SIMPLIFIED 3-D MESH GENERATOR

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Abstract

Wire-grid modelling of continuous surfaces for structures in three dimensions is a tedious and time consuming process. This paper describes a simplified automatic mesh generator that converts a large class of three-dimensional structures into appropriate wire-grid models. The output of the generator can readily be used as the input to wire antenna Moment Method codes. It is however designed specifically for use with the Numerical Electromagnetics Code (NEC).

1. Introduction

Users of Moment Method codes often require the generation of wire-grid models for three-dimensional structures such as ships, vehicles, aircraft, etc. Producing these models manually usually takes a lot of time and effort. Even when working from the manufacturers CAD drawings the user often needs to eliminate unnecessary details and parts of the structure. Although some sophisticated computer software has been developed for this purpose [1], it is not generally available.

The Mesh Generator developed in this work can produce wire-grid models for these 3-D structures according to the required specifications. The structure needs to be represented by flat surfaces of quadrilateral or triangular shape. The grids produced by the generator are generally quasi-orthogonal wires except near one of the vertices in triangular regions; as will be shown later. Limited modelling errors are checked for by the generator; although not as extensively as described in [2].

The output of the generator can be used as a NEC [3] input data file. External graphics facilities need to be used to view the generated wire-grid.

2. Mesh Generation Guidelines

Wire-grid modelling techniques have been studied extensively by many workers. It is not the intention of this paper to give any recommendations in this regard. However, because of their relevance, mesh generation guidelines will be briefly reviewed here. When modelling a solid surface with a wire-grid, three main factors need to be considered:

- Type of the wire-grid
- Cell size of the grid
- Radii of grid wires

The most widely used type of wire-grid is the rectangular one because it was found to be satisfactory in most cases and it is easier to generate than other types. Also, the rectangular grid makes it easier to decide on the values of wire radii using simple formulas. A triangular mesh on the other hand has the advantage of simulating more realistic currents [4, p.117]. Other types of meshes have also been used. The mesh generator described in this paper can produce rectangular and partly triangular grids.

The grid cell size can either be specified in terms of its area, as in [4], or in terms of the spacing between adjacent elements. Because the rectangular mesh is the one that is most commonly used, it is easier to use the second method. The element spacing (size) will depend on the type of structure being modelled and on the parameters of interest. It must be as small as possible, up to the limitations of the MM code used, if these are near field parameters such as input impedance. The grid element size can range from $\lambda/5$, as suggested in [5], to as little as $\lambda/1500$ as used in [6] near the feed point of the antenna. The generally accepted value for element size is $\lambda/10$.

As for the wire radii of the grid, two basic methods have been discussed in the literature. The first specifies the wire radius of the model as a fraction of the wavelength. Studies that have used this method, such as in [7], set the wire radius empirically at 0.005λ but do not give any reasoning for this choice. The second method is much more widely used and relates the overall surface area of the wires, A_s, to the area of the solid surface that is being modelled, A_r. As has been described in [8], modellers have recommended several criteria for this relation. The following table summarises those most commonly used:[1]

Modeller	**Criterion**
Moore & Pizer	$A_s \geq A_r$ up to $5A_r$
Lee, et al	$A_s \approx 2A_r$
Ludwig	$A_s \approx 2A_r$
Elliott & Mcbride	$A_s = A_r$ of one side of a closed surface $A_s = A_r$ of both sides of an open surface
Burke & Poggio	A_s of wires in the direction of each current component $= A_r$. So, for a rectangular mesh, $A_s = 2A_r$

[1] Complete references for these criteria are found in [8].

It is evident that most of these criteria recommend the "twice surface area rule", i.e. $A_s = 2A_r$. If we define the ratio between A_s and A_r to be the overall area factor, AF , then it follows that AF = 2 in the general case. It is however useful to keep AF as a variable set by the user according to what is required. This mesh generator uses the given area factor to calculate the wire radius for the mesh of the modelled surface.

3. Description

The program for this mesh generator is written in standard FORTRAN 77. It can run on a mainframe or a microcomputer. The generator is used to model structures in the following manner:

1. The structure is divided into quadrilateral or triangular flat regions of any orientation in space.
2. Knowing the corners co-ordinates of each individual region and the number of sections required on its sides, the region is converted into a wire-grid accordingly.
3. The wire radius for each region is calculated according to the specified area factor as described below.
4. Similar elements at the junctions of regions sides are then eliminated.
5. Parts of the structure that do not form flat surfaces must be added manually.

A quadrilateral region is defined by the co-ordinates of its four corners C1 to C4. There is no restriction on the shape of the quadrilateral region or its orientation in space as long as it is flat. In the special case of the triangular region, the co-ordinates of two consecutive corners are the same. The region is divided into grid elements by specifying the number of elements on two adjacent sides (N1 and N2 in Fig. 1).

The other two opposite sides are assumed to have the same number of elements as those opposite regardless of their lengths. For triangular regions, there are only three corners, so one of the opposite sides will simply be a vertex. To establish a reference, this type of region is defined as one in which corners 3 and 4 have the same co-ordinates. Consequently, there are three alternatives for the mesh of a triangular region as shown in the three schematics of Fig. 2. By changing the numbering order of the region's three corners, the required mesh can be generated. N1 and N2 were kept the same at 4 and 3 respectively, in all the three combinations in order to illustrate the point. In practice they can be changed to suit the model.

The generator will then produce all elements that make up the wire-grid of the region. The sequence of ordering the elements is shown in Fig. 1 for the first four elements (L1 to L4).

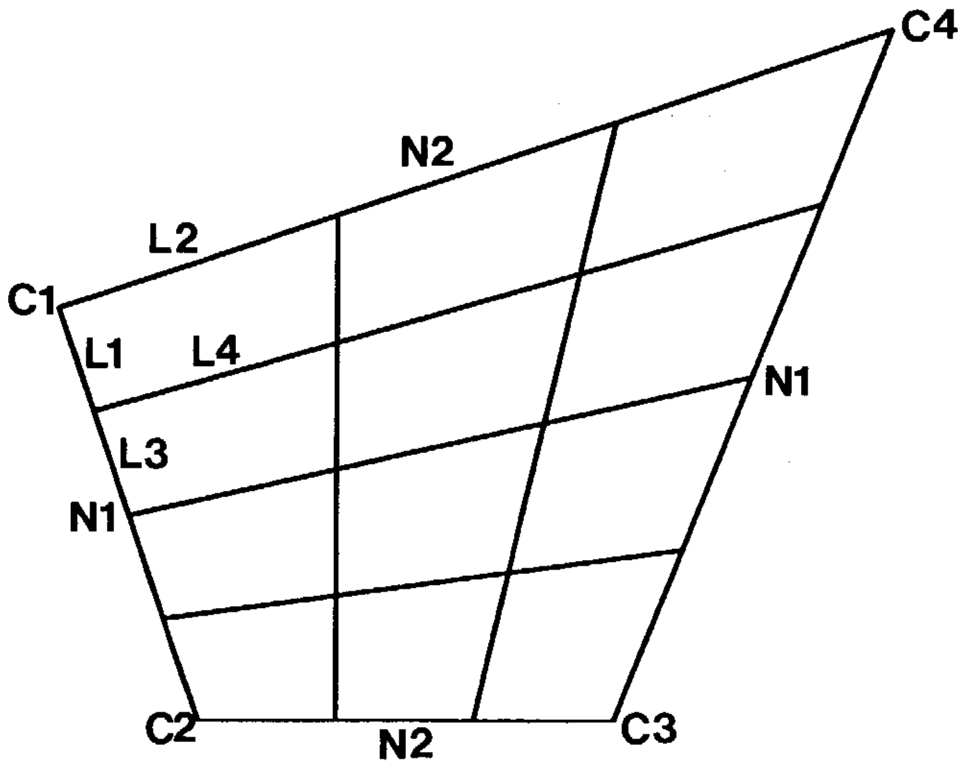

Fig. (1) A schematic of a quadrilateral region and its mesh distribution where N1 = 4 and N2 = 3.

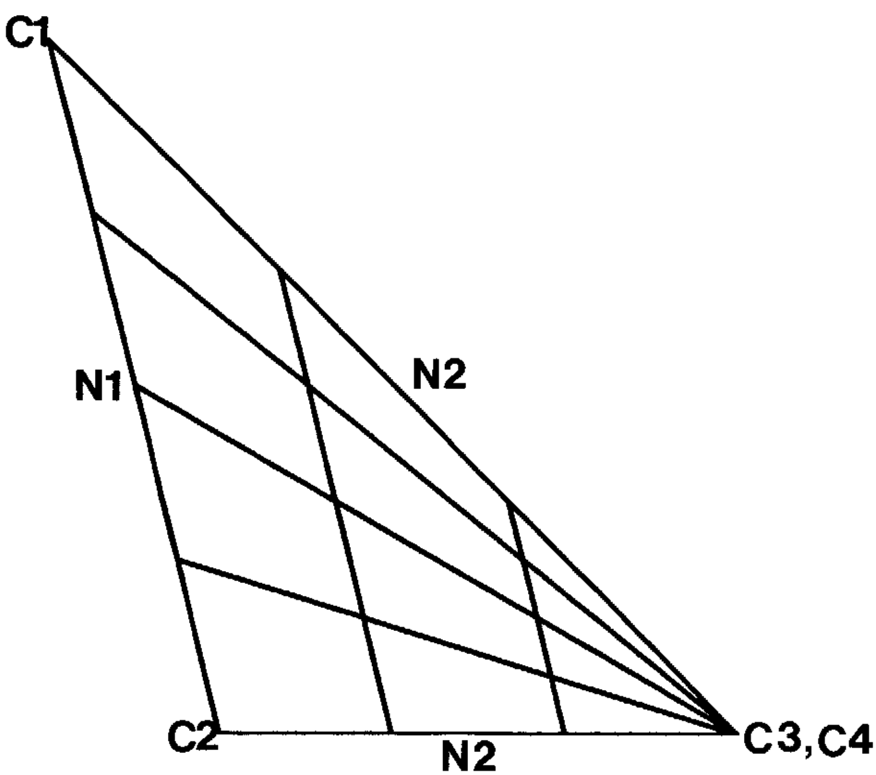

Fig. (2-a) First alternative of a triangular region's mesh.

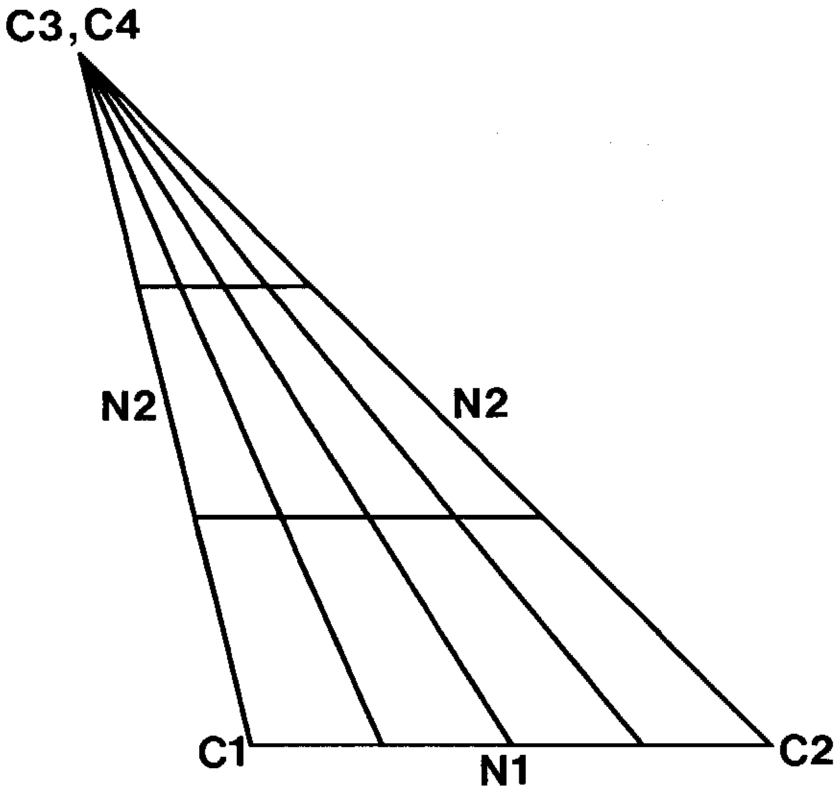

Fig. (2-b) Second alternative mesh of the triangular region in Fig. 2-a

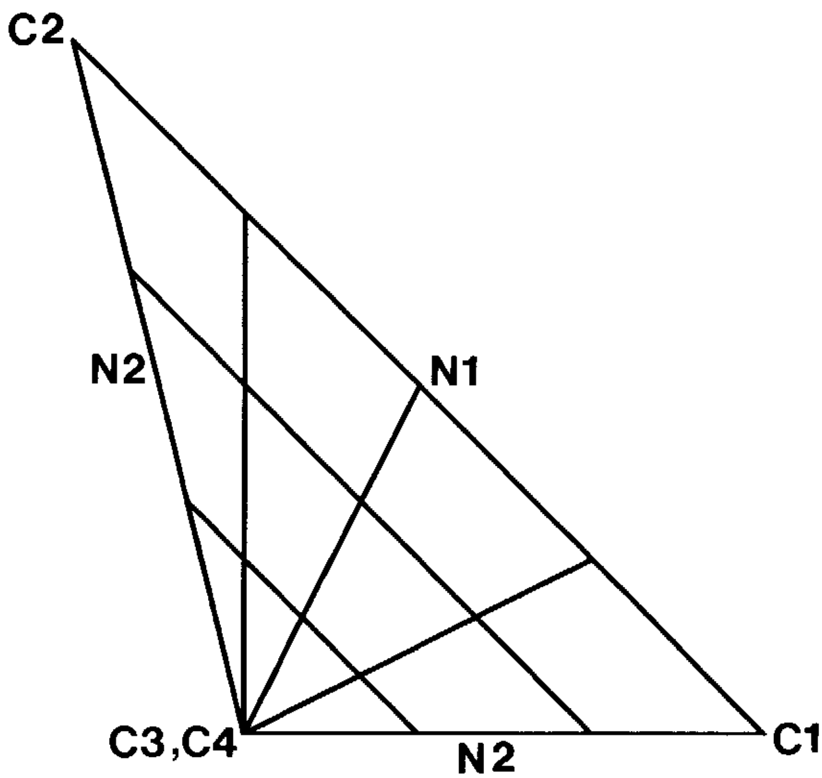

Fig. (2-c) Third alternative mesh of the triangular region in Fig. 2-a

The next step is to calculate the radius of wires in the region using the given area factor. The total surface area of the wires A_s is first calculated by the following formula:

$$A_s = 2\pi a \sum_{i=1}^{k} l_i$$

where

l_i	: The length of the ith element
a	: The radius of the region's wires
k	: The number of elements in the region

The region's area A_r is then calculated by dividing the region into two triangles whose areas are found using Heron's formula [9, p.7] as follows:

$$A_r = A_1 + A_2$$

$$A_1 = \sqrt{S_1(S_1 - L_{12})(S_1 - L_{23})(S_1 - L_{31})}$$

$$S_1 = \frac{L_{12} + L_{23} + L_{31}}{2}$$

$$A_2 = \sqrt{S_2(S_2 - L_{34})(S_2 - L_{41})(S_2 - L_{13})}$$

$$S_2 = \frac{L_{34} + L_{41} + L_{13}}{2}$$

In the above expressions, L_{mn} refers to the length of the region's side connecting corners m and n. The generator will then determine the wire radius a, which is the same for all the elements of the region, using the expression:

$$a = \frac{AF \times A_r}{2\pi \sum_{i=1}^{k} l_i}$$

The above process is repeated for each region in the structure. Since common elements exist at the junctions of regions' sides, all are scanned and the duplicated elements are eliminated. The wire radius of the elements at a junction is determined using the parameters of the region listed first in the input file.

At this stage, most of the structure will have been converted automatically to a wire-grid of the required specification. The user only has to add those parts of the structure that could not be represented by flat surfaces. These for example, may include curved surfaces or single wires.

It is important to note that connected regions should have the same number of elements for the sides at the junctions. It is also advisable that they have similar mesh densities so that any change in stepped wire radius between two connected regions is made as gradual as possible. Different mesh densities for different parts of the structure can be achieved by making a gradual change in the mesh densities of connected regions. After all, the limitations of the Moment Method code that is used will determine the stepped radius factor that it can handle.

In addition, the generator produces some useful information for the different regions of the structure and checks for some of the common modelling errors. The following parameters are produced for each region in the structure:

- Segment length l_s in wavelengths
- Wire radius a in wavelengths
- Ratio of segment length to wire radius l_s/a

The user can specify the error threshold for these parameters or use the default values which are set according to the suggested guidelines in [2]. These are:

$$l_s > \lambda/5$$
$$\lambda/a < 30$$
$$l_s/a < 2$$

The threshold for the l_s/a ratio is set at 2 assuming that the extended thin-wire kernel in NEC will not be used.

Note that the information given for individual regions are for all the elements in the region including those that will be eliminated when the regions are joined together.

4. *Inputs and Outputs of the Generator*

The input data of the generator is read in free format from a file structured as follows:

```
NREG AF FREQ
XX1 XX2 XX3 XX4
YY1 YY2 YY3 YY4
ZZ1 ZZ2 ZZ3 ZZ4
N1 N2
```

where

FREQ	: Frequency of operation in Mega Hertz.
NREG	: The number of regions on the structure.
AF	: The area factor for all the regions.
XX1 ... XX4	: X co-ordinates of the four corners of a region in metres.
YY1 ... YY4	: Y co-ordinates of the four corners of a region in metres.
ZZ1 ... ZZ4	: Z co-ordinates of the four corners of a region in metres.

N1	: Number of elements on the side between corners 1 and 2
N2	: Number of elements on the side between corners 2 and 3

Data for all the regions are input sequentially in the same manner one after the other without leaving spaces. Note that the area factor, AF , is specified only once at the beginning of the file for the entire structure.

Each element generated is simply a one-segment wire. Two output files are produced by the generator:

Geometry output file: which is formatted as a standard NEC geometry file that can be processed using the NEEDS package [10] or a mainframe version of NEC. The file format is accepted by both IGUANA [10] and NECPLOT [3] graphics routines.

Information file: which includes the following:

- The area factor, number of regions, and total number of elements for the structure.
- A_r, A_s, a, and the total length of elements for each region given in metres squared and metres.
- The modelling parameters mentioned in the previous section, grouped for each region separately, and the modelling errors if found.

It was suggested by an anonymous reviewer that one option to this generator would be to specify the number of segments per wavelength between corners of a region and request the wire-grid to be generated accordingly. While this option will be quite useful for the user, its implementation would require substantial review of the software.

5. *Examples*

To illustrate the usefulness of this mesh generator, three examples will be given. The first is a rectangular box consisting of 6 regions, one for each face, and 104 elements. A monopole is mounted in the middle of its top side. The area factor specified for the box is 2.0 and the frequency of operation is 30 MHz. The input file is listed below for illustration:

```
6 2.0 30.00
0. 2. 2. 0.
0. 0. 0. C.
0. 0. 3. 3.
2  3
2. 2. 2. 2.
0. 4. 4. 0.
0. 0. 3. 3.
4  3
```

```
0. 2. 2. 0.
4. 4. 4. 4.
0. 0. 3. 3.
2 3
0. 0. 0. 0.
0. 4. 4. 0.
0. 0. 3. 3.
4 3
0. 2. 2. 0.
0. 0. 4. 4.
0. 0. 0. 0.
2 4
0. 2. 2. 0.
0. 0. 4. 4.
3. 3. 3. 3.
2 4
```

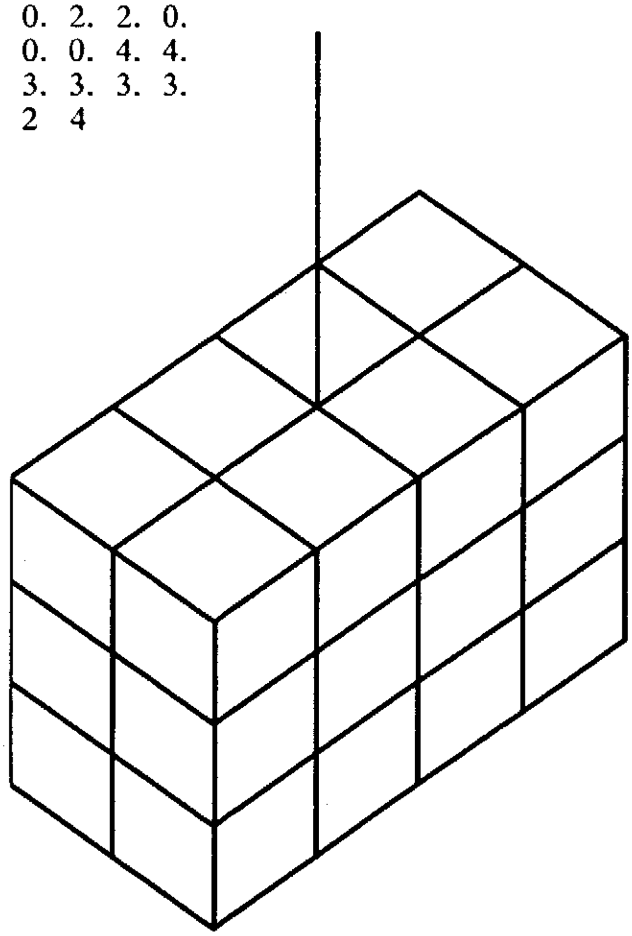

Fig. (3) Wire-grid of a rectangular box consisting of 104 elements and a monopole on top of it.

Only the monopole is added manually after the wire-grid has been generated. Fig. 3 is an isometric view of this simple structure. The second example in Fig. 4, is a pyramid with a trapezoidal base where triangular regions have been used. It consists of 5 regions and 157 elements.

The last example is more practical in that it is a wire-grid of a motor vehicle.

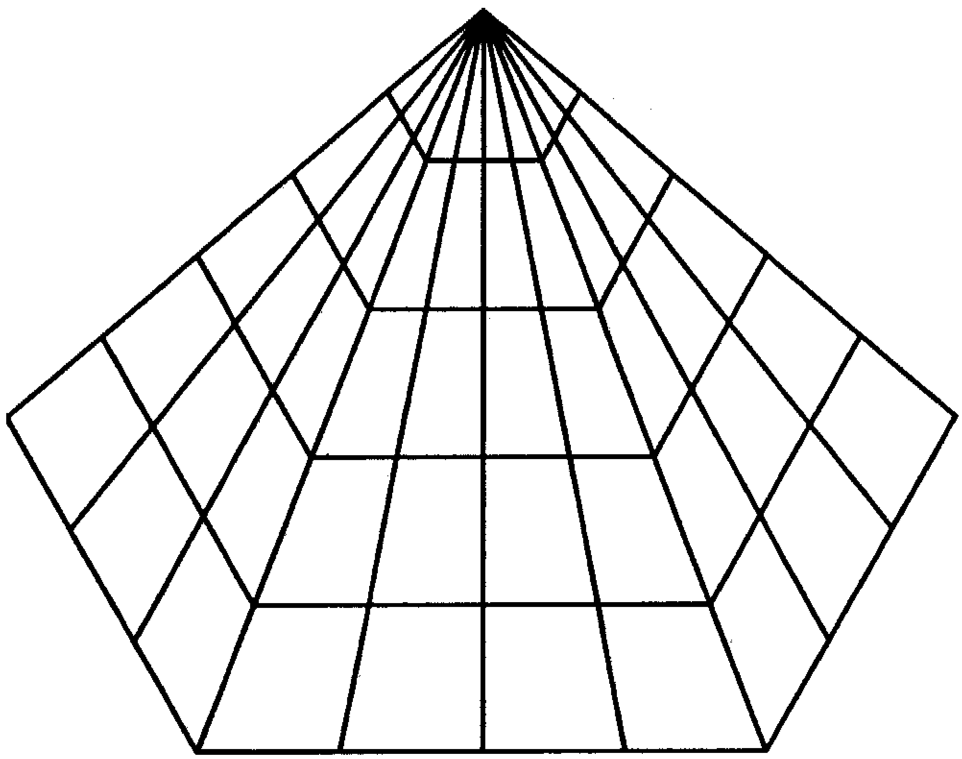

Fig. (4) Wire-grid of a pyramid with a trapezoidal base consisting of 5 regions and 157 elements.

All the body can be represented by flat surfaces except the pillars that support the roof. Because the number of elements where the regions' sides join needs to be the same, 14 regions were used to represent the vehicle body:

1 Region for the roof
1 Region for the bonnet (hood)
1 Region for the boot (trunk) top
1 Region for the front side
1 Region for the back side
3 Regions for the left side
3 regions for the right side
3 Regions for the bottom.

Fig. 5 shows the wire-grid of 270 elements that was produced by the mesh generator. In order to get the final model of the vehicle, the following steps were done manually:

- On each side of the vehicle, remove the two vertical elements marked x in Fig. 5; extend the wire marked y to the left so that it meets with the wire junction J in the adjacent region; and join the top of these two regions by adding a wire between points p1 and p2.

- Add the wires for the roof pillars.
- Increase the number of segments of the two roof elements marked z from 1 to 2 so that pillars join the roof at segment ends, as required by NEC.

The final model is shown in Fig. 6.

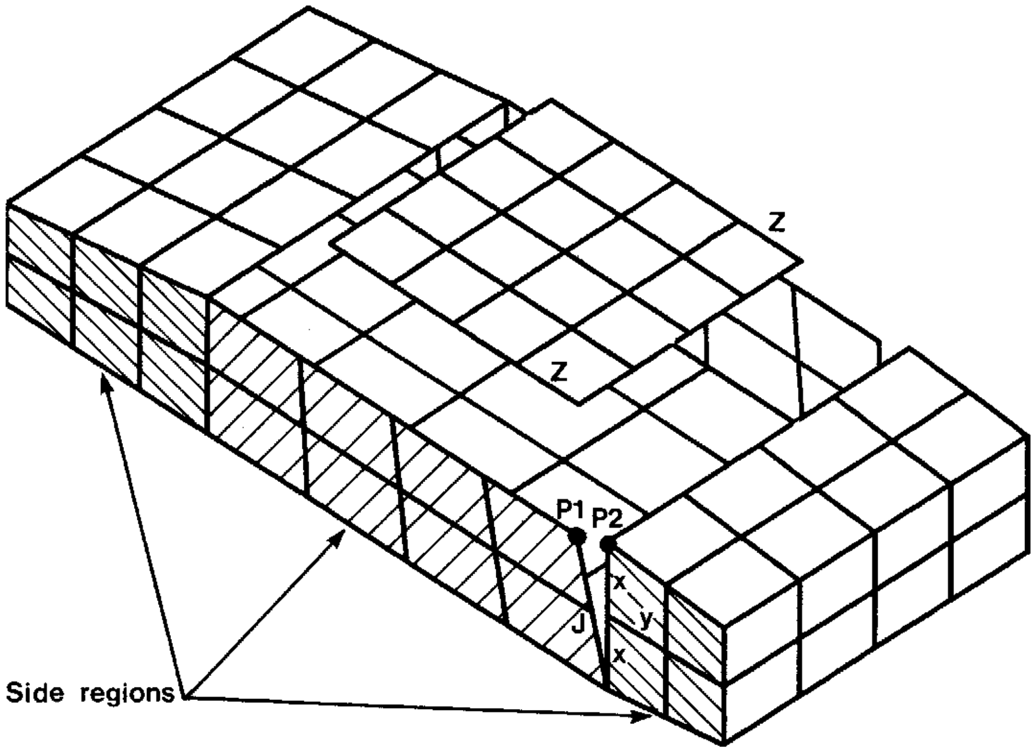

Fig. (5) Wire-grid of a motor vehicle as produced by the mesh generator. It consists of 14 regions and 270 elements.

Typical execution times for these three examples are shown in the table below. They were run using a VAX 11/780 and an 80386 IBM-PC with a coprocessor using the FTN77 compiler. Times shown are those taken to generate the NEC geometry file only without the information file.

Example	**Run Time (sec.)**	
	VAX	**IBM-PC**
Box	2.5	3.1
Pyramid	4.3	4.4
Vehicle	10.0	10.4

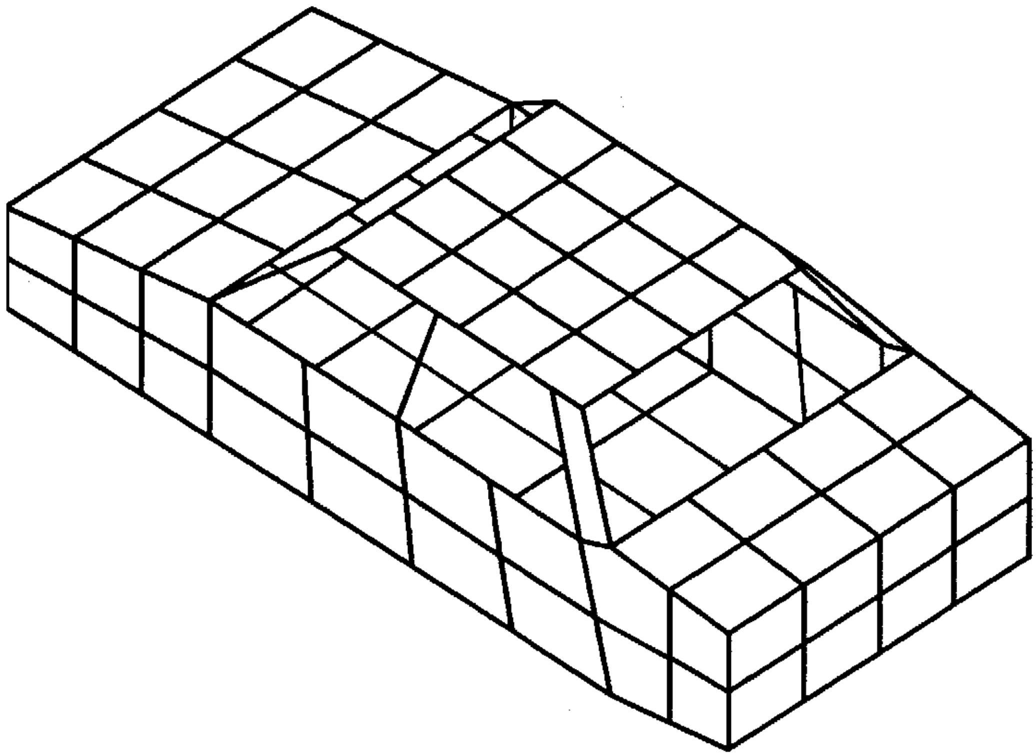

Fig. (6) Wire-grid of the motor vehicle after editing the generated model and adding the roof pillars.

6. Availability of the Software

The software for this mesh generator, including the source code and the input and output files for the examples mentioned above, are available from the author. A nominal fee of £5.00 (or an international money order for US$10.00) is requested to cover duplication and postage. The software will be provided on a 3.5″ MS-DOS 720K floppy disk. Hardcopy supplementary information will also be provided.

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