CHALMERS

CORRELATION OF MOVEMENT BETWEEN CAB, ENGINE AND FRONT AXLE

Master of Science Thesis in the Master Degree Programme, Product Development

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Gothenburg, Sweden, 2012

Master's Thesis 2012:

Volvo Group Trucks Technology Chalmers University of Technology

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Cover:
The Volvo Truck Globetrotter Studio Shoot, Front View of the Truck.

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Abstract

The need to deliver the best in class product requires a best in class development process and methods. Companies try to provide robust and reliable products at a competitive cost but, the development time and testing of prototypes increases the cost of the products. The development and testing cost can be reduced by using CAD and Analysis application like Pro-E, MSC NASTRAN, etc. The products are directly tested using analysis for various tests without developing a prototype.

In heavy vehicle industries (Truck), the development of every part involves a considerable amount of time and cost, to overcome the same, components are tested for various requirements. One of the requirements is the movement of components. When the truck travels on-road the movement of the components in the truck depends on various factors like speed, road condition, temperature, etc. If the complete movement of the components is studied, it can help in developing a robust and reliable component, which can avoid the collision between the components during movement of the truck.

The movement of trucks were initially studied by using Volvo's in-built application Complete Vehicle Model (CVM). The cab, engine and front axle movements were studied in detail for selected truck models. Movements for a single point on each system were extracted from CVM and the movements were studied using Pro-E and by plotting graphs with respect to time. Since the Pro-E and CVM models were not exactly similar, using the movements directly from CVM into Pro-E was not possible; to overcome the issue of difference between Pro-E and CVM, a Matlab application was developed to make use of the movements from CVM to Pro-E.

Using the Matlab application the movement at the point of interest on cab, engine and front axle were calculated, with the movements extracted from CVM. The application assisted in using the movements from CVM into Pro-E thereby the envelope of components was created and the distance between the components in motion for any required test track was studied.

Key words: Correlation, Cab movement, Engine movement, Front Axle Movement.

Acknowledgement

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Gothenburg June 2012

Balaji Ponnusamy

Contents

1. Introduction

The globalization of business has given way to new customers and competitors. As world trade has expanded and international markets have become more accessible, the list of one's toughest competitors now includes firm's that may have grown up in different environment.[1] The level of competition has gone aggressive due to evolution of technology and scientific knowledge. As part of the globalization, customer expectations have also evolved, they are more stylish and demanding. Previously customer's unheard levels of performance and reliability are today the expected standards [1]. Customers are more sensitive to nuances and difference in product, and are attracted to products that provide solutions to their particular problems and needs. Yet they expect these solutions in easy-to-use forms.[1]

According to Karl T. Ulrich and Steven D. Eppinger; a successful product development is characterized by Product Quality, Product Cost, Development Time, Development Cost and Development Capability. The Product development process is a sequence of step or activities which an enterprise employs to conceive, design and commercialize a product.[2] The process involves different phases like Planning, Concept Development, System-level Design, Detail Design, Testing and Refinement, and Production Ramp-up.[2]

In the rapidly changing global market, customers expect high quality products at most reasonable price. It is unfeasible to develop an ideal product without investigating in real time conditions. The time taken to fabricate and test a prototype at each phase of product development can cause late to market situation, thereby leading to loss in business. The issues can be overcome by means of Computer Aided Engineering.

Simulation plays a significant role in the field of Computer Aided Engineering; they assist in analyzing the product for various conditions. Thus, reliable products are developed by ensuring design quality, safety and environmental impact, first to market, customer satisfaction, etc. In the field of heavy vehicle industry, simulation is used for various purposes like analysis of individual component, assembly, kinematics, fuel efficiency, etc.

1.1 Objective

Uncertainty is the difference between the amount of information required to perform the task and the amount of information already possessed by the organization.[3] A truck is built using various mechanical, electrical and electronic components, when the truck moves on-road the components move with respect to the system to which it is attached. The systems move due to various factors like speed of the truck, road condition, climate, etc. To design a robust and reliable truck; the movements of each component on the truck should be determined and analyzed for issues between the systems, due to the movements.

The greater the task uncertainty, the greater the amount of information that must be processes among decision makers during task execution in order to achieve a given level of performance.[3] To determine the movement of every component in the truck using real time test tracks and trucks will cost a lot of time and money, to overcome the issue of cost and time the truck models in CAD systems were used to simulate the movements of the trucks in the virtual test tracks.

The objective of the thesis was to identify the displacement and rotational values of three systems; cab, engine and front axle of trucks, which can cause collision between the systems. The skeleton model of the truck and different test tracks were built using MSC Nastran commands in Volvo's in-house Complete Vehicle Model (CVM). The movements between these systems were studied using Pro-E to determine the critical distance between the different systems of interest.

1.2 Scope and limitation

The critical values identified in this thesis were used to study the behavior of the entire system or any particular part in the system. Thereby giving the complete understanding of the system or the component's in or attached to the same. The Matlab application needs the displacement and rotation of any point on each system to calculate displacement of any points on the system. The identification of critical values was essential because they assisted in verifying the design of the components in the system.

The systems were built using various components and the material properties of the components were not the same, Due to different material properties in the system it was not possible to apply same rigid body equation on the entire system. Hence the three systems were considered to be completely rigid.

The movement values of the truck obtained from the virtual test track had the movement values of the grid point from the starting position of the truck to its rest; this movement involved the total length of the test track and the movement of the grid. When compared to the length of the track the movements were very small, due to which the small or relative movements were ignored by MSC Nastran. To get more accurate movement values, the movements relative to the Chassis were considered.

2 Theory

A rigid body is an ideal solid whose size and shape remains unaltered irrespective of the amount of force applied on it. The angle of rotation in a rigid body is same throughout the entire body; thus if we identify displacement and rotation of one point on a rigid body, we can calculate the movement of any point on the rigid body.[4]

2.1 Rotation Matrix

Let us consider two coordinate systems; a global coordinate system (fixed) with unit vectors e_X e_Y e_Z with respect to the X, Y and Z axes and a local coordinate system (variable) with unit vectors e_x e_y e_z with respect to the *x, y* and *z* axes, Both coordinate systems are positioned with coinciding origin and different orientation. The unit vector in the local coordinate system can be written in terms of the global coordinate system.[4]

$$\boldsymbol{e_x} = \boldsymbol{c_{xX}e_X} + \boldsymbol{c_{xY}e_Y} + \boldsymbol{c_{xZ}} \tag{2. 1}$$

$$\boldsymbol{e_y} = \boldsymbol{c_{yX}e_X} + \boldsymbol{c_{yY}e_Y} + \boldsymbol{c_{yZ}e_Z} \tag{2. 2}$$

$$\boldsymbol{e_z} = \boldsymbol{c_{zX}e_X} + \boldsymbol{c_{zY}e_Y} + \boldsymbol{c_{zZ}e_Z} \tag{2. 3}$$

Where, c_{xI}, c_{yI}, c_{zI} are the directional cosines or scalar product between local unit vectors and the Global unit vectors and

$$\boldsymbol{c_{xI}} = \boldsymbol{e_x} * \boldsymbol{e_I} = \cos\boldsymbol{\theta_{xI}}, \text{ I=X, Y, Z.}$$

$$\begin{pmatrix} e_x \\ e_y \\ e_z \end{pmatrix} = \boldsymbol{R} \begin{pmatrix} e_X \\ e_Y \\ e_Z \end{pmatrix} \tag{2. 4}$$

$$\boldsymbol{R} = \begin{pmatrix} c_{xX} & c_{xY} & c_{xZ} \\ c_{yX} & c_{yY} & c_{yZ} \\ c_{zX} & c_{zY} & c_{zZ} \end{pmatrix} \tag{2. 5}$$

The above equation (2.5) can be used to find the rotation about each axis.

$$\boldsymbol{R_X} = \boldsymbol{R_X}(\boldsymbol{\theta_X}) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_X & \sin\theta_X \\ 0 & -\sin\theta_X & \cos\theta_X \end{pmatrix} \tag{2. 6}$$

$$\boldsymbol{R_Y} = \boldsymbol{R_Y}(\boldsymbol{\theta_Y}) = \begin{pmatrix} \cos\theta_Y & 0 & -\sin\theta_Y \\ 0 & 1 & 0 \\ \sin\theta_Y & 0 & \cos\theta_Y \end{pmatrix} \tag{2. 7}$$

$$\boldsymbol{R_Z} = \boldsymbol{R_Z}(\boldsymbol{\theta_Z}) = \begin{pmatrix} \cos\theta_Z & \sin\theta_Z & 0 \\ -\sin\theta_Z & \cos\theta_Z & 0 \\ 0 & 0 & 1 \end{pmatrix} \tag{2. 8}$$

When an object travels in space, the movement or the position of the object can be defined by the angle between the object and axis, by using a rotation matrix. To calculate the position of an object in space the order in which the object rotates about the axis is important. In space, the object moves around the entire three axes, but at any time "T" the object would have made rotation only about one axis, thus the movement can be obtained by identifying the right order of the rotation.

$$\boldsymbol{R} = (\boldsymbol{R_Z} * \boldsymbol{R_Y} * \boldsymbol{R_X}) \quad \textbf{(2. 9)}$$

Consider a particle or point "P" located at a distance "r" from the origin with respect to local coordinate.

The point P can be expressed with respect to the unit vectors in the local or body fixed coordinate system (x ,y, z)as

$$\boldsymbol{r} = \boldsymbol{x e_x} + \boldsymbol{y e_y} + \boldsymbol{z e_z} \quad \textbf{(2. 10)}$$

The same point P can be expressed in the global coordinate system (X ,Y, Z) as

$$\boldsymbol{r} = \boldsymbol{X e_X} + \boldsymbol{Y e_Y} + \boldsymbol{Z e_Z} \quad \textbf{(2. 11)}$$

When the point P progress; it travel in the global coordinate system, thereby the local coordinate system also moves along with the body. When the body rotates, it rotates in the global coordinate system but, the point "P" remains in the same position with respect to the local or body fixed coordinate system. Hence the point "P" can be expressed in terms of global coordinate through the local coordinate.

$$\boldsymbol{r_{local}} = (\boldsymbol{R} * \boldsymbol{r_{global}}) + \boldsymbol{r_p} \quad \textbf{(2.12)}$$

- Where "R" is the rotation matrix,
- r_{global} is the displacement vector defining the distance between global origin to the point of rotation, i:e; the origin of the components.
- r_{local} is the displacement vector defining the distance between global origin to the point of interest on the component.
- r_P is the displacement vector defining the distance between origin of the component to the point of interest on the same.

2.2 Complete Vehicle Model CVM

CVM is Volvo's inbuilt application to generate Complete Vehicle Models in Nastran format for performing various analyses like

- Static and dynamic load calculation on components.
- Endurance test
- Vibration test
- Comfort
- Handling, etc.

The CVM assist in analyses of unique truck configuration by building the truck from the KOLA database. KOLA is Volvo's inbuilt application to maintain the variants amongst the components. CVM and KOLA ensures a structured way of working .Thereby common standard and quality of work is followed between all users, it also enables users to share the results. The truck model built in CVM will be sent to the Nastran solver to analyze the model for the required test conditions. The CVM is used as an alternative to testing ground, road simulator and rigs. CVM is a virtual development application which aid in efficiency and cost reduction of trucks.

2.3 MSC NASTRAN

The MSC NASTRAN commands were used to build the components of the truck, assemble and build the testing grounds, rigs, etc. The models built using Nastran commands in CVM were inspected in ANSA to verify the correctness of the models. Predefined models were used to study the movement of Cab, Engine and Front Axle. The following commands were used as part of this thesis,

- GRID
- RBE3
- RBAR
- EPOINT
- TF

The syntax and descriptions were used from the MSC NASTRAN User Guide [5].

GRID

Defines the location of a geometric grid point, the directions of its displacement, and its permanent single-point constraints[5]

Grid Point Format:

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X1	X2	X3	CD	PS	SEID	

Example:

$Reference point on CAB for origin

GRID, 195031, 96001, 0, 0, 0, 96001

RBE3

Defines the motion at a reference grid point as the weighted average of the motions at a set of other grid point[5]

RBE3 Format:

RBE3	EID		REFGRID	REFC	WT1	C1	G1,1	G1,2	
	G1,3	WT2	C2	G2,1	G2,2	-etc-	WT3	C3	
	G3,1	G3,2	-etc-	WT4	C4	G4,1	G4,2	-etc-	
	“UM”	GM1	CM1	GM2	CM2	GM3	CM3		
		GM4	CM4	GM5	CM5	-etc-			
	“ALPHA”	ALPHA							

Example:

RBE3, 43013, , 195031, 123456, 1.0, 123456, 195032

RBAR

Defines a rigid bar with six degrees-of-freedom at each end.[5]

RBAR Format:

1	2	3	4	5	6	7	8	9	10
RBAR	EID	GA	GB	CNA	CNB	CMA	CMB	ALPHA	

Example:

RBAR 94002 96001 95031 123456 0 0 123456

EPOINT

Defines extra points for use in dynamics problems[5]

EPOINT Format:

1	2	3	4	5	6	7	8	9	10
EPOINT	ID1	ID2	ID3	ID4	ID5	ID6	ID7	ID8	

Alternate Format:

EPOINT	ID1	“THRU”	ID2						

Example:

EPOINT, 1195031

TF

Defines a dynamic transfer function of the form[5]

TF Format:

TF	SID	GD	CD	B0	B1	B2			
	G(1)	C(1)	A0(1)	A1(1)	A2(1)	-etc-			

Example:

TF, 100, 1195031, , 1.0,1.0E-5,1.0E-8,,,+

+, 95031, 1, 1.0, 0.0, 0.0, , , , +

+, 195031, 1, -1.0, 0.0, 0.0

2.4 PRO-ENGINEER

The models in Pro Engineer were used to create the envelopes for components of interest. An envelope in general is the outer profile of the component but, in this thesis the components moves with respect to time and hence to study the behavior of the component an envelope is generated with respect to time and the maximum movements of the component is viewed. For every specification of the truck an envelope was generated between the components to ensure the clearance between the entire systems or components between them.

Initially a standard set of values as in the below tables were used when checking the maximum and minimum movements of the system.

Table 1: Sample table of Displacement and Rotation

Combination of Motion	Level	Pitch	Roll	Yaw	X-dir	y-dir
1.Max Pitch Backwards	14	2	4	6	22	78
2.Max Pitch Forwards	08	5	9	5	56	16
3.Max Level/Roll/Yaw/move in Dir Y+	90	8	3	7	84	22
3.Max Level/Roll/Yaw/move in Dir Y-	57	1	1	9	11	37
5.Max Level/Yaw	37	3	8	2	27	89
6.Max Level/Roll	10	9	5	14	51	35
7.Max Movement in X	81	4	2	8	43	09

Table 2: Table to simulate combination of motion

Cab Level	$\pm mm$	0.000
Pitch Angle	$\pm$ °	0.000
Roll Angle	$\pm$ °	0.000
Yaw Angle	$\pm$ °	0.000
X direction	$\pm mm$	0.000
Y direction	$\pm mm$	0.000

The tables had defined values within which the Pro-E models were assessed for clearance. The tables provided a generalized movement for every family of truck but, it restricted the user from knowing at what point in time the components or systems came close to each other. The usage of the table also restricted the user from knowing the movement of the systems for the complete test track length, instead it just gave specific values to be checked.

3 Methods

The quality of the product is a vital characteristic for any product, it reflects the market share of the product; the product should satisfy customer needs, be reliable and robust. Customers expect high quality products for competitive price. To deliver the best, at sensible cost, depends upon various factors. The development cost and the development time are major contributors to the product cost.

3.1 Introduction to Product Development

Product development in general comprises various processes and methods to create ideas and develop them into a complete product. According to Karl T. Ulrich and Steven D. Eppinger the product development process is the sequence of steps or activities employed to conceive, design and commercialize a product. The steps or activities involved in the process depend on the intellectual and organization need[6]. The process varies between organizations and in some case it also varies within the same organization to suit the need of the product developed. In every product development process every step or activity is evaluated for inputs and outputs, various methods and processes are used to scrutinize the input and output of each phase. The following shows a typical product development process from planning to production ramp-up.

Figure 1: The Generic Product Development Process.

Planning

Planning is the initial stage of the product development process; it is also referred as “zero-phase”. This phase involves identifying the portfolio of the product to be developed, the time required for development, evaluating technology developments, benchmarking competitors, allocating resources, etc. The planning is re-evaluated during the course of time to verify and update the process according to the market and requirements.

Concept Development

The concept development phase studies the customer needs in details to establish a target specification. Various product concepts are generated, evaluated and one or more concepts are selected and further developed, to satisfy the customer. The concepts are refined to suit any changes in the target specification. During the concept development phase, cross functional teams are involved to suggest new requirements or new concepts in order to deliver the best. Concept generation can be executed with the help of certain product development tools like function means tree, morphological matrix, TRIZ, Brain storming, 6-3-5 etc and these concepts can be evaluated using tools such as Pugh Matrix or Kesselring Matrix.

System Level Design

In system level design the product architecture is defined. The product is divided into various subsystems and components; geometric layouts of the product, assembly processes are defined in this phase. The modularity of products is decided during this phase, Customers care about distinctiveness; costs are driven by commonality.[7] The modularization of products also increases the complexity of the design but it provides a large variety of end products, mass customization, etc.

Detail Design

The product is designed to its every detail like geometry, material and tolerance of all unique parts in the product; the standard parts used are identified and purchased from suppliers. A control document is the output of this phase; it includes detail drawings of the product, the tools used in production, specification of purchased parts, production cost, robust performance, etc.

Testing and Refinement

In this phase the prototype of the product is developed and tested for various conditions. The prototypes are tested individually and as assembly to ensure the functionality and robustness of the parts and the complete product. The prototypes are also tested by customers in their own testing facilities to verify the requirements. Using prototype technologies like digital mock up, digital prototype, virtual prototype, etc; the production process, methods and robustness of the products are tested and verified with customer requirements.

Production Ramp-Up

The production ramp-up is the final phase of the product development process, in this phase the product is made using the actual production system to train the work force and identifies any flaws in the production process. The product developed in this process is supplied to preferred customers to test the product; finally a transition is made from production ramp-up to ongoing production, this transition is done gradually.

3.2 Implementation of the Product Development Process

The various methods and process of product development were tuned to meet the needs of the thesis and the following phases were developed.

Planning

The thesis was initially planned to be executed with following steps and time period.

	Time in Weeks
Literature Study	2
Study of Truck Models	3
Data Collection	2
Analysis of Data	3
Problem Identification	2
Resolve Problem	3
Application Development	3
Testing Solution	2
Recommend the Best Solution	2

But after the start of the thesis due to limitation of time and complexity of the work; the plan was refined to suit the work as below.

	Time in Weeks
Literature Study and initialization of work environment	1
Study of Truck Models and Volvo internal application (CVM)	3
Data Collection and Analysis of Data	4
Problem Identification	3
Solution Identification	2
Application Development using Matlab	3
Testing of Matlab application	2
Recommendation of best solution and steps to follow	1
Thesis Presentation and Report Writing	3

Concept Development

The identified requirements were the Roll, Pitch, Yaw and movement in X, Y, Z directions of the cab, engine and front axle. A Volvo's in-built application, complete vehicle model (CVM), was used to calculate the displacement and rotation of the three systems. The first concept was to directly utilize the rotation and displacement from CVM into Pro-E and create the envelopes for the components or the entire system. The second concept was to obtain the movements from CVM for the origin of the three systems and to calculate the displacement at the point of interest using a Matlab application. The third concept was to sort a set of values from immense displacement and rotation values obtained from CVM, with an assumption of point of rotation for each system.

Due to the difference between the Pro-E and CVM models, a direct use of the displacement was not possible. Identifying a set of rotation and displacement values from the enormous data was not a good idea, because the point of rotation varies with respect to time and a separate method to sort the data has to be developed. The second concept was opted for and it was further developed into an application since it solved the issue of sorting the data and the issue of difference between the Pro-E and CVM models.

System Level Design

The major components of the Matlab application are the functions to calculate the displacement and graphical user interface for easy access to data files. The thesis involved different applications like Pro-E, Matlab, CVM, etc., hence to utilize the data properly a data flow was designed before the start of the detail design phase. The flow of data starts from CVM to Matlab application and the output from the Matlab application is used in Pro-E to generate the envelope for the components of interest.

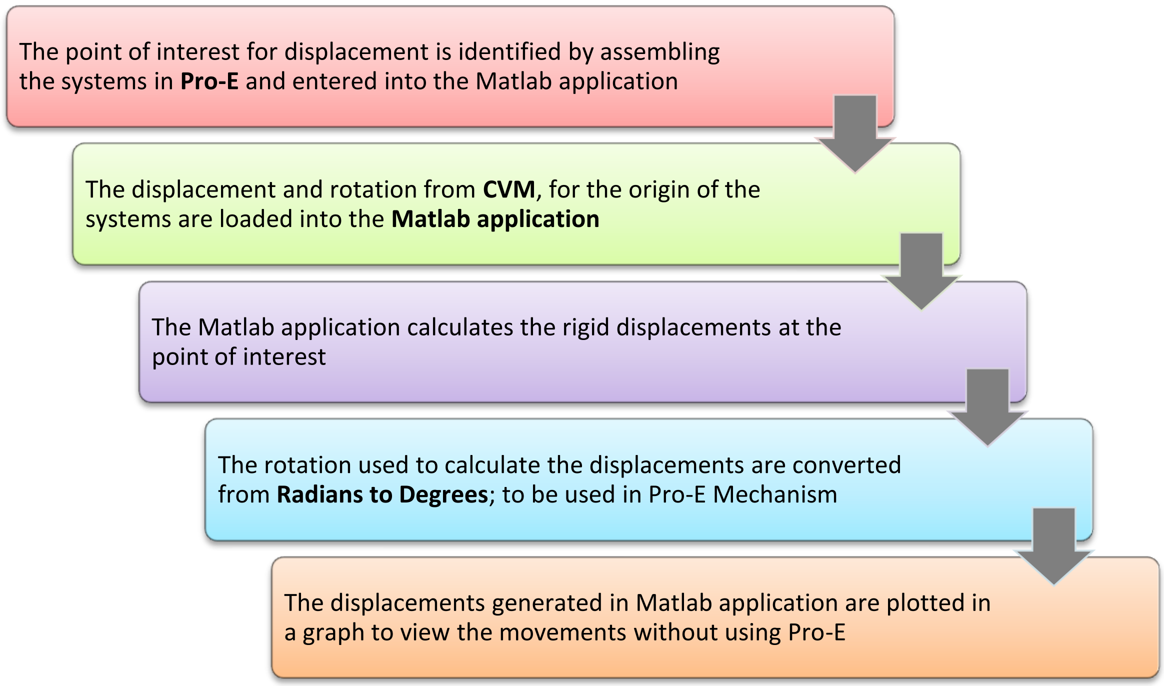

Figure 2: Flow of data in the Matlab Application

Detail Design

The Matlab application requires files from CVM to generate the displacement at the point of interest. To utilize the data from CVM, the data has to be loaded into the Matlab application and the format of data files has to be recognized by the Matlab application. For each system (Cab, Engine, and Front Axle) the point about which the movements are extracted from CVM is saved into the Matlab application, because the displacement at the point of interest is calculated using the same. Once the displacement at the point of interest is calculated the rotation used to calculate the displacements are converted from Radians to Degrees, the rotations in Pro-E are in Degrees. The Matlab application also assists in plotting the displacement and rotation in graph format, so that the movement profile can be studied without using Pro-E.

Testing and Refinement

The Matlab application developed was tested by comparing the displacement generated for the same point on cab, engine and front axle from Matlab application and CVM. The application was tested rigorously to avoid any flaws due to data transfer between different applications, error with GUI, file formats, data types in the files, etc.

The application developed was used to analyze the parts and complete assembly of cab, engine and front axle for movements. The envelope generated using this application assisted in analyzing the movement of the component very close to the reality; thereby a better design was developed and it resulted in easier production.

4 Application

The displacement of cab, engine and front axle were determined from CVM using MSC NASTRAN. The displacement obtained from CVM was used in a Matlab application to calculate displacement at other points on cab, engine and front axle. Pro-E Mechanism was used to generate the envelope of the systems, using the movements from the Matlab application.

4.1 CVM

The skeletal models of truck were pre-defined in a database and the models of interest were taken for the thesis. The cab, engine and front axle were considered to be completely rigid, so that it follows the rules of a rigid body. From the theory, we understand that a rigid body has the same rotation on any point of the body and we can calculate the displacement of a point on the body using displacement and rotational values from any point on the same body.

Chassis

The chassis was considered to be completely rigid and the movements were studied relative to the chassis. Since it is not rigid, to obtain the entire movement of the chassis, a common grid was created between the chassis' and it was connected to the entire chassis as in the Figure 3. The point "A" is the grid connecting every grid on the chassis with a RBE3 element. The RBE3 element only transfers the movements in the chassis to the point "A" and not the forces; thereby the complete movement of the chassis was available at one point.

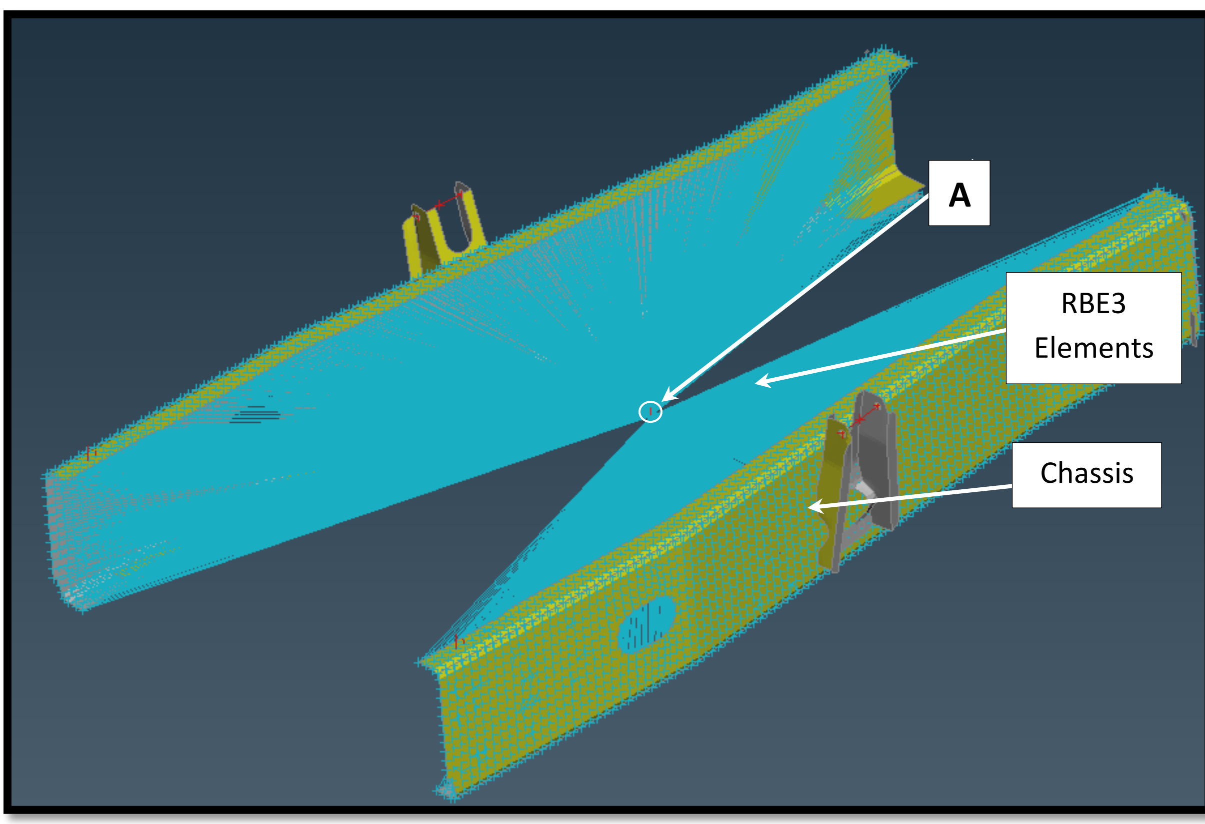

Figure 3: Chassis connected to a common point "A"

Cab

A new grid point “B” was created at the origin of the cab and was connected to the center of gravity of the cab using a rigid element RBAR. Since the point “B” was connected by a RBAR element, the point “B” behaves as a rigid point on the cab. A new grid point “C” as shown in the Figure 4, is created at the same location as the chassis common point “A” (Refer Figure 3: Chassis connected to a common point "A"). The grid at the point “B” is connected to the point “C” by a RBE3 element, the RBE3 element transfer the movements of point “B” to point “C”. Since there are two point at the same location i.e.; point “A” and “C” as the truck moves it causes relative movement between the points. A transfer function “TF”, a Nastran command is used to get the relative movement between the point “A” and “C”. Thereby the relative movement of the cab with respect to the chassis was obtained.`

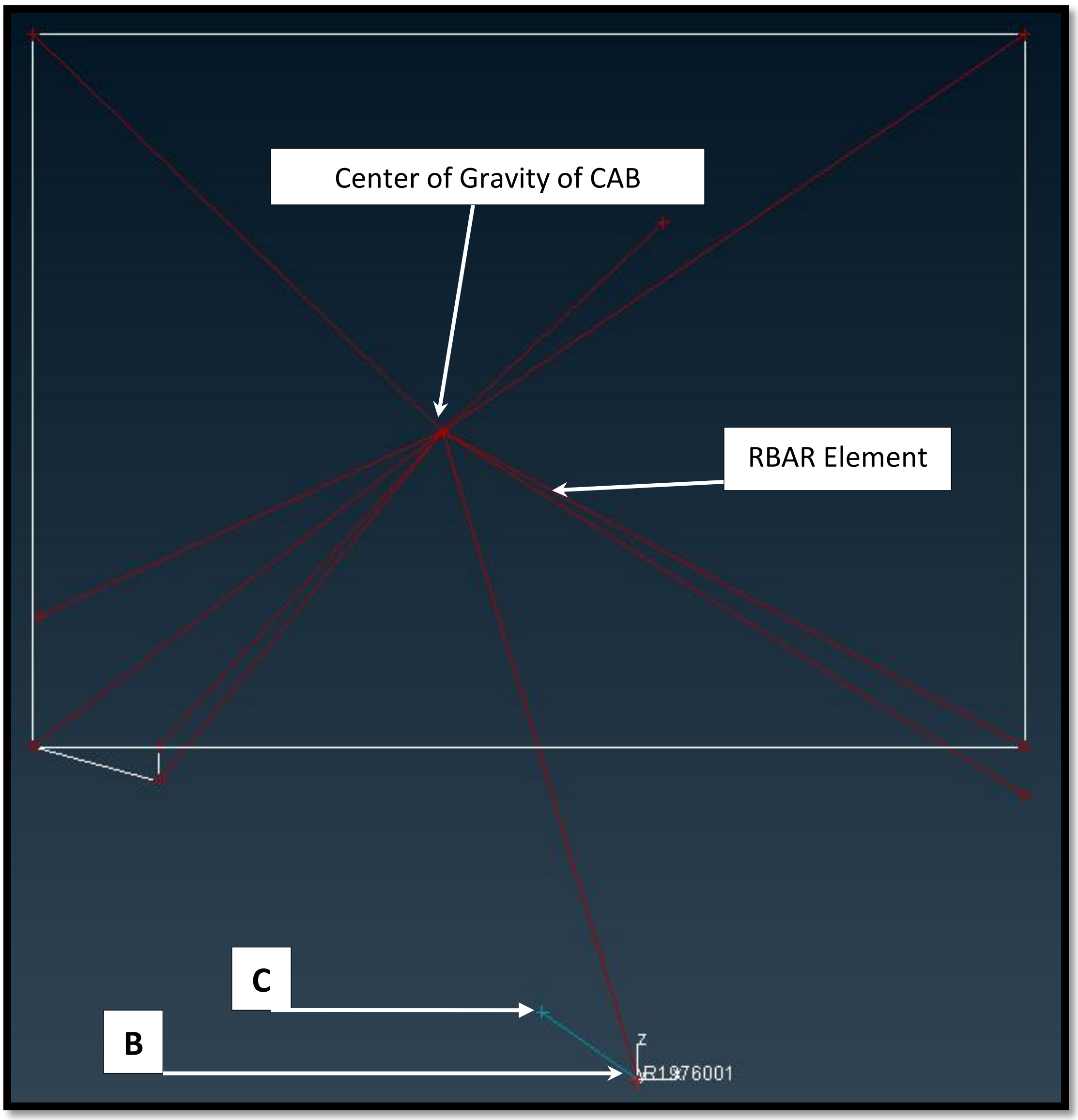

Figure 4: Skeleton model of Truck CAB

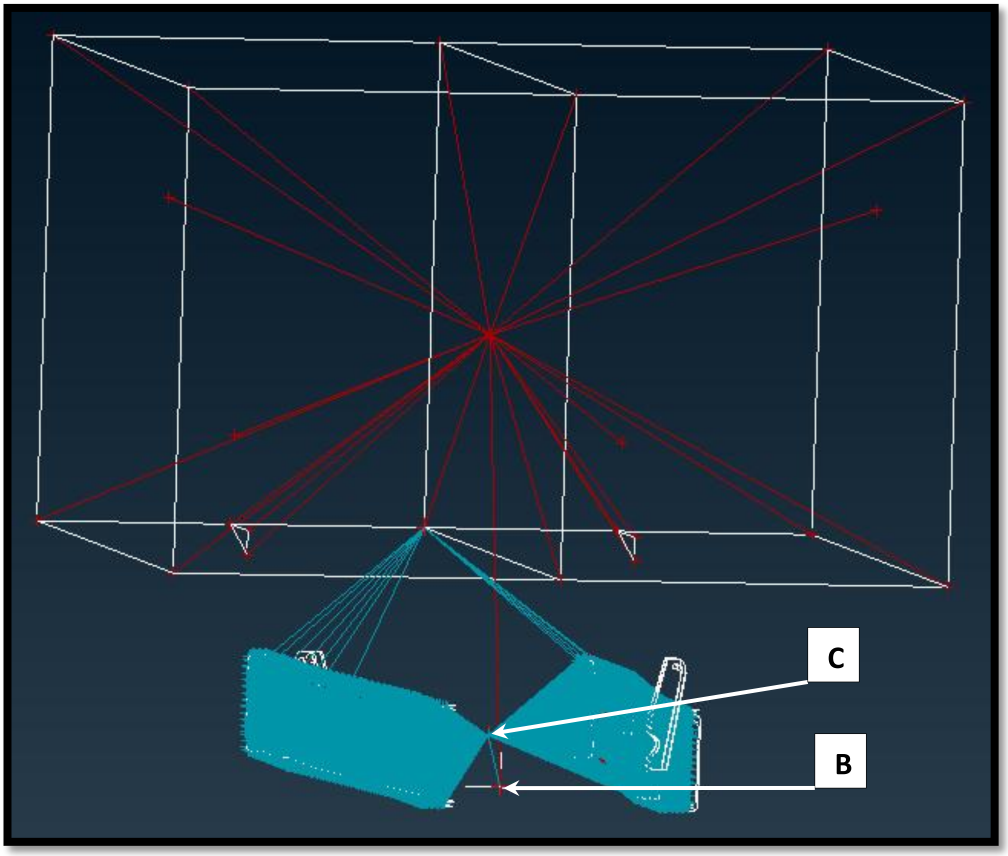

Figure 5: Skeleton model of CAB connected to Chassis

Engine

The engine was completely rigid and was fixed to the chassis and to cab. A new point “D” was created at the origin of the engine and connected the centre of gravity of the engine by a RBAR element. A point “E” was created at the same position as the chassis common point “A” and the points “D” and “E” were connected by a REB3 element. A transfer function, Nastran command “TF” was used to obtain the relative movements between the engine and chassis. Refer the figure below for the points “D” and “E”.

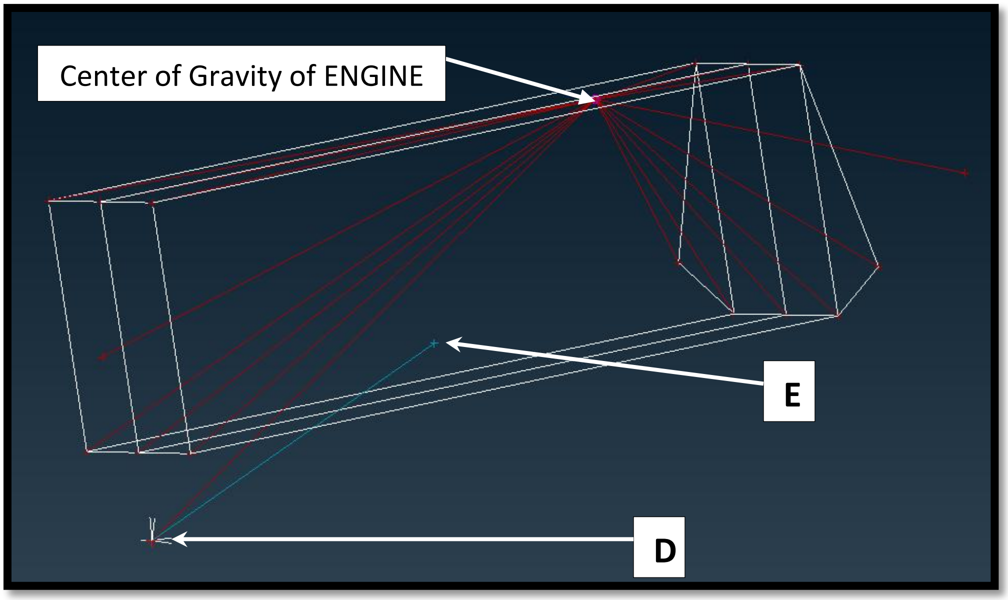

Figure 6: Skeleton model of Truck Engine

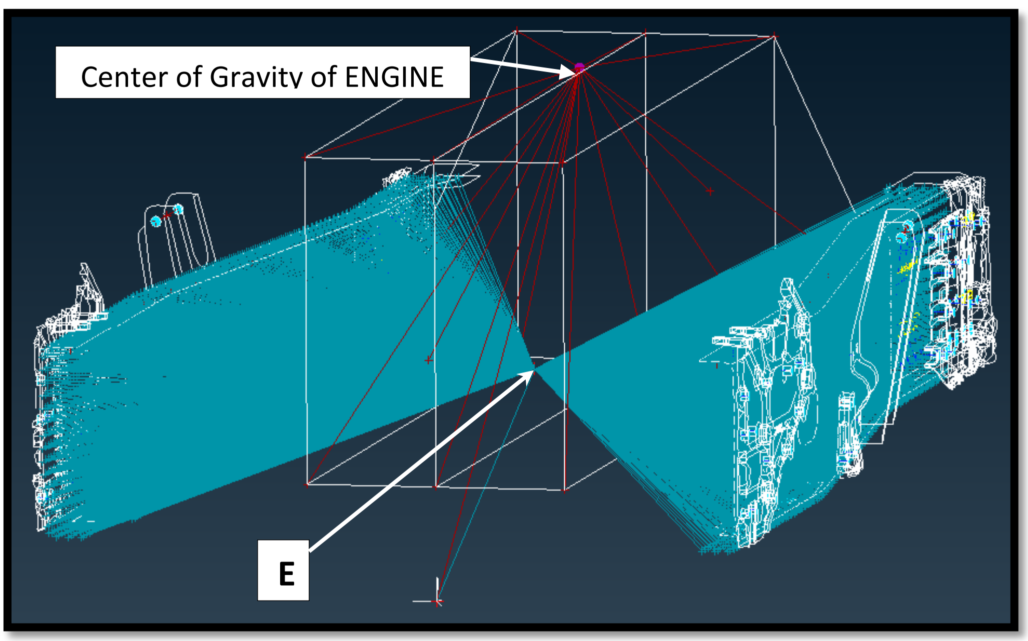

Figure 7: Skeleton model of Truck Engine connected to Chassis

Front Axle

The front axle was not completely rigid, but it was assumed to be rigid to apply the rigid body equations. Similar to cab and engine a grid point "F" was created at the origin of the front axle and connected to the center of gravity of the front axle as shown in the below figures. A grid point "G" was created at the same position as the chassis common point "A". The grid point "F" was connected to the front axle center of gravity by a RBAR element and was also connected to point “G” by a RBE3 element. Using a transfer function, Nastran command “TF”, the relative displacement and rotation between the chassis and front axle were obtained.

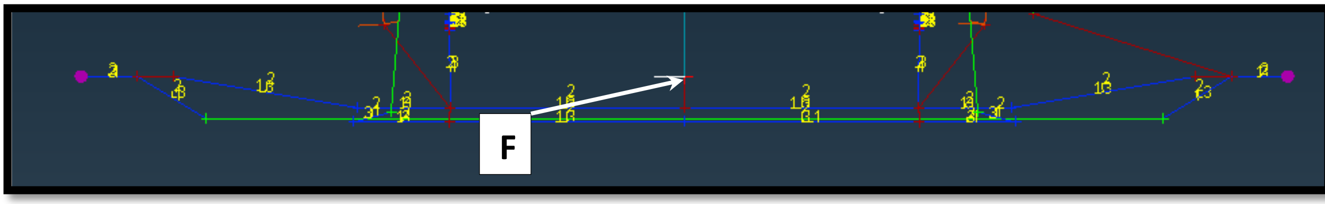

Figure 8: Skeleton model of Front Axle

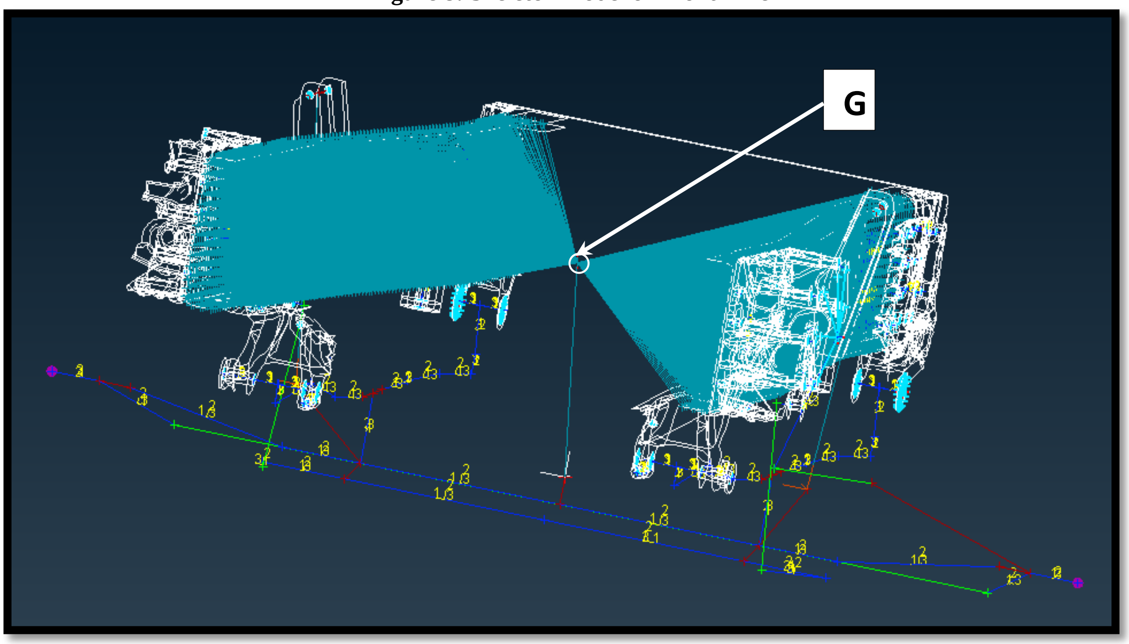

Figure 9: Skeleton model of Front Axle and Chassis

The relative movements from Nastran were obtained in a simple text format; six transfer functions were written to get the three displacement values along the X, Y and Z direction and three rotational values about the X, Y and Z axes. For each system a set of six files with displacement and rotational values were obtained as the output from Nastran. The obtained output movements were for the entire track length; there were twelve different test tracks, thus eighteen files were generated for a single track, six files for each system, totally two hundred and sixteen files were generated for a single truck model. To identify the critical values from these final outputs was a competitive task, hence a Matlab application was developed to use the output from Nastran and identify the critical displacement between the systems.

4.2 Matlab Application

With the relative displacement of cab, engine and front axle with respect to the chassis; one can calculate displacement of any point on the three systems. Using MATLAB[8], an application was developed to use the relative displacement and rotational files obtained from Nastran; the points in global coordinate about which the displacement and rotational values obtained for cab, engine and front axle were saved into the application. Once the input files and the points (in global coordinates) about which the input files were generated in Nastran, the obtained values were loaded into the application. The point of interest on each system or a point on the component in each system with respect to the global coordinates is specified in the X, Y and Z text boxes.

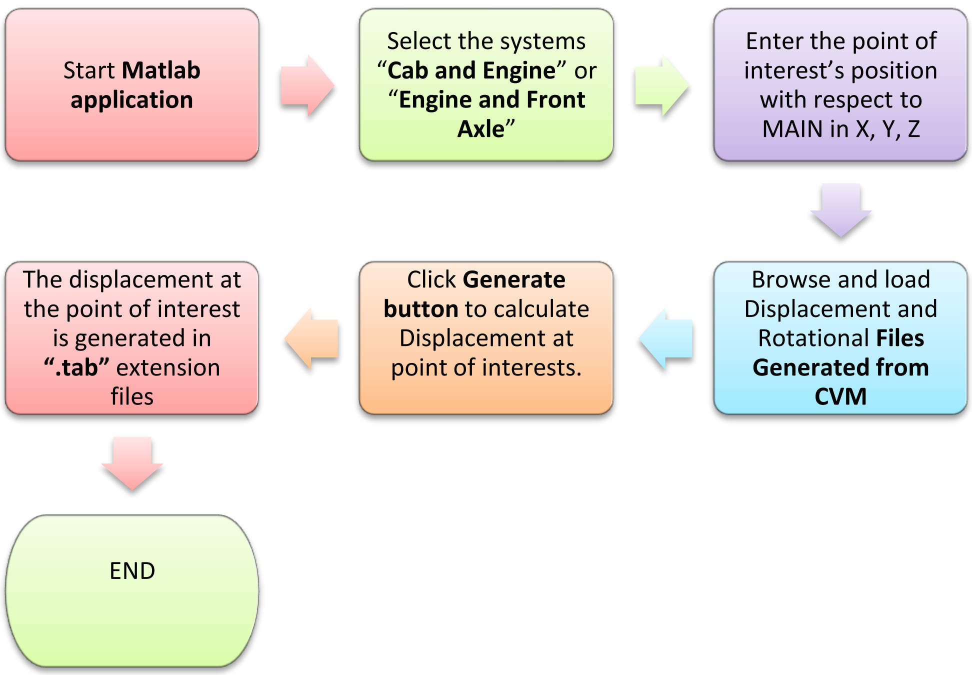

Figure 10: steps to use the Matlab Application

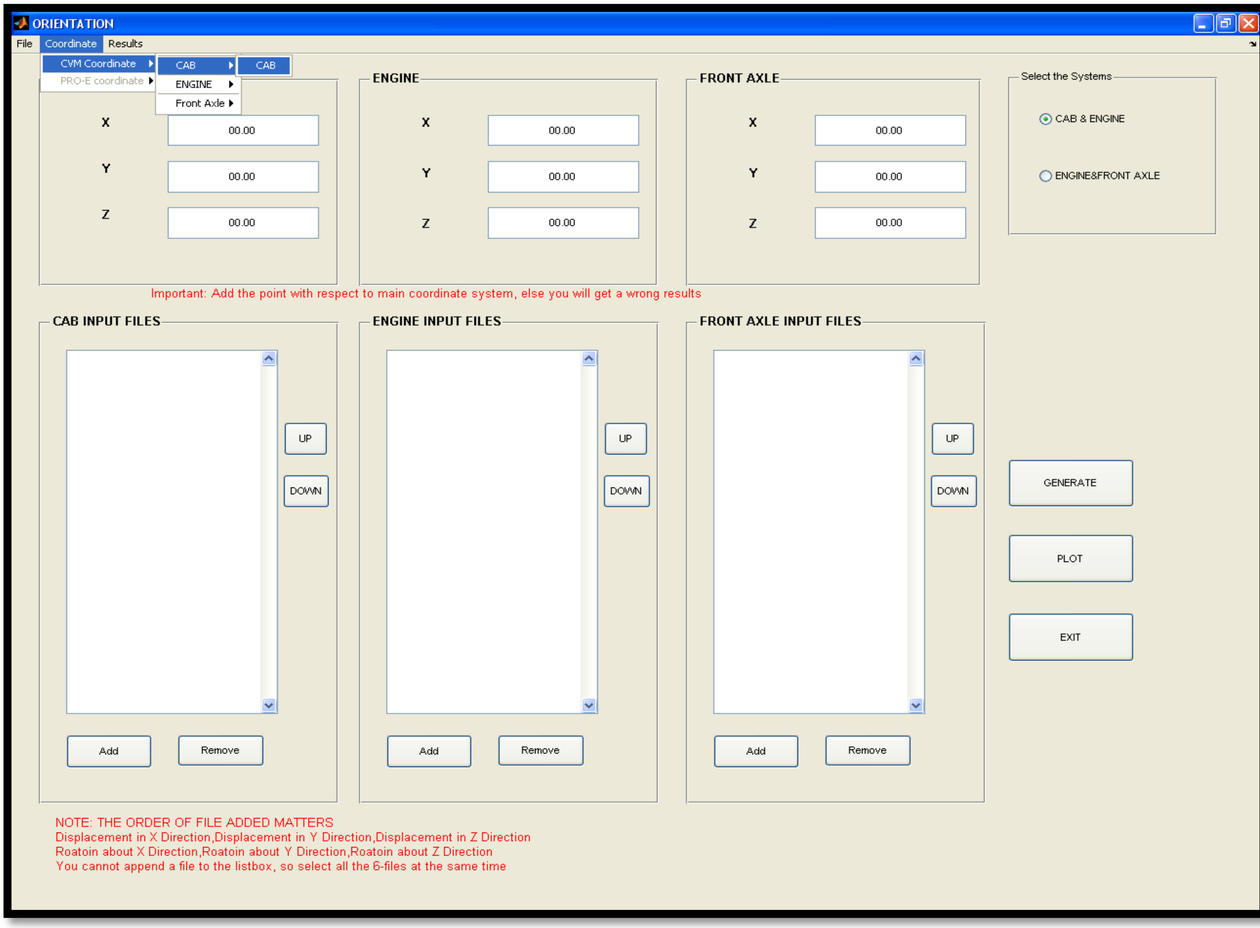

Figure 11: Matlab Application to generate displacement files at point of interest.

Before initializing or loading any files into application, one of the “CAB & ENGINE” or “ENGINE & FRONT AXLE” radio buttons were selected; it was selected to define between which systems the movements were generated. The points about which the displacement and rotational values obtained for Cab, Engine and Front Axle in Nastran were fed by selecting the menu Coordinate--> CAB --> CAB (refer to Figure 11) and the corresponding tab was selected in the Coordinate menu for the corresponding system.

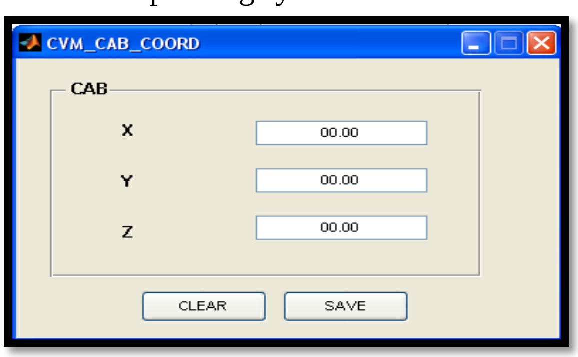

Figure 12: The point about which the movements were obtained from Nastran was saved using the above textbox.

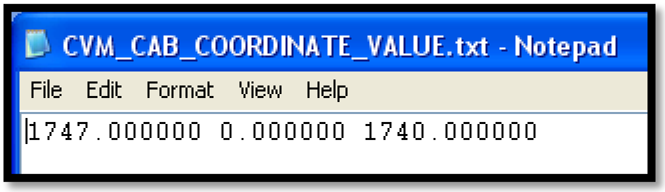

Figure 13: The X, Y, and Z Coordinate saved in text file

The X, Y, Z coordinate of the point about which the displacement and rotational values obtained were saved in a text file as in the above Figure 13. The default value for the point of displacement and rotation is initialized to Zero "0.00".

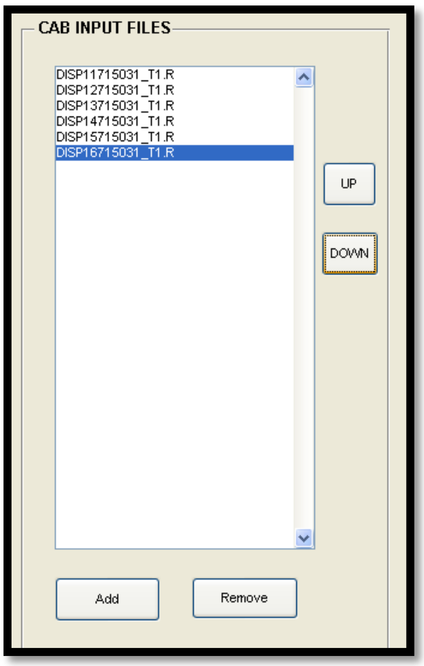

Figure 14: The files from Nastran are loaded and arranged.

The files generated by Nastran were loaded into the application by clicking on "Add" button and browsing through the folders; a set of six files were selected for each test track and for each system. The files have to be rearranged in the order of displacement in X, Y, Z direction and rotation about X, Y, Z axes. All the six files have to be loaded at the same time in the list box.

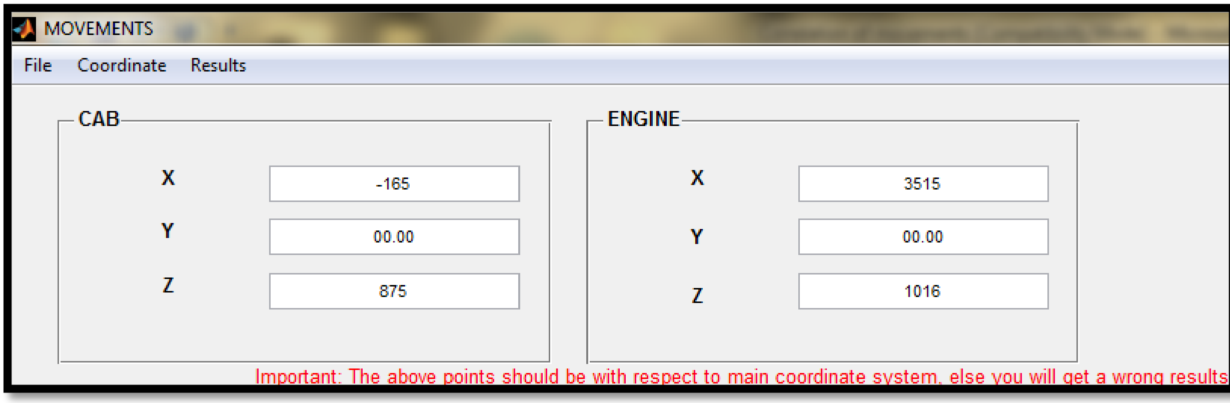

Figure 15: The coordinates of the point of interest were entered in the textbox.

After the files were loaded and point about which the files generated were saved in the application; the points of interest on the components/systems with respect to the global coordinate origin were given in the corresponding system's text box as in the above Figure 15.

Once the files were loaded and the points of interest were entered, the "Generate" button was pressed. The function within the generate button uses the loaded files; coordinates of the points of movement i.e. the values saved in the text files as in the Figure 13 and calculates the displacement at the point of interest on the components/systems.

Figure 16: The ".tab" extension output from Matlab application.

The final outputs of this application consist of two different set of files, the first set of files were ".tab" extension files, and the second set of files were ".txt" format files. The ".tab" extension files contained the displacements of point of interest; three files were generated for each system. Each file contained the displacement of the point of interest in X, Y, Z directions. Since all the systems were considered to be rigid the same rotational values used to find the displacement at the point of interest can be used for the entire system.

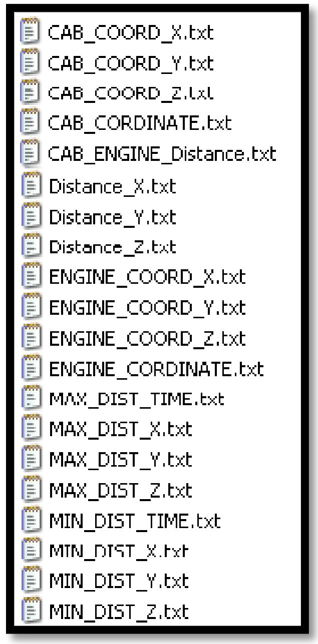

Figure 17: The ".txt" output from Matlab application.

The second set of files were ".txt" format files, they contain the distance between two points (one point on each system), the maximum and minimum distance between the points in X, Y, Z directions, the time on the test track when the maximum and minimum distance occur between the points, etc.

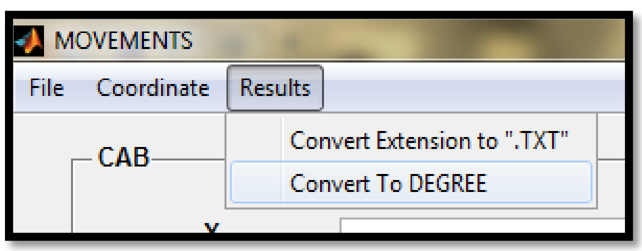

Figure 18: To convert rotational files from Radian to Degree.

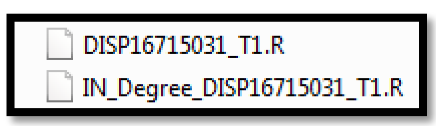

Figure 19: New file name after conversion from Radian to Degree.

The rotational values obtained from Nastran were in Radians, in order to use the rotational values in Pro-E the values have to be converted into Degrees. To convert the rotational files select the menu Results --> Convert to Degree tab and browse through the folders to select the file to be converted. A new file will be created at the same location as the original file (i.e. file in Radian) with "IN_Degree" added to the beginning of the existing file name.

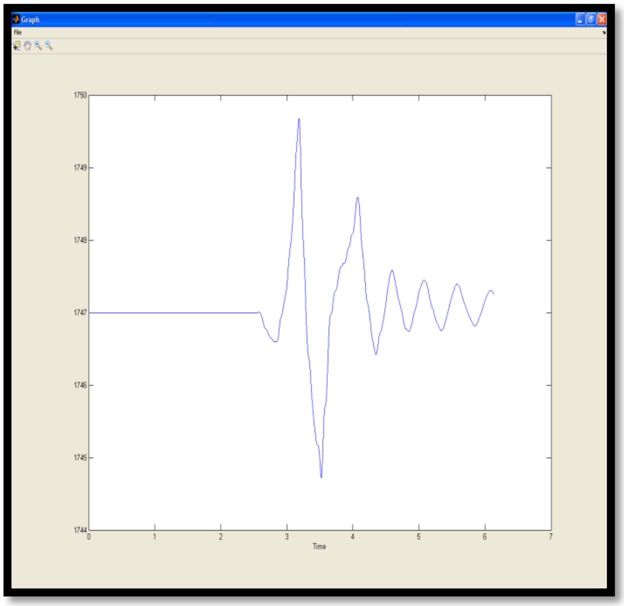

Figure 20: Matlab application window to plot Graph.

The "Plot" button in the application was used to plot graphs of the output files generated in the matlab application. The graphs have time in the x-axis and displacement or rotational values in the y-axis. It gives a better undestanding on the subject of the movements of the truck, the graph shows the movement of the components/system for the entire length of the test track.

4.3 Pro-Engineer

The Final outputs from the Matlab application were used in Pro-E Mechanism. The ".tab" extension files were loaded into Pro-E to check the movements of the components/systems and generate an envelope of the same. The steps involved in assembling the components/systems, adding servo motors to the systems and creating the mechanism analysis are described in the appendix pp34. Once the components were assembled and the outputs from the Matlab application were loaded into Pro-E, the mechanism analysis was executed. As the analysis command is executed, new analysis will be created under Mechanism --> analyses --> "New analysis". Click the "Playback" icon (Figure 21) in mechanism window, and select the envelope icon (Figure 22) to generate the envelope for the components of interest.

Figure 21: Pro-E Mechanism Playback icon

Figure 22: Pro-E mechanism Envelope icon

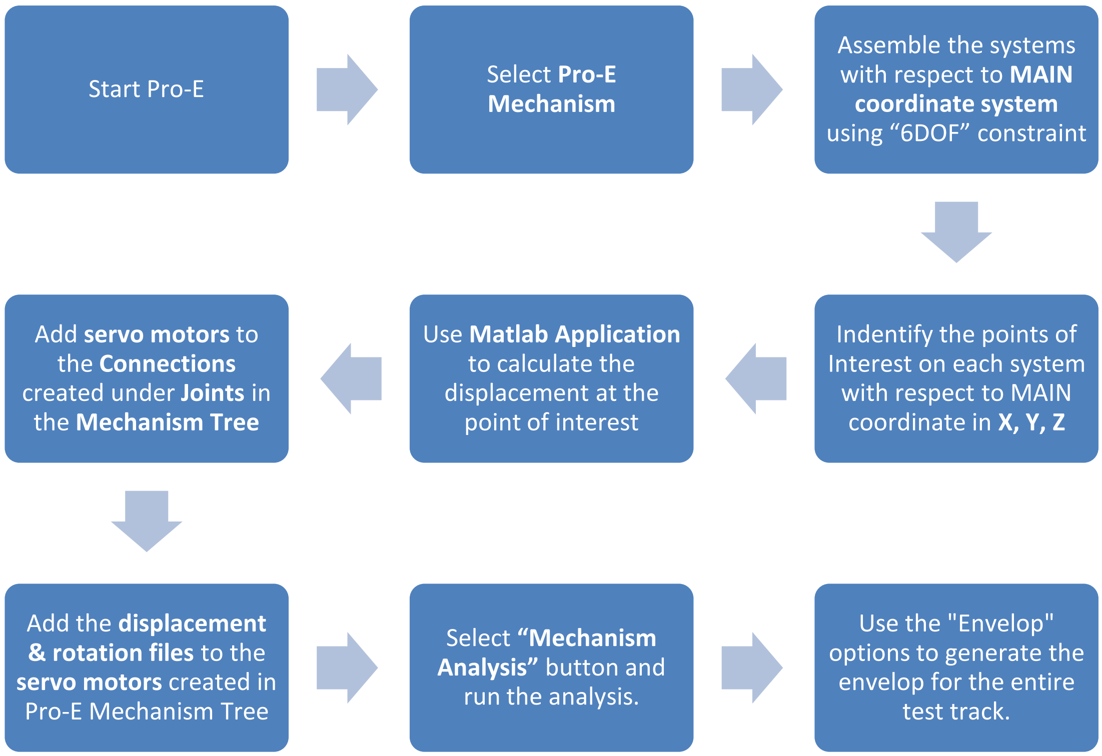

Figure 23: Steps to generate Envelope using Pro-E Mechanism

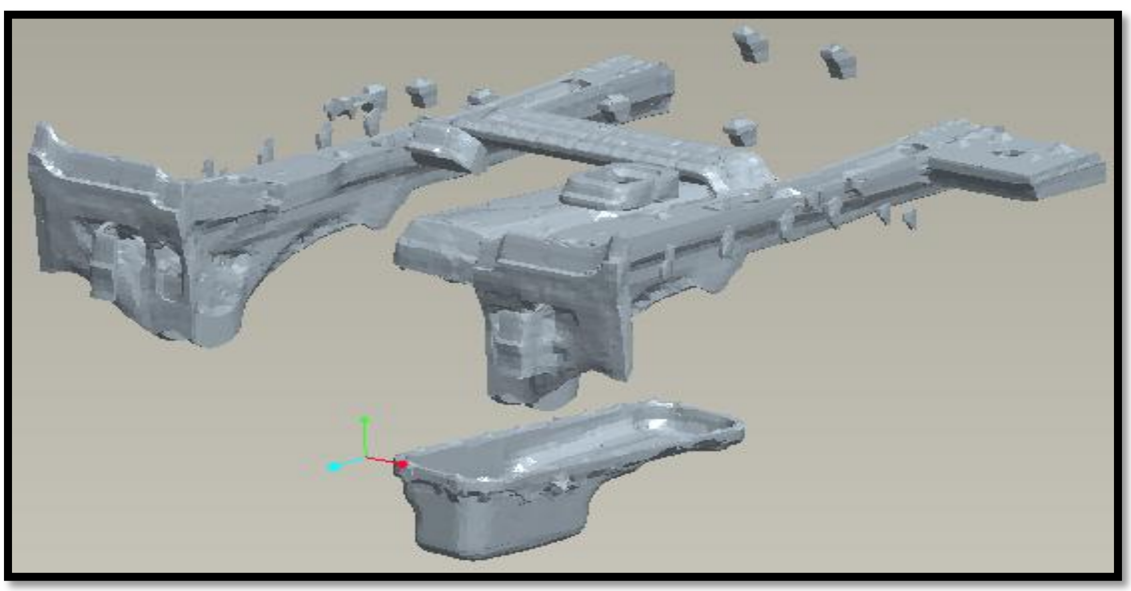

Figure 24: Envelope of Cab floor, Engine cover and Engine oil sump using Pro-E Mechanism.

5 Results

The output from the Matlab application was of high importance. It showed the movement of any point on the front part of the truck for the selected track. The results from the application were verified by cross-referencing the displacement of a point on each system generated by Nastran and the displacement of the same point generated using the Matlab application. The results obtained were very close to each as in the below Figure 25. There are two graphs in Figure 25, 26 and 27. The graphs in green were from Nastran and the blue graph was generated using the Matlab application. The graphs were plotted for movement of CAB in X, Y, Z direction.

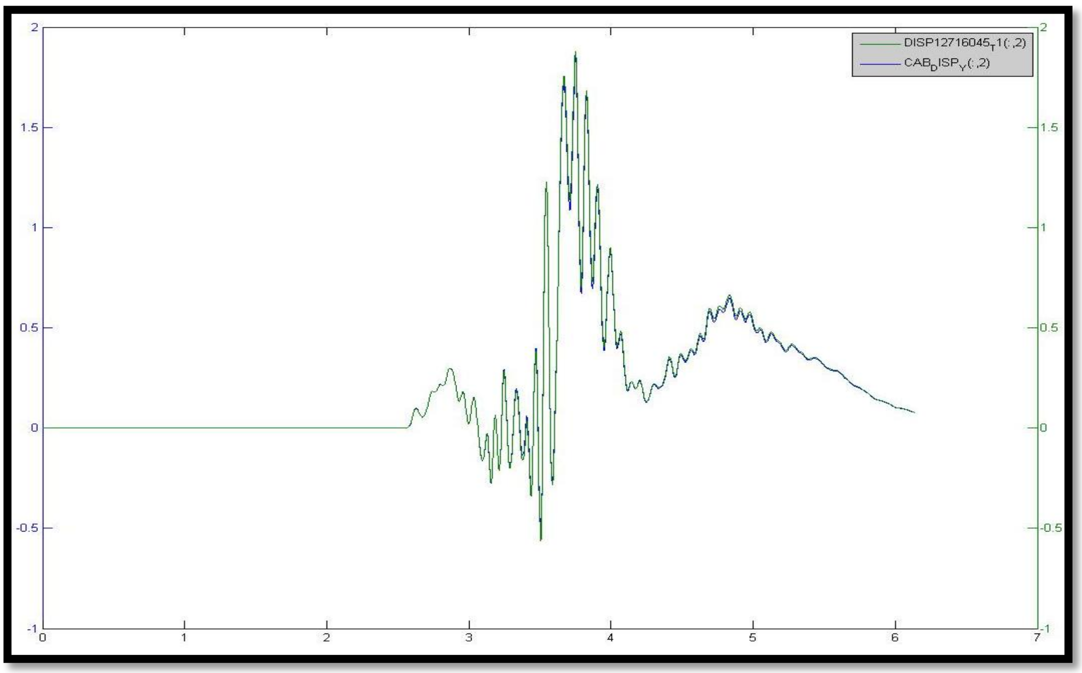

Figure 25: Cab displacement in Y-Direction

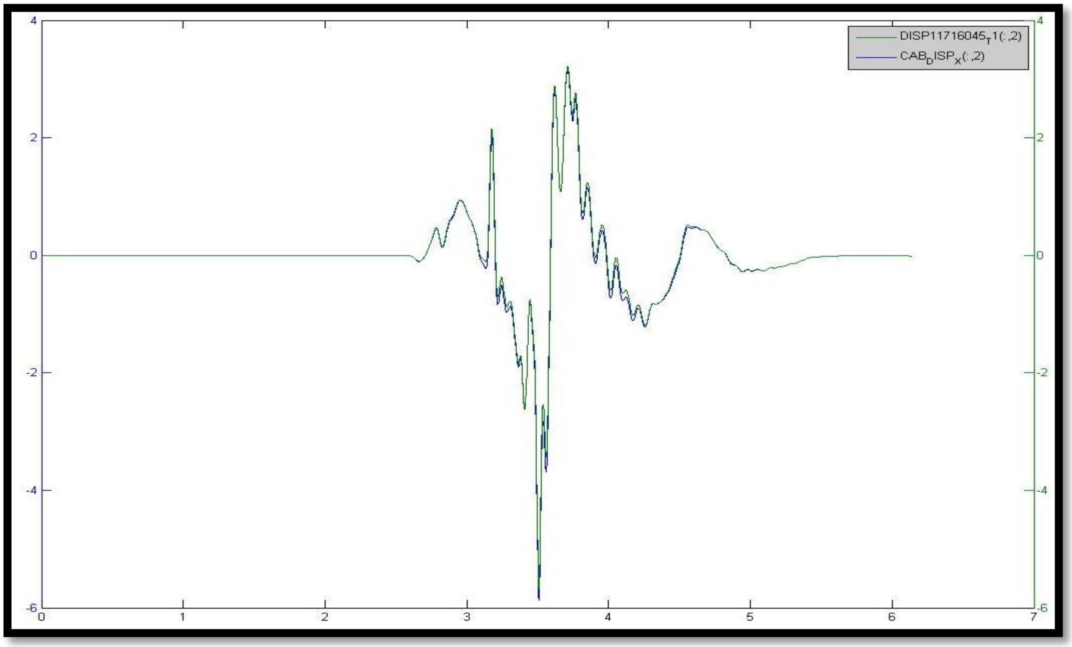

Figure 26: Cab displacement in X-Direction

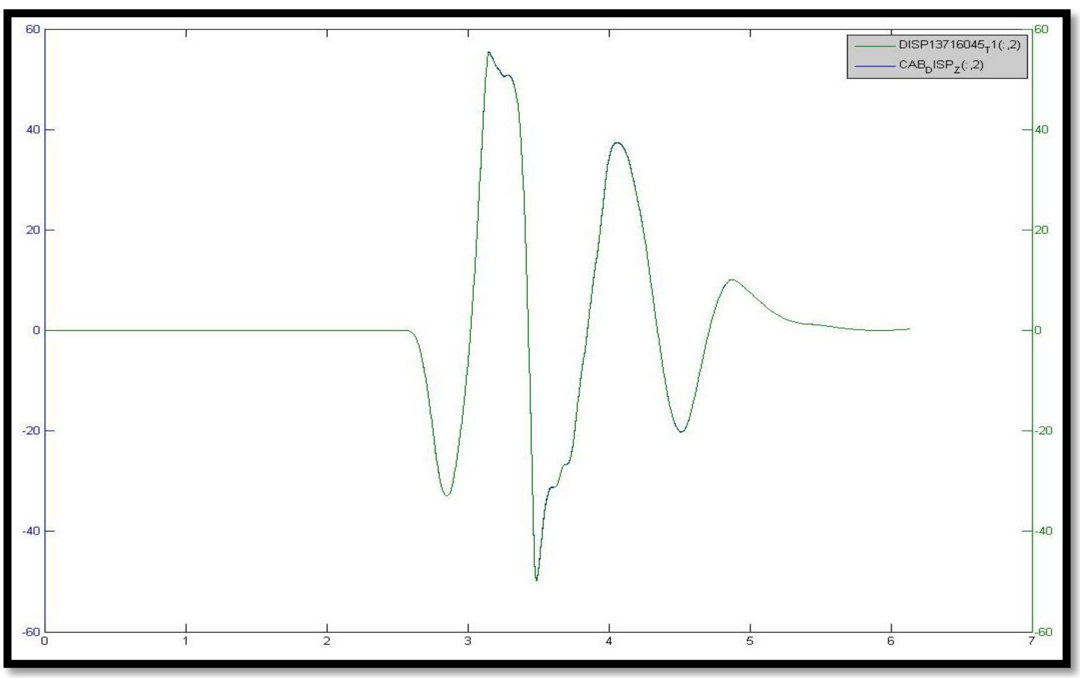

Figure 27: Cab displacement in Z-Direction

The movement values from Nastran and Matlab application for Cab and Engine were the same, but the movement values of the Front Axle were not, as the Cab and Engine, because of the deformation of Front Axle for$\pm 5\ mm$. The output from the Matlab application gave the behavior of Front axle but not the exact values. This issue can be fixed by adding the material properties and bending equation in the application.

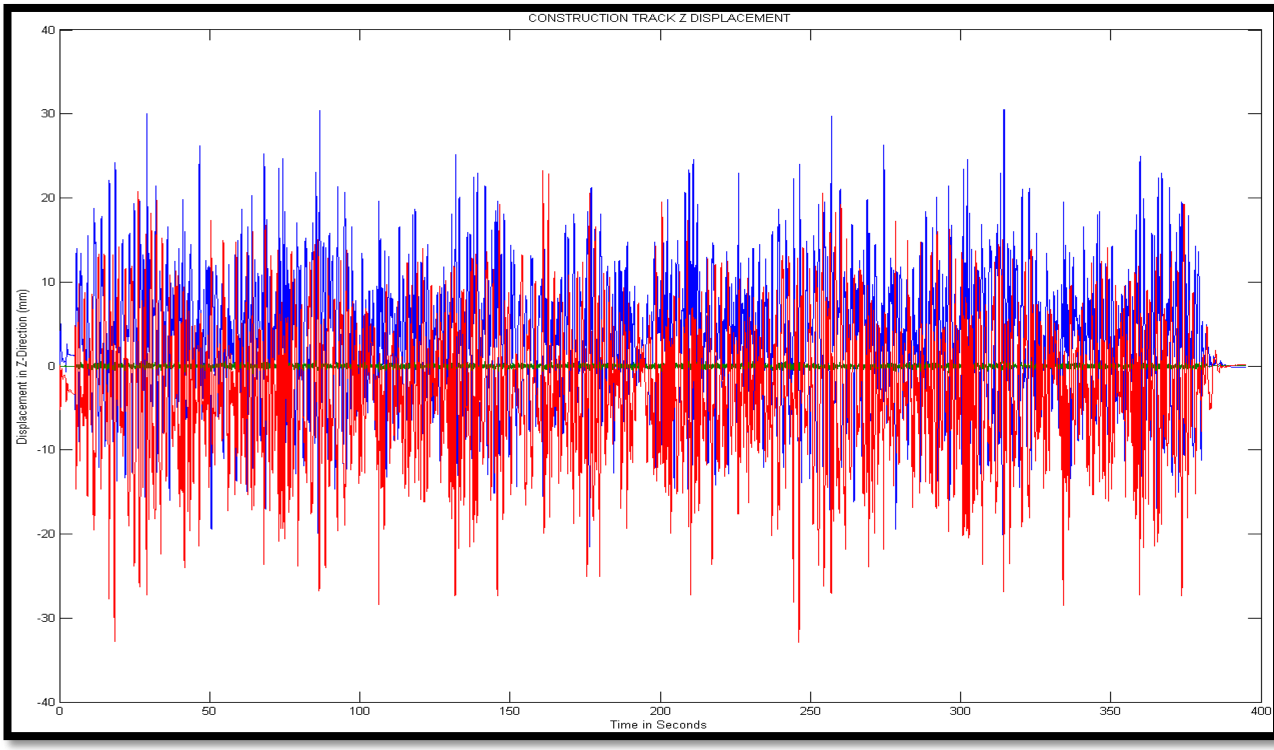

Figure 28: The displacement in Construction track for Cab, Engine and Front Axle. Blue-Displacement of Cab, Red-Displacement of Front axle and Green - Displacement of Engine, in Z direction.

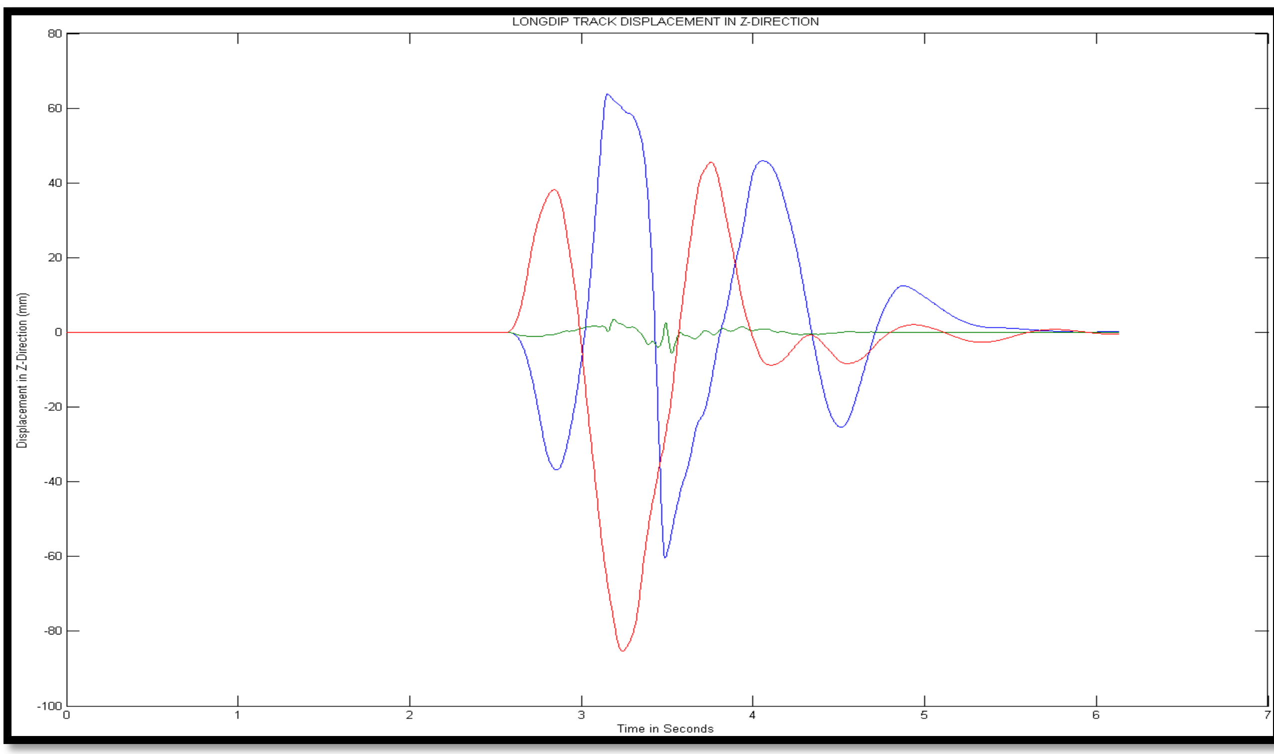

Figure 29: The displacement in Longdip track for Cab, Engine and Front Axle. Blue-Displacement of Cab, Red-Displacement of Front axle and Green - Displacement of Engine, in Z direction

The graphs in Figure 28 and Figure 29 were the sample displacement of Cab, Engine and Front Axle in two different test tracks. The plots in blue were the displacement of CAB, red were the displacement of Front Axle and green were the displacement of Engine. From the Figure 28 and Figure 29 we can identify the maximum and minimum distance between the systems at any point of time for any test track.

6 Discussion

The thesis started with the identification of the models to be studied. Initially twelve different truck models were taken into consideration but, due to time constraint only four truck models were studied. The CVM application was used to make changes in the models and the models were viewed using Ansa. A set of random points on the chassis were connected to the systems while the movement values were extracted from Nastran. Since the Chassis was not completely rigid; considering a set of random point on the chassis did not give an accurate movement value of the other points, thus a common grid connecting the entire chassis was used to determine the movements of other point on the systems.

The movement values obtained from the Matlab application can be made more accurate by adding the equations of bending and material properties. This application assists in cutting down time by calculating the movements without using the truck model rather from a point’s movement on each system of interest.

7 Future Development

As a part of the future development a script can be written to create a point at the origin of each system and extract movements of the same. The output from Nastran can be uploaded into KOLA against the corresponding components used in Nastran. Once the Nastran output were loaded into KOLA for every specification of truck selected in KOLA its corresponding movements can also be extracted along with the CAD files, thereby the architects can just built the truck model and directly check the correlation of movements between any systems.

The models developed in CVM and Pro-Engineer had few variations due to which the data from CVM were not used directly in the Pro-Engineer models. A common ground can be established between CVM and Pro-Engineer to enable a direct link between the models.

8 Conclusion

The objective of this thesis was to identify the critical values between the systems but, to identify a particular value for rotation and displacements of the system in enormous data files were complicated and time consuming. More over, the identification of values would have been for a family of truck rather, than for every specific truck and specific customer. The architects worked with an existing set of values, without being able to authenticate the actual movement of the truck in Volvo's test tracks.

Instead of sorting down the text files with movement values, a much better process for identifying the critical values between the systems was suggested. For each truck model a point at the origin of CAB, ENGINE and FRONT AXLE were created and its movements were extracted from Nastran. Using those movement values, the movements at any point on the three systems were calculated. A Matlab application was developed to use the output from Nastran and generate the movements at the point of interest.

The new process gave a better understanding of the movements of the truck; it generated movements for the entire test track length. The Matlab application also assisted in identifying the maximum and minimum distance between the points of interest, the time at which the points came close to each other in test track and to plot the movement of the point of interest.

9 Bibliography

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[8] Matlab, "Matlab 2011b," R2011b(7.13.0.564) ed. Natick, Massachusetts: The MathWorks Inc, 2011.

Appendix A MSC NASTRAN COMMANDS

GRID Remarks:

Field	Contents
lD	Grid point identification number. (0 Y Integer Y 100000000, see Remark 9.)
CP	Identification number of coordinate system in which the location of the grid point is defined. (Integer [0] or blank)
X1, X2, X3	Location of the grid point in coordinate system CP. (Real; Default Z 0.0)
CD	Identification number of coordinate system in which the displacements, degrees-of freedom, constraints, and solution vectors are defined at the grid point. (Integer [J1] or blank)
PS	Permanent single-point constraints associated with the grid point. (Any of the Integers 1 through 6 with no embedded blanks, or blank)
SEID	Superelement identification number. (Integer 0; Default Z (0))

1. All grid point identification numbers must be unique with respect to all other structural, scalar, and fluid points.
2. The meaning of X1, X2, and X3 depends on the type of coordinate system CP as follows (see the CORDij entry descriptions):

Type	X1	X2	X3
Rectangular	X	Y	Z
Cylindrical	R	$\theta\ (degrees)$	Z
Spherical	R	$\theta\ (degrees)$	$\emptyset\ (degrees)$

3. The collection of all CD coordinate systems defined on all GRID entries is called the global coordinate system. All degrees-of-freedom, constraints, and solution vectors are expressed in the global coordinate system.
4. The SEID field can be overridden by use of the SESET entry.
5. If CD Z J1, then this defines a fluid grid point in coupled fluid-structural analysis. This type of point may only connect the CAABSF, CHACBR, CHACAB, CHEXA, CPENTA, and CTETRA elements to define fluid elements.
6. A zero (or blank if the GRDSET entry is not specified) in the CP and CD fields refers to the basic coordinate system.
7. In p-version analysis, the hierarchy set to resolve the conflicts arising in the global system input data is described under Remark 10 of the GMBC entry description.
8. CID can reference GMCORD type coordinate systems only when the GRID is connected to p-version elements.
9. For SOL 600, ID may range from 1 to (214748647) starting with MD Nastran R3 if there are no OUTR options specified on the SOL 600 entry. IF any OUTR option is specified the limit are 100000000.

RBE3 Remarks:

Field	Contents
EID	Element identification number. Unique with respect to all elements. (0 < Integer Y 100,000,000)
REFGRID	Reference grid point identification number. (Integer =0)
REFC	Component numbers at the reference grid point. (Any of the integers 1 through 6 with no embedded blanks.)
WTi	Weighting factor for components of motion on the following entry at grid points Gi,j. (Real)
Ci	Component numbers with weighting factor WTi at grid points Gi,j. (Any of the integers 1 through 6 with no embedded blanks.)
Gi,j	Grid points with components Ci that have weighting factor WTi in the averaging equations. (Integer =0)
"UM"	Indicates the start of the degrees-of-freedom Belonging to the dependent degrees of-freedom. The default action is to assign only the components in REFC to the dependent degrees-of-freedom. (Character)
GMi	Identification numbers of grid points with degrees-of-freedom in the m-set. (Integer =0)
CMi	Component numbers of GMi to be assigned to the m-set. (Any of the Integers 1 through 6 with no embedded blanks.)
"ALPHA"	Indicates that the next number is the coefficient of thermal expansion. (Character)
ALPHA	Thermal expansion coefficient. (Real > 0.0 or blank)

1. Two methods are available to process rigid elements: equation elimination or Lagrange multipliers. The Case Control command, RIGID, selects the method.
2. For the Lagrange method, the REFC must be "123", "456", or "123456". No other combination is allowed.
3. For the Lagrange method, MD Nastran will create internally the Lagrange multiplier degrees-of-freedom in addition to the displacement degrees-of-freedom given by connected grid points. The number of Lagrange multiplier degrees-of-freedom is equal to the number of degrees-of-freedom given by REFC.
4. For the linear method, the dependent degrees-of-freedom indicated by REFC will be made members of the m-set. For Lagrange rigid element, they may or may not be members of the m set, depending on the method selected on the RIGID Case Control command. However, the rules regarding the m-set described below apply to both types of methods.
5. We recommend that for most applications only the translation components 123 be used for Ci. An exception is the case where the Gi,j are collinear. A rotation component may then be added to one grid point to stabilize its associated rigid body mode for the element.
6. Blank spaces may be left at the end of a Gi,j sequence.
7. For the Lagrange method, the default for "UM" must be used. For the linear method, the default for "UM" should be used except in cases where the user wishes to include some or all REFC components in displacement sets exclusive from the m-set. If the default is not used for "UM":

- The total number of components in the m-set (i.e., the total number of dependent degrees of freedom defined by the element) must be equal to the number of components in REFC (four components in the example). The components specified after "UM" must be a subset of the components specified under REFC and (Gi,j, Ci).
- The coefficient matrix [Rm] described in Section 9.4.3 of the MSC.Nastran Reference Manual must be nonsingular. PARAM, CHECKOUT in SOLs 101 through 200 may be used to check for this condition.

8. Dependent degrees-of-freedom assigned by one rigid element may not also be assigned dependent by another rigid element or by a multipoint constraint.
9. Rigid elements, unlike MPCs, are not selected through the Case Control Section
10. Forces of multipoint constraint may be recovered in all solution sequences, except SOL 129, with the MPCFORCE Case Control command.
11. Rigid elements are ignored in heat transfer problems.
12. The m-set coordinates specified on this entry may not be specified on other entries that define mutually exclusive sets. See.
13. The formulation for the RBE3 element was changed in Version 70.7. This change allowed the element to give consistent answers that are not dependent upon the units of the model. Only models that connected rotation degrees-of-freedom for Ci were affected. Note that these models are ignoring the recommendation in Remark 5. The formulation prior to Version 70.7 may be obtained by setting SYSTEM (310) =1.
14. For the Lagrange method, the thermal expansion effect will be computed, if user supplies the thermal expansion coefficient ALPHA, and the thermal load is requested by the TEMPERATURE (INITIAL) and TEMPERATURE (LOAD) Case Control commands. The temperature of the element is taken as follows: the temperature of the bar connecting the reference grid point REFGRID and any other grid point Gij are taken as the average temperature of the two connected grid points.
15. For SOL 700, RBE3 are presently converted to MPC's.

RBAR Remarks:

Field	Contents
EID	Element identification number. (0 < Integer < 100,000,000)
GA, GB	Grid point identification number of connection points. (Integer > 0)
CNA, CNB	Component numbers of independent degrees-of-freedom in the global coordinate system for the element at grid points GA and GB. (Integers 1 through 6 with no embedded blanks, or zero or blank.)
CMA, CMB	Component numbers of dependent degrees-of-freedom in the global coordinate system assigned by the element at grid points GA and GB. (Integers 1 through 6 with no embedded blanks, or zero or blank.)
ALPHA	Thermal expansion coefficient. (Real > 0.0 or blank)

1. Two methods are available to process rigid elements: equation elimination or Lagrange multipliers. The Case Control command, RIGID, selects the method.
2. For the Lagrange method, Nastran will create the Lagrange multiplier degrees-of-freedom internally in addition to the 12 displacement degrees-of-freedom given by grid points GA and GB. The number of Lagrange multiplier degrees-of-freedom is equal to the number of dependent degrees-of-freedom.
3. For the linear method, the total number of components in CNA and CNB must equal six; for example, CNA = 1236, CNB = 34. Furthermore, they must jointly be capable of representing any general rigid body motion of the element. For the Lagrange method, the total number of components must also be six. However, only CNA = 123456 or CNB = 123456 is allowed. If both CNA and CNB are blank, then CNA = 123456. For this method, RBAR1 gives the simpler input format.
4. If both CMA and CMB are zero or blank, all of the degrees-of-freedom not in CNA and CNB will be made dependent. For the linear method, the dependent degrees-of-freedom will be made members of the m-set. For the Lagrange method, they may or may not be member of the m-set, depending on the method selected in the RIGID Case Control command. However, the rules regarding the m-set described below apply to both methods.
5. The m-set coordinates specified on this entry may not be specified on other entries that define mutually exclusive sets. See Degree-of-Freedom Sets, 1013 for a list of these entries.
6. Element identification numbers should be unique with respect to all other element identification numbers.
7. Rigid elements, unlike MPCs, are not selected through the Case Control Command, MPC.
8. Forces of multipoint constraint may be recovered in all solution sequences, except SOL 129, with the MPCFORCE Case Control command.
9. Rigid elements are ignored in heat transfer problems. If used in a multi-physics coupled problem using SUBSTEP, they participate in the mechanical sub step but are ignored in the heat transfer sub step through automatic deactivation. For more information on deactivation, see the DEACTEL keyword under the NLMOPTS Bulk Data entry and the associated Remark 9 for that entry.
10. See Rigid Elements and Multipoint Constraints (R-type, MPC) (p. 168) in the MD Nastran Reference Manual for a discussion of rigid elements.
11. For the Lagrange method, the thermal expansion effect will be computed for the rigid bar element if user supplies the thermal expansion coefficient ALPHA, and the thermal load is requested by the TEMPERATURE (INITIAL) and TEMPERATURE (LOAD) Case Control commands. The temperature of the element is taken as the average temperature of the two connected grid points GA and GB.

EPOINT Remarks:

Field	Contents
IDi	Extra point identification number. (1000000 > Integer > 0; for “THRU” option, ID1 < ID2).

1. All extra point identification numbers must be unique with respect to all other structural, scalar, and fluid points for direct methods of solution. For modal methods, they must be larger than the number of eigenvectors retained for analysis.
2. EPOINT is used to define coordinates used in transfer function definitions (see the TF and DMIG entries).
3. If the alternate format is used, extra points ID1 through ID2 are also defined to be extra points.
4. See the MSC. Nastran Dynamics Users Guide for a discussion of extra points[5].

TF Remarks:

Field	Contents
SID	Set identification number. (Integer > 0)
GD, G(i)	Grid, scalar, or extra point identification numbers. (Integer > 0)
CD, C(i)	Component numbers. (Integer zero or blank for scalar or extra points, anyone of the Integers 1 through 6 for a grid point.)
B0, B1, B2 A0(i), A1(i), A2(i)	Transfer function coefficients. (Real)

1. Transfer function sets must be selected with the Case Control command TFL = SID.
2. Continuation entries are optional.
3. The matrix elements defined by this entry are added to the dynamic matrices for the problem.
4. The constraint relation given in Eq. (8-28) will hold only if no structural elements or other matrix elements are connected to the dependent coordinate. In fact, the terms on the left side of Eq. (8-28) are simply added to the terms from all other sources in the row for u_d
5. See the MSC.Nastran Dynamics Users Guide for a discussion of transfer functions.
6. For each SID, only one logical entry is allowed for each GD, CD combination.
7. For heat transfer analysis, the initial conditions must satisfy Eq .
8. RC network does not support TF for thermal analysis.

Appendix B Pro-E Mechanism

Create the mechanism for Front part of truck.

Open a new mechanism.
Rename the coordinate system to “MAIN”

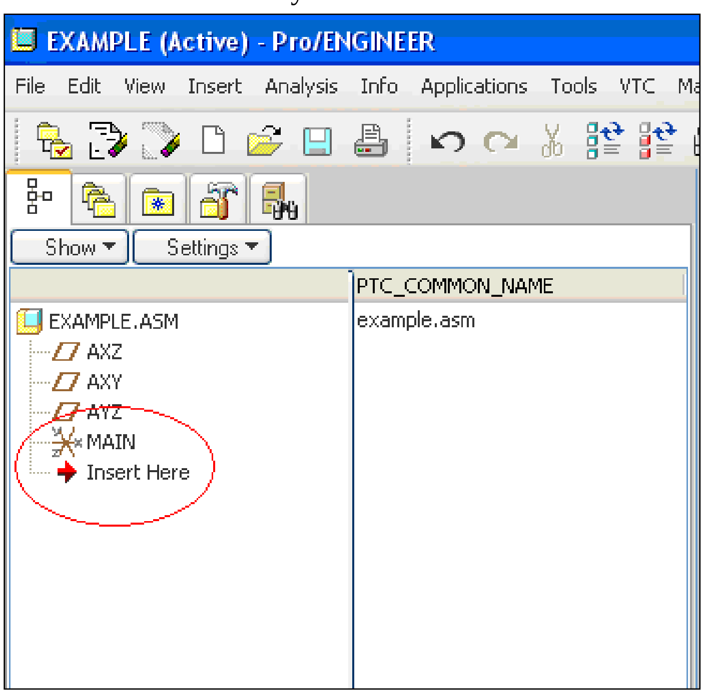

Figure: 1

Insert only the coordinate systems of the parts whose envelop is to be generated or studied.
In this example, I have added the following coordinate system
CAB (TYPE_FH_PC24.PRT), ENGINE (ENG-VE13.PRT),FRONT AXLE (FAP3040.PRT).

Insert → Component → Assemble

You will get a new component window as in the picture below Figure: 3.
Click inside the component window and press “Ctrl+F” to search in the component to be inserted in

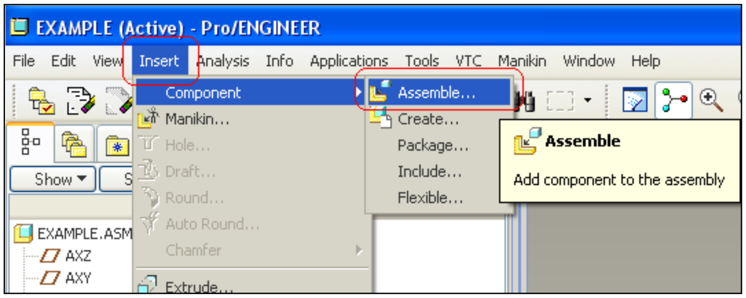

Figure: 2

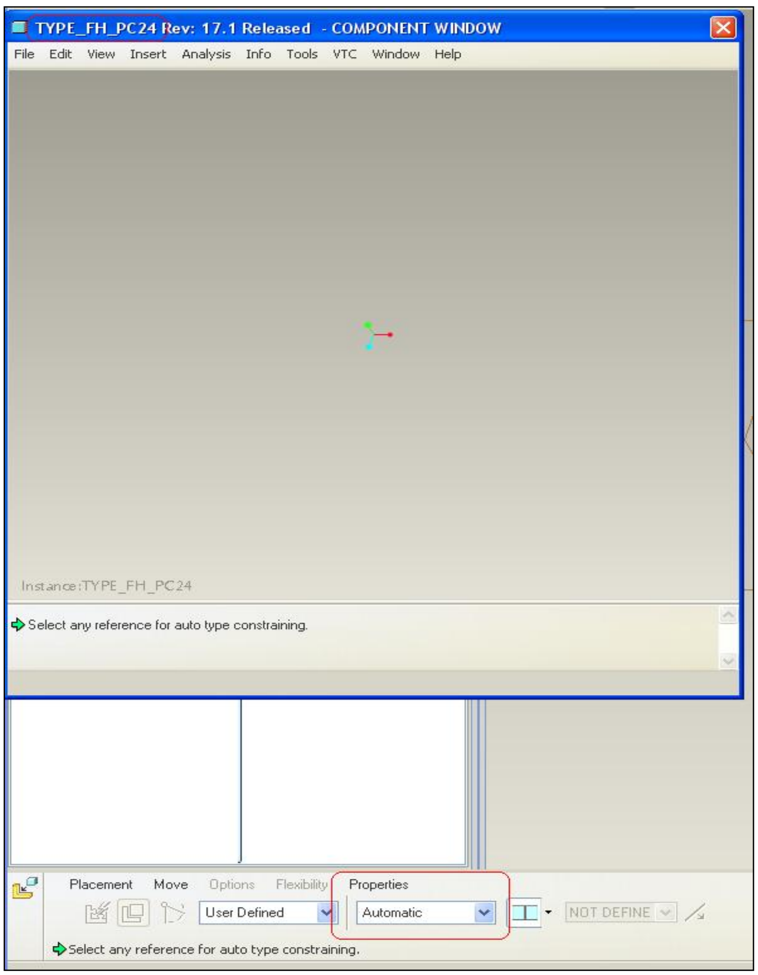

Figure: 3

Choose the “Coord Sys” in the “Automatic” Dropdown box as shown in the below picture Figure: 4.

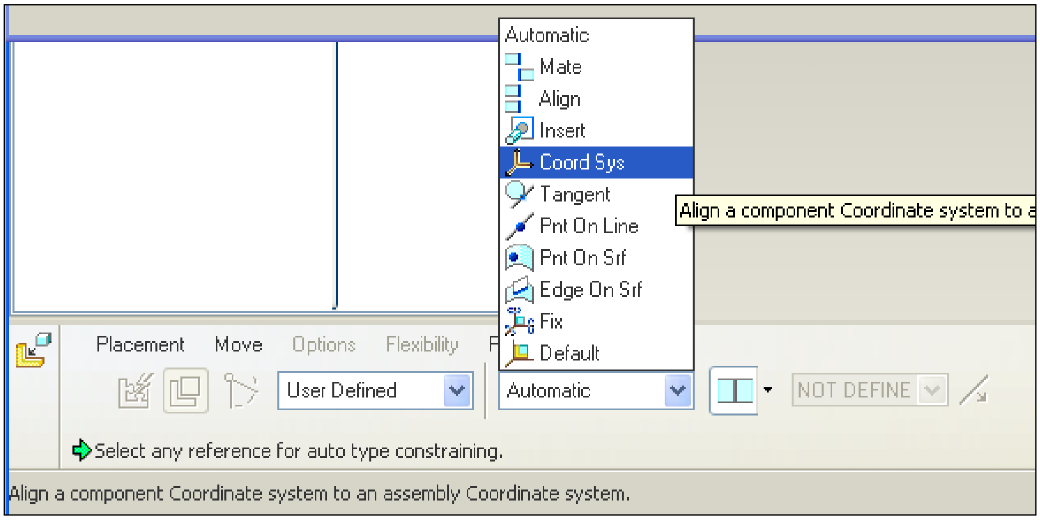

Figure: 4

Select the coordinate system about which the model is to be assembled.
In the example I used the “TO_MAIN” csys and “MAIN” csys

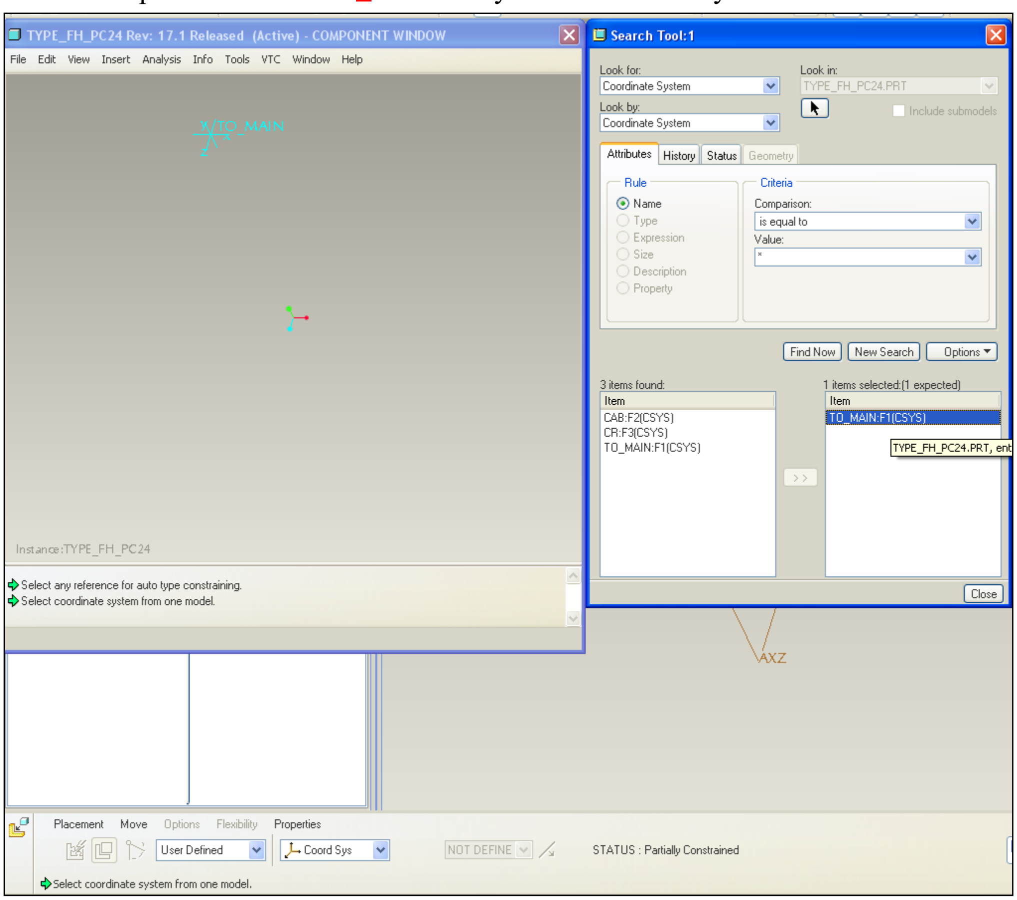

Figure: 5

The “TYPE_FH_PC24.PRT” is assembled as shown below Figure: 6

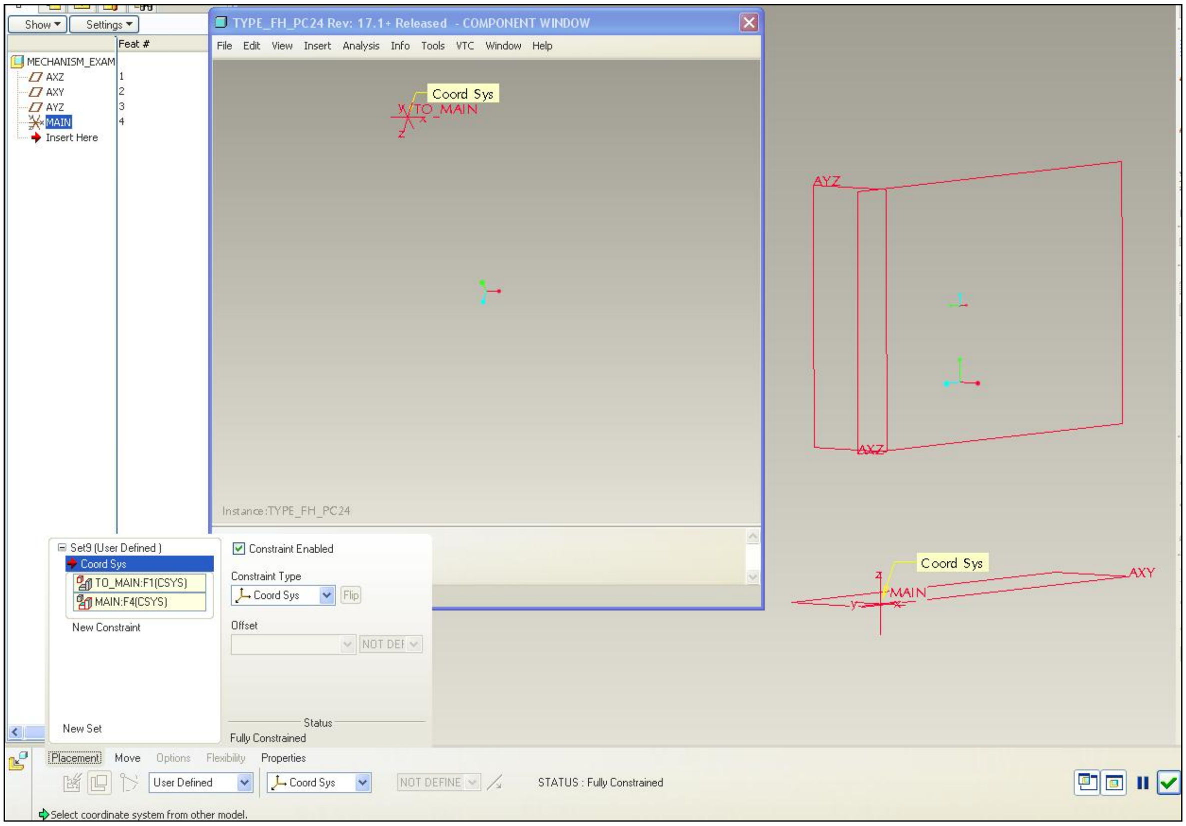

Figure: 6

Similarly the cab floor is assembled with respect to the “CAB” csys of the “CAB FLOOR” (82095368.PRT) and “TYPE_FH_PC24.PRT”. But before finishing the assembly select “6DOF” in the “USER DEFINED” dropdown box as shown in the Figure: 8

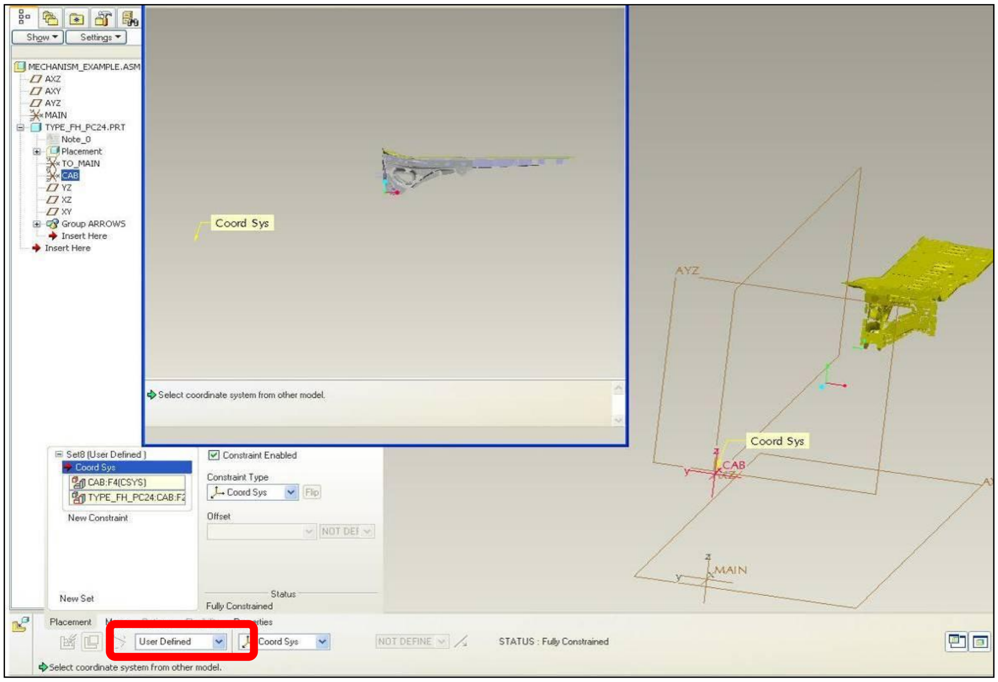

Figure: 7

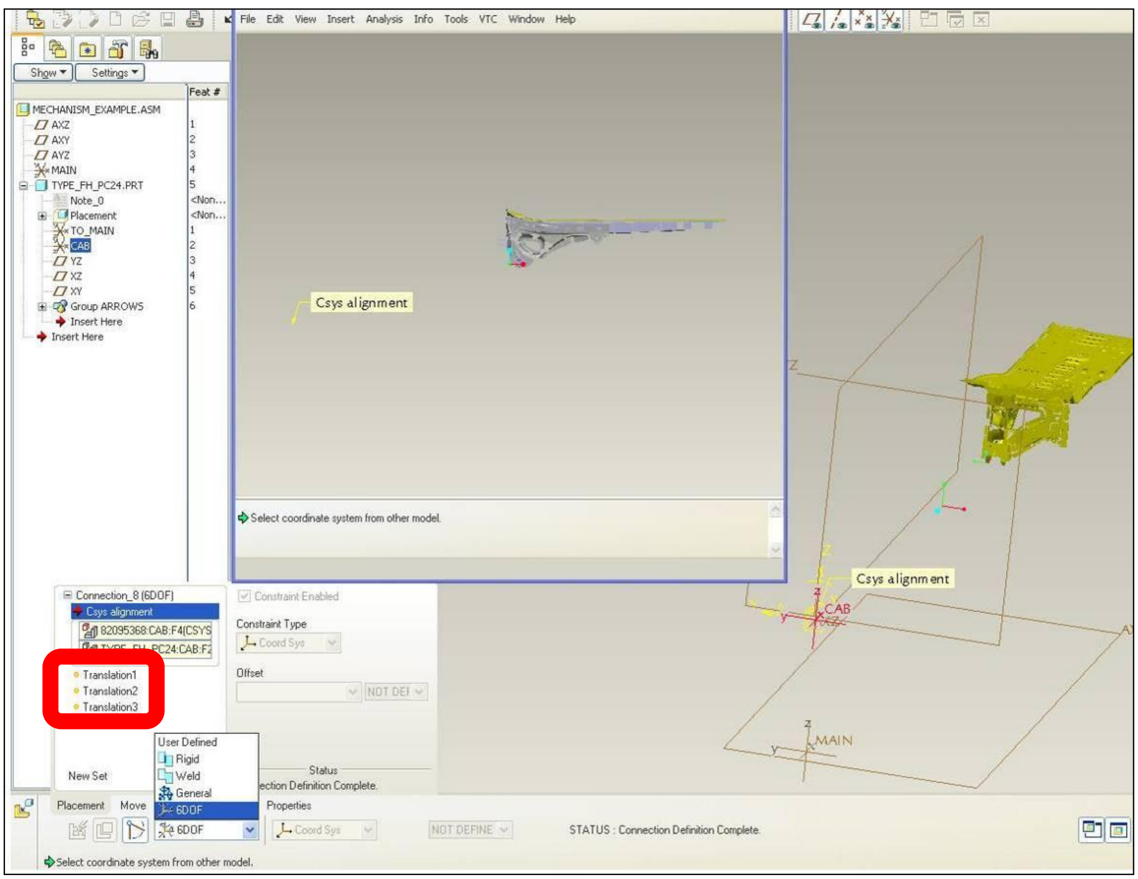

Figure: 8

Note: The assembly will not be fully constrained, because the “translation1”, “translation2”, “translation3” are not defined.

Once the necessary part are assembled, select Application→Mechanism
You will get a mechanism tree as shown in Figure: 9

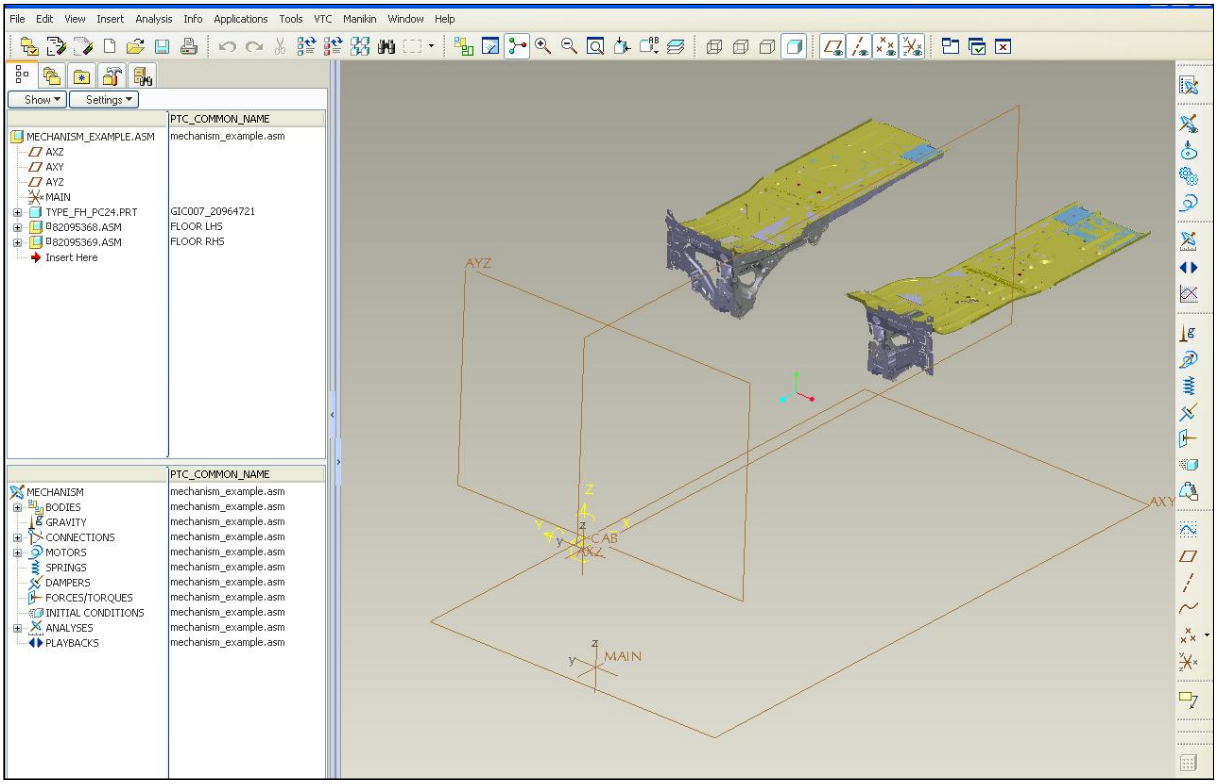

Figure: 9

Expand the connection and select the translation Axis’s, you will be able to see the selected axis in “RED” colour as in the below Figure: 10

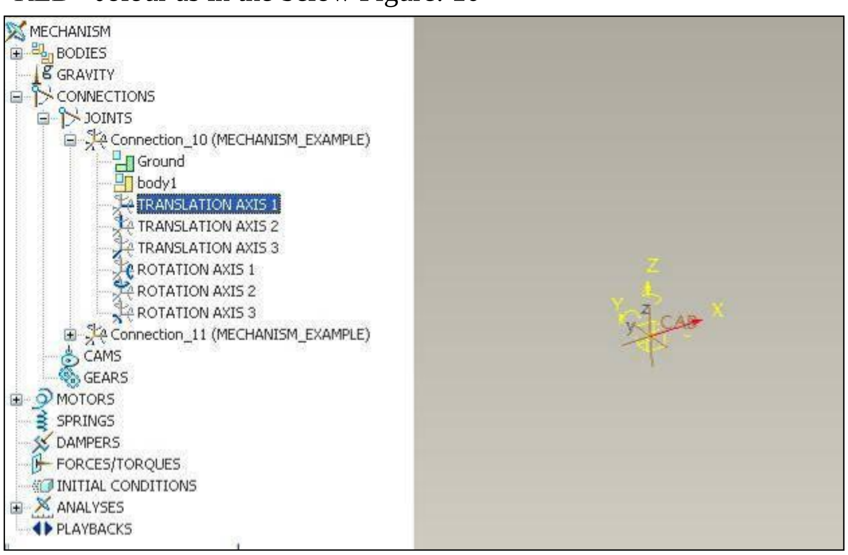

Figure: 10

Right click on the "Translation Axis 1" and select "SERVO MOTOR"

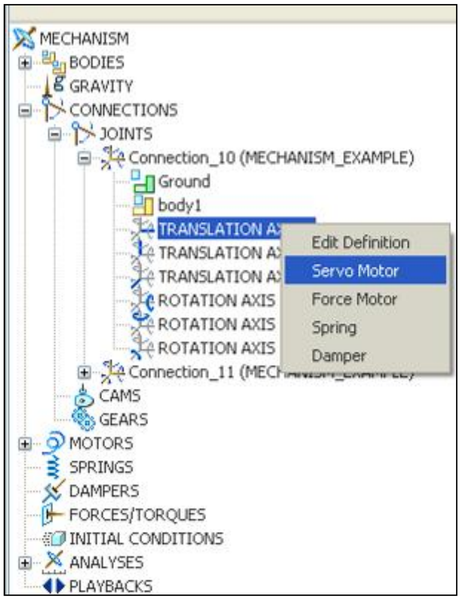

Figure: 11

You will get a new window to define a servo motor for the selected translation axis

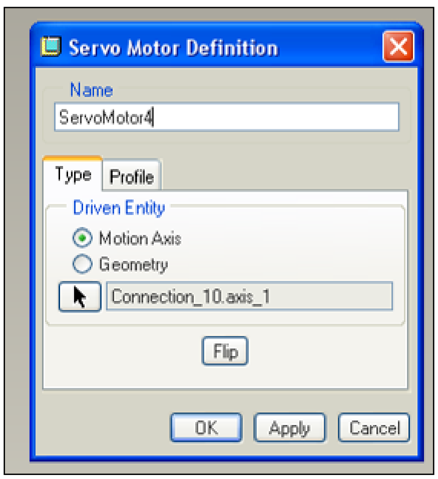

Figure: 12

Select the "Profile" tab and select "Table" from the "Magnitude" dropdown box as in the below Figure: 13

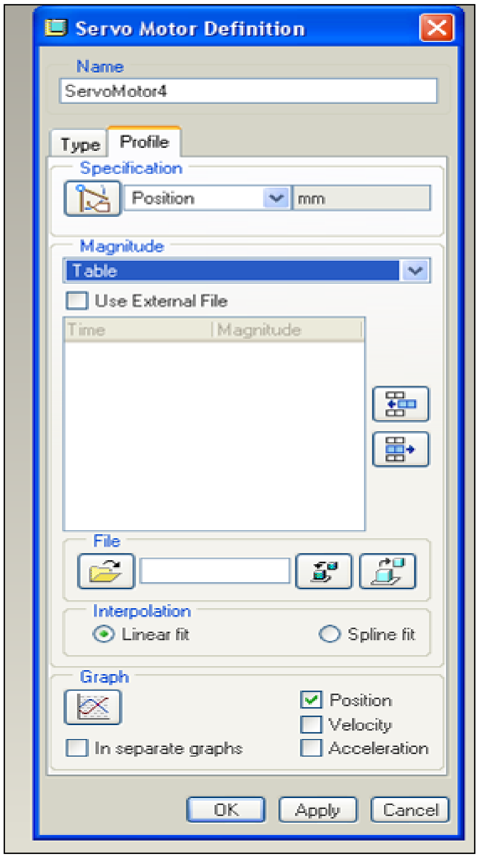

Figure: 13

Click the “open folder icon”, a new window to browse the folder will appear.
Browse to the location where you have the displacement (X, Y, and Z) and rotation (Roll, Pitch and Yaw) files. The right file has to be selected, if not the assembly will behave differently.

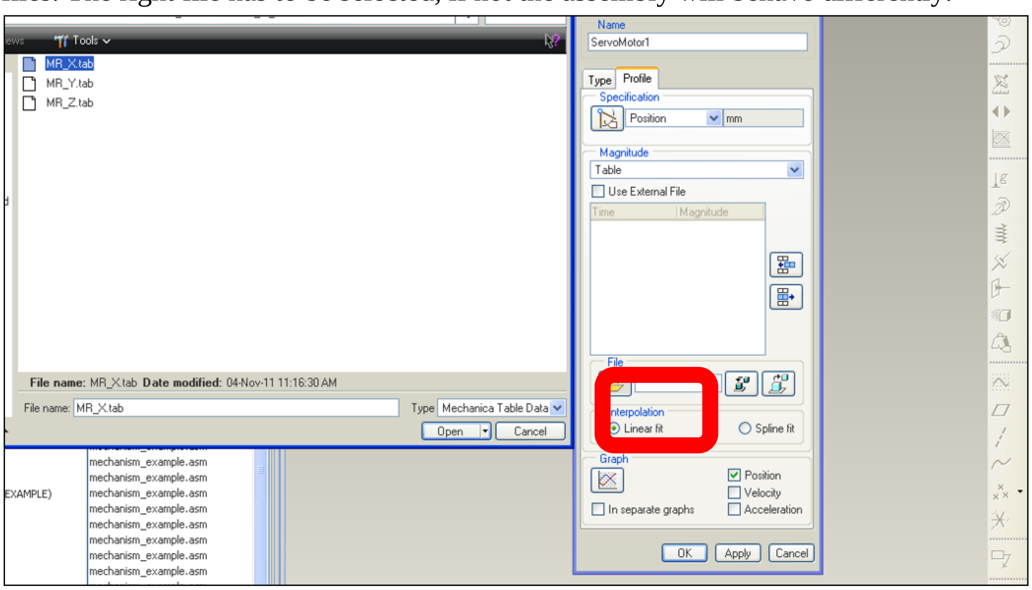

Figure: 14

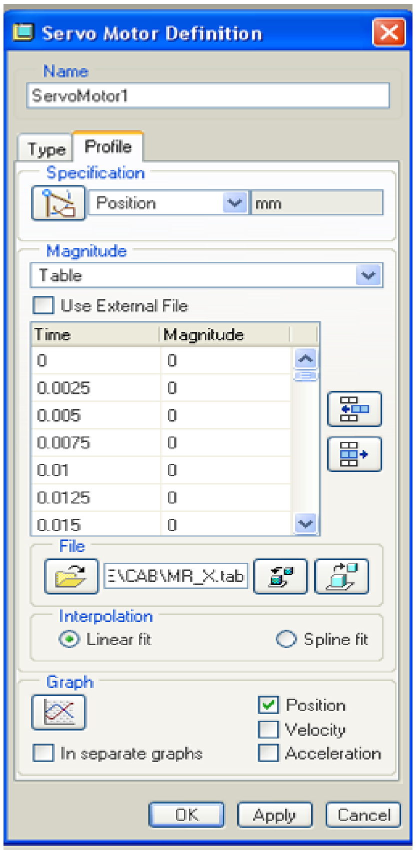

Figure: 15

Once the file is selected, the table will be populated with values from the file. Select "ok" and expand the "MOTORS" in the "MECHANISM" tree. You will find a servomotor added under "SERVO".

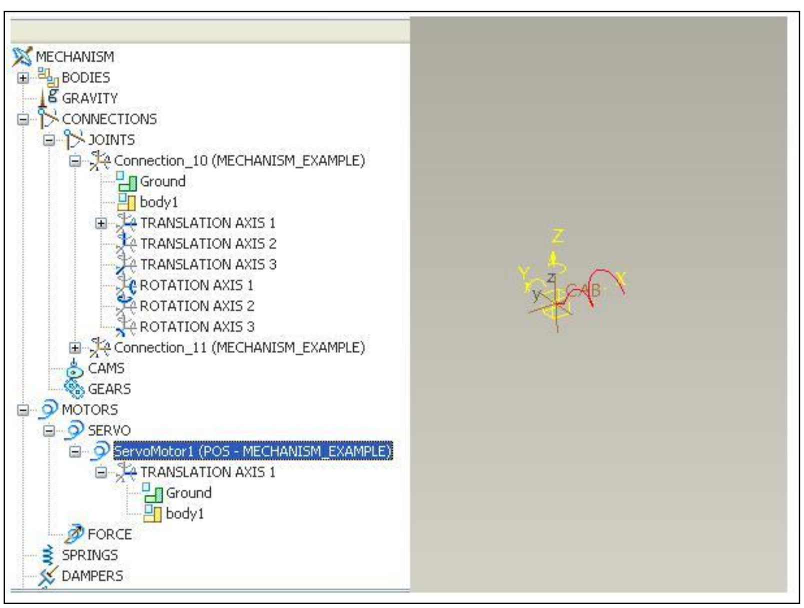

Figure: 16

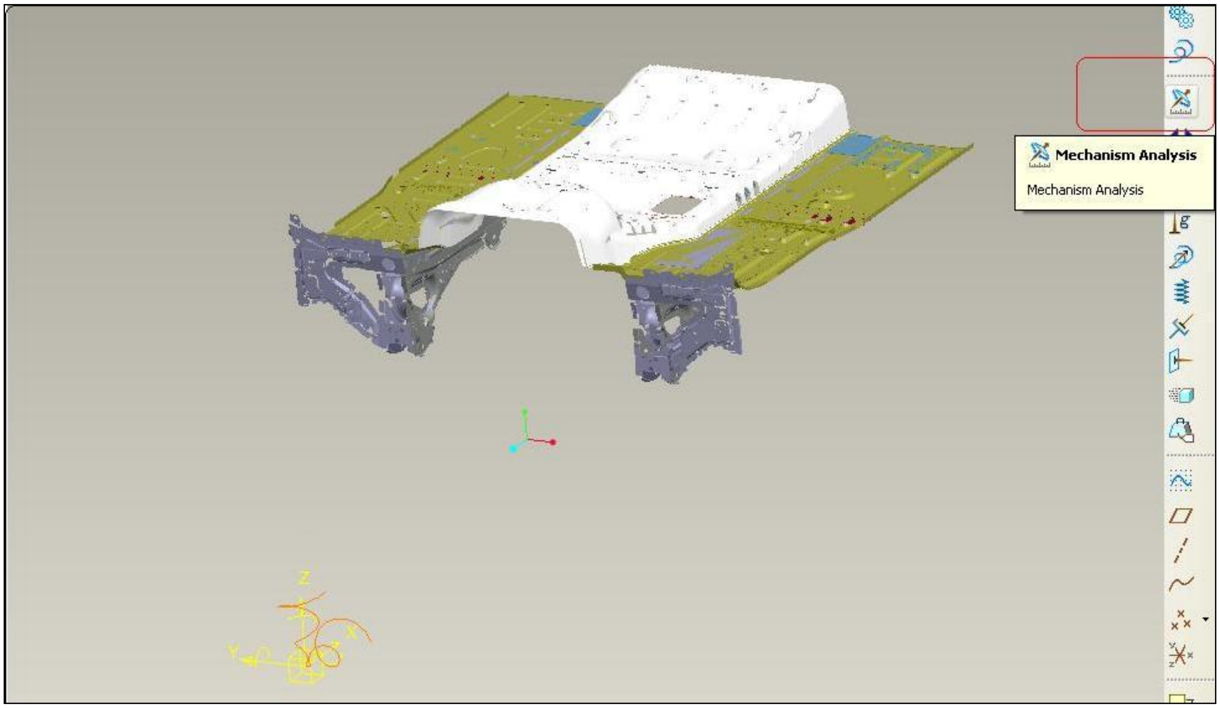

Figure: 17

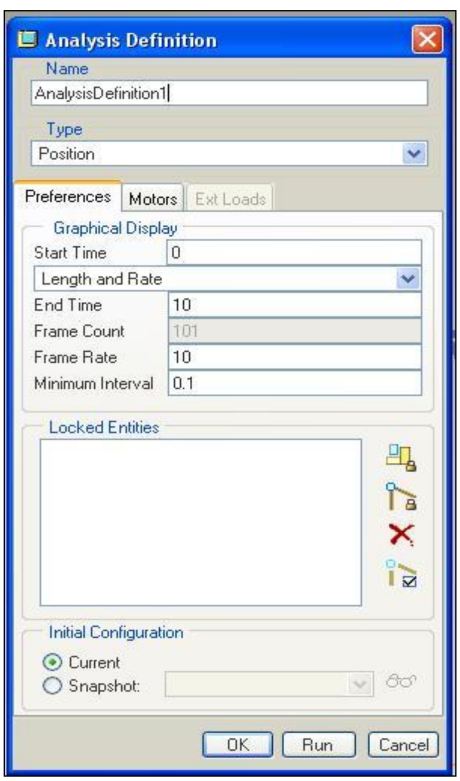

Figure: 18

The end time has to be changed to the time taken in the test track.