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Automated Configuration Design of a Deployable Polyhedral Truss for Large Antenna

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Abstract—**Deployable space structures are made of bays, which concatenate in a repeatable fashion to form a desired closed loop structure. Each bay undergoes a determined relative motion between the links to transform from an initially folded to the deployed configuration. The typical deployable space structure is a Deployable Polyhedral Truss (DPT) used for the large antenna. These systems are very complex to model as they have large number of joints and links. In the initial design phase a change in length/orientation or type of joint calls for repeated modelling. The repeated modelling representing large joints without inbuilt automation is time consuming and also prone to errors. In order to reduce the time required for modelling and eliminate manual errors, an automated model building procedure is required. This paper describes the steps to automate the model building process in MSC ADAMS through macros. A virtual model realistically simulating the full motion behaviour of such a complex system can be made. The model developed through this process helps in studying kinematic simulation and deployment simulation.**

Index Terms—- **Deployable Polyhedral Truss (DPT), Macro, Kinematics, Large space structures**

I. INTRODUCTION

Large deployable mesh reflector is a widely studied topic for satellite communication with the advantage of compact folding, light weight, large aperture. Several types of antennae based on deployable rigid links with several joints, unfurlable cable net with tensegrity concepts and inflatable concept are being investigated in the space-industry [1]-[5]. The kinematic design of large deployable support structure with possibility of providing actuation in horizontal or vertical members of deployable truss structures is presented in [6].

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The kinematics of large deployable support structure with scissor-type links and its closed form kinematic equations are presented in [7]. The deployment simulation of these structures is studied in [8] by using multi-body dynamics software MSC ADAMS. Quite often, there arises a need to carry out some changes in the existing configuration of deployable systems; it is customary to build a model from the scratch corresponding to that desired configuration. Such an activity is not only time consuming but also prone for modelling errors. This paper presents the details of the general purpose macro created to automatically generate the requisite model of deployable truss structure with given hardware details like number of bays, deployed height, deployed width of each bay and the length of the diagonal members.

II. KINEMATIC STRUCTURE OF THE DPT

The DPT comprises of number of bays forming a regular polygon. The kinematic structure for each bay consists of six links, six revolute joints with prismatic joint at the diagonal member as shown in the Fig.1.

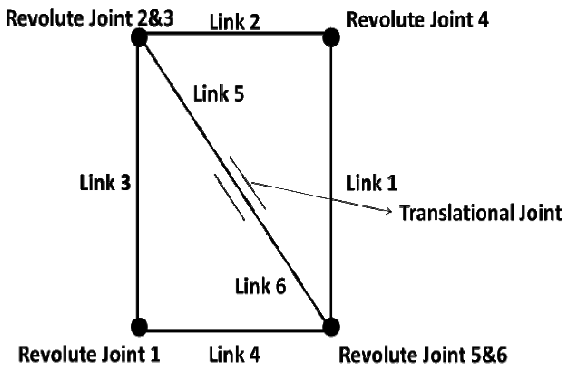


Fig.1: Identification of the Links and Joints of a Bay

When the prismatic pair on the diagonal member is actuated, the diagonal link changes its length and hence the mechanism deploys. Each bay is a mirror image of the previous bay and is connected to the adjacent bays at link 1 or link 3. The mechanism is deployed by shortening a cable which continuously runs through the prismatic pair of the DPT. Deployment synchronization is achieved through gears which connect the adjacent bays.

III. FEATURES OF THE MACRO

A macro is a single command that is created to execute a series of commands. To create a macro, the user gives ADMAS/view the list of commands that are to be executed, as well as a new command that will execute them. The user writes the commands using ADAMS/view command language. It is possible to automate the repetitive process by creating a macro of a command or a group of commands that are used frequently in building a model. With respect to the present work, a macro is designed to create the different elements associated with deployment mechanism of the DPT viz.

- Geometry of the links
- Hinge Brackets at joints
- Gears
- Deployment Springs at joints

The purpose of a macro is to automate model building, simulating, and reviewing.

For examples:

- Generate a series of units with joints/links
- Build an entire model
- Generates a series of plots for simulation

The main advantage of automating the model building process using macro includes:

- Solution can be obtained quickly
- Model generation is very fast and is free from modelling errors

The following sections describe the details of creating a macro and making a macro more flexible by making use of parameters.

A. *Creating a Macro*

The user can enter the macro in the command window, select it from the command navigator, include in other macro, or execute it from custom dialog boxes or buttons. ADAMS/view contains tools to automate the creation of macros and these tools let the user interactively record, play and test the macros and command files. In this work, the macro is written in text-editing applications, in which it is possible to modify the existing macros or create them from the scratch. The macro written for the present work is highlighted in the following sections.

B. *Using Parameters*

Instead of building an individual model of a DPT with a given parameters like number of bays, one bay stowed width, deployed height, one bay deployed width, length of the diagonal members (inner and outer); the approach followed in this work is to develop a generalised interface for building the requisite model of the DPT in ADAMS/view by writing a macro. In order to generalise the model building process of the DPT, it is customary to use parameters in the macro. Parameters give a way to send data to the macro each time the user execute the macro. Parameters are the placeholders for information that is provided by the user when the macro is actually executed. Using parameters in the macro makes it more generic. The definition of the variables used in creating the macro as shown in Fig.2.

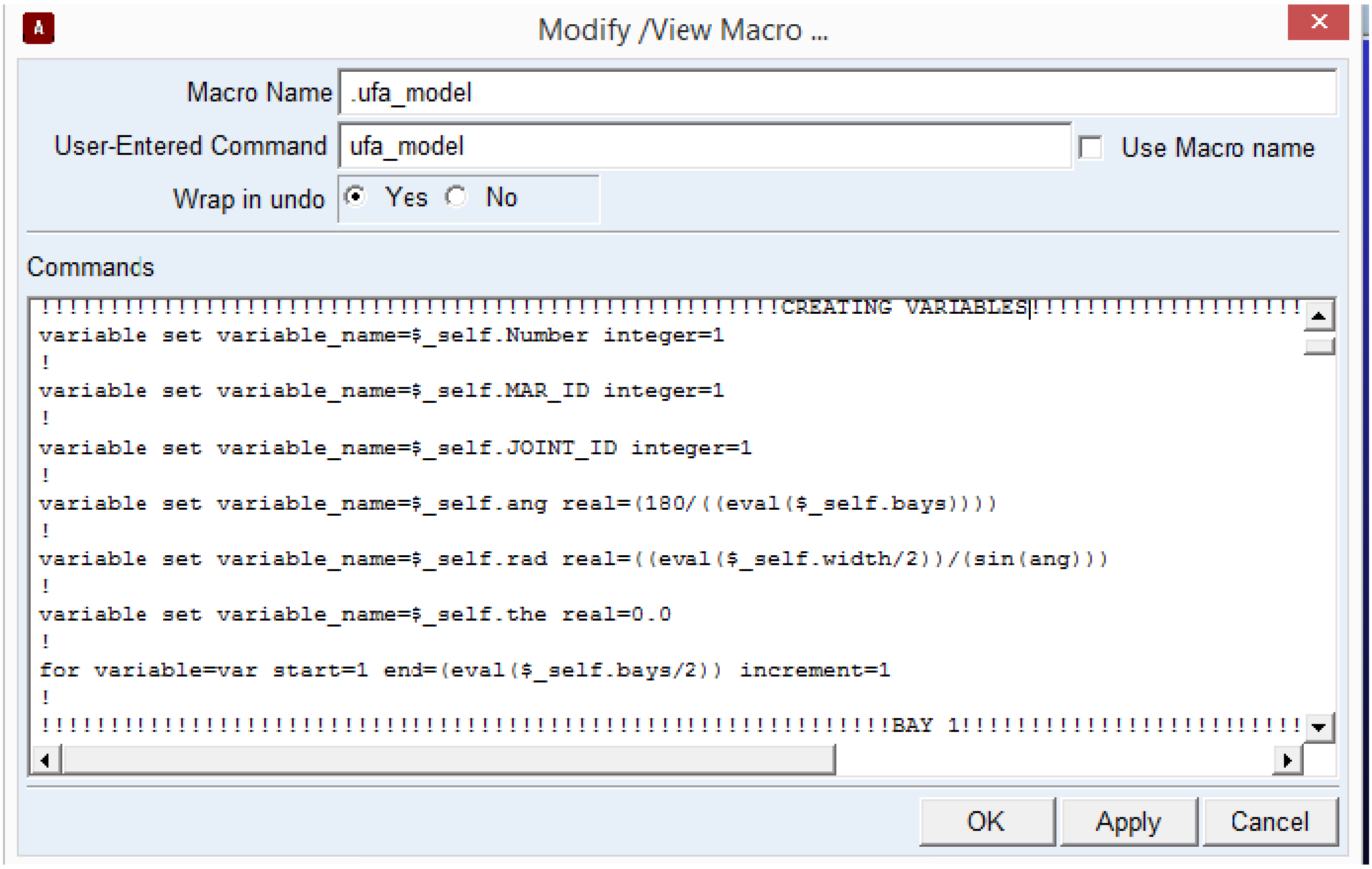


Fig.2: Macro for Creating Variables

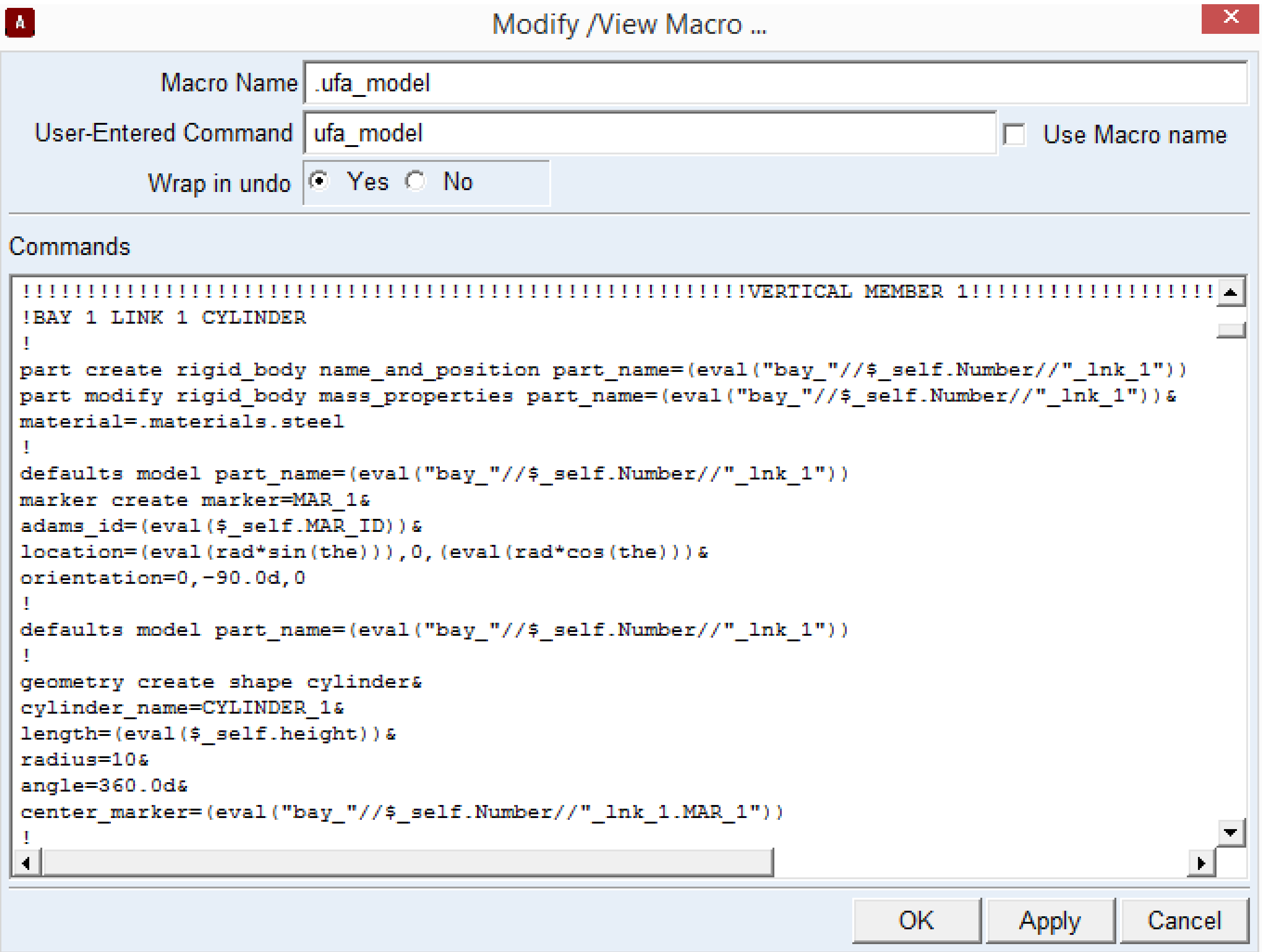


Fig.3: Macro for Creating Links

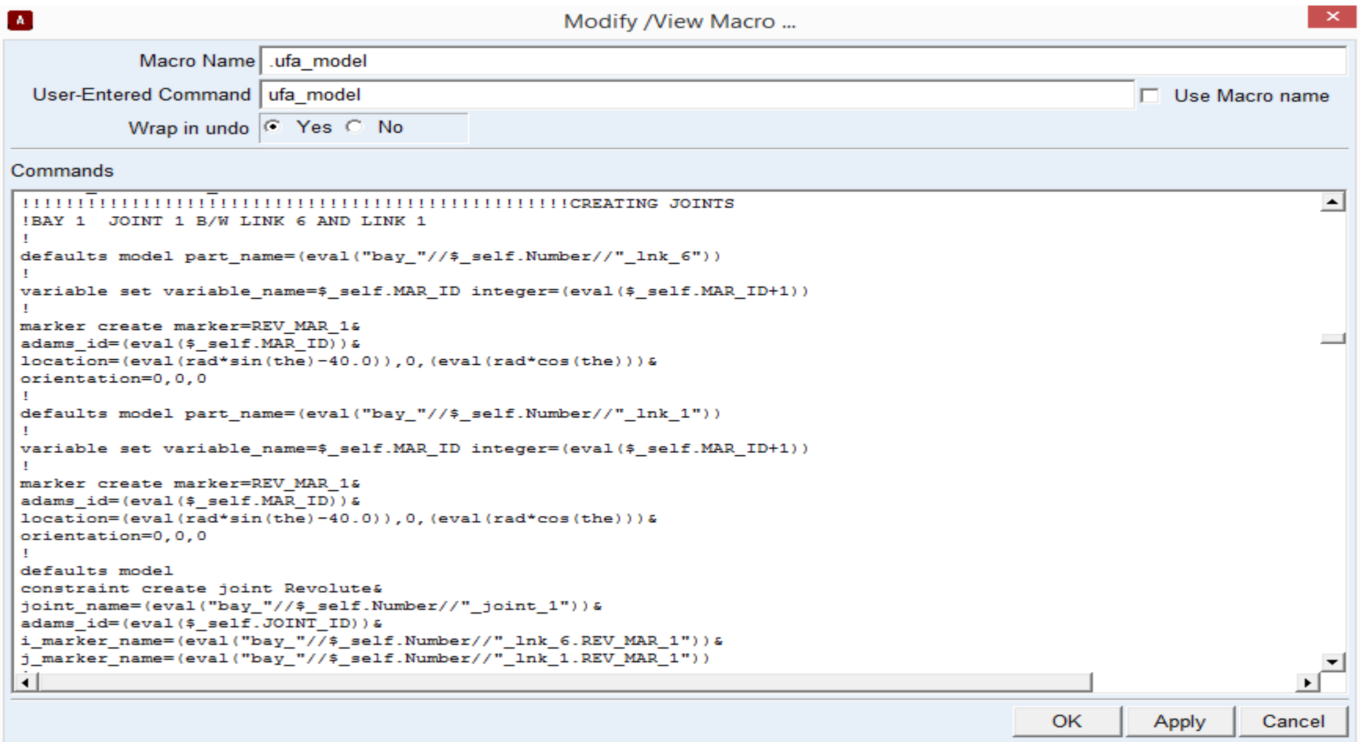


Fig.4: Macro for Creating Joints

C. Geometric Modeling

As mentioned in section II, each bay is made of six links i.e. two vertical members, two horizontal members and two diagonal members. The members are connected in a proper manner either by means of a 5-J bracket (bracket where five links meet) or by means of a 3-J bracket (bracket where 3 links meet). These members are modelled as cylinders of a known length and diameter.

The 5-J bracket and 3-J bracket are modelled as links of fixed length, width and depth. To deploy the bays in an accordion manner gear joints are defined at the 3-J hinge bracket. So, building the geometric model of the DPT includes modelling of the members/links having appropriate mass and inertia properties, revolute joints and translational joints at appropriate locations, gears to transfer the motion from one bay to another in a synchronous manner. Fig.3 to Fig.5 highlights the macro written to create the geometric model of the DPT in ADAMS/view.

Fig.3 shows a part of the macro written for modelling the links of a bay as cylinders. The length of the cylinder is parameterised. To create a joint between two links, one reference marker is to be defined on each link.

Fig.4 highlights the macro written to create anoint between the two links of a bay.

Fig.5 shows the macro written to rotate the bays with respect to each other in order to get a closed loop rim type structure. As shown in the Fig.6a it can be observed that by rotating the bays as described before will not make the DPT a perfectly closed loop rim type structure. Therefore, a separate macro is written to align the DPT in perfect closed loop structure as shown in the Fig.6b.

Fig.6a: Not Perfectly Closed DPT

Fig.6b: Perfectly Closed DPT

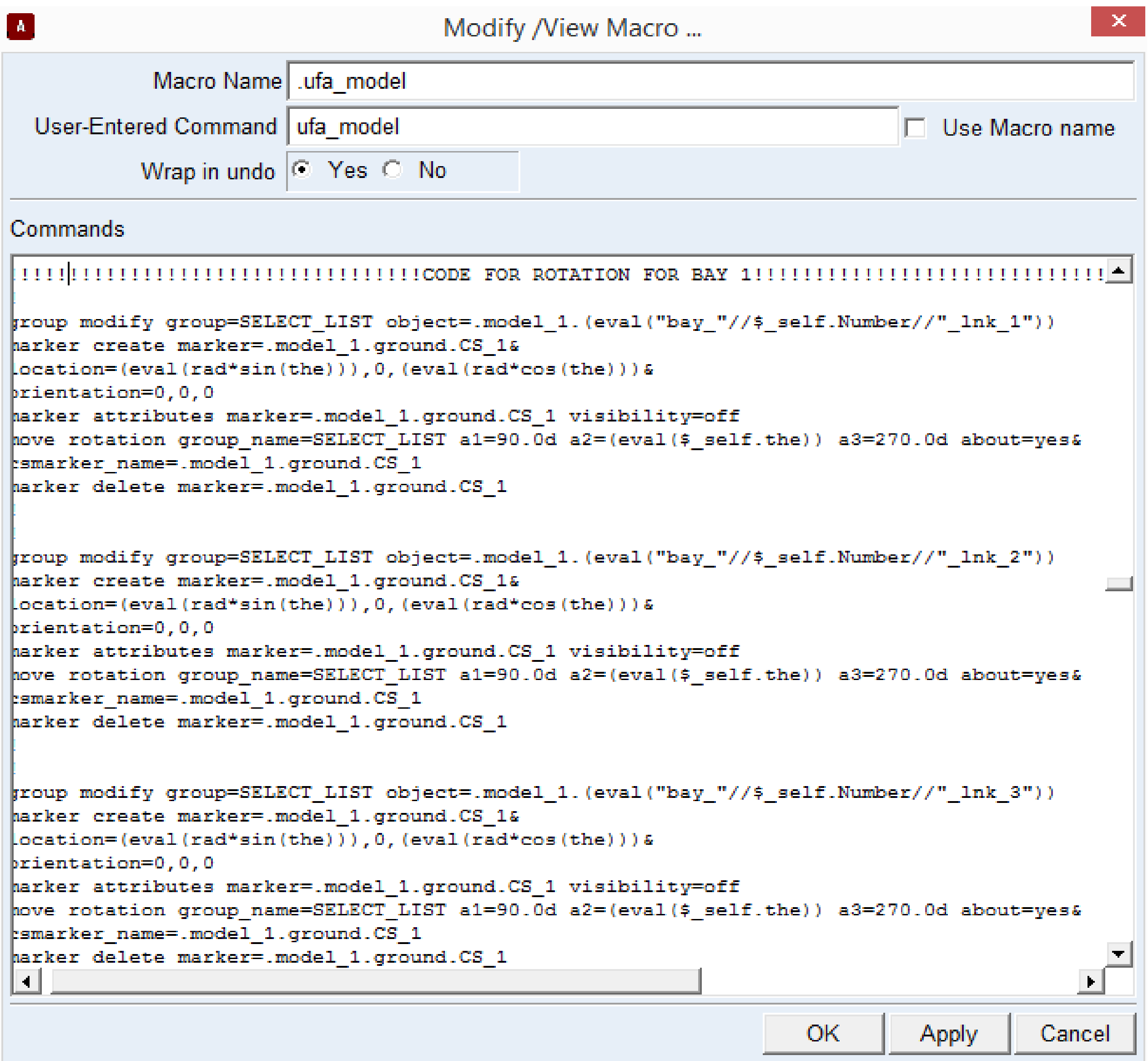
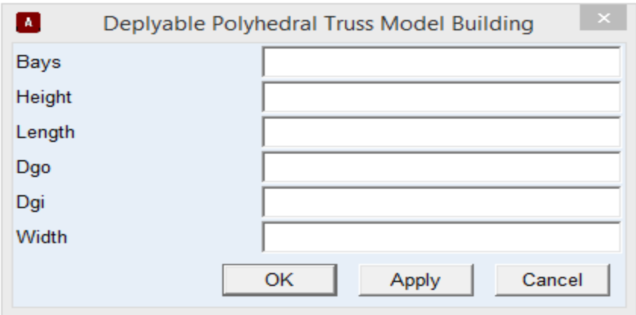


Fig.5: Macro for Rotating the Bays

A menu has been created to display a dialog box as shown in Table 1 for entry of typical input data given by the user.

Table I: Typical Input Dialog Box to Build the Model of a DPT



The details of the various terms used in the dialog box are given below:
Bays- Number of Bays, *Height*- Deployed height of the DPT, *Length*- One bay deployed width, *Dgo*- Length of the outer diagonal member, *Dgi*- Length of the inner diagonal member, *Width*- One bay stowed width

The following flowchart describes the modelling procedure carried out using macro

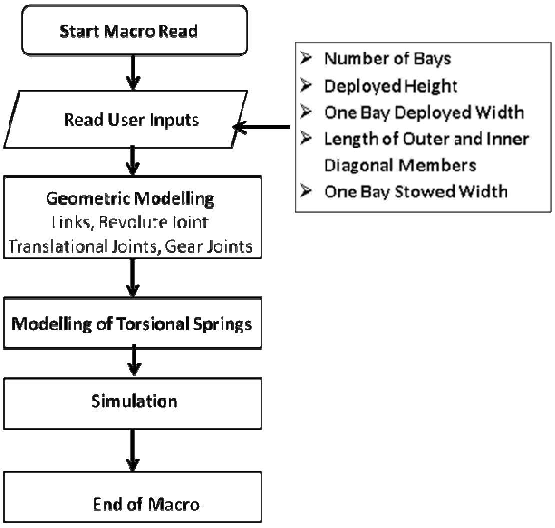


Fig.7: Flowchart for Modelling of a DPT using Macro

Based on the input data DPT with 6bays, 18 bays and 30 bays are constructed. Fig.8 to 10 shows the stowed, partially deployed and deployed configuration of DPTs.

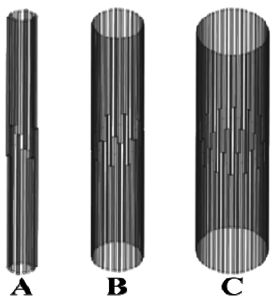


Fig.8: Stowed Configuration of Different Sizes of DPT(A= 6 Bays, B= 18 Bays, C= 30 Bays)

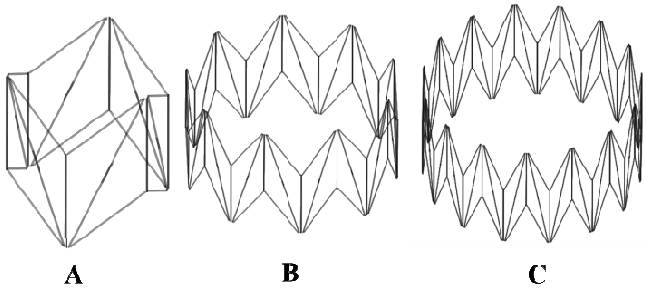


Fig.9: Partially Deployed Configurations of Different Sizes of DPT (A= 6 Bays, B= 18 Bays, C= 30 Bays)

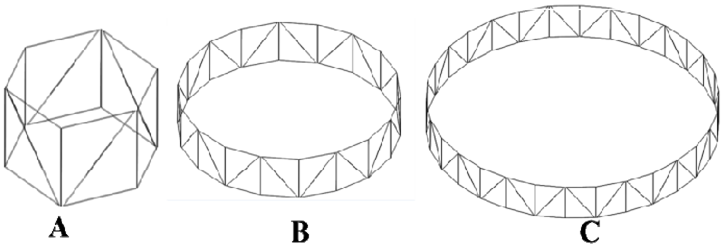
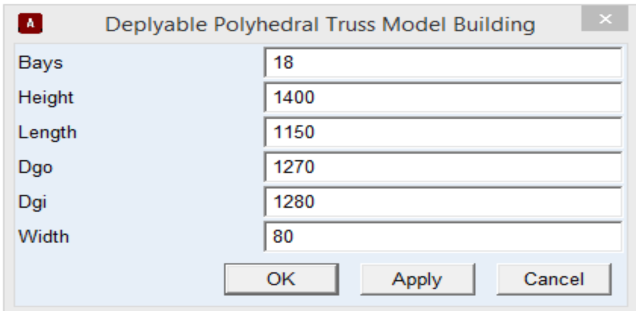


Fig.10: Fully Deployed Configurations of Different Sizes of DPT(A= 6 Bays, B= 18 Bays, C= 30 Bays)

IV. RESULT AND DISCUSSIONS

In this section the results of the kinematic simulation carried out for a DPT in ADAMS is presented. The DPT is modelled using a macro having the following hardware details as shown in the Table 2:

Table II: Typical Input Dialog Box to Build the Model



A. Kinematic Simulation

The following assumptions are made:

- The members of the DPT are rigid
- The clearances in joints and gears are neglected
- The drive cable axial extension due to tension is negligible

As the system is a single degree of freedom, one translation motion input is given to the telescopic member (diagonal member) of the first bay. The motion gets transmitted to the next and subsequent bays through gears. Each bay gets locked when the displacement of the telescopic member reaches 0.772 m. as the velocity input given to the translation joint is 0.01 m/s, it takes 77.2 seconds for the total deployment of the truss

B. Ground Deployment

The DPT is deployed on ground several times to validate the functions of each of the sub-assemblies and to check the whole system. As the dimension of the DPT in the deployed configuration is very large, this can induce large forces and moments on the support system, due to self-weight, if the DPT is supported only at root. The deflections caused by the individual bays due to self-weight may hinder the deployment. In order to overcome this difficulty, the whole system needs to be supported to off load its self-weight, during deployment. Hence, each bay of the DPT needs to be supported by means of spring loaded turnbuckle assembly. This assembly has to move along with DPT during ground testing. Hence, a simulation is carried out to evaluate the trajectory of the centre point of the horizontal members. The trajectory is presented in Fig.11. It can be observed that the trajectories of these bays are radial spatial curves from the support point. Hence, it is difficult to have a zero set up for this configuration. However, the trajectories of centre point of bottom links are radial straight lines from the support point.

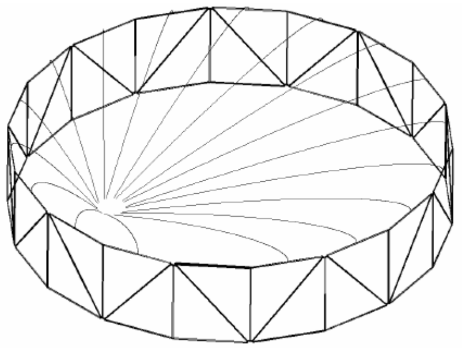


Fig.11: Path Traced by Mid-Point of the Top Links

To overcome this difficulty another option was considered. In this option, all the top links were constrained to move in one plane. This was done by providing a slider mechanism at the root, in this configuration, bottom links were allowed to move in all the three directions. The path traced by the centre point of the top links is shown in Fig.12. It can be observed from this figure that the path traced by the top links lie in a plane. This option simplifies the trajectory scheme of the zero-g fixture.

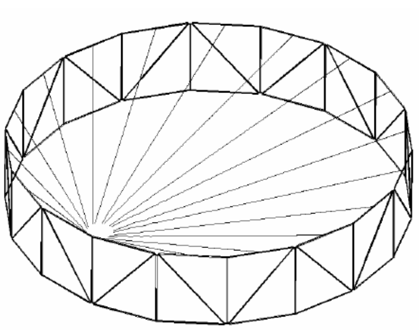


Fig.12: Path Traced by the Mid-Point of Top Links When they are constrained to move in a single plane

In this section the results for DPT of 18 bay is presented. The simulations can be carried out for the DPT with 6 bays/30 bays or any number of bays quickly with this macro

V. CONCLUSION

A macro has been developed using the software MSC ADAMS to execute a series of ADAMS/view commands and to generate the complete kinematic model of a DPT. A DPT with 18 bays is simulated using macro to study its deployment simulation. The kinematic simulation was carried out and this was useful in arriving at a suitable trajectory for the zero-g testing on ground. Even though the time required for building the model using macro is larger than the conventional way of modeling, macro helps in quickly creating several models with various configurations with different link parameters which are required in the initial design phase.

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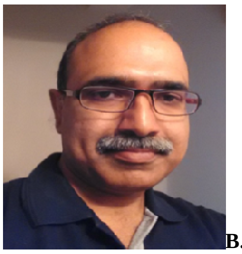

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