventor platform to model the machine and test some parameters.

2.1 Description of the machine

The multi- crop thresher is a machine designed to thresh many different types of grain crops such as Soybean, Millet, Maize, Sorghum, Sunflower, Rice and Wheat. The thresher can be powered by electric motor or diesel/ petrol engines which is placed on a section of the frame designed for that purpose. The components of the thresher include:

Feeding unit: this is a chute which acts as the hopper of the machine through which the materials to be threshed are fed into the machine as shown in Figure 1.

Threshing unit: This is made up of the threshing drum which consists of a series of pegs attached to a cylindrical drum throughout the section of the drum except for the edge which a series of fan blades are attached as shown in Figure 2.

Separating unit: The separating unit is majorly the concave sieve as represented in Figure 3 which is located at the base of the threshing unit. It is made of aperture which just allows the grains and some underflow particles (dusts, chaffs) to pass through and prevent the overflow particles such as broken cobs from going through. The concave sieve can be changed based on the grains to be threshed such that the apertures on the sieve will suit the grain.

Cleaning unit: This is another separation process which is performed by the fan as shown Figure 4 in the machine assembly. It is designed in such a way that as the underflow particles fall through the concave sieve, it separates the chaffs from the grains based on the principle of terminal velocity. Since the grains are heavier and denser than the chaffs and dusts, they would be blown through an outlet located at the rear end of the threshing machine

Power transmission system: This is made up of a belt and pulley connection as shown in Figure 5 which transfers power from the power source to the fan and threshing units.

Main frame: This is a connection of angle irons that supports the weight of the whole machine and transfers the loads to the ground. The frame is shown in Figure 6.

2.2 Operation principle

The machine was designed in a way that as the materials to be threshed are fed into the machine, it moves to the threshing section which comprises of a threshing component and a concave sieve such that the grains are threshed by the impact of the beaters attached to the threshing drum. As the threshing is taking place, the overflow particles that cannot pass through the aperture of the concave sieve would be transferred by rotational action to the outlet designed to receive them. The underflow particles pass through the concave sieve and are further separated by the cleaning action of the fan by the principle of terminal velocity such that the air velocity is just sufficient enough to blow the grain dusts and chaff through a rear outlet without carrying the grains along, then the cleaned grains are then collected at the product outlet.

2.3 Finite element analysis of the threshing drum

2.3.1: Bearing load

Given that 'BS 292_ Part 1 - 7305 - 25 x 62 x 17' bearing was used in the model, with a density of 7.850 g/cm^3 since the material make-up is mild steel.

$mass(m) = density(\rho) \times volume(v)$ .... (1)

$where;$

$$density = 7850\frac{kg}{m^3}\ and$$

$$volume = 25 \times 62 \times 17 = 26350\ mm^3 = 2.635 \times 10^{-5} m^3$$

$$mass = 7850\frac{kg}{m^3} \times 2.635 \times 10^{-5} m^3 = 0.2068475\ kg$$

$Bearing\ load = mg$ .... (2)

Where;

g = 9.81 N

$\therefore Bearing\ load = 0.2068475\ kg \times 9.81\ N = 2.029173975\ N$

2.3.2 Determination of threshing torque

The torque, T, is given by:

$T = F \times r$ .... (3)

$where;$

$F\ is\ the\ force\ available\ along\ the\ threshing\ drum\ and$

$r\ (160\ mm) is\ the\ threshing\ radius$

To determine the force (F) available along the threshing drum: The threshing bars, which are attached to the threshing drum, rotate with the shaft, giving rise to centripetal force.

$F = m \times \omega^2 \times r$ .... (4)

Where;

F = centripetal force;

m = mass of the threshing bars;

w = angular velocity;

r = radius of the arm of the threshing drum ($7.5\ mm$).

To determine the mass, m, of the threshing bars applying equation 5

$volume\ of\ the\ threshing\ bars = \pi r^2 h$ .... (5)

$where;$

$r\ is\ radius\ of\ the\ bar\ (7.5\ mm)\ and$

$h\ is\ the\ height\ (94\ mm)$

$\therefore volume = \pi \times 0.0075^2 \times 0.094 = 1.662 \times 10^{-5}\ m^3$

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The material makeup of the threshing bar is stainless steel, so, the density of the threshing bar is 8000 kg/m^3 (Autodesk Inventor).

$\therefore$ *mass of the threshing bars*

$$= 8000\frac{\text{kg}}{m^3} \times 1.662 \times 10^{-5}\, m^3$$
$$= 0.1329\, kg$$

Since the threshing drum has 24 bars attached to it,

$\therefore$ *Total mass of the threshing bars* $= 24 \times 0.1329\, kg$
$$= 3.19\, kg$$

To determine the angular velocity (ω):

$Angular\ velocity\ (\omega) = \frac{2\pi N}{60}$ ….………….. (6)

Where;

N = speed of the shaft in r.p.m.

Using a speed of 300 r.p.m which was the best threshing speed for maize according to Alsharifi, 2018.

$$Angular\ velocity\ (\omega) = \frac{2\pi \times 300}{60} = 31.42\ \ r.p.m.$$

The force available along the threshing drum(F) *according to equation* 4;

$$F = m \times \omega^2 \times r = 3.19 \times 31.42^2 \times 0.0075 = 23.619\, N$$

From equation 3, the threshing torque can be determined;

$\therefore$ *The threshing torque* $(T) = F \times = 23.619\, N \times 0.160\, m$
$$= 3.779\, Nm$$

2.3.3 Determination of the force exerted by feed load on a single run

To determine the feed load on a single run assuming the thresher is running at full capacity and maize is the feed material.

The volume of the threshing housing $(V_1) = \pi r^2 h$ .. (7)

Where;

r = radius of the threshing housing (180 mm) and

h = length of the threshing housing (605 mm)

$$\therefore (V_1) = \pi r^2 h = \pi \times 0.18^2 \times 0.605 = 0.342\, m^3$$

The volume of the threshing drum(V_2)

$= 0.249\, m^3$(*gotten from Autodesk Inventor*)

volume occuppied by the feed $= V_1 - V_2$
$$= 0.342 - 0.249 = 0.093\, m^3$$

Force exerted by the feed on the threshing drum $(F_f) = \rho V g$………. (8)

Where;

ρ = density of the maize cob (721 kg/m^3 according to aquacalc)

V = volume occupied by the feed and

g = acceleration due to gravity

$$F_f = \rho V g = 721 \times 0.093 \times 9.81 = 657.789\, N$$

Since there are 24 bars attached to the threshing drum, the force exerted on each bar (F_b):

$$F_b = \frac{F_f}{24} = \frac{657.789}{24} = 27.41\, N$$

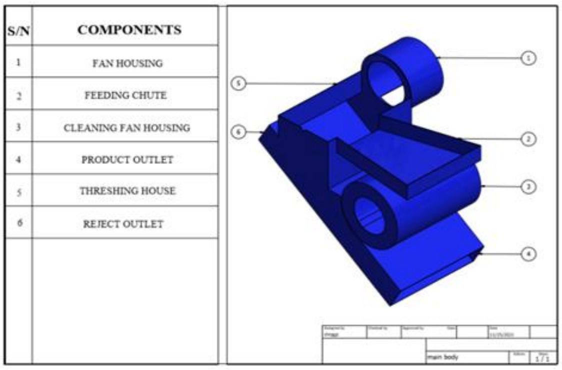


Figure 1: The Main body of the machine showing the feeding unit.

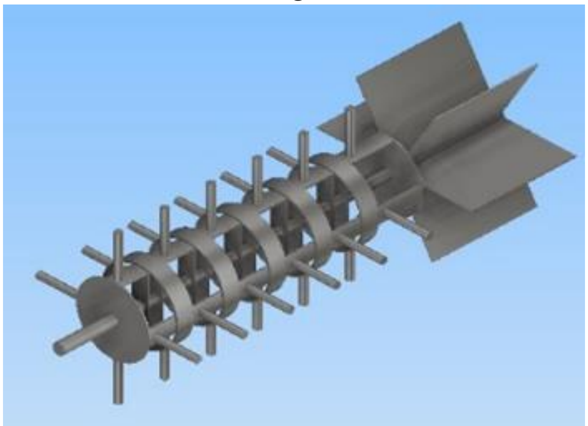
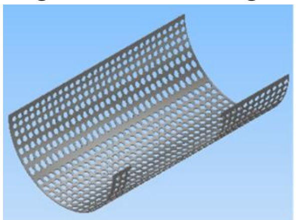


Figure 2: The threshing drum of the multi-crop thresher



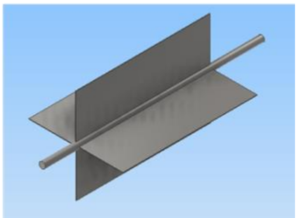


Figure 3: The multi-crop thresher screen. Figure 4: Separating fan.

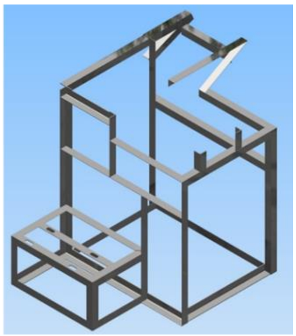


Figure 5: Belt and pulley connection. 6: The main frame of the machine.

3.0 RESULTS AND DISCUSSION

3.1 Assembly of the multi-crop thresher

The various components of the machine were assembled in the assembly environment of the software as shown in Figure 7. For the part drawing represented in Figure 8, the assembled components were first exploded into the various component parts in the presentation environment before it was brought to the drawing environment to give detailed information about the machine, the autographic projection of the machine is shown in Figure 9 while the dimensioned drawing is shown in Figure 10. The autographic and dimensioned drawing are done in the drawing environment of the software.

3.2 Finite element analysis of the threshing drum

To determine the finite element analysis of the threshing drum:

1. The force of gravity was applied as shown in Table 1.
2. It was assumed to be fixed at both ends as represented in Figure 11 below, taking into consideration the reaction of the drum to the pillow blocks.
3. Bearing load of 2.029173975 N was used as shown in Table 2.
4. A threshing torque of 3.779 Nm was used as shown in Table 3.
5. A point load of 27.41 N was used as the acting force on each bar as represented in Figure 12 as a result of the feed material.

3.2.1Properties of the threshing drum

The physical properties of the threshing drum as displayed by the FEA of the threshing drum are represented in Table 4 and the material properties are shown in Table 5 while the reaction forces and moments on it are represented in Table 6.

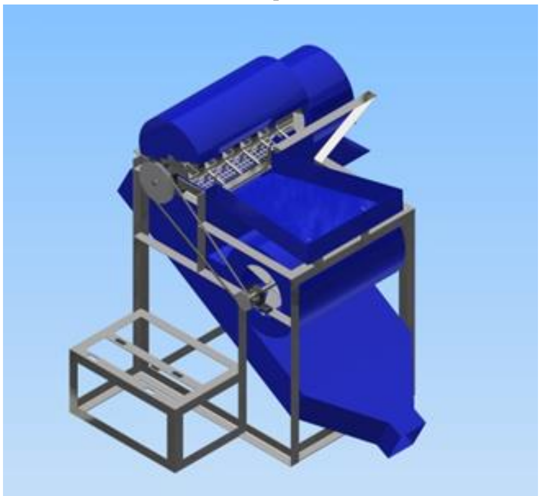


Figure 7: Isometric Projection of the Multi-crop thresher.

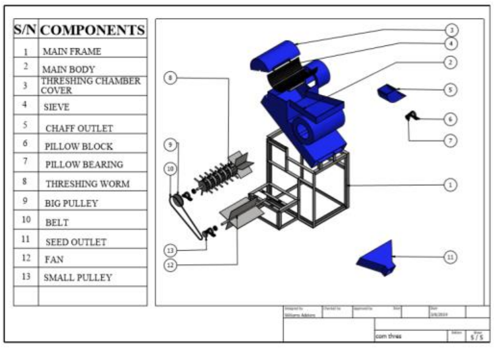


Figure 8: Parts Drawing (Exploded view) of the Multi-crop thresher.

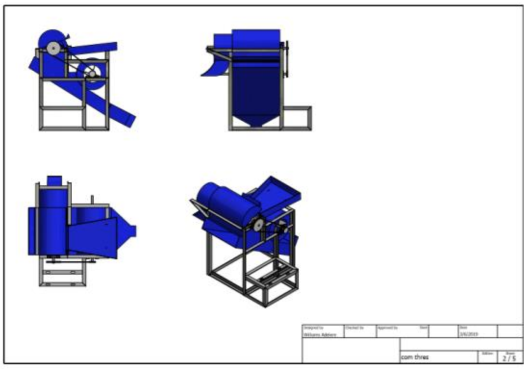
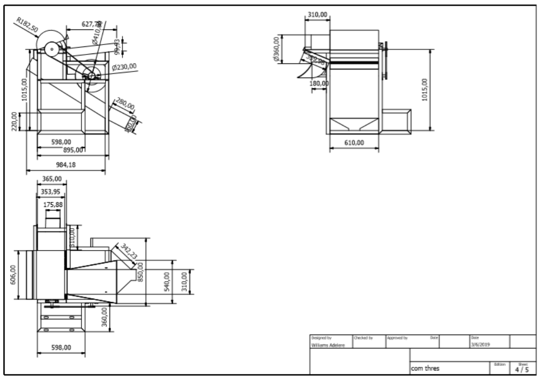


Figure 9: Autographic View of the Machine.



Note: Dimensions are in mm.

Figure 10: Dimensioned drawing of the thresher.

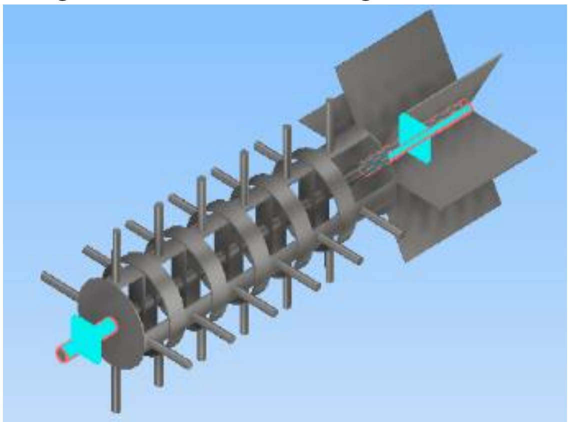


Figure 11: The position of the fixed constraints on the threshing drum.

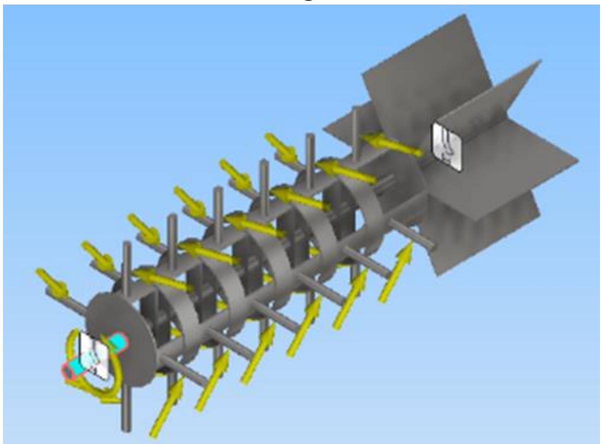


Figure 12: Operating condition of the force of the feed material

Table 1: Operating condition of the force of gravity

Load Type	Gravity
Magnitude	9810.000 mm/s^2
Vector X	9810.000 mm/s^2
Vector Y	0.000 mm/s^2
Vector Z	0.000 mm/s^2

Table 2: Operating condition of the bearing load on the threshing drum

Load Type	Bearing Load
Magnitude	2.029 N
Vector X	0.000 N
Vector Y	0.000 N
Vector Z	-2.029 N

Table 3: Operating condition of the torque on the threshing drum

Load Type	Moment
Magnitude	3779.000 N mm
Vector X	0.000 N mm
Vector Y	0.000 N mm
Vector Z	N mm

Table 4: Physical properties of the threshing drum

Material	Stainless Steel
Density	8 g/cm^3
Mass	19.9277 kg
Area	1123430 mm^2
Volume	2490960 mm^3
Center of Gravity	x=0.00125606 mm y=-0.00341895 mm z=426.406 mm

Table 5: Properties of the material of make of the threshing drum

Name	Stainless Steel	
General	Mass Density	8 g/cm^3
	Yield Strength	250 MPa
	Ultimate Tensile Strength	540 MPa
Stress	Young's Modulus	193 GPa
	Poisson's Ratio	0.3 ul
	Shear Modulus	74.2308 GPa
Part Name(s)	threshing comp	

Table 6: Reaction force and moments on constraints

Constraint Name	**Reaction Force**		**Reaction Moment**	
	Magnitude	**Component (X,Y,Z)**	**Magnitude**	**Component (X,Y,Z)**
Fixed Constraint: 1	203.945 N	-201.241 N	20.4417 N m	0 N m
		-1.09209 N		-13.1422 N m
		33.0818 N		-15.6572 N m

Table 7: Summary of the results from the Finite Element Analysis

Name	**Minimum**	**Maximum**
Volume	2490950 mm^3	
Mass	19.9276 kg	
Von Mises Stress	0.000117762 MPa	2.24576 MPa
1st Principal Stress	-0.315738 MPa	2.10896 MPa
3rd Principal Stress	-1.95758 MPa	0.263865 MPa
Displacement	0 mm	0.0360034 mm
Safety Factor	15 ul	15 ul
X Displacement	-0.00374604 mm	0.0360004 mm
Y Displacement	-0.0155779 mm	0.0155334 mm
Z Displacement	-0.00206302 mm	0.00158662 mm
1st Principal Strain	-0.000000171418 ul	0.00000990351 ul
3rd Principal Strain	-0.00000927745 ul	0.000000102105 ul

Note: ul = unit level

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4.2.2 Summary of the results from the Finite Element Analysis

The summary of the results from the Finite Element Analysis of the threshing drum is shown in Table 7.In carrying out the FEA of the threshing drum, the result was exaggerated to 10 times the actual result on the model so that the distortion of the model can be visualized since it's makeup material is steel where the actual deformation is usually too small to notice and it was discretized into meshes which contains 18701 elements and 37806 nodes as shown in Figure 13.

4.2.2.1 Von Mises Stress

Von Mises stress according SimScale is a value used to determine if a given material will yield or fracture and is mostly used for ductile materials such as metals. The von mises yield criterion states that if the von mises stress of a material under load is equal or greater than the yield limit of the same material under simple tension then the material will yield. According to the FEA analysis performed on the threshing drum, the maximum von mises stress is 2.24576 MPa which is less than the yield strength of the threshing drum of 250 MPa implying that the threshing drum passed the von mises stress criterion as shown in Figure 14.

Von mises stress handles any complex 3D loading condition, regardless of the mix of normal and shear stresses. It converts the combination of stresses down to a single number that can be compared to the material's yield strength.

4.2.2.2 1st Principal Stress and Strain

The 1st principal stress according to Autodesk is the value of stress that is normal to the plane in which the shear stress is zero (principal plane). It is the maximum tensile stress induced in the component part due to loading conditions while the strain as a result of this stress is the 1st principal strain. The FEA of the 1st principal stress and strain on the threshing drum as presented in Figure 15 and 16 shows that the maximum tensile stress and strain induced on it as a result of the operating conditions is 2.10896 MPa and 0.00000990351 ul which is concentrated at the fan section of the threshing drum. The color codes (and values) beside the model is used to interpret the level of stress and strain with red being the highest and blue the lowest. From the results generated, it can be inferred that the model is safe in tensile deformation since the maximum values are very low.

4.3.2.3 3rd Principal Stress and Strain

The 3rd principal stress according to Autodesk is the value of stress that is normal to the plane in which the shear stress is zero (principal plane). It is the maximum compressive stress induced in the component part due to loading conditions while the strain as a result of this stress is the 3rd principal strain. It is the exact opposite of the 1st principal stress and strain, so, it is colored in reverse as presented in Figure 17 and 18. The maximum value of the 3rd principal stress and strain of 0.263865 MPa and 0.000000102105 ul are very low implying that the model is safe in compressive deformation.

4.3.2.4 Displacement

Displacement is a measure of how far the model deforms as a result of the operating conditions while the X, Y and Z displacement are the deformation of the threshing drum in those axis and they are shown in Figure 19, 20, 21 and 22. The figures and values show that the maximum displacement occurs in the X axis though it is experienced by a fraction of the fan section of the threshing component while though the displacement in the Y axis is lower, it is more affects a greater portion of the fan section of the threshing drum but the displacement in the Z axis is experienced by the bars attached to the threshing drum. From the low value of the maximum displacements it can be inferred that the model is safe in displacement.

4.3.2.5 Factor of safety

This is based on the material's properties and a high factor of safety means a safe model. The factor of safety for the model is 111.32 as gotten in the calculation below:

$$factor\ of\ safety = \frac{yield\ strength}{working\ stress} = \frac{yield\ strenght}{von\ mises\ stress}$$

$$= \frac{250}{2.24576} = 111.32$$

But because the factor of safety of the Inventor software peaks at 15 as presented in Figure 23 below., that was the result displayed in the FEA. The high factor of safety indicates that the threshing drum is a safe model.

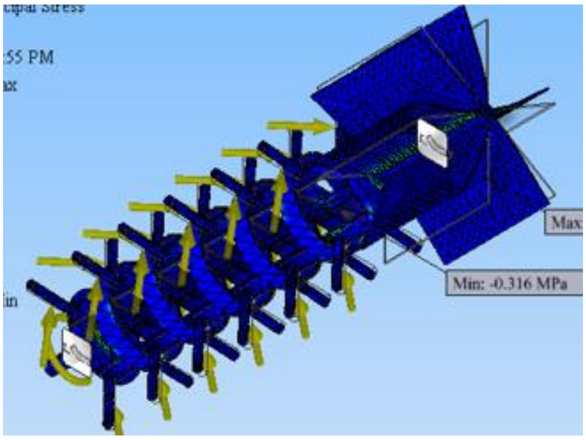

Figure 13: Finite elements of the threshing drum.

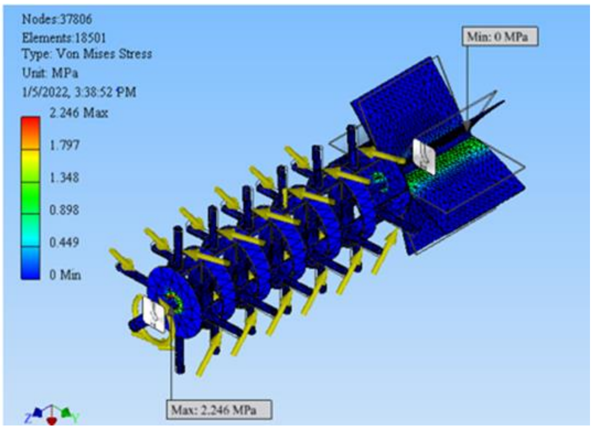

Figure 14: Von Mises Stress.

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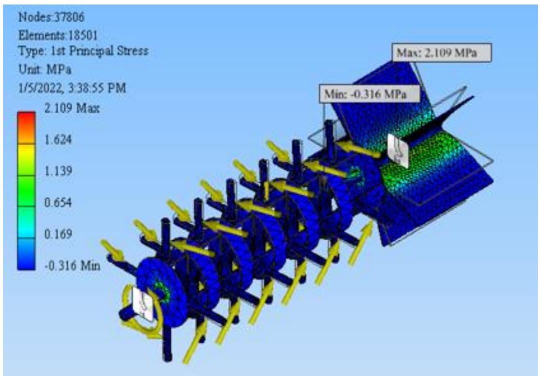

Figure 15: 1st Principal Stress

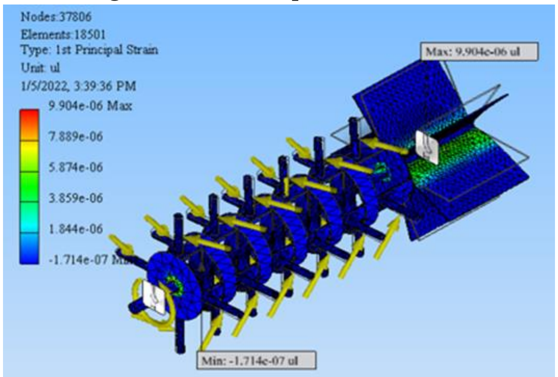

Figure 16: 1st Principal Strain

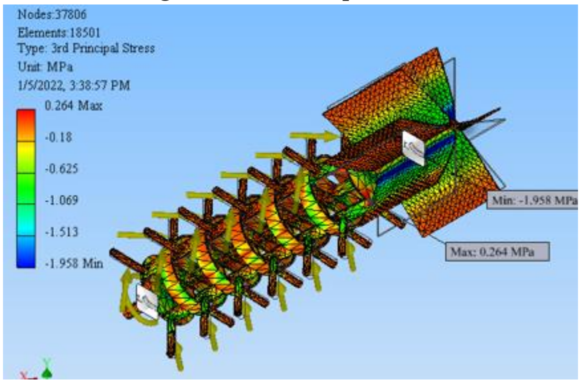

Figure 17: 3rd principal stress

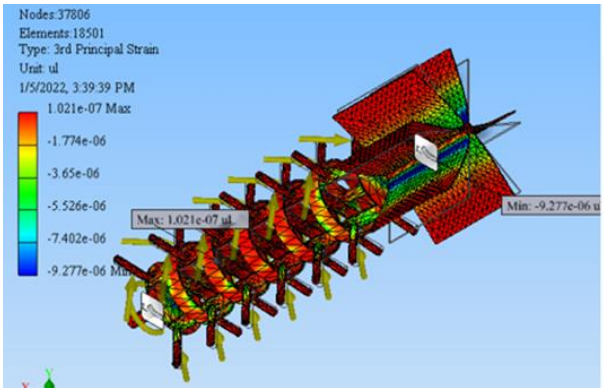

Figure 18: 3rd principal strain.

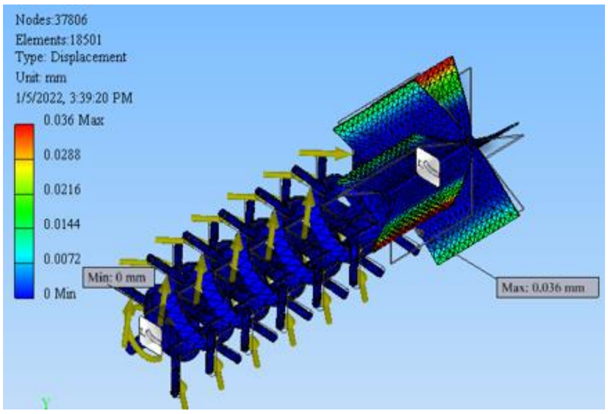

Figure 19: Displacement of the threshing drum.

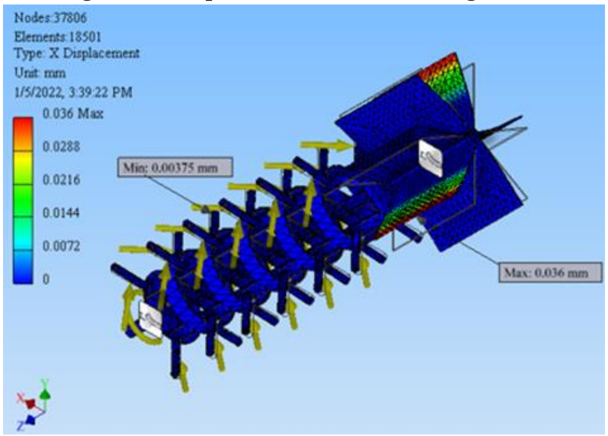

Figure 20: X displacement.

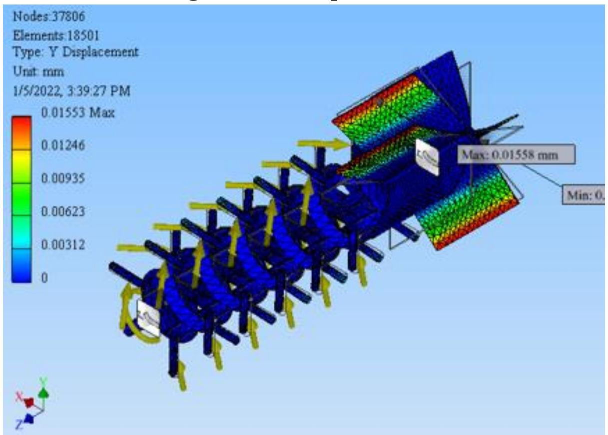

Figure 21: Y displacement

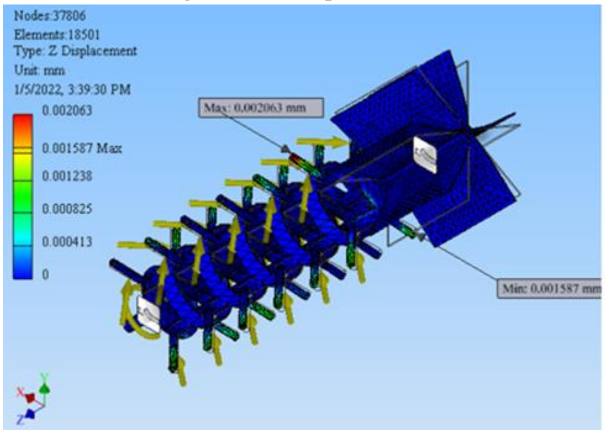

Figure 22: Z displacement.

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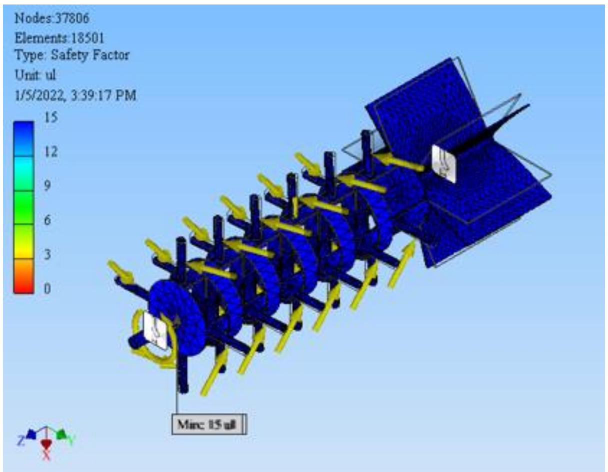

Figure 23: Factor of safety

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The following conclusions can be reached:

1. The advent and development of CAD software have made engineering designs less stressful, time efficient and less costly.
2. The transition from the engineering design to fabrication is made easier since after the designs are done, every possible drawing needed for the fabrication of the model can be made available with relative ease for the fabricator.
3. The stress of destroying a model after fabrication as a result of poor or inefficient performance is eliminated since the operation of the models can be simulated by CAD software.
4. Through FEA brought about by CAD software, destructive testing of machine components in order to determine their reactions under various operating conditions can be eliminated as seen from the FEA of the threshing drum of the multi-crop thresher which showed that it would perform optimally under the operating conditions with little deformation.

4.2 Recommendations

Finite element analysis of the threshing drum should be conducted under other operating conditions such as the threshing of rice, wheat, millet and sorghum since their operation parameters are different.

Discrete element analysis (DEM) of the multi-crop thresher should be conducted using various feed materials and model validation of the threshing drum should be done.

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*Corresponding Author: Adelere Olusegun William