DESIGN AND ANALYSIS OF EARTH MOVER – WHEEL LOADER VEHICLE

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PROJECT

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I certify that this student has met the requirements for format contained in the University format manual, and that this project is suitable for shelving in the Library and credit is to be awarded for the Project.

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Design and analysis of multi body system is a challenging task that requires the knowledge of machine design, computer aided design (CAD), finite element analysis and structural dynamics. Wheel loader vehicle is a type of earth moving machine which falls in the category of multi body system. This project is based on the concepts of reverse engineering where in which the wheel loader is designed and analyzed to precision. Initially the dimensions of the wheel loader are documented by using vernier caliper and full scale ruler. These dimensions are vitally implemented in generating the 3D model of the wheel loader. SolidWorks has been used for 3D model creation. In order to run the design to real time standards a few design modifications are taken into account. Design of lift arm cylinders, lift arms, tilt/bucket cylinder and connecting rod are modified to real time standards. Kinematics of wheel loader has been analyzed in SolidWorks. For kinetics and structural analysis the model has been exported from SolidWorks to MSC Visual Nastran Desktop 4D. In order to analyze the structural dynamics, the method of
finite element analysis is used. The results obtain from the stress analysis are within the range of yield stress of materials used for designing of wheel loader. The design is verified to be real time with the factor of safety 1.2. Reverse engineering process is helpful to analyze the existing model and helps in improving design.

_______________________, Committee Chair
Jose Granda, Ph.D.

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Date
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Chapter 1

INTRODUCTION

This project represents a designing and analysis of earth mover – wheel loader vehicle using SolidWorks 2009 and MSC Visual Nastran Desktop 4D. Wheel loader vehicle is a multi body system and to design and analyze such system requires profound knowledge of highly challenging subjects like Computer Aided Design, Finite Element Analysis, machine design, reverse engineering and structural dynamics etc. This project work shows how to implement engineering fundamentals into the real world application. In this project, designing has been done by implementing reverse engineering concept. Initially, the dimensions of wheel loader toy have been documented by vernier caliper and full scale ruler. These dimensions are vitally implemented in generating the 3D model of the wheel loader. SolidWorks has been used for 3D model creation. In order to run the design to real time standards a few design modifications are taken into account. Design of lift arm cylinders, lift arms, tilt/bucket cylinder and connecting rod are modified to real time standards. SolidWorks 2009 has been used for kinematic analysis of wheel loader. While MSC Visual Nastran Desktop 4D has been used for kinetics and structural analysis the model. To perform this analysis 3D model of wheel loader has been exported from SolidWorks to MSC Visual Nastran Desktop 4D has been exported from SolidWorks to MSC Visual Nastran Desktop 4D.
1.1 What is Reverse Engineering?

Engineering is the process of designing, manufacturing, assembling, and maintaining products and systems. There are two types of engineering, forward engineering and reverse engineering. Forward engineering is the traditional process of moving from high-level abstractions and logical designs to the physical implementation of a system. In some situations, there may be a physical part/product without any technical details, such as drawings, bills-of-material, or without engineering data. “Reverse engineering is the process of discovering the technological principles of a device, object or system through analysis of its structure, function and operation. It often involves taking something (e.g., a mechanical device, electronic component, or software program) apart and analyzing its workings in detail to be used in maintenance, or to try to make a new device or program that does the same thing without using or simply duplicating (without understanding) any part of the original.” Reverse engineering is also defined as the process of obtaining a geometric CAD model from 3-D points acquired by scanning/digitizing existing parts/products. The process of digitally capturing the physical entities of a component, referred to as reverse engineering (RE), is often defined by researchers with respect to their specific task (Motavalli & Shamsaasef 1996). Abella et al. (1994) described RE as, “the basic concept of producing a part based on an original or physical model without the use of an engineering drawing”. Yau et al. (1993) define RE, as the “process of retrieving new geometry from a manufactured part by digitizing and modifying an existing CAD model”. Reverse engineering is now widely used in numerous applications, such as manufacturing, industrial design, and jewelry design and reproduction. For example, when a new car is launched on the market, competing manufacturers may buy one and disassemble it to learn how it was built.
and how it works. In software engineering, good source code is often a variation of other good source code. In some situations, such as automotive styling, designers give shape to their ideas by using clay, plaster, wood, or foam rubber, but a CAD model is needed to manufacture the part. As products become more organic in shape, designing in CAD becomes more challenging and there is no guarantee that the CAD representation will replicate the sculpted model exactly. [1]

Reverse engineering provides a solution to this problem because the physical model is the source of information for the CAD model. This is also referred to as the physical-to-digital process. Another reason for reverse engineering is to compress product development cycle times. In the intensely competitive global market, manufacturers are constantly seeking new ways to shorten lead times to market a new product. Rapid product development (RPD) refers to recently developed technologies and techniques that assist manufacturers and designers in meeting the demands of shortened product development time. For example, injection-molding companies need to shorten tool and die development time drastically. By using reverse engineering, a three-dimensional physical product or clay mock-up can be quickly captured in the digital form, remodeled, and exported for rapid prototyping/tooling or rapid manufacturing using multi-axis CNC machining techniques. [1]

1.2 Why use Reverse Engineering?

Following are some of the reasons for using reverse engineering:

• The original manufacturer is no longer exists, but a customer needs the product, e.g., aircraft spares required typically after an aircraft has been in service for several years.
• The original manufacturer of a product is no longer produces the product, e.g., the original product has become obsolete.
• The original product design documentation has been lost or never existed.
• Creating data to refurbish or manufacture a part for which there are no CAD data, or for which the data have become obsolete or lost.
• Inspection and/or Quality Control–Comparing a fabricated part to its CAD description or to a standard item.
• Some bad features of a product need to be eliminated e.g., excessive wear might indicate where a product should be improved.
• Strengthening the good features of a product based on long-term usage.
• Analyzing the good and bad features of competitors’ products.
• Exploring new avenues to improve product performance and features.
• Creating 3-D data from a model or sculpture for animation in games and movies.
• Creating 3-D data from an individual, model or sculpture to create, scale, or reproduce artwork.
• Architectural and construction documentation and measurement.
• Fitting clothing or footwear to individuals and determining the anthropometry of a population.

1.3 Typical Phases in Reverse Engineering

To understand the phases in RE, consider the stages shown in Figure 1.3.1. The first step in the RE process is to make measurements of an object and to collect the points for CAD model. This step can be achieved either by using 3D scanner for complex objects or by conventional tools like vernier caliper and scale for simple and comparatively smaller objects. In the second step the
points collected in the first step placed in to CAD softwares to generate 3D - CAD model. After creating a complete model, different analysis can be perform on the model as per necessities to check whether its satisfied the design requirements or not. This step is shown in the Figure 1.3.1 as CAE system. If the model has fulfilled the essential design requirements it can be moved to CAM system, if not then required design changes will be implemented until its satisfied necessary design requirements. Final product will be ready once the model has come out of CAM system.

Figure 1.3.1: Phases in Reverse Engineering
1.4 What is Wheel Loader?

A wheel loader is a type of tractor, usually wheeled, sometimes on tracks, that has a front mounted square wide bucket connected to the end of two booms (arms) to scoop up loose material from the ground, such as dirt, sand or gravel, and move it from one place to another without pushing the material across the ground. A loader is commonly used to move a stockpiled material from ground level and deposit it into an awaiting dump truck or into an open trench excavation. Figure 1.4.1 shows Volvo L120E wheel loader.

Figure 1.4.1: Volvo L120E Wheel Loader [3]
1.5 What Does Wheel Loader Consist of?

Wheel loader usually comprises five equipment systems: traction, structure, powertrain, control and information. It also consists of bucket, bucket lever and lift-arms impelled by hydraulic cylinders, connecting rod and cabin which have shown in the Figure 1.5.1.

![Wheel Loader Parts](image)

- **Bucket**: A deep shape throat that can be raised and tipped.
- **Bucket Cylinder**: Hydraulic device consisting of a telescopic arm that controls the back and-forth motion of the bucket.
- **Bucket Lever**: Part impelled by the bucket hydraulic cylinder that allows the bucket to swivel on a horizontal axis.
- **Lift Arms**: Lever that connects the loader to the tractor; it raises and lowers the loader.
• Lift Arm Cylinders: Hydraulic telescopic device that raises and lowers the lift arm.
• Cabin: Compartment from which the operator controls the wheel loader.

1.6 How Does Wheel Loader Work?

As mentioned above, wheel loader comprises 5 important parts which are helpful for the complete loading and dumping motion.

![Figure 1.6.1: Loading and Dumping Motion of Wheel Loader](image)

As shown in the Figure 1.6.1, during loading motion bucket can tilt up to 43° on its own axis from ground, during dumping motion it can swivel up to +59° and -45° on its own axis, through the combine motion of bucket cylinder, bucket lever and
connecting rod. Lift arms and lift arm cylinders are accountable for lifting of bucket from in loading to dumping motion.

1.7 What is Computer – Aided Engineering?

Computer-aided engineering (CAE) is the broad usage of computer software to aid in engineering tasks. Software tools that have been developed to support these activities are considered CAE tools. CAE tools are being used, for example, to analyze the robustness and performance of components and assemblies. The term encompasses simulation, validation, and optimization of products and manufacturing tools. CAE areas covered include:

- Stress analysis on components and assemblies using FEA (Finite Element Analysis)
- Thermal and fluid flow analysis Computational fluid dynamics (CFD)
- Kinematics
- Mechanical event simulation (MES)
- Analysis tools for process simulation for operations such as casting, molding, and die press forming.
- Optimization of the product or process.[5]
Chapter 2

DESIGNING OF WHEEL LOADER

2.1 Design Phase 1

As this project is based on reverse engineering, I needed some reference to get the detail dimensions of wheel loader to create 3D model. To get the data from any wheel loader manufacturing company is a daunting task. And even if, I could get it from somewhere it was not possible to disclose here in this project. To overcome this situation, I had purchased a wheel loader toy from Wal-Mart. Disassembled a toy into small but meaningful parts and measured the dimensions of those parts with the help of vernier caliper and ruler. After measuring all the parts, I had started creating 3D model of those parts into SolidWorks.

2.1.1 3D Modeling of Wheel Loader Parts

As mentioned above, SolidWorks has been used to meet 3D modeling needs of this project. Before we go into a depth of this project, it is necessary to study about SolidWorks software and its capabilities which has explained in Appendix B. I have explained below how to create a 3D model from scratch for one of the parts called bucket. One can apply same methodologies to generate other parts. The list of parts has been listed below. Figure 2.1.1.41 to 2.1.1.51 shows the 3d model of all the components. Mass properties of these parts are listed in Appendix A.
1) **Bucket**

1) Open SolidWorks.

2) Click on New tab from File menu as shown in the Figure 2.1.1.1. File → New

![Figure 2.1.1.1 Open New File from File Menu](image)

3) Select Part from “New SolidWorks Documents” popup menu as shown in the Figure 2.1.1.2.

4) Click OK

5) It will open a new file with “Part1” as a file name

6) Change Units to IPS (inch, pound, second) if necessary

7) Click on Options tab from Tool Menu. Tool → Options

8) It will open “System Options” popup menu

9) Click on Document Properties tab
10) On left hand side menu you can see Unit option.

11) Click on Unit

12) It will show you list of unit systems at right hand side as shown in the Figure 2.1.1.3.

13) Select IPS (inch, pound, second) from the list.

14) Click OK

15) Left hand side, in the FutureManager, right click on Front Plane, Top Plane and Right Plane and click on “Show” icon as shown in the Figure 2.1.1.4.
16) It will show the 3 planes (front, right, top) which were hidden before as shown in the Figure 2.1.1.5.

![Figure 2.1.1.3: Change Unit Settings from Tool→Options](image)

![Figure 2.1.1.4: Show Hidden Planes](image)
17) Select right plane and right click on it.

18) Select “sketch” icon on opened popup menu as shown in the Figure 2.1.1.6.
19) Draw a sketch, apply necessary dimensions and make the sketch fully constrained. All the sketch entities will turn into black color once fully defined which has shown in the Figure 2.1.1.7.

![Figure 2.1.1.7: Draw a Sketch.](image)

20) Once you are done with drawing a sketch, click on finish sketch symbol at upper right corner as shown in the Figure 2.1.1.8.

![Figure 2.1.1.8: Right Symbol to Complete Sketch.](image)
21) Sketch of bucket will look as shown in the Figure 2.1.1.9.

![Completed Sketch of Bucket](image1)

Figure 2.1.1.9: Completed Sketch of Bucket

22) Click on Features toolbar and click on Extruded Boss/Base as shown in Figure 2.1.1.10.

![Extruded Boss/Base Command](image2)

Figure 2.1.1.10: Extruded Boss/Base Command
23) In PropertyManager of Boss-Extrude, select the options shown in the Figure 2.1.1.11. Sketch of the bucket will become 3dimensional which has also shown in the Figure 2.1.1.11.

![PropertyManager and Bucket in 3 Dimensions](image)

Figure 2.1.1.11: PropertyManager and Bucket in 3 Dimensions

24) Click on right symbol on upper right corner of the file.

25) Figure 2.1.1.12 is showing the view of the bucket after successfully completed extruded command.

26) Now creates a rounded internal face along one edge in solid with the help of Fillet command.
Figure 2.1.1.12: View of Bucket after First Completed Extruded Command

27) Click on Fillet in Features toolbar as shown in Figure 2.1.1.13

Figure 2.1.1.13: Fillet Command
28) It will open Fillet selection menu in PropertyManager

29) Select the bottom edge of bucket, enter 0.02 as fillet radius and other options and click on right symbol at the upper right corner of the file to complete a command as shown in the Figure 2.1.1.14.

![Figure 2.1.1.14: Selection Menu of Fillet Command](image)
30) Fig 2.1.1.15 shows comparison of bucket before and after the successfully completed fillet command.

Figure 2.1.1.15: Comparison of Bottom Edge after Applying Fillet

31) Now remove material from a solid body to create a thin-walled feature with the help of Shell command. Click on shell command as shown in the Figure 2.1.1.16.

Figure 2.1.1.16: Shell Command
32) It will open Shell selection menu in PropertyManager.

33) Select the front face of bucket to remove material from solid, enter 0.05 inch as thickness as shown in Figure 2.1.1.17.

![Selection Menu of Shell Command](image)

Figure 2.1.1.17: Selection Menu of Shell Command

34) Figure 2.1.1.18 shows bucket after successfully completed shell command.

35) Now create extrude boss/bass on already generated solid body.

36) Select right plane and right click on that.

37) Select sketch symbol ( ) in opened popup menu.
Figure 2.1.1.18: View of Bucket after Completed Shell Command

38) Click on view orientation (symbol located at upper middle portion of file.

39) Select normal to option from view orientation as shown in the Figure 2.1.1.19.

Figure 2.1.1.19: Normal to Top Option
40) Draw a sketch on right plane as shown in the Figure 2.1.1.20.

![Figure 2.1.1.20: Sketch on Right Plane](image)

41) Click on extrude boss/base.

42) On left hand side, in PropertyManager of Boss – Extrude, select Sketch Plane in From, Mid Plane in Direction 1, enter 0.794 inch as a required length, select checkbox option Merge result and click on right symbol on upper right corner of the file as shown in the Figure 2.1.1.21.
Figure 2.1.1.21: Extrude Boss/Base on Already Generated Solid Body

43) Extruded feature has shown in the Figure 2.1.1.22.

Figure 2.1.1.22: Completed Extruded Feature
44) Now use extruded cut feature to cut a solid model by extruding a sketched profile in one or two directions.

45) Before using extruded cut feature we should have sketch profile to use.

46) To generate a sketch profile repeat steps 37 to 40.

47) Click on the face as shown in the Figure 2.1.1.23.

![Figure 2.1.1.23: Selection of Face](image)

48) Click on Convert Entities as shown in the Figure 2.1.1.24.

![Figure 2.1.1.24: Convert Entities Feature](image)
49) It will generate a sketch on the right plane as shown in the Fig 2.1.1.25.

![Generated sketch on right plane](image)

Figure 2.1.1.25: Generated Sketch on Right Plane

50) Click on Extruded Cut feature on feature toolbar as shown in Figure 2.1.1.26.

![Extruded Cut feature](image)

Figure 2.1.1.26: Extruded Cut Feature
51) On left hand side, in PropertyManager, select Sketch Plane in From, Mid Plane in Direction 1, enter 0.57 inch as a required length and click on right symbol on upper right corner of the file as shown in the Figure 2.1.1.27.

![Figure 2.1.1.27: Selection Menu of Cut Extrude Feature](image)

52) Figure 2.1.1.28 shows successfully completed extruded cut command.

53) Now, create holes in solid.

54) Right click on the face and click on sketch icon as shown in the Figure 2.1.1.29.

55) Follow the steps 39 and 40 to rotate and zooms the model to the view orientation normal to the selected face.
56) Now, draw a circle on selected face.
57) Click on Circle feature in feature toolbar as shown in the Figure 2.1.1.30.

![Circle Feature](image)

**Figure 2.1.1.30: Circle Feature**

58) Draw a circle on selected face of diameter 0.08 inch whose center coincides with the outer circle and click on finished sketch symbol on upper right corner of the file as shown in the Figure 2.1.1.31.

![Draw a Circle](image)

**Figure 2.1.1.31: Draw a Circle**

59) Now select that sketch of the circle and click on Extrude Cut feature, it will popup Cut-Extrude PropertyManager, select Sketch Plane in From, Through All in Direction 1 and click on right symbol as shown in the Figure 2.1.1.32.

60) Figure 2.1.1.33 shows holes through solid.
61) Now create teeth at the bottom edge of bucket.

62) Select the face as shown in the Figure 2.1.1.34.
63) Follow the steps 39 and 40.

64) Now, draw a sketch on selected face as shown in the Figure 2.1.1.35.

65) Click on finished sketch symbol at the upper right corner of the file.

66) Click on Extrude Cut feature in feature toolbar.

67) On left hand side, in PropertyManager, select Sketch Plane in From, Through All in Direction 1, and click on right symbol on upper right corner of the file as shown in the Figure 2.1.1.36.
Figure 2.1.1.35: Sketch for Tooth

Figure 2.1.1.36: Extrude Cut Command For Tooth

68) Figure 2.1.1.37 is showing the generated tooth at the bottom of the bucket edge.
Figure 2.1.1.37: Generated Tooth

69) Now, use Linear Pattern to generate the same kind of tooth along the bottom edge.

70) Click on Linear Pattern feature in feature toolbar as shown in the Figure 2.1.1.38.

Figure 2.1.1.38: Linear Pattern Feature
71) In PropertyManager, select the edge 1 for Direction 1, enter 0.443 inch for spacing and 7 for number of instances and click on right symbol as shown in the Figure 2.1.1.39.

![Figure 2.1.1.39: Linear Pattern Command for Similar Teeth along the Edge](image)

72) Figure 2.1.1.40 is showing successfully completed command of Linear Pattern.

![Figure 2.1.1.40: Generated Teeth through Linear Pattern](image)
2) **Upper Body**

Figure 2.1.1.41: Upper Body

3) **Bottom Body**

Figure 2.1.1.42: Bottom Body
4) **Cabin**

![Cabin](image1)

Figure 2.1.1.43: Cabin

5) **Wheel**

![Wheel](image2)

Figure 2.1.1.44: Wheel
6) **Axle**

![Axle](image)

Fig: 2.1.1.45: Axle

7) **Front Railing**

![Front Railing](image)

Figure 2.1.1.46: Front Railing

8) **Rear Railing**

![Rear Railing](image)

Figure 2.1.1.47: Rear Railing
9) **Link1**

![Figure 2.1.1.48: Link1](image1)

10) **Link2**

![Figure 2.1.1.49: Link2](image2)
11) Link3

Figure 2.1.1.50: Link3

12) Link4

Figure 2.1.1.51: Link4
13) **Linkage**

![Linkage](image)

Figure 2.1.1.52: Linkage

### 2.1.2 Assembly of Wheel Loader Parts

Figure 2.1.2.1 and Figure 2.1.2.2 shows the assembly model of wheel loader.

![Wheel Loader Assembly](image)

Figure 2.1.2.1 Isometric View of Wheel Loader Assembly
2.2 Design Phase 2

2.2.1 3D Modeling of Wheel Loader Parts

3d model generated in the design phase 1 was only a replica of wheel loader toy which has been purchased from the Wal-Mart. It was not meeting any kinetics, kinematics and structural requirements of wheel loader. Therefore, it was necessary to implement new components as well as some design modification of previously designed parts to meet the requirements mentioned above. Below are the mentioned design implementation and modification in Design Phase 2.

- Implementation of Tilt/Bucket Cylinder
- Implementation of Lift Arm Cylinder
- Implementation of Connecting Rod
• Modification of Bucket Lever

• Modification of Lift Arm

Figure 2.2.1.1 to 2.2.1.7 shows the above mentioned changes.

1) **Bucket/Tilt Cylinder**

![Bucket/Tilt Cylinder](image1)

Figure 2.2.1.1 Bucket/Tilt Cylinder

2) **Bucket/Tilt Piston**

![Bucket/Tilt Piston](image2)

Figure 2.2.1.2 Bucket/Tilt Piston
3) **Lift Arm Cylinder**

![Lift Arm Cylinder Image]

Figure 2.2.1.3 Lift Arm Cylinder

4) **Lift Arm Piston**

![Lift Arm Piston Image]

Figure 2.2.1.4 Lift Arm Piston

5) **Connecting Rod**

![Connecting Rod Image]

Figure 2.2.1.5 Connecting Rod
6) **Modified Bucket Lever**

Figure 2.2.1.6 Modified Bucket Lever

7) **Modified Lift Arm**

Figure 2.2.1.7 Modified Lift Arm
2.2.2 Assembly of Wheel Loader Parts

Figure 2.2.2.1 to Figure 2.2.2.5 shows the assemblies of piston - cylinder and 3d model of wheel loader.

Figure 2.2.2.1 Piston – Cylinder Assembly

Figure 2.2.2.2 Isometric View of Wheel Loader after Implementing Design Changes
2.3 Design Phase 3

Design phase 3 is all about implementing new systems to make the wheel loader design more realistic. It consists of the following major system implementation.

- Front wheel steering and suspension mechanism
- Rear suspension mechanism.

2.3.1 Front Wheel Steering and Suspension Mechanism

1) Front Wheel
2) **Front Control Arm**

Figure 2.3.1.2 Isometric View of Control Arm
3) **Front Left Steering Knuckle**

![Isometric View of Front Left Steering Knuckle](image)

Figure 2.3.1.3 Isometric view of Front Left Steering Knuckle

4) **Front Right Steering Knuckle**

![Isometric View of Front Right Steering Knuckle](image)

Figure 2.3.1.4 Isometric View of Front Right Steering Knuckle
5) **Front Wheel Steering and Suspension Mechanism Assembly**

Figure 2.3.1.5 Isometric view of Front Wheel Steering and Suspension Mechanism Assembly

**2.3.2 Rear Suspension Mechanism**

1) **Rear Wheel**

Figure 2.3.2.1 Isometric View of Rear Wheel
2) **Rear Control Arm**

![Rear Control Arm Image](image)

Figure 2.3.2.2 Isometric View of Rear Control Arm

3) **Rear Suspension**

![Rear Suspension Image](image)

Figure 2.3.2.3 Isometric View of Rear Suspension
4) **Rear Suspension Cylinder**

![Image of Rear Suspension Cylinder](image1)

Figure 2.3.2.4 Isometric View of Rear Suspension Cylinder

5) **Rear Suspension Mechanism Assembly**

![Image of Rear Suspension Mechanism Assembly](image2)

Figure 2.3.2.5 Isometric View of Rear Suspension Mechanism Assembly
2.3.3 Assembly of Wheel Loader Parts

Figure 2.3.3.1 Bottom View of Wheel Loader

Figure 2.3.3.2 Isometric View of Wheel Loader
Figure 2.3.3.3 Isometric View of Wheel Loader in Different Position
Chapter 3

KINEMATICS AND FINITE ELEMENT ANALYSIS OF WHEEL LOADER

To run any analysis in any software, it is necessary to have your 3D model compatible with that software. Most of the current designing and analysis softwares in the market allow direct import of geometry from designing software to analysis software through Application Programming Interface (API). But, what if your analysis software does not have any support for direct import of geometry? In that case, engineers have to manually convert geometries one by one in known file format like IGES or STEP, so their analysis software can recognize and allow imports. Once all the geometries are converted to known file format, engineers have to manually define all the required constraints between the geometries to assemble them. As Visual Nastran Desktop 4D does not have API support for SolidWorks, I had also taken this approach to make it work. Following steps shows the procedure to convert SolidWorks geometries in Visual Nastran Desktop 4D.

3.1 Steps to Convert SolidWorks Geometries into VND4D

1) Open any part file in SolidWorks which you want to convert into STEP file format.

2) Click on File ➔ Save As option.

3) It will open Save As dialog box.
4) In Save As dialog box, keep the file name as it is while change the Save as Type to STEP AP203 or STEP AP214 as per your requirements. Also check the box for Save as Copy as shown in the Figure 3.1.1.

![Save as SolidWorks Part File to STEP File](image)

Figure 3.1.1 Save as SolidWorks Part File to STEP File

5) Repeat step number 1 to 4 for all the parts that needs to be converted into STEP file format.

6) Now, open Visual Nastran Desktop 4D. Click on File Open. Open dialog box will pop up as shown in the Figure 3.1.2. Select any file that you want to open. Check radio button for Specify length unit and select inch (in) from drop down list.

7) Assemble all the parts by defining all required constraints between geometries.
3.2 Kinematics Analysis of Wheel Loader

"Kinematics is the branch of classical mechanics or mechanical engineering that describes the motion of bodies (objects) and systems (groups of objects) without consideration of the forces that cause the motion." [6]

In this project, the kinematic analysis has been done with the help of MSC Visual Nastran Desktop 4D. The core purpose of kinematic analysis was to comprehend whether the assembly performs the loading and dumping motion flawlessly or not. Figure 3.2.1 shows wheel loader assembly in Visual Nastran Desktop 4D.
Wheel loader performs its loading and dumping motion with help of bucket/tilt cylinder, lift arm cylinder, lift arms, bucket/tilt lever and connecting rod. Figure 3.2.2 shows all above mentioned parts more closely.
Now, to perform loading and dumping motion of wheel loader follow the following steps.

1. In Visual Nastran Desktop 4D, right click on Bucket/Tilt cylinder as shown in the Figure 3.2.3.

![Figure 3.2.3 Right Click on Bucket/Tilt Cylinder](image)

2. It will open Properties menu as shown in the Figure 3.2.4.

3. Click on Actuator tab in Properties menu.

4. Select Length/Displacement in Actuator Type as shown in Figure 3.2.4.

5. Also, check the box for Point – to – Point.

6. Click on browse button to edit the Value field.
7. It will open Edit Table menu as shown in the Figure 3.2.5.

![Figure 3.2.4 Properties Menu](image1.png)

![Figure 3.2.5 Edit Table Menu](image2.png)
8. Click on browse button and select the .txt file which contains values as shown in the Table 3.2.1.

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Table 3.2.1 Length of Actuator (m) Against Time (s) Values for Bucket/Tilt Cylinder

9. Figure 3.2.6 shows the graph of above tabulated values with Time (s) in X-direction and Length of Actuator (m) in Y-direction.

10. Click OK on Edit Table menu.

11. Click on Apply and Close the Properties menu.

12. Now, Right Click on one of the Lift Arm Cylinders.

13. Click on Properties as shown in the Figure 3.2.3.


15. Keep the selection same as shown in the Figure 3.2.4.
Figure 3.2.6 Time(s) vs. Length of Actuator (m) Graph for Built/Tilt Cylinder

16. Click on browse button and select the .txt file which contains values as shown in the Table 3.2.2.

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</tr>
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<td>0.0586</td>
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</tr>
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<td>0.0658</td>
</tr>
<tr>
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<td>0.0662</td>
</tr>
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<td>9</td>
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</tr>
<tr>
<td>10</td>
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</tr>
<tr>
<td>11</td>
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<td>28</td>
<td>3.7</td>
<td>0.0674</td>
</tr>
<tr>
<td>12</td>
<td>2.1</td>
<td>0.061</td>
<td>29</td>
<td>3.8</td>
<td>0.0678</td>
</tr>
<tr>
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<td>0.0614</td>
<td>30</td>
<td>3.9</td>
<td>0.0682</td>
</tr>
<tr>
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<td>2.3</td>
<td>0.0618</td>
<td>31</td>
<td>4</td>
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<tr>
<td>15</td>
<td>2.4</td>
<td>0.0622</td>
<td>32</td>
<td>4.1</td>
<td>0.069</td>
</tr>
<tr>
<td>16</td>
<td>2.5</td>
<td>0.0626</td>
<td>33</td>
<td>4.2</td>
<td>0.0694</td>
</tr>
<tr>
<td>17</td>
<td>2.6</td>
<td>0.063</td>
<td>34</td>
<td>4.3</td>
<td>0.0698</td>
</tr>
</tbody>
</table>

Table 3.2.2 Length of Actuator (m) Against Time (s) Values for Lift Arm Cylinder

17. Figure 3.2.7 shows the graph of above tabulated values with Time (s) in X-direction and Length of Actuator (m) in Y-direction.

18. Click OK on Edit Table menu.

19. Click on Apply and Close the Properties menu.
20. Repeat steps 13 to 20 for remaining Lift Arm Cylinder.

Figure 3.2.8 shows the graph of length (m) of bucket/tilt cylinder and lift arm cylinder against time (s). As shown in the figure, displacement of bucket/tilt cylinder starts at time 0 second. From 0 to 1 second the length of bucket/tilt cylinder increases from 0.0567 m to 0.0599 m. As bucket cylinder connected to bucket lever at upper end, the increase in length of bucket cylinder push forward the bucket lever at upper end and push back the lower portion. As connecting rod connected to lower side of bucket lever at one end while with bucket at other end, the push back motion of lower side of bucket lever also push back the connecting rod which ultimately tilt the bucket to its desired angle. At time 1 second, bucket cylinder comes to rest for another 1.5 second while the length of lift arm cylinders starts increasing at 1 second to 4.3 seconds from 0.0566 m to 0.0698m which
led off the lifting of bucket from ground. From time 2.6 to 6.7 seconds, the length of bucket cylinder starts decreasing from 0.0599 m to 0.0467 m which begins the dumping motion. Please also referred to video “Loading and Dumping Motion” with attached CD.

![Graph of Time(s) vs. Length of Actuator (m) for Bucket and Lift Arm Cylinder](image)

Figure 3.2.8 Time(s) vs. Length of Actuator (m) Graph for Bucket and Lift Arm Cylinder

### 3.3 Finite Element Analysis of Wheel Loader

“Finite Element Analysis is a computerized method for predicting how a component/assembly will react to environmental factors such as forces, heat and vibration. It is called "analysis", but in the product design cycle it is used as a "virtual prototyping" tool to predict what is going to happen when the product is used.” [7]
“Finite element analysis, as related to the mechanics of solids, is the solution of a finite set of algebraic matrix equations that approximate the relationships between load and deflection for static analysis as well as velocity, acceleration and time for dynamic analysis.” [7]

“The finite element method works by breaking a real object down into a large number (1000's or 100,000's) of elements (e.g. cubes). The behavior of each little element, which is regular in shape, is readily predicted by set mathematical equations. The summation of the individual element behaviors produces the expected behavior of the actual object.” [7]

“The "finite element" is a small, but not infinitesimal, part of the mechanical structure being modeled that incorporates complex strength of materials formulations into a relatively simple geometric shape. The simplest examples are rods, beams and triangular plates. More complicated elements include quadrilateral plates, curved shells and 3-dimensional solids such as hexahedrons (bricks).” [7]

“The "Finite" in Finite Element Analysis comes from the idea that there are a finite number of elements in a finite element model. Previously, engineers employed integral and differential calculus techniques to solve engineering analysis problems. These techniques break objects down into an infinite number of elements, for problem solving.” [7]
3.3.1 FEA Process

- **Finite Element Modeling:** “Finite Element Analysis begins with the finite-element modeler (sometimes called a mesher or preprocessor). The cost-effectiveness of FEA is heavily dependent on the Pre-Processor since the vast majority of human time involved in Finite Element Analysis is spent in creating the model for analysis. In order to effectively incorporate analysis into the design cycle, you must be able to quickly create the required models. The modeler creates the physical data necessary for analysis by creating a mesh of elements utilizing either an imported 3D CAD model or one generated internally.” [7]

“There are two basic mesh types characterized by the connectivity of their points. Structured meshes have a regular connectivity, which means that each point has the same number of neighbors (for some grids a small number of points will have a different number of neighbors). Unstructured meshes have irregular connectivity (e.g. each point can have a different number of neighbors.)” [7]

“Unstructured meshes have been developed mainly for the finite element method. There is a large range of possible shapes for finite elements: tetrahedra, prisms, blocks, and there can be arbitrary connectivity, leading to unstructured meshes. Meshes can be generated fully automatically using triangles in 2D and tetrahedra and now blocks in 3D.” [7]
Finite Element Solvers: “Solvers are the engines of finite-element analysis. They take the elements, boundary conditions, and loads and output a solution containing all of the information needed to review and understand results. Solvers may be divided into two categories: linear and nonlinear.” [7]

“Linear FEA is differentiated from nonlinear in that all deflections are assumed small, no boundary conditions change during the analysis and material properties are linear (i.e., elastic)” [7]

Post Processing: “Postprocessors--or visualizers--utilize the data generated by the solver to create easily understandable graphics and reports.” [7]

3.3.2 List of Parts Included in FEA and Their Properties

Following are the list of parts and properties that have been included in Finite element Analysis.

1) Bucket: Figure 3.3.2.1 shows bucket with generated mesh.

![Figure 3.3.2.1 Bucket with Generated Mesh](image)
Table 3.3.2.1 Properties of Bucket

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel - ANSI C1020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>0.155 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>1.98e-5 m³</td>
</tr>
<tr>
<td>Mesh</td>
<td></td>
</tr>
<tr>
<td>Default Mesh Size</td>
<td>0.005 m</td>
</tr>
<tr>
<td>Mesh Factor</td>
<td>13.3</td>
</tr>
<tr>
<td>Nodes</td>
<td>7293</td>
</tr>
<tr>
<td>Elements</td>
<td>3590</td>
</tr>
<tr>
<td>Coefficient of Restitution</td>
<td>0.5</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.5</td>
</tr>
</tbody>
</table>

2) **Main Body**: Figure 3.3.2.2 shows a main body with generated mesh.

Figure 3.3.2.2 Main Body with Generated Mesh
### Table 3.3.2.2 Properties of Main Body

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel - ANSI C1020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>2.71 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>0.000345 m³</td>
</tr>
<tr>
<td><strong>Mesh</strong></td>
<td></td>
</tr>
<tr>
<td>Default Mesh Size</td>
<td>0.5 m</td>
</tr>
<tr>
<td>Mesh Factor</td>
<td>2.07e + 7</td>
</tr>
<tr>
<td>Nodes</td>
<td>27637</td>
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<tr>
<td>Elements</td>
<td>15583</td>
</tr>
<tr>
<td>Coefficient of Restitution</td>
<td>0.5</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.5</td>
</tr>
</tbody>
</table>

3) **Lift Arms:** Figure 3.3.2.3 shows a lift arm with generated mesh.

![Figure 3.3.2.3 Lift Arm with Generated Mesh](image)
Table 3.3.2.3 Properties of Lift Arm

<table>
<thead>
<tr>
<th>Material</th>
<th>Steel - ANSI C1020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>0.0229 kg</td>
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<tr>
<td>Volume</td>
<td>2.96e-6 m³</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mesh</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Default Mesh Size</td>
<td>0.005 m</td>
</tr>
<tr>
<td>Mesh Factor</td>
<td>23.4</td>
</tr>
<tr>
<td>Nodes</td>
<td>1406</td>
</tr>
<tr>
<td>Elements</td>
<td>601</td>
</tr>
<tr>
<td>Coefficient of Restitution</td>
<td>0.5</td>
</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4) **Bucket Lever:** Figure 3.3.2.4 shows a bucket lever with generated mesh.

![Bucket Lever with Generated Mesh](image)
<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Material</strong></td>
<td>Steel - ANSI C1020</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>0.02 kg</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>2.54e-6 m³</td>
</tr>
<tr>
<td><strong>Mesh</strong></td>
<td></td>
</tr>
<tr>
<td>Default Mesh Size</td>
<td>0.0005 m</td>
</tr>
<tr>
<td>Mesh Factor</td>
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<tr>
<td>Elements</td>
<td>832</td>
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<tr>
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</tr>
<tr>
<td>Coefficient of Friction</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3.3.2.4 Properties of Bucket Lever

5) **Connecting Rod**: Figure 3.3.2.5 shows a connecting rod with generated mesh.

Figure 3.3.2.5 Connecting Rod with Generated Mesh
3.3.3 Case Study 1

In this study, wheel loader dumps a cube of 1 kg. Figure 3.3.3.1 shows the initial condition of the study. At time 0 second, cube is resting on the bucket. Between 0 to 1 second, bucket cylinder starts increasing its length and that led off the tilting of the bucket upward from the ground. At time 1 second, bucket cylinder comes at rest and lift arm cylinder starts expanding its length till 4.3 second which led off the lifting of the bucket. Around 2.5 seconds, bucket cylinder starts contracting till 6.7 seconds which led off the dumping motion of bucket.

<table>
<thead>
<tr>
<th>Mesh</th>
<th>Material</th>
<th>Steel - ANSI C1020</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mass</td>
<td>0.00115 kg</td>
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<tr>
<td></td>
<td>Volume</td>
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<td></td>
<td>Default Mesh Size</td>
<td>0.005 m</td>
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<tr>
<td></td>
<td>Mesh Factor</td>
<td>2.84</td>
</tr>
<tr>
<td>Mesh</td>
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<td></td>
<td>Elements</td>
<td>198</td>
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<tr>
<td></td>
<td>Coefficient of Restitution</td>
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</tr>
<tr>
<td></td>
<td>Coefficient of Friction</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3.3.2.5 Properties of Connecting Rod
Figure 3.3.3.1 Initial Condition of Wheel Loader (Case Study 1)

Figure 3.3.3.2 Von Mises Stress (Pa) in Left Lift Arm (Case Study 1)
Figure 3.3.3.2 shows the Von Mises Stress (Pa) distribution in left lift arm. As shown in the figure, the maximum value of Von Mises Stress is 0.525 GPa which is well below than the Steel’s 230 GPa tensile strength.

Figure 3.3.3.3 Average Deformation (m) in Left Lift Arm

Figure 3.3.3.3 shows the average deformation and the deformation of left lift arm in x direction. As shown in the figure, the maximum value for the average deformation is 0.044 mm while maximum value for the displacement in x direction is 0.0438 mm.
Figure 3.3.3.4 Deformed Left Lift Arm in Y and Z Directions

Figure 3.3.3.4 shows deformation of left link arm in y and z direction. As shown in the figure, the maximum value for the displacement in y and z direction is 0.0184 and 0.00176 mm respectively.

<table>
<thead>
<tr>
<th>Table 3.3.3.1 Stress and Displacement Values for Left Link Arm (Case Study 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Von Mises Stress (GPa)</strong></td>
</tr>
<tr>
<td><strong>Delta_Mag Displacement (mm)</strong></td>
</tr>
<tr>
<td><strong>Delta_x Displacement (mm)</strong></td>
</tr>
<tr>
<td><strong>Delta_y Displacement (m)</strong></td>
</tr>
<tr>
<td><strong>Delta_z Displacement (m)</strong></td>
</tr>
</tbody>
</table>
3.3.4 Case Study 2

In this study, wheel loader dumps a cube of 5 kg. Figure 3.3.4.1 shows the initial condition of this study. At time 0 second, cube is resting on the bucket. Between 0 to 1 second, bucket cylinder starts increasing its length and that led off the tilting of the bucket upward from the ground. At time 1 second, bucket cylinder comes at rest and lift arm cylinder starts expanding its length till 4.3 second which led off the lifting of the bucket. Around 2.5 seconds, bucket cylinder starts contracting till 6.7 seconds which led off the dumping motion of bucket.

Figure 3.3.4.1 Initial Condition of Wheel Loader (Case Study 2)
Figure 3.3.4.2 Von Mises Stress (Pa) in Left Lift Arm (Case Study 2)

Figure 3.3.4.2 shows the Von Mises Stress (Pa) distribution in left lift arm. As shown in the figure, the maximum value of Von Mises Stress is 2.26 GPa which is well below then the Steel’s 230 GPa tensile strength.
Figure 3.3.4.3 Delta_MAG Displacement (m) (Case Study 2)

Figure 3.3.4.3 shows the average deformation in wheel loader system. As shown in the figure, the maximum value for the average deformation is 0.188 mm.

Figure 3.3.4.4 Delta_X Displacement (m) (Case Study 2)
Figure 3.3.4.4 shows the deformation in x direction in wheel loader system. As shown in the figure, the maximum value for the deformation in x direction is 0.187 mm.

Figure 3.3.4.5 shows the deformation in y direction in wheel loader system. As shown in the figure, the maximum value for the deformation in y direction is 0.0783 mm.
Figure 3.3.4.5 shows the deformation in z direction in wheel loader system. As shown in the figure, the maximum value for the deformation in z direction is 0.0307 mm.

![Figure 3.3.4.6 Delta_Z Displacement (m) (Case Study 2)](image)

<table>
<thead>
<tr>
<th>Stress and Displacement Values (Case Study 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Von Mises Stress (GPa)</td>
</tr>
<tr>
<td>Delta_Mag Displacement (mm)</td>
</tr>
<tr>
<td>Delta_x Displacement (mm)</td>
</tr>
<tr>
<td>Delta_y Displacement (m)</td>
</tr>
<tr>
<td>Delta_z Displacement (m)</td>
</tr>
</tbody>
</table>

Table 3.3.4.1 Stress and Displacement Values (Case Study 2)

### 3.3.5 Results

From Table 3.3.4.1 and 3.3.4.2, the maximum Von Mises Stress in the system is 0.525 and 2.26 Gpa which is well below then the tensile strength (230 GPa) of Steel – ANCI C1020 with Factor of Safety is 1.2 which shows that design is to be real time for the given case studies.
REFERENCES


