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FIRST ORDER ANALYSIS OF TRUCK PANELS USING STRUCTURAL SURFACE METHOD

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ABSTRACT

Computer Aided Engineering (CAE) has been widely used to evaluate the structural behaviour of an automobile. As CAE can only be operated by well-trained and experienced engineers to yield sensible results, a less complicated and inexpensive tool called First Order Analysis (FOA) is introduced. First Order Analysis has been proposed to verify automobile designs in the initial design stage. Simple Structural Surface (SSS) method and Microsoft Excel are employed as the FOA tools to handle the shortcomings of CAE and to obtain optimal design quickly. The main idea of this paper is to present the graphical interfaces using Microsoft Excel to achieve a product oriented analysis based on the knowledge of mechanics of materials. SSS method is utilized to rationalize the truck panels load path. Force equilibrium equations are established based on the simplifying assumptions to uncover whether the model idealization is statically determinate. Outline of the application of these complementing tools are presented.

Keywords: computer aided engineering, first order analysis, structural surfaces, panels.

INTRODUCTION

Simple Structural Surface (SSS) Method

At the early concept design stage, the available design data often change quickly over a rather short period of time as sales, packaging and manufacturing issues are reconciled and requirements are updated progressively. Various design alternatives may be debated. The design process must consider the structural strength and vibration of the product [1-4]. The design process is in constant change state. For any engineer that is operating in the analysis mode, it is analogous to catch a high speed moving train. Time constraint plays an important role. Having ‘close to right’ requirements to start with ensure effective synthesis downstream. These requirements contributed to the global structural specification and guidelines to create the geometry or model for analysis. The simple structural surface (SSS) method, which originated from the work of Pawlowski of the Warsaw Technical University; is offered as a means of organizing the process for rationalizing the basic vehicle body load paths [5]. The vehicle to be modelled using SSS method will be represented using a number of plane surfaces or panels. Each plane surface must be held in equilibrium by a series of forces. These forces are created due to the weight of the components attached to them. The rails that are attached to adjacent plane surfaces would provide reactions to maintain equilibrium. Equal and opposite forces will be exerted to the adjacent members. The loads on each SSS member is propagated through the whole structure from one rail to the other until the overall equilibrium is achieved. This way, any deficiency of the plane structures such as discontinuity in load path can be determined easily. Any SSS that is not supported adequately due to omission of a suitable adjacent component or panel will be revealed. This in turn indicates stiffness deficiency. Types of static loading condition, be it bending loads, shear loads, tension or compression loads can be identified by the engineer as well.

First Order Analysis (FOA)

There is a vast range of Computer Aided Engineering (CAE) tools offering precision and economy of design in automotive industries [6]. The Structural Dynamics Research Corporation (SDRC, purchased by Siemens AG in 2007) introduced Mechanical Computer Aided Engineering (MCAE) in the 70’s which has been widely accepted to date [7]. In order to make sound quantitative judgment, specific knowledge and skills are required for the sophisticated operations of CAE or MCAE. This problem is compounded by lack of legacy data to construct exact geometry or model for analysis in the early design stage. In that, it necessitates the need to entrust a CAE expert. Besides, CAE does not have the ability to maintain and inherit design activities, such as concept design and design know-how. This is because current applications of CAE are based on conventional procedures in which a shape is first obtained and then analysis is performed, and lacking in that they cannot be used to establish a concept before the start of modeling or idealization in CAE.

In this paper, we addressed the above issues by introducing FOA, a complimentary tool to CAE to quickly estimate ‘close to right’ design before embarking in expensive and time consuming CAE. By using FOA, internal force and moment distribution can be determined in due course based on basic knowledge of mechanics of materials such as beam and shell theory. This information will be used to configure the appropriate section property values and yield structural function values. Microsoft Excel that is employed in the FOA tool is remarkably effective in the initial design stage as it enables design engineers to freely propose geometry changes while viewing the stress state and other function values. Needless to say, outputs from FOA (forces and moments) transferred to detailed CAE will shorten the process of structural optimization eventually as sensible geometry is provided to start with as shown in Figure-1.

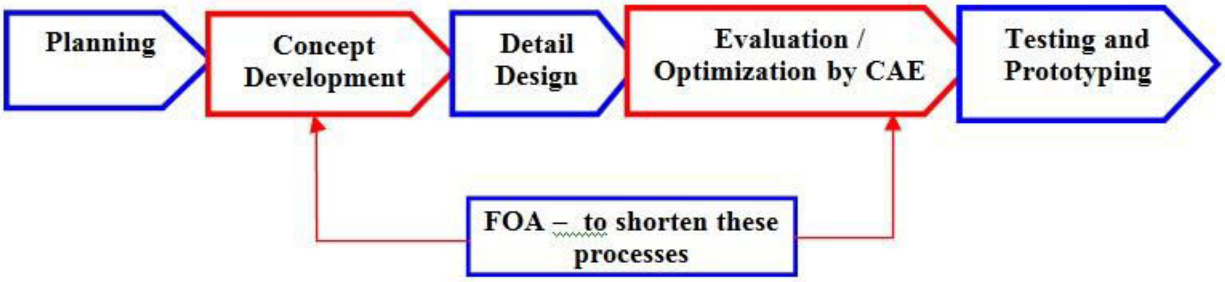

Figure-1. Application of FOA in the product development process.

Load Flow Analysis Using SSS Method

The SSS method used prior to and during the initial design stage can complement computer aided design and synthesis notably. In the beginning stage of a new vehicle design, for example as shown in Figure-2, there are normally insufficient data available to develop a complete finite element model for analysis. Model at this stage is generally being represented by sticks or beams and structure surfaces by panels. Figure-3 shows a simplified model of a truck panels to demonstrate the SSS method.

Figure-2. Example of a new vehicle.

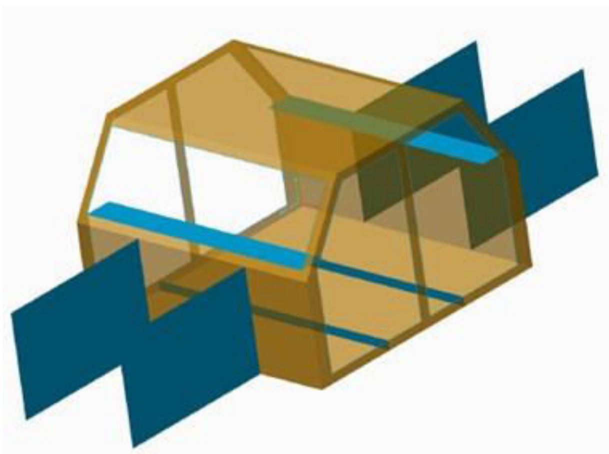

Figure-3. Hypothetical truck: SSS idealization.

The truck structure when viewed in side elevation (Figure-4) can be considered as a simply supported beam, the supports are the front and rear axles. Figure-4 also shows the baseline loads that are being considered for the bending case. These loads are the power-train F_{pt}, the front passengers F_{pf}, the rear passengers F_{pr}, and the luggage F_l. Table-1 provides the masses and longitudinal positions of these loads. Subsequently, the front (R_F) and rear (R_R) reaction forces can be determined accordingly. Referring to Figure-4, by taking moments about the rear suspension mounting; the front suspension reaction is given by Eqn. (1):

$$R_F = \frac{F_{pt}(L+a) + F_{pf}(L-b) + F_{pr}(L-c) - F_l d}{L} \tag{1}$$

Similarly, taking moments about the front suspension mounting:

$$R_R = \frac{F_{pf}b + F_{pr}c + F_l(L+d) - F_{pt}a}{L} \tag{2}$$

Table 1. Masses and longitudinal positions of major loads.

Type	Mass [kg]	Length from Y axis [m]
Power Train, F_{pt}	370	0.60
Luggage, F_l	1000	4.46
Front Passenger, $F_{pf} \times 2$	160	2.19
Rear Passenger, $F_{pr} \times 3$	290	3.16

Many more components such as front bumper, radiator, instrument panel, fuel tank, exhaust, rear bumper and distributed loads due to the weight of the structure can be considered to provide a more accurate model. Similar procedure can be applied to calculate the reaction forces.

Free body diagrams and equilibrium equations for each truck panel

Exploded Figure-3 into Figure-5, it can be clearly seen that edge loads and end loads are needed to ensure equilibrium in all SSSs. These loads are represented by the forces K_1 to K_{13}. Starting from the central floor cross panels, bending analysis is carried out to identify the internal loads associated with each SSS. It is assumed that

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the passenger loads are taken up by the two transverse floor beams SSS (1) and (2). These floor beams are supported at each end by the side forces K_1 and K_2, and there is an equal but opposite force acting on the sideframe. Repeating the same procedure with all the panels, and by using the equations of statics, i.e. resolving forces and taking moments; all the side forces can be determined accordingly.

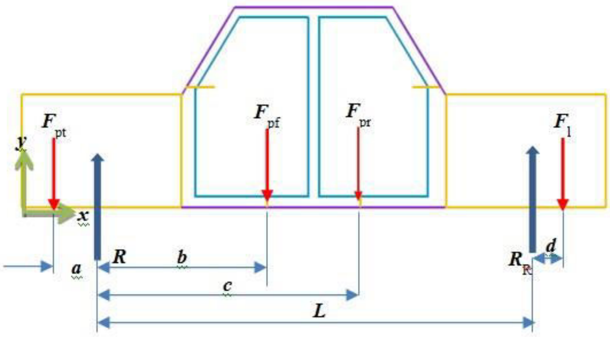

Figure-4. Major loads distribution.

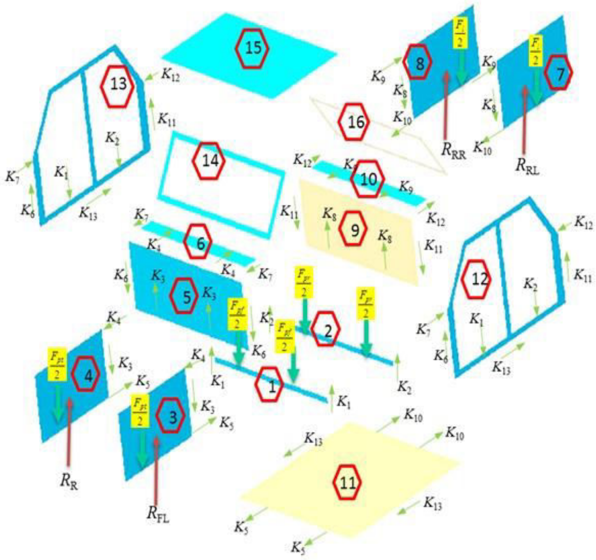

Figure-5. End and edge loads for bending case in exploded view.

It should be noted that all these loads are applied in the planes of simple structural surfaces in order to ensure sufficient strength and stiffness can be achieved. Based on the shear and bending loads evaluated on each panel, satisfactory stress levels can be assessed. All surfaces are separated and forces that flow between each member are clearly stated. By considering the truck to be in equilibrium condition, equations for the internal forces K_1 to K_{13} are derived based on the relevant forces in each member as shown below.

Transverse floor beam (front 1 and rear 2)
Resolving forces vertically and by symmetry:

$$K_1 = \frac{F_{pf}}{2} \tag{3}$$

$$K_2 = \frac{F_{pr}}{2} \tag{4}$$

Left and right front inner wing panel 3 and 4
Resolving forces vertically for the left-hand panel:

$$K_3 = R_{FL} - \frac{F_{pt}}{2} \tag{5}$$

Taking moments about the rear lower corner:

$$K_4 = \frac{R_{FL} l_1 - \frac{F_{pt}}{2}(l_1 + l_{pt})}{h_1} \tag{6}$$

Resolving forces horizontally:

$$K_5 = K_4 \tag{7}$$

Dash panel 5

This SSS is subjected to equal and opposite reaction forces from the wing panels, K_3.
Resolving forces vertically and by symmetry:

$$K_6 = K_3 \tag{8}$$

Front parcel shelf 6

This SSS is subjected to equal and opposite reaction forces from the inner wing panels, K_4.
Resolving forces vertically and by symmetry:

$$K_7 = K_4 \tag{9}$$

Rear quarter panels 7 and 8
Resolving forces vertically for the left hand panel:

$$K_8 = R_{RL} - \frac{F_l}{2} \tag{10}$$

Taking moments about the front lower corner:

$$K_9 = \frac{R_{RL} l_2 - \frac{F_l}{2}(l_1 + l_2)}{h_2} \tag{11}$$

Resolving forces horizontally:

$$K_{10} = K_9 \tag{12}$$

Panel behind the rear seats 9 (rear firewall)
Resolving forces vertically and by symmetry:

$$K_{11} = K_8 \tag{13}$$

Rear parcel shelf 10

Resolving forces vertically and by symmetry:

$$K_{12} = K_9 \tag{14}$$

Floor panel (11)
Resolving forces horizontally:

$$2K_{13} = 2(K_{10} - K_5) \tag{15}$$

Left-hand and right-hand side frames (12) and (13)
Both side frames are loaded identically. Examining the forces acting on the side frames, it is obvious that these forces can be obtained from equations (3), (4), (8), (9), (13), (14), and (15). It is essential to use the equations of statics to check if the equilibrium conditions are satisfied.
Resolving forces vertically:

$$K_6 + K_{11} - K_1 - K_2 = 0 \tag{16}$$

Resolving forces horizontally:

$$K_7 + K_{13} - K_{12} = 0 \tag{17}$$

For this bending case, windscreen frame (14), roof panel (15), and backlight (16) SSSs are not taking up loads.

The above simultaneous equations (relatively 'sparse') can be solved using Microsoft Excel mathematical modeling and solving technique [8] or alternatively, they can be rearranged and put in matrix form to be solved using Gaussian reduction method, they are:

$$\underbrace{\begin{bmatrix} 1&0&0&0&0&0&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&0&0&0&0&0&0\\ 0&0&0&-1&1&0&0&0&0&0&0&0&0\\ 0&0&-1&0&0&1&0&0&0&0&0&0&0\\ 0&0&0&-1&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&0&0&0&1&0&0&0&0\\ 0&0&0&0&0&0&0&0&-1&1&0&0&0\\ 0&0&0&0&0&0&0&-1&0&0&1&0&0\\ 0&0&0&0&0&0&0&0&-1&0&0&1&0\\ 0&0&0&0&2&0&0&0&0&-2&0&0&1 \end{bmatrix}}_{\text{Equilibrium matrix}} \underbrace{\begin{bmatrix} K_1\\ K_2\\ K_3\\ K_4\\ K_5\\ K_6\\ K_7\\ K_8\\ K_9\\ K_{10}\\ K_{11}\\ K_{12}\\ K_{13} \end{bmatrix}}_{\text{Edge forces}} = \underbrace{\begin{bmatrix} \frac{F_{pf}}{2}\\ \frac{F_{pr}}{2}\\ R_{FL}-\frac{F_{pt}}{2}\\ \frac{R_{FL}l_1-\frac{F_{pt}}{2}(l_1+l_{pt})}{h_1}\\ K_4\\ K_3\\ K_4\\ R_{RL}-\frac{F_l}{2}\\ \frac{R_{RL}l_2-\frac{F_l}{2}(l_1+l_2)}{h_2}\\ K_9\\ K_8\\ K_9\\ K_{10}-K_5 \end{bmatrix}}_{\text{Input forces}}$$

SSS linked with Microsoft Excel

Embedded CAD model drafting with Excel is one of the Excel features that let the user to link the data between CAD and Excel. AutoCAD drawings, pictures, and clip art of an existing Visio drawing can be inserted by using commands on the Insert menu. Visual Basic for Application (VBA), a macro language in Microsoft Excel, is used to perform functions such as (i) reading and writing data; (ii) transfer to other sheets; (iii) numerical calculations; (iv) import from and export to external files; and (v) initiate an external program.

Graphical user interface (GUI) created using Excel allows simulating specific pathways of interest by prompting for inputs and presenting results only relevant to those pathways. It works by receiving inputs from the user through option buttons, slider bars, check boxes, and input text boxes. Subsequently, communicates the inputs to an underlying Excel spreadsheet model [9-10]. At last displays results in the form of tables in another Excel output file. When designing the GUI for this system, it is easy and efficient to investigate problems encountered as it is possible to switch among the individual sheets quickly in the workbook when editing the spreadsheet. Figure-6 shows the CAD embedded truck panels in Excel. Clicking '*External forces*' text button will open up the sheet that used to determine the external forces for the baseline model. By manipulating the slider bars on the *External forces* sheet, the value of the major loads such as power train, luggage load, as well as the panel dimensions would be changed accordingly. Internal forces would be displayed by clicking the relevant text button such as *front transverse beam*.

To interrogate the model in more detail, clicking on the respective sheet will display values for shear forces and bending moment with respect to the length of the panel as shown in Figure-7. The same procedure can be repeated for any other panels to investigate the internal forces simply by manipulating sheets in the workbook.

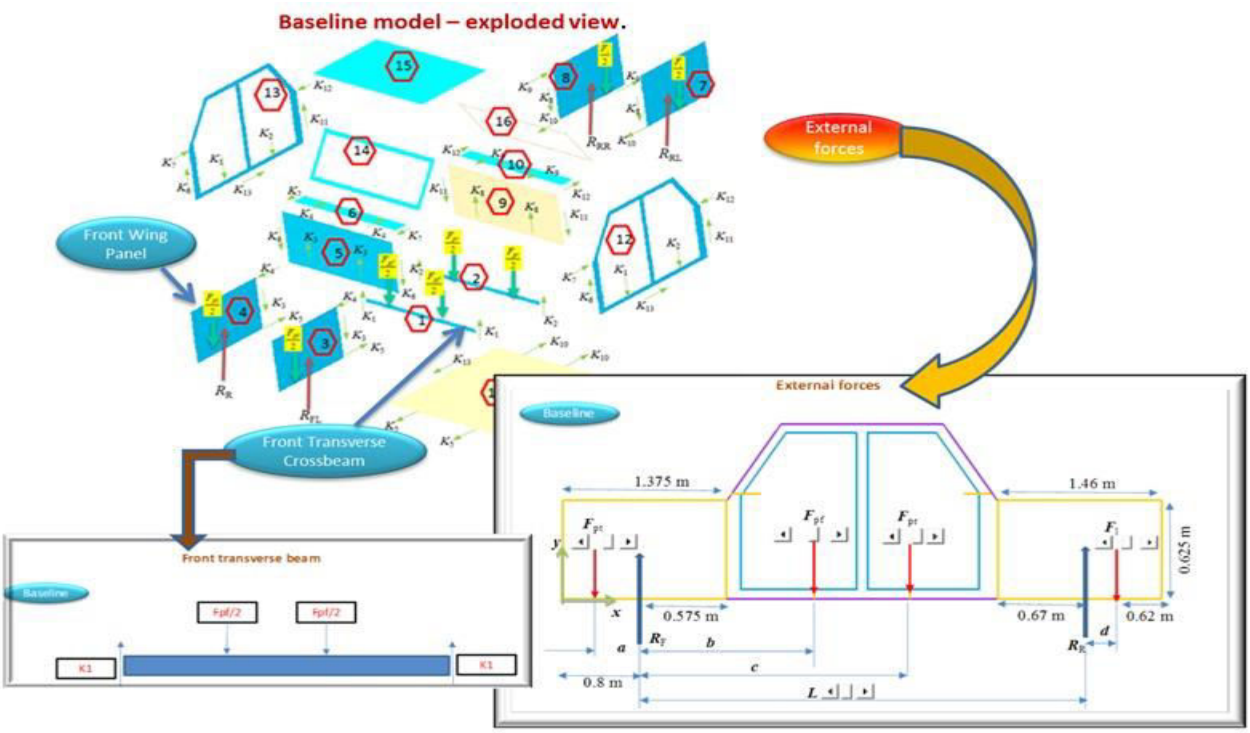

Figure-6. Truck panels embedded in Excel linked with SSS.

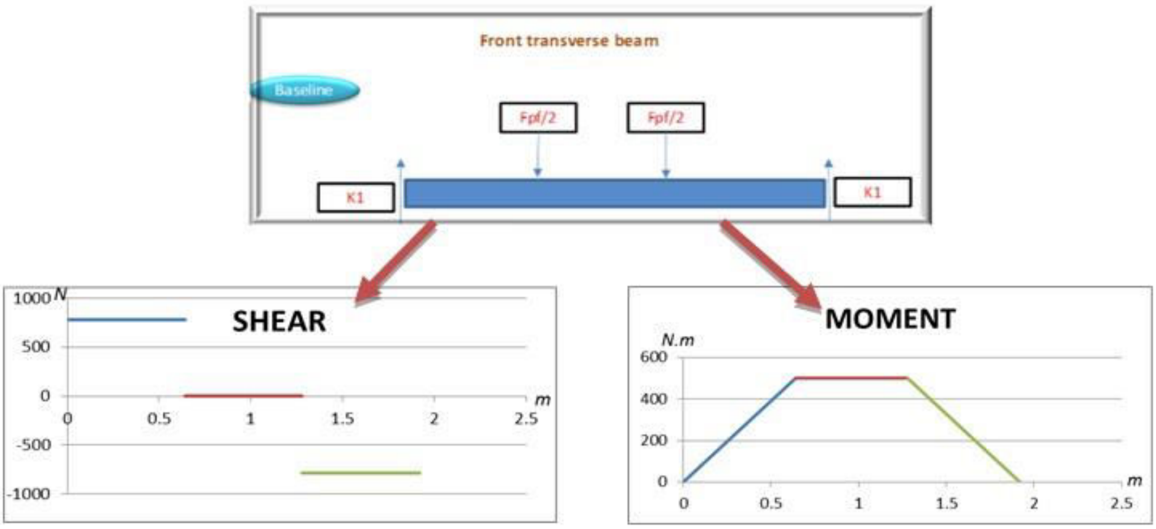

Figure-7. Shear force and bending moment of front transverse beam.

CONCLUSIONS

From the shear and bending moment diagrams computed using SSS linked with Excel, maximum moment and shear forces are then determined to evaluate the minimum moment of inertia that the panels must be designed for. Areas that require reinforcement or enlargement are revealed. It is also obvious that only basic equations are used to provide appropriate sections for the above mentioned loadings. This approach is applicable for visualizing internal load path when only limited information such as length, height, external load inputs about the vehicle body structure are available since very basic parameters are known or estimated especially during the initial design stage. FOA using Excel can be used as a template for any new designer to reveal the internal load path at the design concept stage and during the ongoing evaluation stage by CAE. GUI that is developed in Excel embedded with calculation results for the panels or models mimic the designer thinking process and to address 'what if' scenario throughout the product development cycle. With this, design know-how is retained within the model instead of the designer.

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