# Acknowledgement

This section is dedicated to express my outmost gratitude towards each and everyone that has provided me with knowledge, guidance and the support to me throughout this entire research project. Without them, this study will not be a success.

First of all, I would like to thank my lecturer cum supervisor for this study, AP Ir. Dr. Nasir Shafiq and Mr. Muhammad Sanif Maulut for the endless support and guidance given to me. I'm very thankful for their kindness, tolerance and ability to understand their students well. I'm also thankful for the efforts and time they had spent in guiding me in this research project.

Secondly, I would like to thank my university, Universiti Teknologi PETRONAS, for providing me with the essential platform and materials to perform this study. Without this opportunity, there will be a lot of difficulty in performing this study.

Last but not least, I would also like to thank my family and friends who have been helping me along the way in this study both by moral support and also their understanding.

# ABSTRACT

Retractable, foldable and deployable structures can vary their structural shape automatically from a compact, packaged configuration to an expanded, operational configuration. The first properly engineered deployable structures were used as stabilization booms on early spacecraft. Later on, more multifaceted structures were devised for solar arrays, communication reflectors and telescopes. In other field there have been a variety of developments including retractable roofs for stadiums, foldable components for cars, portable structures for temporary shelters and exhibition display. In this project, three main themes will be discussed: concepts, working principles and mechanics of deployable structures for a satellite dish and satellite dish reflector. The design structures of a deployable satellite dish will involve the structural analysis in both two dimensional and three dimensional analyses. Such analyses would include stress-strain analysis, joints analysis, and deflection analysis, by means of manual calculations and using engineering software. The deployable and retractable satellite structure designs will be developed for the usage of space oriented satellites and also earth bound satellites, whenever there is a need in the deployable design structure. The critical aspect in this development is to develop healthy structural concepts which provide for the capability to change configuration, in other word, structure which able to produce different working geometries and also able to move from one configuration to another.

# CERTIFICATION OF APPROVAL

## Retractable Mechanism of Foldable Bar Structures for Satellite Dish

by

Amier Avril Leiking

A project dissertation submitted to the Civil Engineering Programme
Universiti Teknologi PETRONAS
In fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(CIVIL ENGINEERING)

Approved by,

(Assoc. Prof. Dr. Nasir Shafiq)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

Jan 2007

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AMIER AVRIL LEIKING

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Future space project will involve more use of the intelligent structures, whose geometric and inherent structural characteristic can be changed beneficially to meet practical requirements, either through remote commands or automatically in response of external environmental variations. Earth bound satellite which are getting bigger in size would need some mechanism for an easier mobilization and easier installation.

Thus from the view point of structural engineering, a key element in this development is to develop robust structural concepts, which provide for the capability to change configuration.

Retractable structures are type of structures which are implemented on not only space structures, but also in every day life structures. This type of structures has the deployable mechanism in it design which make it appear to be foldable, extendable and retractable by applying suitable force on its structural joints.

## 1.2 Problem Statement

The increase of the number of satellite to be launched and installed both on earth and in space over the next several decades and the increasing number of usage of satellite tracking device for research purposes need the emphasize of the reduction of hardware mass, storage volume, and cost.

One approach in realizing these reductions is through the use of inflatable, foldable, retractable and deployable space structures.

Thus to summaries the problem statement, the project aims to find a mechanism topology which can produce a desired output movement for a given input movement, in deploying the satellite disk structure from its base structure.

## 1.3 Objectives

There are five (5) main objectives which is to be accomplish in order to complete the proposed topic, which are:

☑ To obtain suitable retractable structural designs for a satellite disk.
☑ To design a movement mechanism for the satellite disk's foldable bar structures.
☑ To research and obtain the most suitable material for the retractable satellite disk structures.
☑ To design a retractable structure for the satellite disk reflectors.
☑ To simulate the designed satellite disk retractable structures using Solidworks software.

## 1.4 Scope of Study

The scope of study which will be done in completing this project will include the following area:

☑ Designing a retractable satellite disc.
☑ Deployable/movement mechanism on the satellite disk and satellite reflector structures.
☑ Material analysis on the satellite disk and satellite disk's reflector structures.
☑ Structural integrity analysis on the satellite disk structures.
☑ The analysis will be concentrated more on the earth bound satellite disc.

# CHAPTER 2
# Literature Review

## 2.1 Foldable Bar Structure

Most of the sources for this project's literature review were obtain from the engineering sites in the internet and structural text books and a few journals. The main source of theory for the retractable structure concept is mostly from Z. You and S. Pellengrino research from the Department of Engineering, Cambridge University.

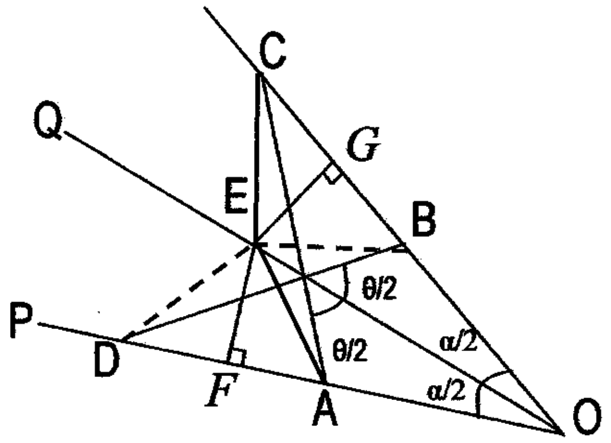
According to Z. You and S Pellengrino: "A simple, two-dimensional foldable structure can be made form two sets of parallel, straight rods connected by pivots, or scissor hinges at all intersection points. A scissor hinge is a revolute joint whose axis is perpendicular to the plane of the structure. During folding each set of collinear pivots remains collinear, and all pivots become collinear –in theory, at least-in the fully folded configuration." (p.1827)

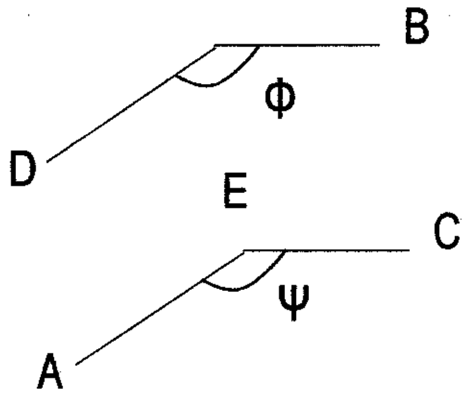
There are two different ways of extending this simple, intuitive concept to more general shapes. One option is to look for a repeating building block with an internal degree of freedom which allows folding. Another option is to design a complete structure, whose shape is determined mainly by its particular application and then to modify its geometry, member properties and layout, connections, etc until the structure can be folded and deployed without damage, albeit with some elastic deformation of its member.

The advantage of the first, modular approach is that, once a suitable building block has been found, then a whole class of foldable structures may become available simply by changing the number and size of the blocks. Two and three dimensional assemblies of pairs of straight bars connected by scissor hinges which form single degree-of-freedom mechanism have been used as building blocks for many complex structural mechanisms. However it is not generally true that a structure consisting of foldable modules is always foldable: it is also required that the interfaces between modules deform in a compatible fashion, and in some cases there may be one or more global conditions that need to be satisfied.

The second global approach to the design of foldable bar structures has been pioneered by Pinero (1961) and Zeigler (1981, 1984, 1987, 1993) and has been further developed by Escrig *et al* (1989) and Escrig and Valcarcel (1993). This idea is to design foldable structures by two-stage process. First the overall geometry of the structure is decided, such that all members are unstrained both in the required, fully deployed configuration and also in the folded configuration, usually a compact bundle where all bars are theoretically parallel. Second, a detailed structural analysis of the folding process is carried out to check that any strains induced by the folding process are sufficiently small. Most foldable structures based on this approach consist of pairs of straight rods connected by off-center scissor hinges. In general the achievement of satisfactory behavior during folding is at the expense of low deployable stiffness and hence locking elements are usually incorporated in structures of this type.

Z. You and Pellegrino has discovered an approach to foldable bar structures which combines the key advantages of the two approaches described above. "This new approach makes use of a new, large family of foldable building blocks, which called *generalized angulated elements*. These elements subtend a constant angle during folding, as Hoberman's simple angulated elements, but afford much greater freedom than all other elements that have been used previously. A series of contiguous angulated rods can be replaced with a single, multi- angulated rod, which is an extension of the straight with collinear pivots used in the simple foldable structure, thus reducing significantly the number of component parts of a structure and the complexity of its joins" (p.1828). These two discoveries open up a range of new applications for large scale, foldable bar structures.





A relationship between α, the subtended by this element and *θ*, the deployable angle can be obtained by noting that

$$\tan \alpha/2 = [\,(CE - AE) / AC]\,\tan \theta/2$$

*Generalised Angulated Elements (GAE) – Type II*

GAE is a set of interconnected angulated rods that form a chain of any number of parallelograms with either isosceles triangles (Type I GAE) or similar triangles (Type II GAE) on similar ends. A GAE embraces a constant angle as the element is folded or expanded. (Z. You and Pellegrino, 1996, p.1829)

The relationship between α and *θ* is as follows for GAE Type II.

$\alpha = 180^\circ - \Phi$

$\alpha = 360^\circ / n$ ;where n is the no of elemental pairs

Thus $\Phi = 180^\circ - (360^\circ / n)$

Characteristics of GAE Type II:

$AE / DE = CE / BE$ and $\Phi = \Psi$

$\Delta BEG = \Delta DEF$

## 2.2 Structural Analysis

R.C Hibbeler mentioned that if a truss is in equilibrium, then each of its joints must also be in equilibrium. Hence the method of joints consists of satisfying the equilibrium conditions $\Sigma Fx = 0$ and $\Sigma Fy = 0$ of the forces exerted on the pin at each joint of the satellite retractable structure. In the three dimensional (3D) analysis of the retractable satellite structure, an extra equilibrium condition, $\Sigma Fz = 0$ is added. When using the method of joints, it is necessary to draw each joint's free body diagram before applying the equilibrium equations. (p.82)

The line of action of each member force action of each member force acting on the joint is specified from the geometry of the truss, since the force in a member passes along the axis of the member. There effects are clearly demonstrated by using the method of sections and isolating the joint with small segments of the member connected to the pin. Notice that pushing and pulling on these small segments indicates the effect of the member being either in compression of tension (see Chapter 5: Calculation).

In all cases, the join analysis should start at a joint having at least one know force and at most two unknown forces. In this way, application of $\Sigma Fx = 0$ and $\Sigma Fy = 0$ yields two algebraic equations that can be solved for the two unknowns. When applying these equations, the correct sense of an unknown member force can be determined using one of tow possible methods.

Always assume the unknown member forces acting on the joint's free-body diagram to be in tension of pulling on the pin. If this is done, then numerical solution of the equilibrium equations will yield positive scalars for members in tension and negative scalars for members in compression. Once an unknown member force is found, use its correct magnitude and sense (T or C) on subsequent joint free-body diagrams.

The correct sense of direction of an unknown member force can, in many cases is determined by inspection. In more complicated cases, the sense of an unknown member force can be assumed: then after applying the equilibrium equations, the assumed sense can be verified from the numerical results. A positive answer indicates that the sense is correct, whereas a negative answer indicates that the sense shown on the free-body diagram must be reserved.

According to Hibbeler, "Deflection of structures can occur from various sources, such as loads, temperature, fabrication errors, or settlement". (p.269). In design, deflection must be limited in order to prevent cracking of attached materials. More important, deflections at specified points in a structure must be determined if one is to analyze statically indeterminate structures. The deflections to be considered in this project apply only to linear elastic material response. Under this condition, the structure designed subjected to a load will return to its original un-deformed position after the load is removed. The deflection of a structure is caused by its internal loadings such as normal force, shear force of bending moment.

The three common types of connections which join a built structure to its foundation are; roller, pinned and fixed. This is often idealized as frictionless surface. All of these supports can be located anywhere along a structural element. They are found at the ends, at midpoints, or at any other intermediate points. The type of support connection determines the type of load that the support can resist. The support type also has a great effect on the load bearing capacity of each element and therefore the system. In this project, the connection type used to assemble the elements in the structure design is the pinned support.

A pinned support can resist both vertical and horizontal forces but not a moment. They will allow the structural member to rotate, but not to translate in any direction. Many connections are assumed to be pinned connections even though they might resist a small amount of moment in reality. It is also true that a pinned connection could allow rotation in only one direction; providing resistance to rotation in any other direction. The knee can be idealized as a connection which allow rotation in only one direction and provide resistance to lateral movement. The design of a pinned connection is a good example of the idealization of the reality. The representation of a pinned support includes both horizontal and vertical forces.

## 2.3 Material Analysis

There are several materials which have been taken into consideration to be applied in the structural design. The materials are chosen by taking into account the material strength, the material density, the general cost and material availability. The material chosen are; Alloy Steel 4140, Aluminum Alloy 2014, Stainless Steel 13-8, Titanium, and Duralumin.

Alloy Steel 4140, is one of the chromium, molybdenum, manganese low alloy steels noted for toughness, good torsional strength and good fatigue strength. Alloy Steel 4140 is used in a tremendous variety of applications. This alloy is hardened by heating to 1550 F and quenching in oil. It is best to normalize the alloy by heating at 1675 F for a long enough time to permit thorough heating, followed by air cooling, prior to the hardening treatment. Tempering temperatures range from 400 F to 1200 F depending upon the hardness level desired. The lower the tempering temperature, the greater will the hardness of the alloy.

Aluminum Alloy 2014 is a precipitation hardening alloy with good strength after heat treatment, commonly used in the manufacture of aircraft structures, and truck frames. Hardening is accomplished by a precipitation heat treatment at 935 F followed by water quench. This produces T4 temper. Other tempers (mechanical properties) result from additional cold work after this treatment and then by a 320 F heat treatment for T6510 and T6511 tempers.

Stainless Steel 13-8 is a precipitation, age harden able stainless steel. Its principal features are high transverse toughness, good resistance to general and stress corrosion cracking, and high strength that is developed by a single low temperature heat treatment. This alloy has been used in aircraft components such as landing gear and structural sections, valves, shafts, and components in the petrochemical and nuclear industries. This is a tough machining stainless steel. Although it can be machined in all conditions, best results can be obtained in condition H1150M. Compared to type 304 stainless, speeds should be roughly 25 % lower for optimum tool life and finish.

Titanium s a lustrous silver-white metallic element used principally to make light, strong alloys. The metal has a low density, good strength, and has excellent corrosion resistance.The element is the ninth most abundant in the earth crust but is never found in the pure state. It occurs as an oxide in the minerals ilmenite (FeTiO3), rutile (TiO2) and sphene (CaO. TiO2. SiO2) but it mainly contains rutile and ilmenite. Titanium is a strong, light metal. It is as strong as steel and twice as strong as aluminum, but is 45% lighter than steel and only 60% heavier than aluminum. Titanium is not easily corroded by sea water and is used in propeller shafts, rigging and other parts of boats that are exposed to sea water.

Titanium and titanium alloys are used in airplanes, missiles and rockets where strength, low weight and resistance to high temperatures are important. Since titanium does not react within the human body, it is used to create artificial hips, pins for setting bones and for other biological implants. Unfortunately, the high cost of titanium has limited its widespread use. Titanium is increasingly targeted for defense applications and armor components in particular.

The metal's lightweight (45% lighter than steel at equivalent strength levels) and excellent ballistic properties are the two main reasons for its popularity. Additionally, some titanium alloys are corrosion resistant in harsh environments (such as salt water); are non-magnetic; can be fabricated with conventional processing methods; are available in many forms (wrought products such as plate, sheet, rod, pipe, wire, extrusions, stampings, castings, forgings, powders, super-plastic forms, etc.); have been proven in military applications; and are affordable.

Duralumin is an alloy of aluminum (over 90%) with copper (about 4%), magnesium (0.5%–1%), and manganese (less than 1%). Before a final heat treatment the alloy is ductile and malleable; after heat treatment a reaction between the aluminum and magnesium produces increased hardness and tensile strength. Because of its lightness and other desirable physical properties, duralumin is widely used in the aircraft industry. Although the addition of copper improves strength, it also makes these alloys susceptible to corrosion. For sheet products, corrosion resistance can be greatly enhanced by metallurgical bonding of a high-purity aluminum surface layer. These sheets are referred to as *Alclad*, and are commonly used by the aircraft industry.

These materials' mechanical properties are shown in the Appendices. Please refer Appendix A1.

# CHAPTER 3

# METHODOLOGY

The methodology of the proposed topic is divided into two main sections which are the methodology which were done in Final Year Project 1 (FYP1) and the methodology and in the Final Year Project 2 (FYP2).

## 3.1 The methodology which will be done in Final Year Project 1 (FYP1) is as the following:

### 3.1.1 Literature Review

- Understanding the retractable mechanism concepts
- Construct a practical conceptual model

### 3.1.2 Structural analysis (Manual Analysis).

- Joint Analysis
- Making assumptions for the analysis
- Calculation of stress-strain on each joints
- Deflection analysis on members
- Calculating the suitable angle for the retractable structures
- Drafting the satellite dish initial structural design.

### 3.1.2 Structural Analysis using engineering software

- Learning to operate the ANSYS software
- Make some simulation on the drafted design structure

### 3.1.3 Constructing Conceptual Model.

- 2-D Model
- 3-D Model

3.2 The methodology which will be done in Final Year Project 2 (FYP2) is as the following:

3.2.2 Modifying the initial design in FYP1

- Searching for better designs in order to accomplish the project objectives.

3.2.3 Material Selection Analysis

- Research on the type of material most suitable for the satellite dish retractable structures.
- Investigating the pros and cons of every material
- Investigating the effect of materials on space environment
- Material Comparison

3.2.4 Structural Analysis

- Continue on analyzing the structural integrity of the modified retractable satellite dish design.

3.2.5 Costing and commercial value analysis.

- Research on the cost of the designed satellite dish structures.
- Cost comparison for every material and design.

3.2.6 Constructing a prototype.

- Basic scaled down prototype
- Concentrating on showing the mechanism

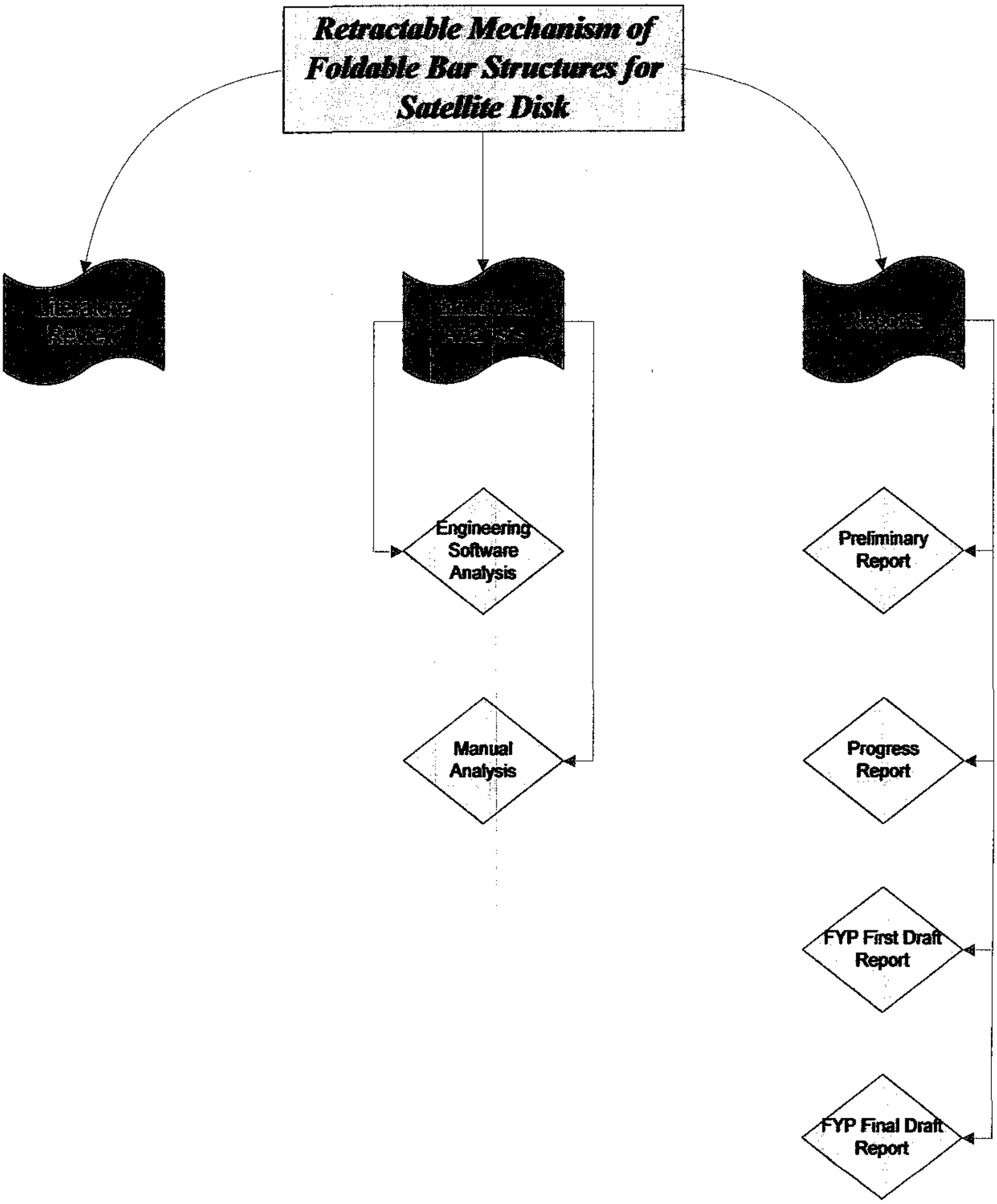


Figure 3.1: Retractable Mechanism of Foldable Bar Structures for Satellite Disk's Project Flowchart (FYP1)

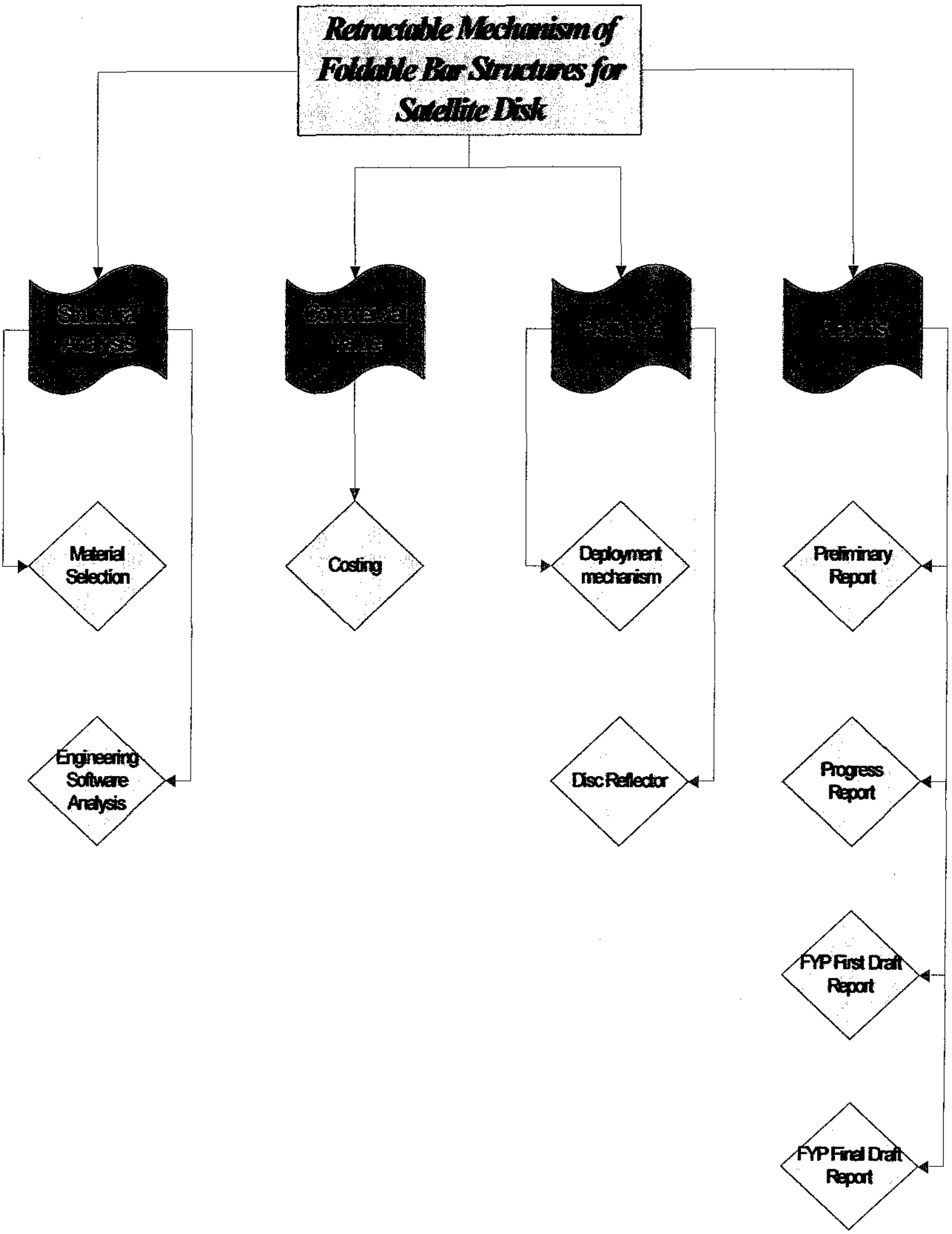


Figure 3.2: Retractable Mechanism of Foldable Bar Structures for Satellite Disk's Project Flowchart (FYP2)

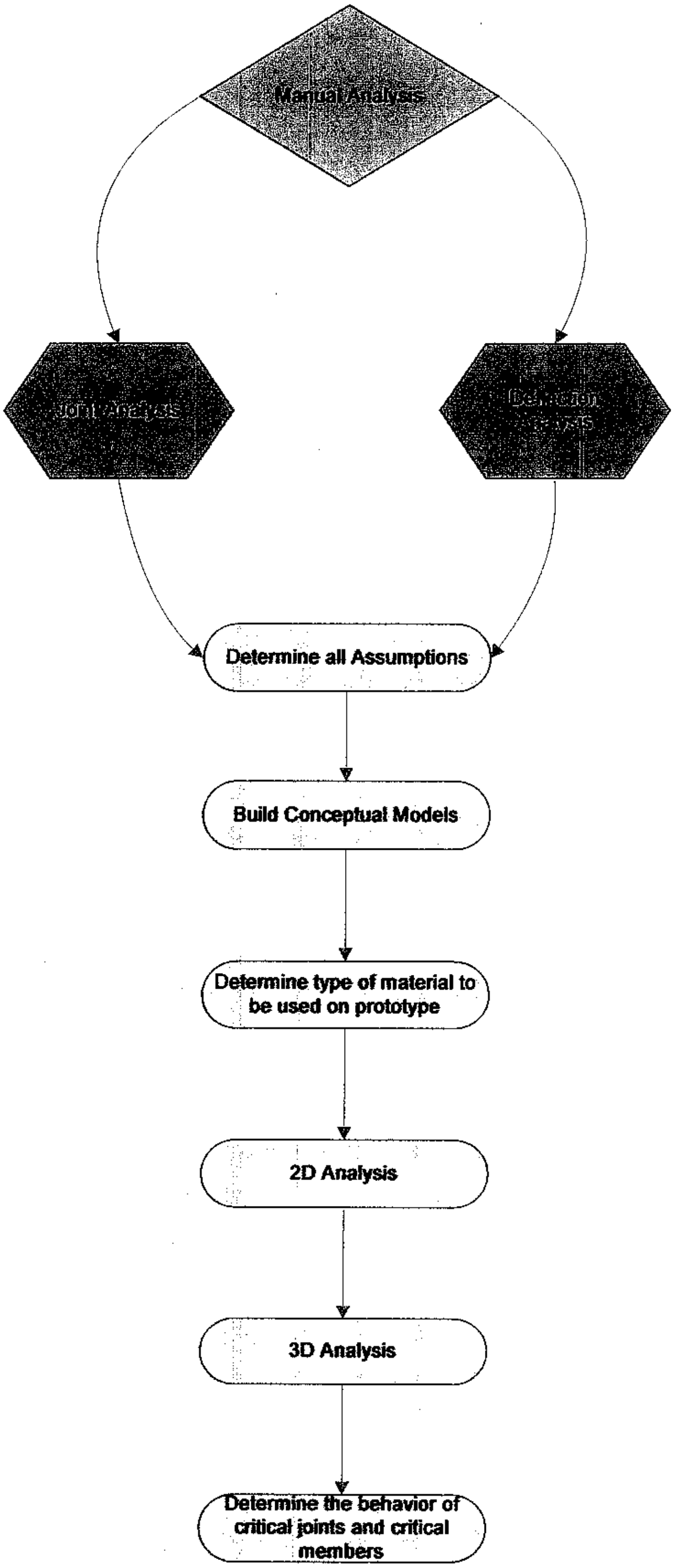


Figure 3.3: Manual Analysis Flowchart

# CHAPTER 4
## Results

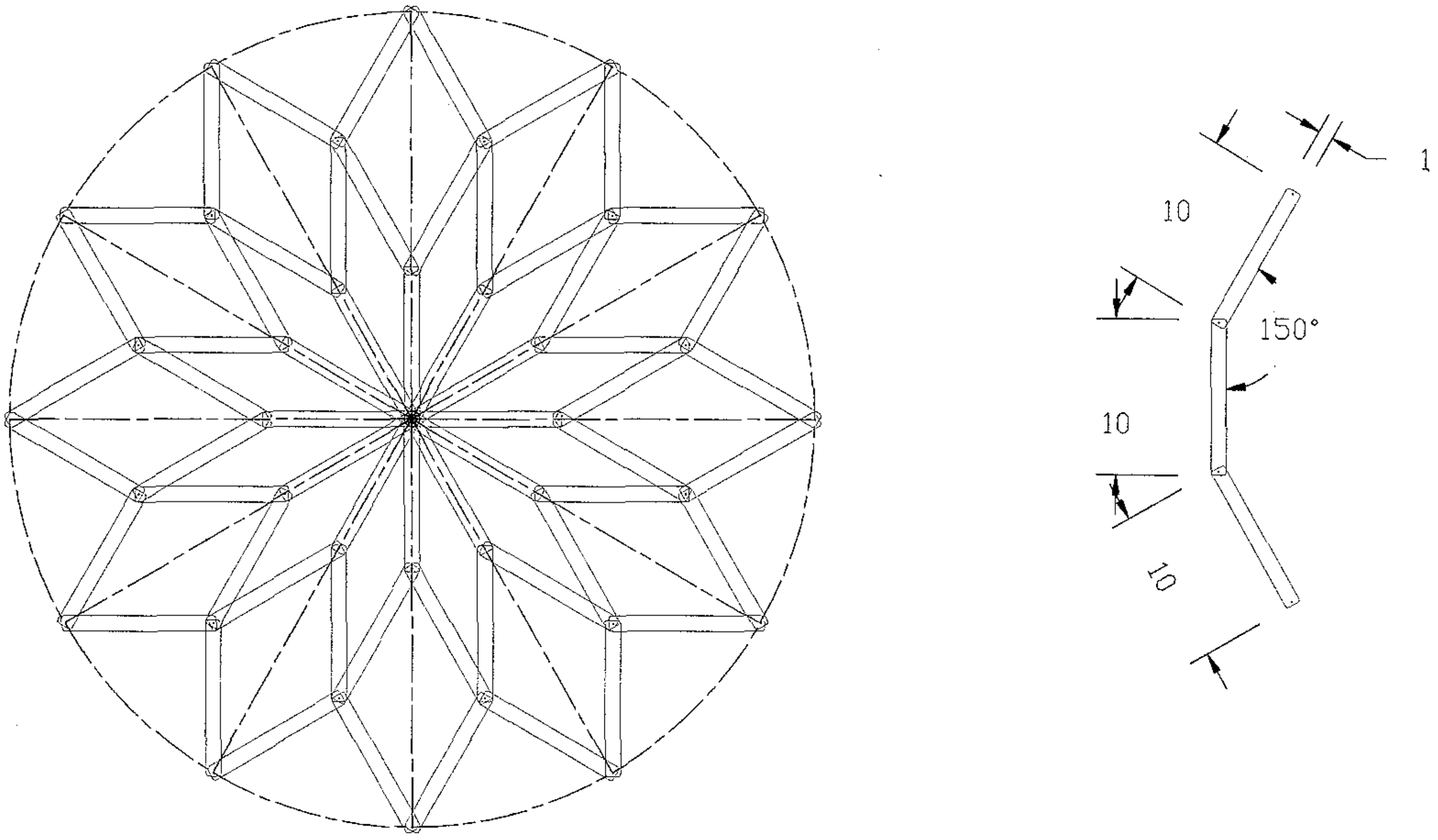


Figure 4.1: Initial Three-members angulated bar design and dimensions.

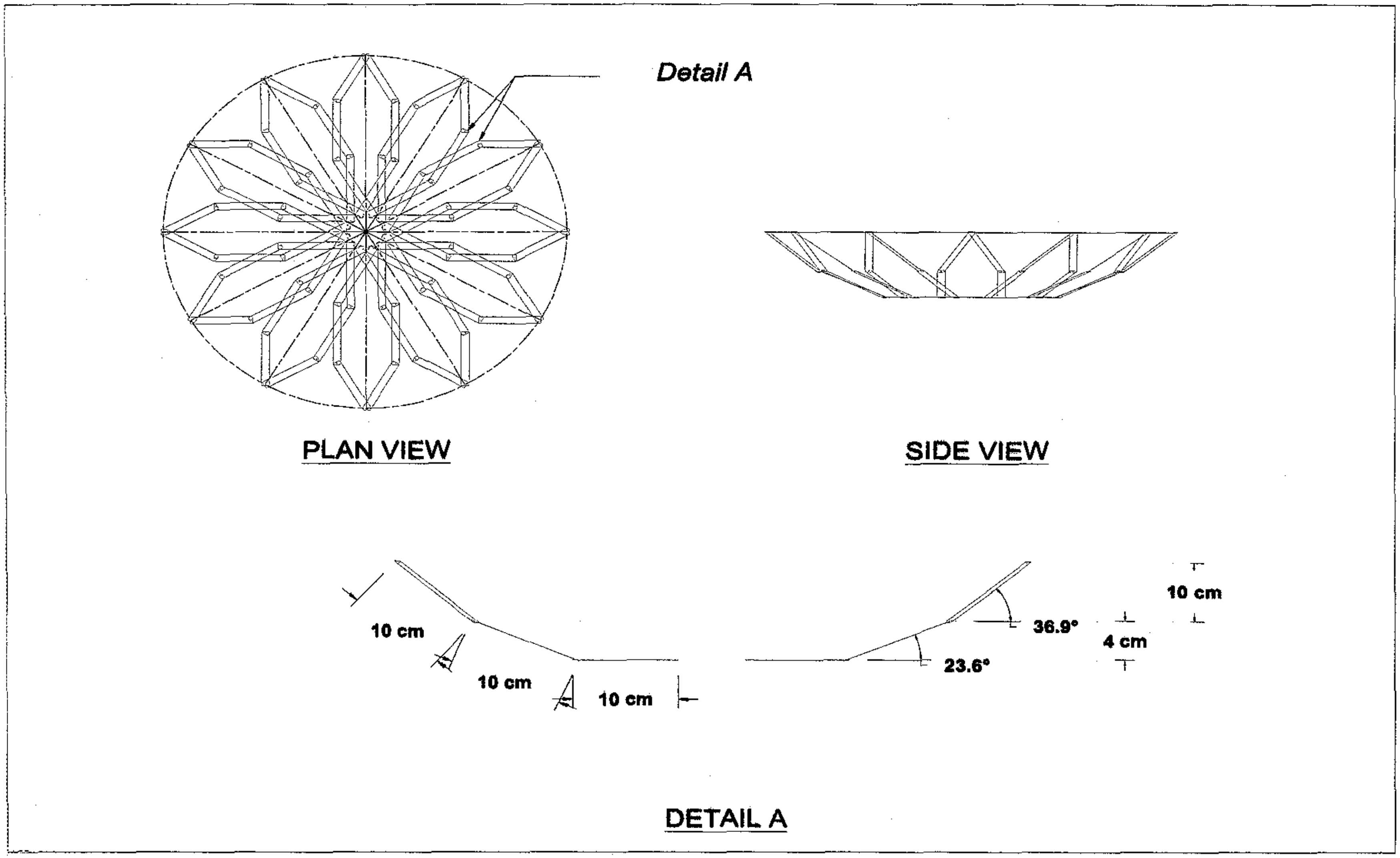
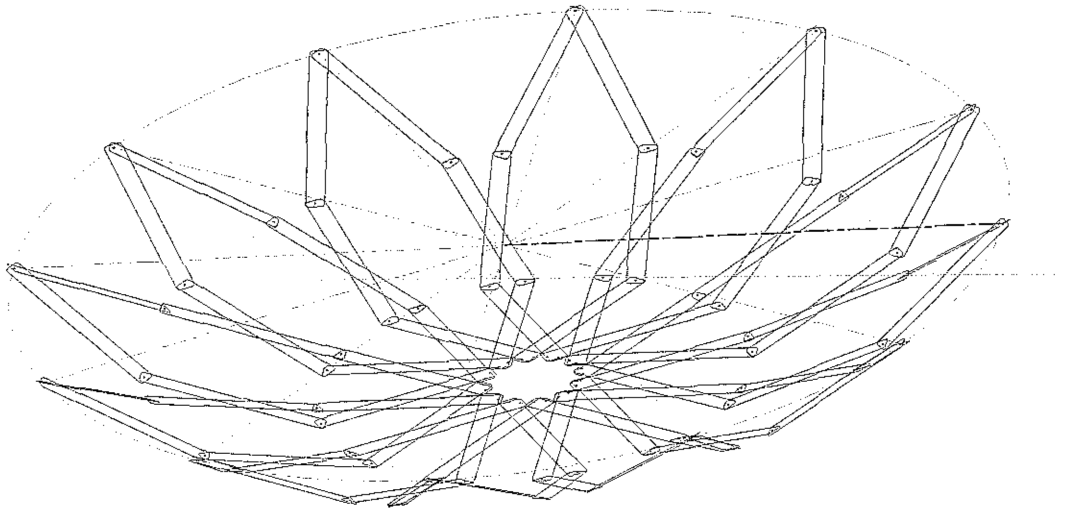
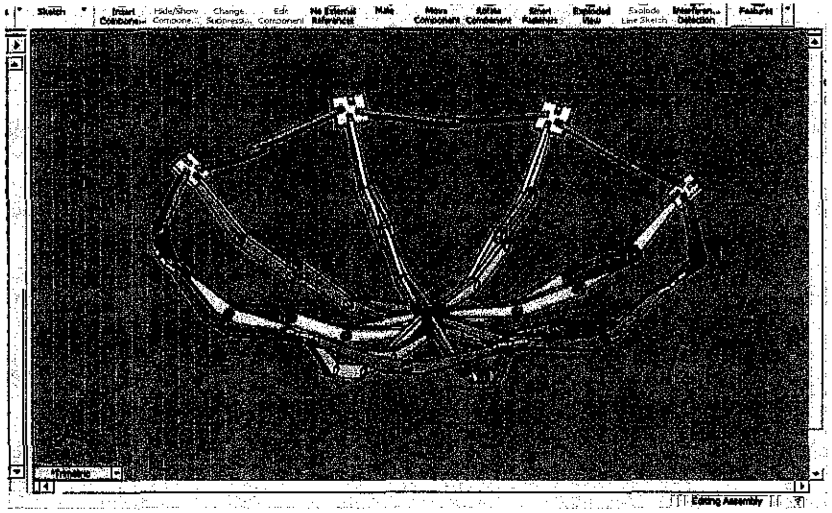


Figure 4.2: Initial Three-members angulated bar design and dimensions; Plan view and Side View.

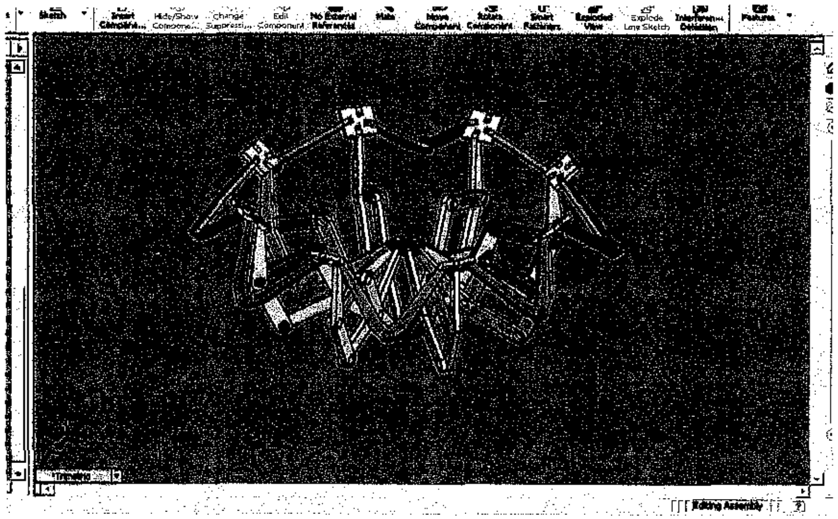


**3D - VIEW**

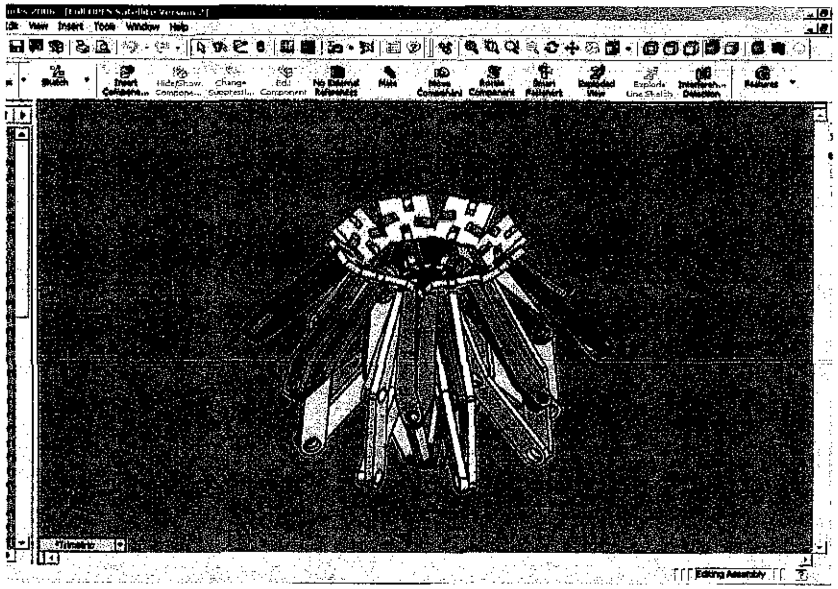
Figure 4.3: Initial Three-members angulated bar design and dimensions; 3D view.



(a)



(b)



(c)

Figure 4.4: Overview of the retractable mechanism of the satellite dish.
(a) Fully Expanded Configuration
(b) Intermediate Expanded Configuration
(c) Retracted Configuration

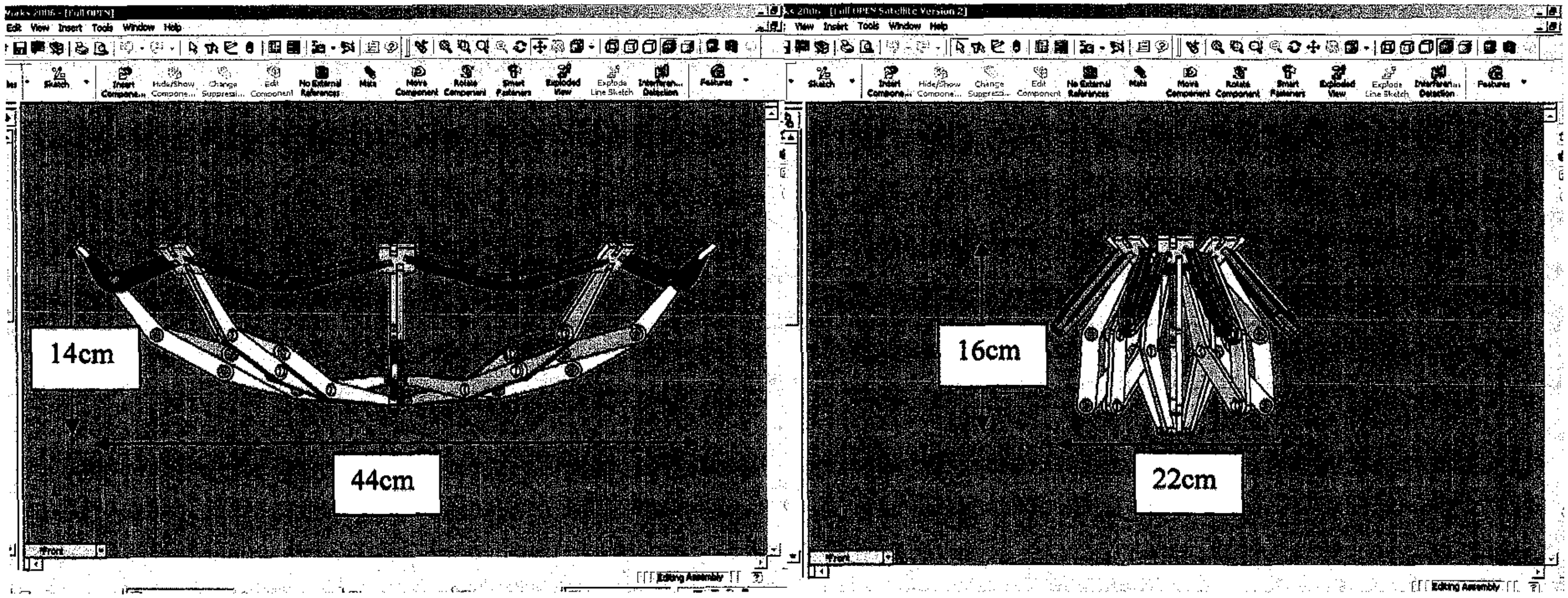


Figure 4.5: The difference of length and height between the structures's expanded configuration and retracted configuration.

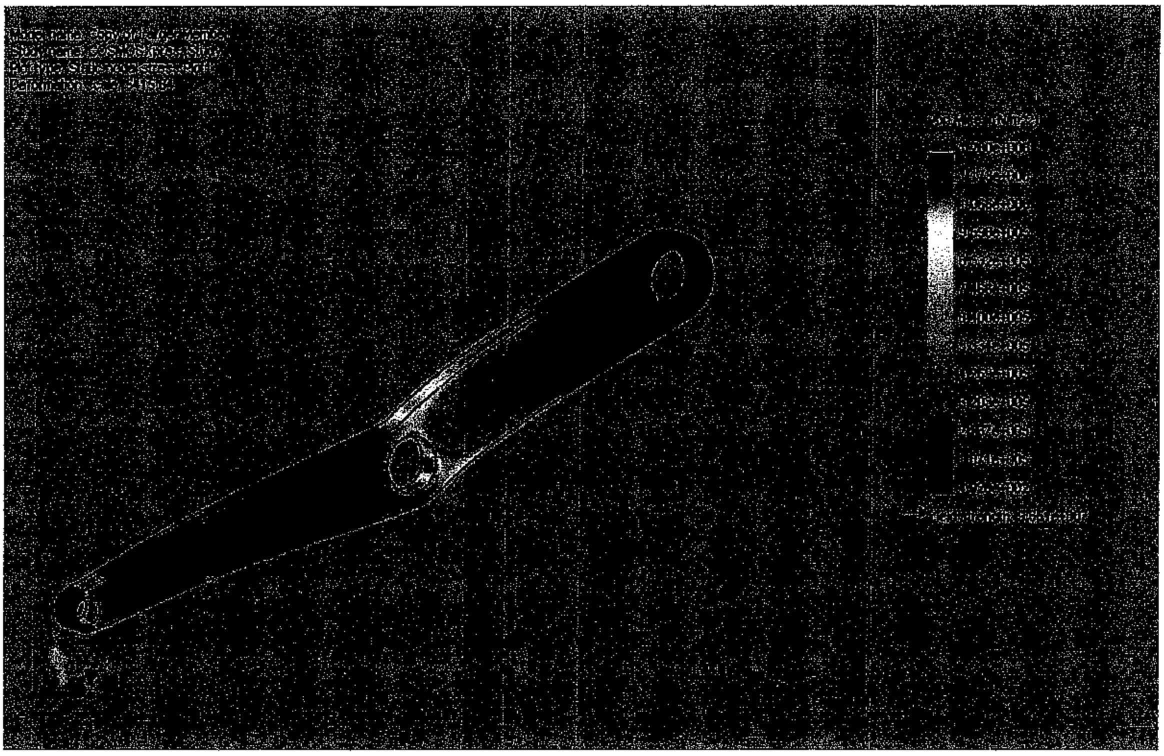


Figure 4.6: The General Stress Distribution of the critical member.

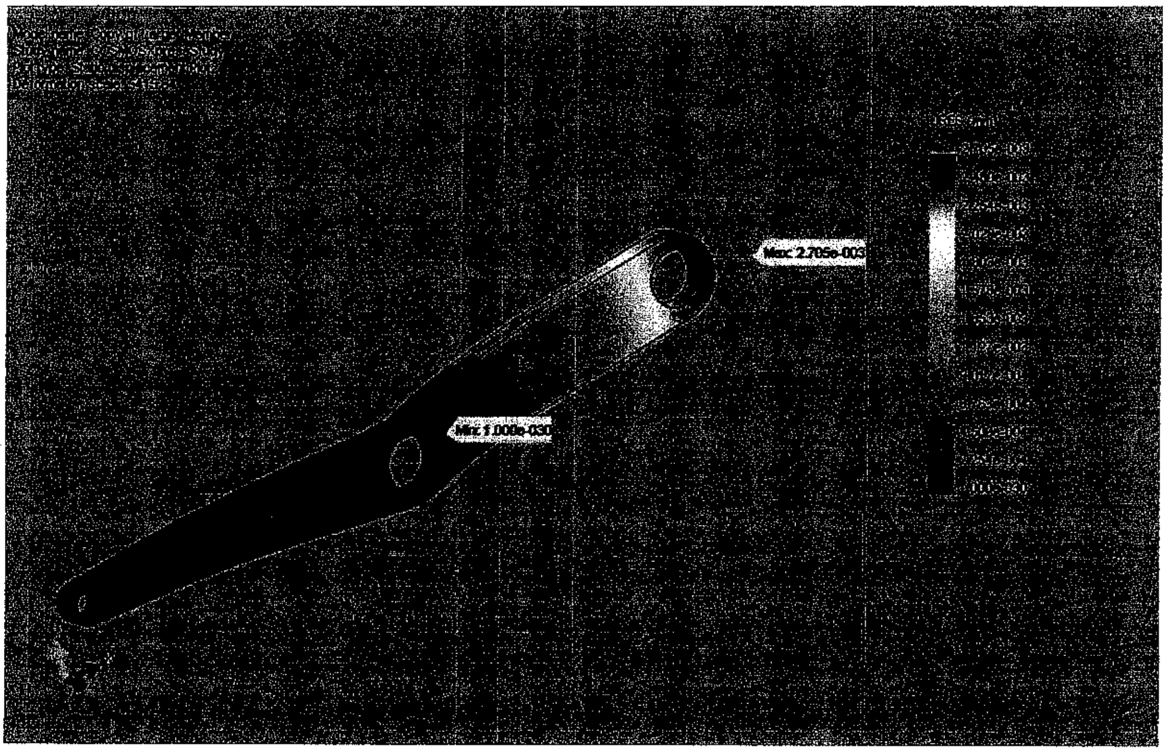


Figure 4.7: The General Displacement Distribution of the critical member.

Table 4.1: Results of the material analysis and structural analysis

| Materials | Density (g/m³) | Coeficient of Friction | External Load to move the structure (N), P | Total Mass (kg) | Young's Modulus (Gpa), E | Moment of Inertia kgm^2, I | Deflection (mm) | Max Load to cause 5mm deflection (kN) | Price ($ per kg) | Estimated Total Price ($) |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminum Alloy 2014 | 2.70 | 1.05 | 69.16 | 15.40 | 70.00 | 20862.19 | 0.0048 | 71527.51 | 2.78 | 42.82 |
| Alloy Steel 4140 | 7.85 | 0.42 | 246.80 | 59.90 | 200.00 | 81145.78 | 0.0015 | 794897.58 | 0.53 | 31.80 |
| Stainless Steel 13-8 | 7.75 | 0.22 | 126.25 | 58.50 | 192.60 | 79249.22 | 0.0008 | 747595.20 | 0.86 | 50.60 |
| Titanium | 4.40 | 0.36 | 87.94 | 24.90 | 105.00 | 33731.72 | 0.0025 | 173477.44 | 5.86 | 145.91 |
| Duralumin | 2.87 | 0.30 | 47.97 | 16.30 | 71.00 | 22081.41 | 0.0031 | 76789.23 | 3.45 | 56.28 |

## 4.1 Calculation

### 4.1.1 Assumptions Made

As the retractable mechanism of foldable bar structure is still quite a new concept, several assumptions have to be made in order to facilitate the structural analysis calculations. The assumptions made for this project are as shown below:

i. The material which will be considered in the structural analysis will be Alloy Steel 4140, Aluminum Alloy 2014, Stainless Steel 13-8, Titanium, and Duralumin.

ii. Friction factor, μ on the joints is assumed to be according to the material used, please refer to Table 4.1.

iii. Dead loads acting on the structural members are from its self weight.

iv. Live loads acting on the structural members are from the wind loads.

v. Wind loads are assumed to be:
   i. Earthbound Satellite Structure: 60km/hr – 120 km/hr
   ii. Space Satellite Structure : 100km/hr

vi. Temperature is assumed to be:
   i. Earthbound Satellite Structure: 26°C - 38°C
   ii. Space Satellite Structure : -275°C

vii. When friction force, Fr equals to the external force applied, Fe, the structure is static.

viii. In order to make the structure move, external force must be larger than the friction force of the structure, Fe>Fr.

ix. The method of structural analysis on the satellite structure will be on joint analysis.

x. For a 10 m/s wind velocity, a pressure of 2.7 lb/ft$^2$ will be exerted on the structural surface.

xi. In the joint analysis, the retractable satellite structure is assumed to be in the "closed" condition.

xii. In the joint analysis, it is assumed there is no wind load acting on the retractable satellite structure, in order to observe the behavior of each retractable member.

xiii. In the deflection analysis, the angle of the critical member is assumed to remain the same even after deflection.

xiv. The load to move the structure is assumed to be evenly distributed along the critical member through the octagonal connector.

xv. The structure is assumed to be fabricated in complete symmetrical along the octagonal angles.

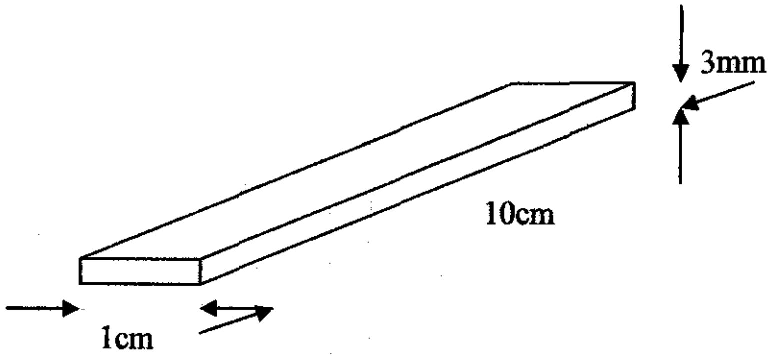
xvi. The connection type is assumed to be pinned type for both joint analysis and deflection analysis.

xvii. For the moment of inertia values, the critical member is assumed to act as a simple beam.

## 4.1.2 Joint analysis on the Three-members angulated bar design

Dimensions of one member:

10cm L x 1cm W x 3mm THK



Area, A = 2(10 x 1) + 2 (10 x 0.3) + 2(1 x 0.3)
= 26.6 $cm^2$

Volume, V = 10 x 1 x 0.3
= 3.0 $cm^2$

### 4.1.2.1 Material which will be considered in the analysis is Aluminum.

Density of aluminum, $\rho_{al}$ = 2.7 x $10^3$ kg/$m^3$
= 2.7g/$cm^3$

Thus the weight of one member = 2.7 g/$cm^3$ (3 $cm^3$)
= 8.1 g
= 0.0081 kg
= 0.081 N

Total weight of whole structure = 0.0081 kg x 3 members x 24 nos
= 0.5832 kg
= 5.832 N

Friction Force, $F_R$ = $\mu$ * mass of structure * g

Mass of structure = 0.5832 kg
= 5.832 N

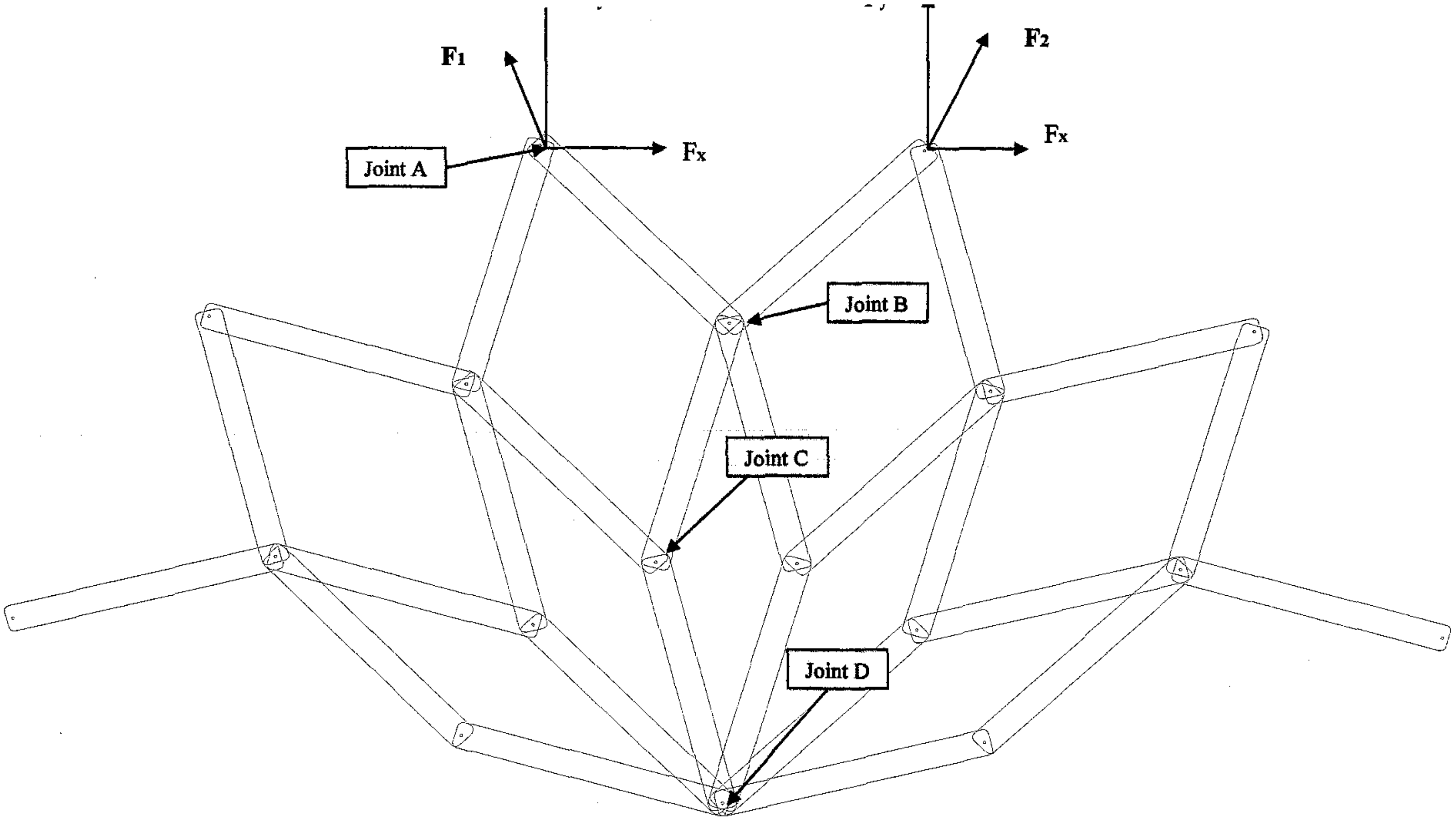


Figure 4.8: Critical Joints to be considered in the Joint Analysis

Friction Coefficient, $\mu$ = 0.18 (lubricated galvanized steel on joint)

Thus $F_R$ = 0.18 * 0.5832 * 9.80665
= 1.0295 N

Structure will be in static motion when $F_R$ equals to $F_E$.

Thus $F_E > F_R$ to make the structure move, for that reason, $F_E$ is assume to be 1.05N

$$F_E \doteq 1.05\ N$$

The wind load velocity of 120km/hr will be considered in this project.

A wind velocity of 10m/s could cause a pressure of 2.7 lb/ft².

120km/hr x 1000m/1km x 1hr/3600s = 33.33m/s

Then a 33.33m/s of wind velocity could cause a pressure of

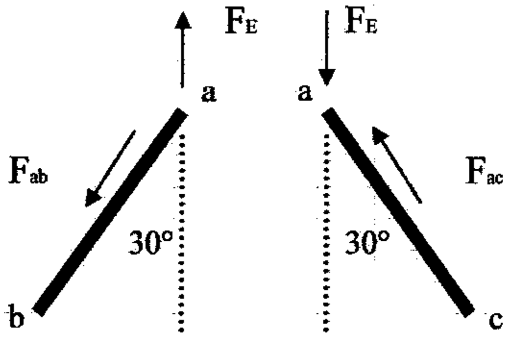
2.7lb/ft² x 33.33m/s ÷ 10m/s = 8.9991 lb/ft²

8.9991 lb/ft² x 4.536N/lb x 1ft²/929.0304cm² = 0.0439 N/cm²

For this project, a wind load pressure of ***0.05 N/cm²*** would be considered and to be subjected onto the retractable satellite structure.

## 4.1.2.2 Two-Dimensional (2D) Joint Analysis with no wind loads

### *Joint A*



***Member ab:***

$\Sigma + \uparrow F_y = 0;$ $\quad 1.05 - F_{ab} \cos 30° = 0$

$F_{ab} = 1.05/\cos 30°$

$= $ ***1.212 N (C)***

***Member ac:***

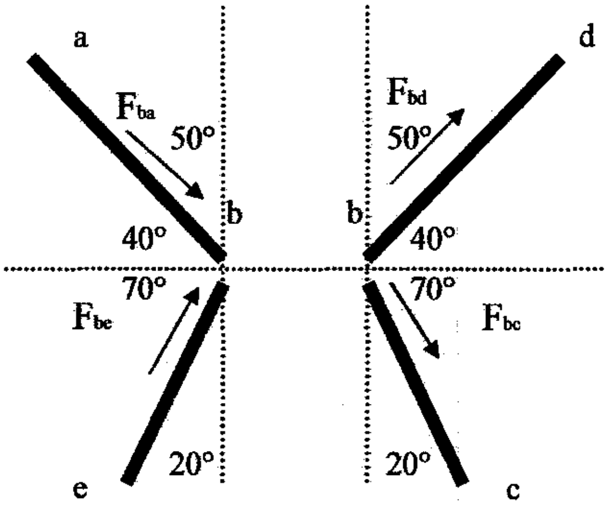
$\Sigma + \uparrow F_y = 0;$ $\quad -1.05 - F_{ac} \cos 30° = 0$

$F_{ac} = -1.05/\cos 30°$

$= -1.212$ N

$= $ ***1.212 N (T)***

### ***Joint B***



***Member ab, be:***

$F_{ba}$ = 1.212 N (T)

$\Sigma + \uparrow Fy = 0;$ $-F_{ba}\cos 50° - F_{be}\cos 20° = 0$

$F_{be} = -F_{ba}\cos 50°/\cos 20°$

$= -1.212 \cos 50°/\cos 20°$

$= -0.829$ N

$=$ ***0.829 N (T)***

***Member db, bc:***

$F_{bd}$ = 1.212 N (C)

$\Sigma + \uparrow Fy = 0;$ $+F_{bd}\cos 50° - F_{bc}\cos 20° = 0$

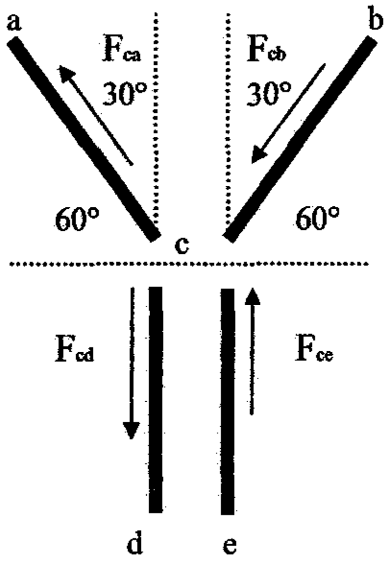
$F_{bc} = +F_{bd}\cos 50°/\cos 20°$

$= 1.212 \cos 50°/\cos 20°$

$= 0.829$ N

$=$ ***0.829 N (C)***

## *Joint C*



**Member ac, cd:**

$F_{ca}$ = 0.829 N (C)

$\Sigma + \uparrow F_y = 0;$

$$F_{ca} \cos 30° - F_{cd} = 0$$
$$F_{cd} = F_{ca} \cos 30°$$
$$= 0.829 \cos 30°$$
$$= \boldsymbol{0.7179\ N\ (C)}$$

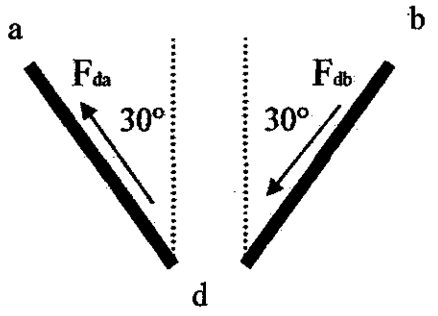
**Member bc, ce:**

$F_{cb}$ = 0.829 N (T)

$\Sigma + \uparrow F_y = 0;$

$$-F_{cb} \cos 30° - F_{ce} = 0$$
$$F_{ce} = -F_{cb} \cos 30°$$
$$= -0.829 \cos 30°$$
$$= -0.7179\ N$$
$$= \boldsymbol{0.7179\ N\ (T)}$$

## *Joint D*

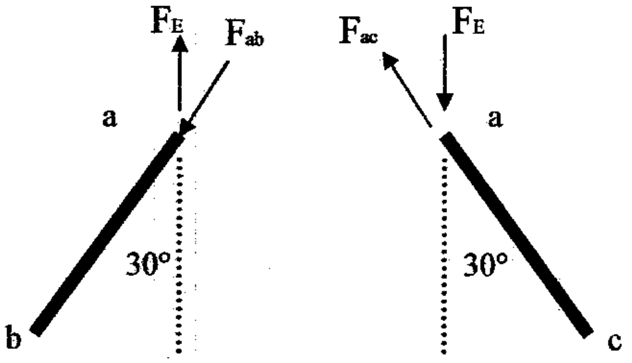


$F_{da}$ = ***0.7179 N (C)***

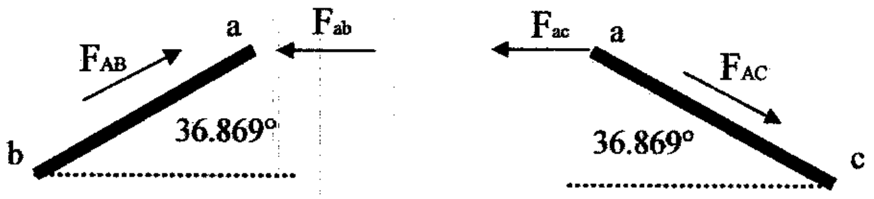
$F_{db}$ = ***0.7179 N (T)***

## 4.1.2.3 Three-Dimensional (3D) Joint Analysis with no wind loads

### *Joint A*



PLAN VIEW



SIDE VIEW

***Member ab:***

$\Sigma + \uparrow F_y = 0;$ $\quad 1.05 + F_{ab} \cos 30^\circ = 0$

$F_{ab} = -1.05/\cos 30^\circ$

$= \boldsymbol{-1.212\ N}$

$= 1.212\ \mathrm{N}\ (\mathrm{C})$

$$\begin{aligned}
\Sigma + \rightarrow F_x = 0; \qquad -F_{ab} + F_{AB}\cos 36.869^\circ &= 0\\
F_{AB} &= F_{ab}/\cos 36.869^\circ\\
&= 1.212/0.8000094\\
&= 1.5149\ \text{N}\\
&= \boldsymbol{\mathit{1.5149\ N\ (T)}}
\end{aligned}$$

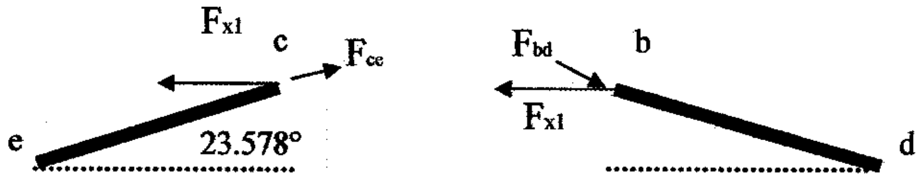
***<u>Member ac:</u>***

$$\begin{aligned}
\Sigma + \uparrow F_y = 0; \qquad F_{ac}\cos 30^\circ - F_E &= 0\\
F_{ac} &= F_E/\cos 30^\circ\\
&= 1.212\ \text{N}\\
&= 1.212\ \text{N (T)}
\end{aligned}$$

$$\begin{aligned}
\Sigma + \rightarrow F_x = 0; \qquad -F_{ac} + F_{AC}\cos 36.869^\circ &= 0\\
F_{AC} &= F_{ac}/\cos 36.869^\circ\\
&= 1.212/0.8000094\\
&= 1.5149\ \text{N}\\
&= \boldsymbol{\mathit{1.5149\ N\ (C)}}
\end{aligned}$$

## ***Joint B***

PLAN VIEW



SIDE VIEW

***Member ac, ce:***

$$\begin{aligned}
\Sigma + \uparrow F_y = 0; \qquad F_{AC}\cos 50^\circ + F_{ce1}\cos 20^\circ &= 0\\
F_{ce1} &= F_{AC}\cos 50^\circ / \cos 20^\circ\\
&= 1.5149\cos 50^\circ / \cos 20^\circ\\
&= 1.0362\ \text{N}\\
&= 1.0362\ \text{N (T)}
\end{aligned}$$

$\Sigma + \rightarrow F_x = 0;$

$$(F_{AC}\cos 70^\circ)\cos 36.869^\circ + F_{ce1}\cos 23.578^\circ + F_{x1} = 0$$

$$\begin{aligned}
F_{x1} &= -[(F_{AC}\cos 70^\circ)\cos 36.869^\circ + F_{ce1}\cos 23.578^\circ]\\
&= -[(1.5149\cos 70^\circ)\cos 36.869^\circ + 1.0362\cos 23.578^\circ]\\
&= -(0.4145 + 0.94969)\\
&= -1.36419\ \text{N}\\
&= 1.36419\ \text{N} (\leftarrow)
\end{aligned}$$

$\Sigma + \rightarrow F_x = 0;$

$$\begin{aligned}
F_{ce}\cos 23.578^\circ - F_{x1} &= 0\\
F_{ce} &= F_{x1} / \cos 23.578^\circ\\
&= 1.4885\ \text{N}\\
&= \boldsymbol{1.4885\ N\ (T)}
\end{aligned}$$

***Member ab, bd:***

$$\begin{aligned}
\Sigma + \uparrow F_y = 0; \qquad -F_{AB}\cos 50^\circ - F_{bd1}\cos 20^\circ &= 0\\
F_{bd1} &= -F_{AB}\cos 50^\circ / \cos 20^\circ\\
&= -1.5149\cos 50^\circ / \cos 20^\circ\\
&= -1.0362\ \text{N}\\
&= 1.0362\ \text{N (T)}
\end{aligned}$$

$\Sigma + \rightarrow F_x = 0;$

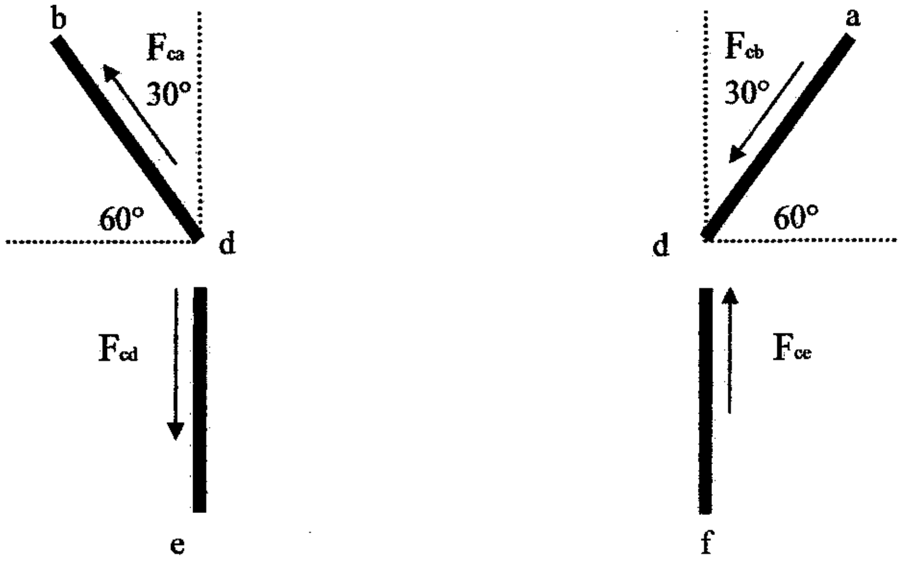
$(F_{AB} \cos 70°) \cos 36.869° + F_{bd1} \cos 23.578° - F_{x1} = 0$

$$
\begin{aligned}
F_{x1} &= [(F_{AB} \cos 70°) \cos 36.869° + F_{bd1} \cos 23.578°] \\
&= [(1.5149 \cos 70°) \cos 36.869° + 1.0362 \cos 23.578°] \\
&= (0.4145 + 0.94969) \\
&= 1.36419 \text{ N} \\
&= 1.36419 \text{ N } (\leftarrow)
\end{aligned}
$$

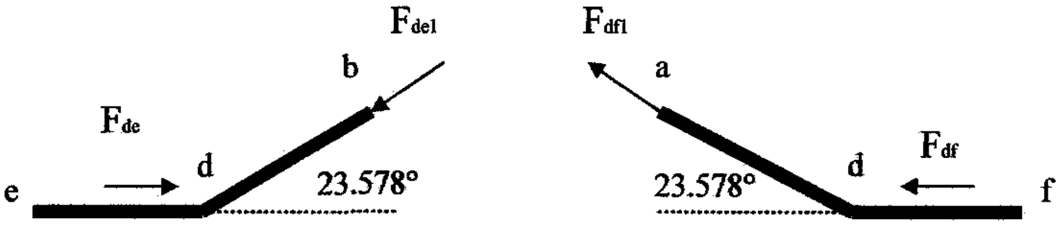
$\Sigma + \rightarrow F_x = 0;$

$$
\begin{aligned}
-F_{bd} \cos 23.578° - Fx1 &= 0 \\
F_{bd} &= -F_{x1}/ \cos 23.578° \\
&= -1.36429/0.91652 \\
&= -1.4885 \text{ N} \\
&= \boldsymbol{1.4885\ N\ (C)}
\end{aligned}
$$

### *Joint C*



PLAN VIEW



SIDE VIEW

### *Member bd, de:*

$$\begin{aligned} \Sigma + \uparrow F_y = 0; \qquad F_{cd} \cos 30^\circ - F_{del} &= 0 \\ F_{del} &= F_{bd} \cos 30^\circ \\ &= 1.4886 \cos 30^\circ \\ &= 1.2892\ \mathrm{N}\ (\downarrow) \end{aligned}$$

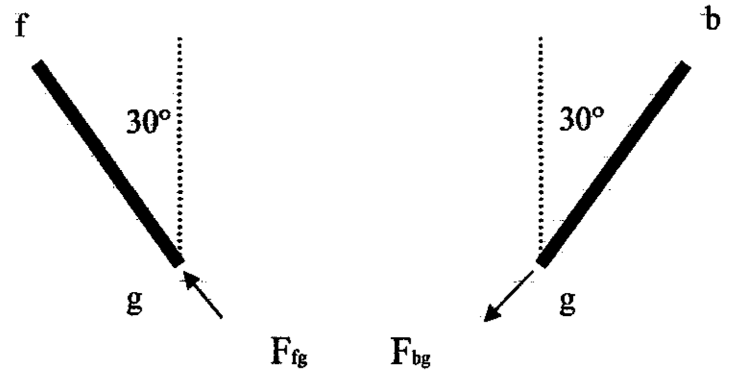
$$\begin{aligned} \Sigma + \rightarrow F_x = 0; \qquad - F_{del} \cos 23.578^\circ + F_{de} &= 0 \\ F_{de} &= F_{del} \cos 23.578^\circ \\ &= 1.2892 \cos 23.578^\circ \\ &= \boldsymbol{1.18157\ N\ (T)} \end{aligned}$$

### *Member ad, df:*

$$\begin{aligned} \Sigma + \uparrow F_y = 0; \qquad -F_{ad} \cos 30^\circ + F_{dfl} &= 0 \\ F_{dfl} &= F_{ad} \cos 30^\circ \\ &= 1.4886 \cos 30^\circ \\ &= 1.2892\ \mathrm{N}\ (\uparrow) \end{aligned}$$

$$\begin{aligned} \Sigma + \rightarrow F_x = 0; \qquad - F_{dfl} \cos 23.578^\circ - F_{df} &= 0 \\ F_{df} &= -F_{dfl} \cos 23.578^\circ \\ &= -1.2892 \cos 23.578^\circ \\ &= -1.18157\ \mathrm{N} \\ &= \boldsymbol{-1.18157\ N\ (C)} \end{aligned}$$

### *Joint D*



$F_{fg}$ = $F_{de}$
= ***1.18157 N (T)***

$F_{bg}$ = $F_{df}$
= ***1.18157 N (C)***

### 4.1.3 Deflection Analysis on the Final Design of the Retractable Satellite Dish Using The Double Integration Method

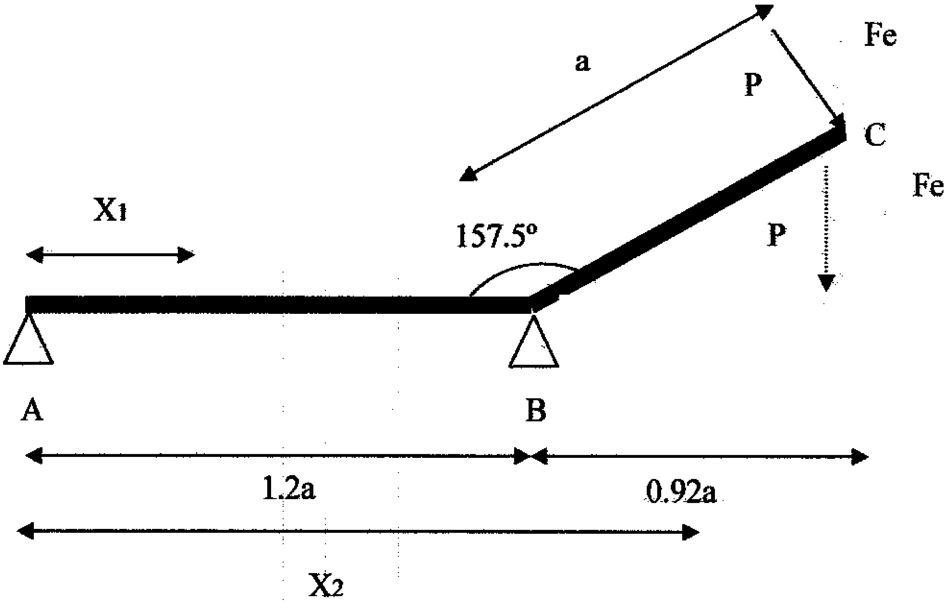


Figure 4.9: Loads acting on the Critical Member.

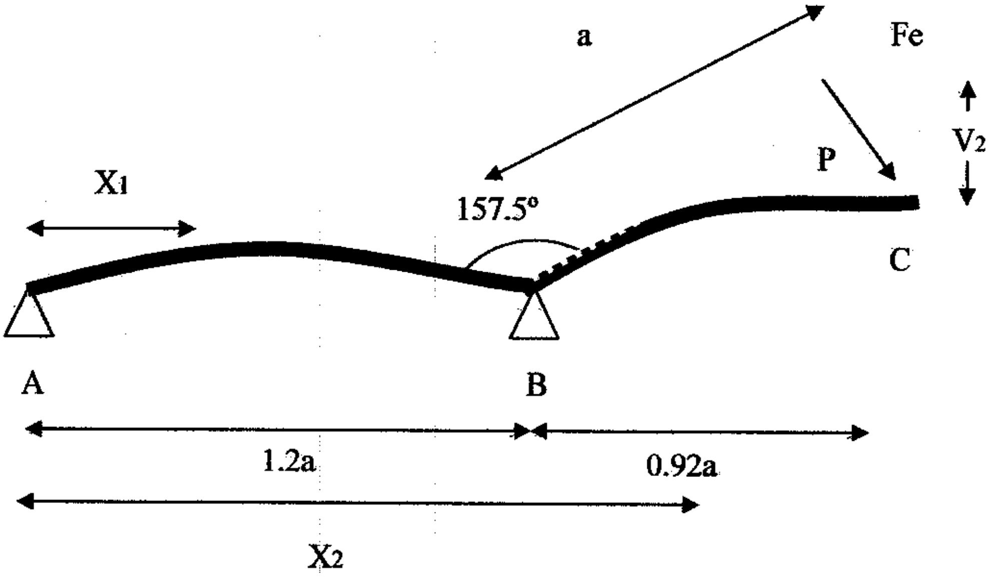


Figure 4.10: Expected view of the critical member's elastic curve.

$$M_1 = -0.77Px_1 \qquad 0 \le x_1 \le 1.2a$$

$$M_2 = -0.77Px_1 + 1.77P(x_2 - 1.2a) \qquad 1.2a \le x_1 \le 2.12a$$
$$= Px2 - 2.124Pa$$

For $X_1$

$$EI\frac{d^2v_1}{dx_1^2} = -0.77Px_1$$
$$EI\frac{dv_1}{dx_1} = -0.385Px_1 + C_1 \leftarrow (1)$$
$$EIv_1 = -0.128Px_1 + C_1x_1 + C_2 \leftarrow (2)$$

For $X_2$

$$EI\frac{d^2v_2}{dx_2^2} = Px_2 - 2.124Pa$$
$$EI\frac{dv_2}{dx_2} = \frac{P}{2}x_2^2 - 2.124Pax_2 + C_3 \leftarrow (3)$$
$$EIv_2 = \frac{P}{6}x_2^3 - 1.062Pax_2 + C_3x_2 + C_4 \leftarrow (4)$$

V1 = 0 at X1= 0; $0 = 0 + 0 + C_2$

V1 = 0 at X1 = 1.2a; $0 = -0.128P(1.2a)^3 + C_1(1.2a) + C_2$

V2 = 0 at X2 = 1.2a; $0 = \frac{P(1.2a)^3}{6} - \frac{2.124Pa(1.2a)^2}{2} + C_3(1.2a) + C_4$

$$\frac{dv_1(1.2a)}{dx_1} = \frac{dv_2(1.2a)}{dx_2}; -0.355P(1.2a)^2 + C_1 = \frac{P}{2}(1.2a)^2 - 2.124Pa(1.8a) + C_3$$

Solving the equation above, we would obtain

$$C = 0.183Pa^2$$
$$C_2 = 0$$
$$C_3 = 1.453Pa^2$$
$$C_4 = -0.1966Pa^3$$

Putting the C's values inside equation (4), we would obtain

$$v_2 = \frac{1.59Pa^3}{EI} - \frac{4.77Pa^3}{EI} + \frac{3.08Pa^3}{EI} - \frac{0.197Pa^3}{EI}$$
$$v_2 = \frac{-0.297Pa^3}{EI}(\downarrow)$$

Note that a=7cm as for the longer span of the critical member's dimensions. (Please refer to Figure A7 in the appendix)

The values of v2 will depend on the material used in the design and the loads that it would withstand and also the material's mechanical properties. The calculated values of v2 are shown in Table 4.1 in Chapter 4 of this report.

## 4.2 DISHUSSION

### 4.2.1 Design Specification

The designs dimensions shown in Chapter 4 are designed to the scale of 1:1 in order to compare the retractable design with the typical one-piece un-retractable satellite dish within the market. The initial design using 3-members-bar element in Figure 4.1, Figure 4.2 and Figure 4.3 was obtained by applying the Hoberman's Angulated Element Concept and Type II Generalized Angulated Elements (GAE) onto the structure design. Simple 3-members-bar elements were chosen to be put in the design in a single planar. The 3 members retractable bar structure was selected for the structure analysis as it would assist the conceptual study and structural analysis in an easier approach. It's not a complicated design as the 3 numbers of members would help to understand the concept of retractable structure before heading for a much more complicated retractable member design.

However the initial design is not suitable in order to accomplish the project's objectives, thus another design has being developed. By modifying the 2D design from a complete connected circle (refer to Figure A1 in the Appendices Section) and divided it into four. The four main segments will later on connected at the center by a connector (refer to Figure A2 and A11). This type of connection will enable the retractable mechanism to be implemented directly onto both horizontal planar and the vertical planar. Design stability is increased by connecting another four similar segments to the connector at the center of the design.

The 3D design obtained from the steps above would produce a complete "bowl" shaped satellite dish. In order to achieve the outmost signal reflection on the dish, the 3D design is further "cut" its segments at its 45° on the vertical planar (refer to Figure A3 and Figure A4). Similar angulated members (Figure A5) are connected on top of the "cut" design to provide horizontal solidity onto the structure.

### 4.2.2 Advantages of Design

Several advantages can be obtained from the 3D design. The three main advantages are listed as follow:

#### 4.2.2.1 Reduce area of packaging

According to Figure 4.11, the length of the structure when it's in "expanded" condition would be 44cm, and when its in "retracted" condition, is 22m, a reduction of 50% in length. If the structure is to be packaged, a minimum of 616 cm$^2$ is required to wrap up the typical one-piece un-retractable satellite dish (having similar dimensions), whereas, the "retracted" final retractable satellite dish design would only need 352 cm$^2$, a reduction of 42.8 % in packaging area.

#### 4.2.2.2 Easier Mobilization and Remote Usage

Due to the smaller area of packaging needed to package the structure and the retractable mechanism in the design itself, it will be easier to mobilize the structure when it is not in use. Other than that, it would serve better for military purposes and research purposes in remote as the design enables the structure to be deployed and un-deployed when necessary.

### 4.2.3 Critical Members

By referring to the stress distribution in each element within the dish structure, the larger member element (Figure A7) is identified as the critical member. This critical member receives the most stress from the external loads compared to the other type of member element within the structure. Thus the structural analysis was done concentrating on the critical member, as if the critical member has a design dimension which will withstand the maximum load allowable, the other non critical member would also withstand the loadings. By referring to Figure 4.6, it is identified that the stress distribution focuses more on the joints of each critical member. Therefore the structural analysis was done by taking the stresses distribution on the joint into consideration.

### 4.2.4 Structural Analysis

In chapter 5: Calculation, it can be observed from the joint analysis that the forces acting on members in the 3D analysis have larger magnitude compared to the forces acting on the members in the 2D analysis. The reason for this is that in the 3D analysis, larger external force, Fe, has to be applied onto the structure in order to move each of its member, as the 3D structural design were elevated at a height on joint type A and joint type B, whereas all the joints in the 2D design are on the same planar.

In the result of the 2D and 3D joint analysis calculation, it can be observed that the magnitude of force acting on each on each type of joints, decreases as it reach nearer to the center of the retractable structure. This is caused by the retractable mechanism of the structure itself, where interconnected members which is linked at a certain angle at the pin joints would exert some force to the adjoining members, reducing the external force, Fe needed to move that particular members at the joints nearer to the center of the structure (for example, Joint B, Joint C and Joint D)

Pinned type support is assumed within the joint analysis and deflection analysis as pin connectors are used within the design. Point C is chosen in determining the deflection as it is the point where the critical member is connector to the octagonal connector and received most of the external force in order to "expand" the retractable satellite dish design. The deflection values at point C varies with the type of material being used within the design. However the material used in fabricating the connectors (Figure A11and Figure A12) will be constantly stainless steel. Stainless steel is used as the connectors' material as it has the greater ultimate strength in tension, 4 x 10^8 N/m$^2$ to 6 x 10^8 N/m$^2$.

According to the results in Table 4.1, the material which has the least amount of deflection is the stainless steel 13-8, followed by alloy steel 4140, titanium and the material having the largest amount of deflection is aluminum. The amount of loads can be applied onto the design structure before it deformed 5mm, depends on what type of material being used. A load of 747595kN is needed to deflect stainless steel 13-8 design and 794897kN to deflect alloy steel 4141 design at 5mm. whereas a load of only 71527kN is needed to deflect the aluminum alloy 2014 at 5mm.

In comparison to the typical satellite dish in the market, the mass of the retractable satellite dish design using aluminum or duralumin, is similar (about 15kg in weight). However if steel is being used within the retractable satellite dish design, it would weight nearly 60kg, which would defy the project's objective in order to provide easier mobilization for the structure. Thus at the moment, aluminum and duralumin is the most appropriate material to be used in the design in order to accomplish the project's objectives. Both aluminum and duralumin has acceptable ultimate yield strength and has very minor deflection if loads are being applied onto the structure. Titanium is another type of material which can be used in the design. Even though it has slightly heavier mass compared to aluminum and duralumin, but it has higher capacity in handling stress and tension from external loads. It is as strong as steel and twice as strong as aluminum, but is 45% lighter than steel and only 60% heavier than aluminum.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 CONCLUSION

Most of the objectives of this research project have been met. The Hoberman's Angulated Element Concept together with the Type II Generalized Elements Concept can applied in the design of the retractable satellite dish structure on both horizontal and vertical planar. The critical angulated member plays an important role in choosing the structure's materials, as it is the critical angulated member which will receive most of the impact from external forces and internal forces applied within the structure. Different type of material will results in different outcome in the structural analysis. The choosing of material will depend on ones priority. If the priority is on minimum cost, then the material alloy steel 4140 would be the best. If the priority is on structural quality and lightness, then the material titanium would be the best option. The material duralumin would be best in meeting both quality and costing purposes. This research project will be the stepping stone for further development on the retractable mechanism, not only on the satellite dish but also onto other type of equipments and facilities. Better modification can be made onto current retractable satellite dish structure.

## 5.2 RECOMMENDATION

There are several recommendation in order improve the results of this research project, and also in helping the future researcher of this project.

### 5.2.1 Structural Analysis should include temperature effects.

This project was done more onto the earth bound satellite dish structure. In order to obtain better results on the structural analysis, temperature effects should be taken into consideration. Extreme heat and extreme cold should be considered within the design so that the research could be expanded onto space bound satellite dish structure.

### 5.2.2 Designing the retractable mechanism for the satellite's reflector.

The design obtained in this research project was only on the supporting structure of the retractable satellite dish, and has not included the satellite reflector. In order to have a complete functioning satellite, a reflector should be attached onto it. A retractable mechanism design should be researched onto the dish reflector in order that it would be deployed and un-deployed together with the retractable bar structures.

### 5.2.3 Further material analysis.

Further material analysis should be made so that an even better design having an ultra light material yet capable of withstanding extreme loads and extreme temperature, could be made. Other than that, costing should also be included in the material analysis to obtain the best material to be used in a design which require good structural integrity yet fabricated using as minimum as possible on the cost.

### 5.2.4 Propose UTP to acquire Solid works Software for future use.

As the Solidworks Engineering Software has helped me tremendously in designing the retractable satellite dish structure, I would like to recommend to UTP to buy or renew the license of the engineering software mentioned in its premises.

# REFERENCES

The references are as follow:

Zhong You & S. Pelle, Oxford University Civil Engineering
<http://www-civil.eng.ox.ac.uk/research/deplyoable/sm/html>

David P.Cadogan and Mark S. Grahne, "Deployable Control Mechanisms for Inflatable Space Structures" in the 33rd Aerospace Mechanisms Conference May 1999.

David Fraser, Hank Kleespies, Cliff Vasicek, Fall 1991 "Spacecraft Structures".

Prof Sergio Pellegrino and Frank Jenson, "Planar Retractable Roofs"
http://www.civ.eng.cam.ac.uk/dsl/roof/planar/html

R.C Hibbeler "Structural Analysis" 5th Edition, Prentice Hall Inc, Upper Saddle River, New Jersey 2002.

Metal Sourcing Guide Online www.metalsuppliersonline.com

A to Z Journal of Material Online http://www.azom.com/default.asp

Metal Prices Online http://www.metalprices.com/

ENGINEERS EDGE Solution by Design "Properties of Metal – Thermal" and "Modulus of Elasticity, Strength Properties of Metals"
http://www.engineersedge.com/

EFUNDA Engineering Fundamentals "Metal Alloy Properties"
http://efunda.com/materials/alloys/alloy_home/alloys.cfm

Jefferson Lab "Properties of Titanium"
http://education.jlab.org/itselemental/ele022.html

# Appendices

Table A1: Summary of metal mechanical properties

| Material | Density x103kg/m3 | Specific resistance at 00x10-8, Ωmm | Ultimate strength x108 newton/ m2 | Young modulus x1010, N/m2 | Heat capacity x102 Joule/kg 0C | Melting point, 0C | Thermal coefficient of resistivity, x10-3 |
|---|---|---|---|---|---|---|---|
| Aluminum | 2.7 | 2.62 | 1.5 | 7.2 | 0.95 | 660 | 4.2 |
| Beryllium bronze | 8.22 | 7.2-9.0 | 3.4-4.6 | - | 0.14 | - | - |
| Tungsten | 19.3 | 3.1 | 10-30 | 35 | 0.14 | 3410 | 4.2 |
| Duralumin | 2.75 | 3.3 | 3.5 | 7.1 | 0.93 | 650 | 2.2 |
| Cadmium | 8.64 | 7 | 0.7-0.9 | 5-7 | 0.23 | 321 | 4.3 |
| Brass L68 | 8.5 | 7 | 4-6 | 11 | 0.38 | 900 | 1.5 |
| Brass L62 | 8.9 | 7.2 | 4.1-6.4 | 10 | - | 900 | - |
| Brass L59 | 8.9 | 7.2 | 3.4-4.2 | 9-10 | - | 900 | - |
| Solid copper | 8.7 | 1.58 | 4.1 | 11-63 | 1 | 1083 | 4.3 |
| Cadmium solid drawn copper | 8.9 | 2.1 | 6 | 12.6 | - | - | 4 |
| Molybdenum | 10.2 | 4.5-5 | 14-25 | 35 | 0.272 | 2.620 | 4.3 |
| Silver | 10.5 | 1.5 | 3.8 | 7.5 | 0.234 | 960 | 4 |
| Steel | 7.8 | 10-33 | 4-6 | 21-22 | 0.47 | 1300 | 9 |
| Nickel | 8.5 | 7.2 | 4-4.5 | 21 | 0.46 | 1450 | 6.1 |
| XOT Alloy | 8.87 | 2.5-2.9 | 7-7.5 | 11 | - | 1200 | - |
| Zirconium bronze | 8.85 | 2.08 | 48 | 13.7 | - | 1250 | - |
| Zr 0.4 | | | | | | | |

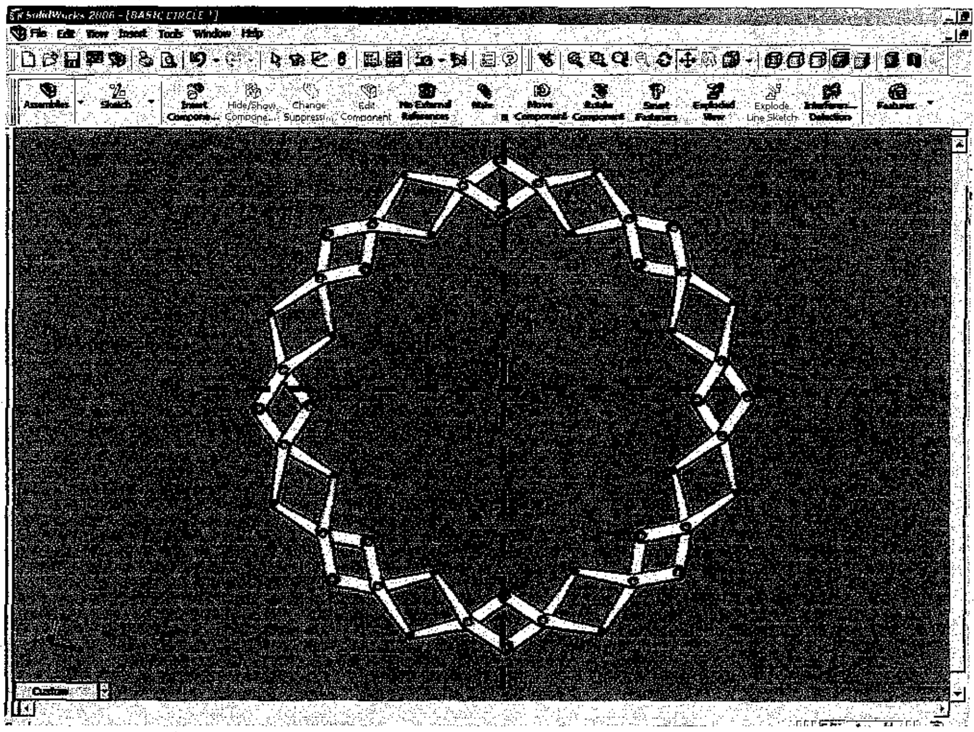


Figure A1: Two-members angulated bar design fully connected into a complete circular shape.

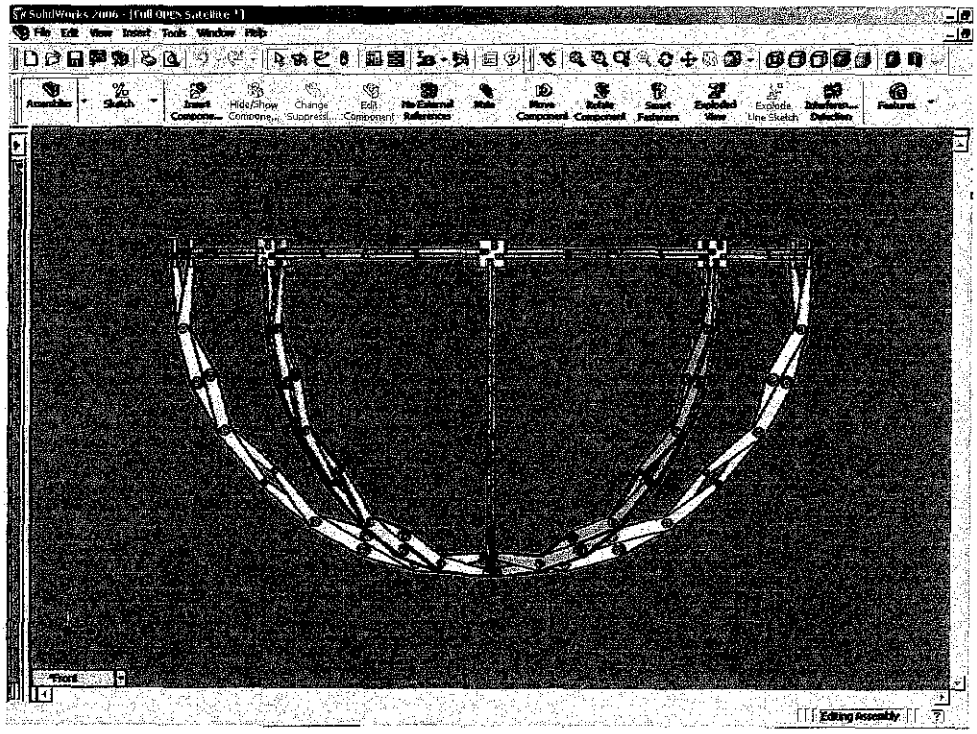


Figure A2: Two-members angulated bar design connected at the center using a connector.

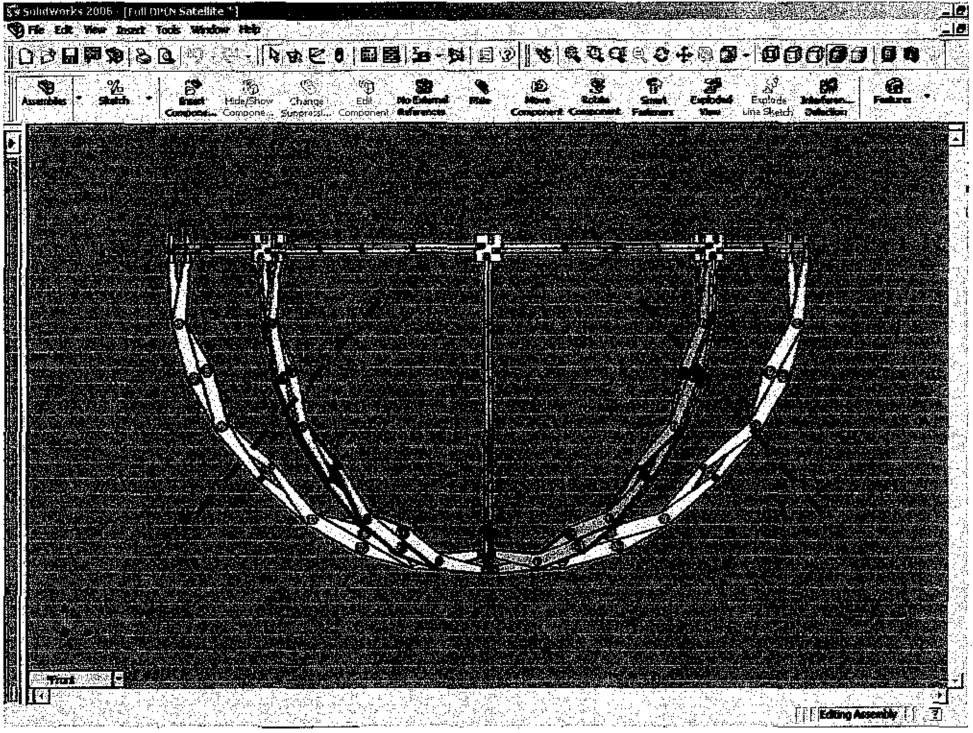


Figure A3: Two-members angulated bar design is being “cut” at an angle of 45° on the horizontal planar.

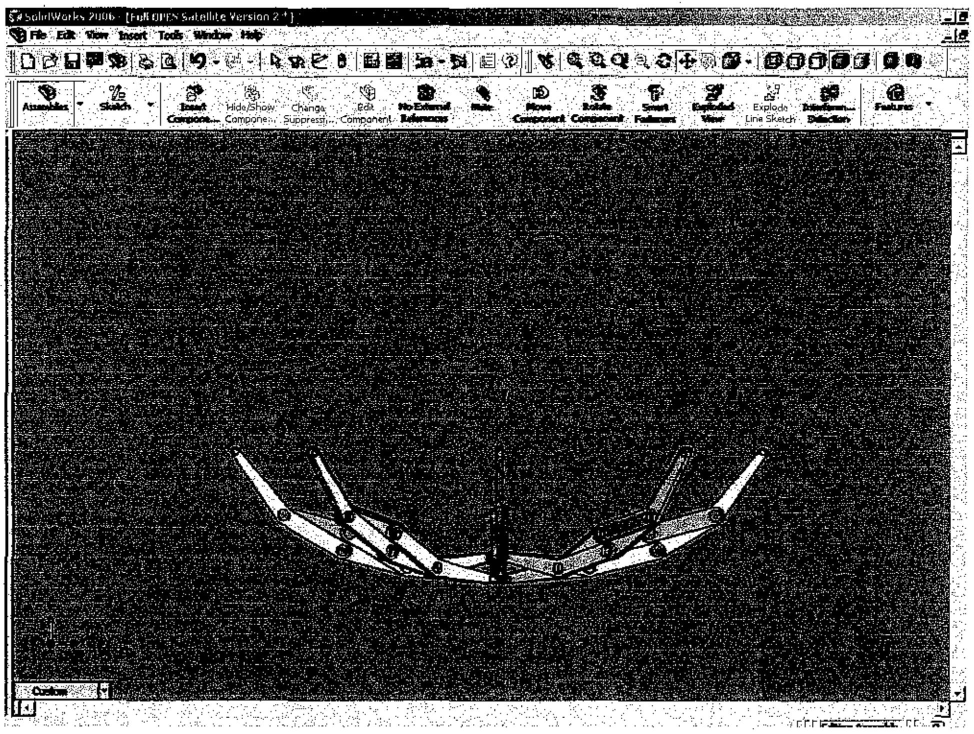


Figure A4: Two-members angulated bar design which has being “cut”.

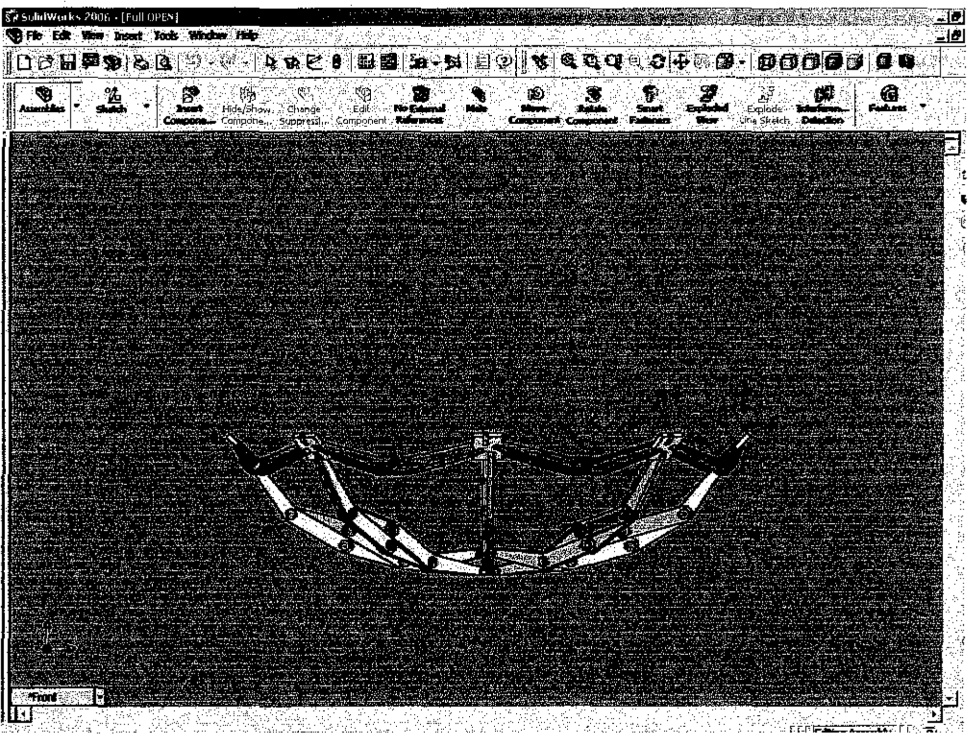


Figure A5: Another smaller two-member angulated bar element being connected to the main two-members angulated bar through a connector.

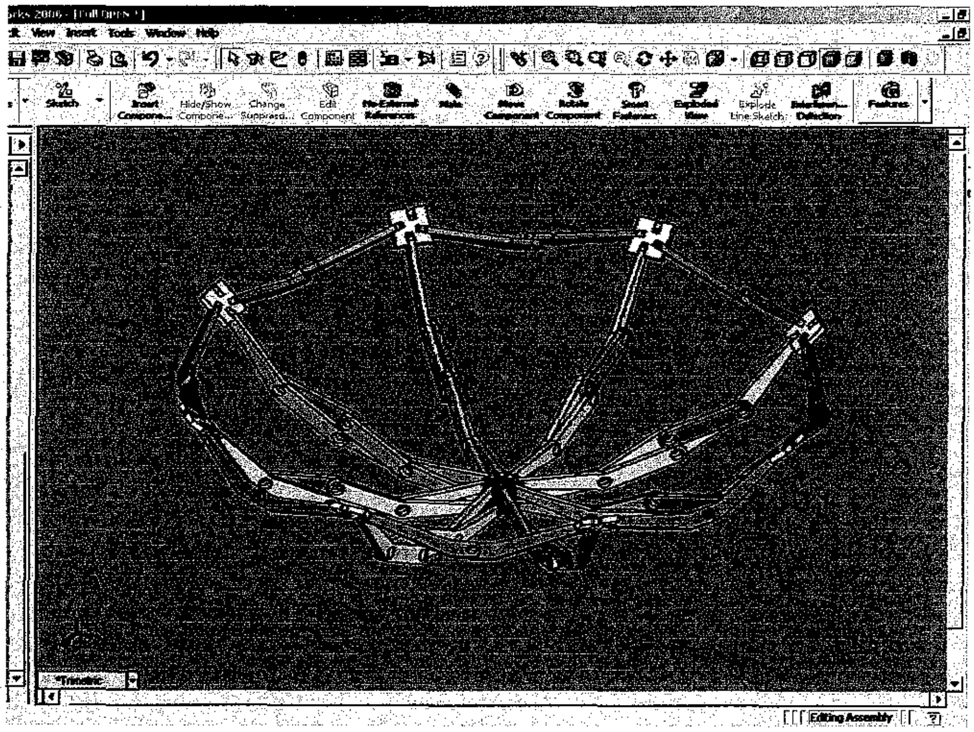


Figure A6: Fully expanded of the Final Design of retractable satellite dish structure.

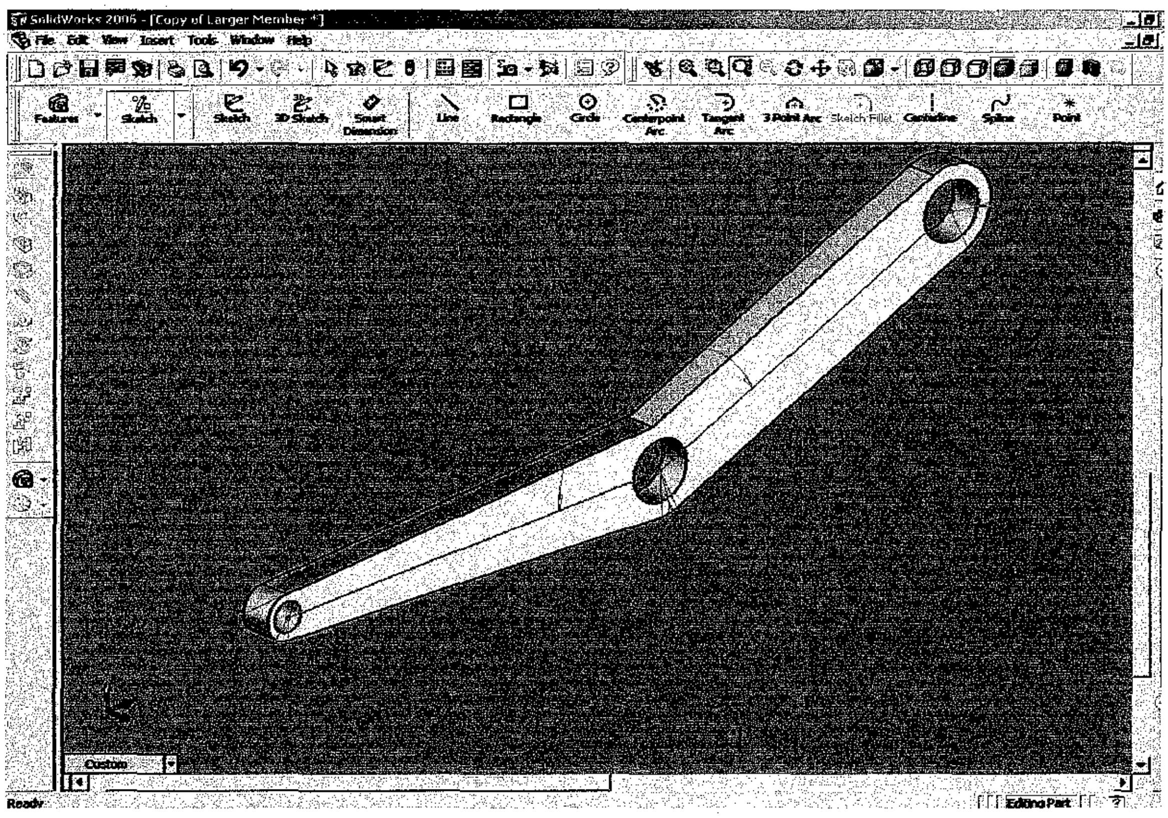


Figure A7: The Type A member of the retractable satellite dish structure.

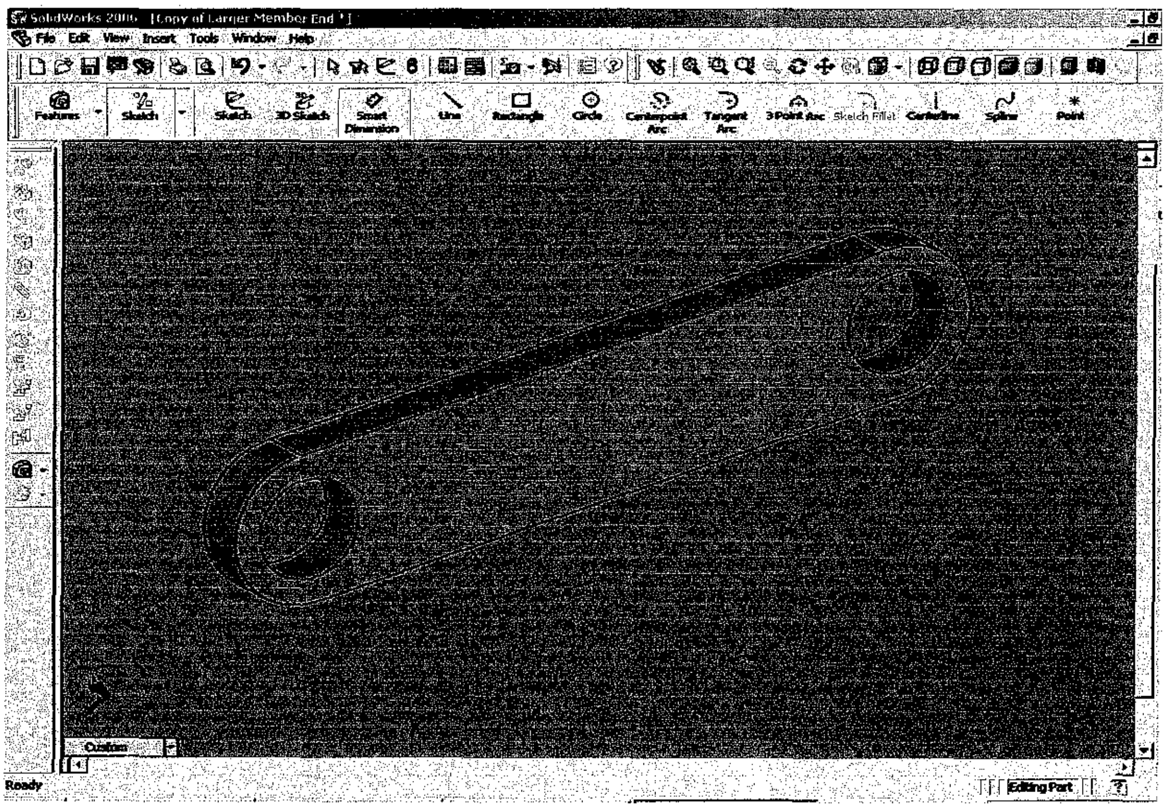


Figure A8: The Type B element of the retractable satellite dish structure.

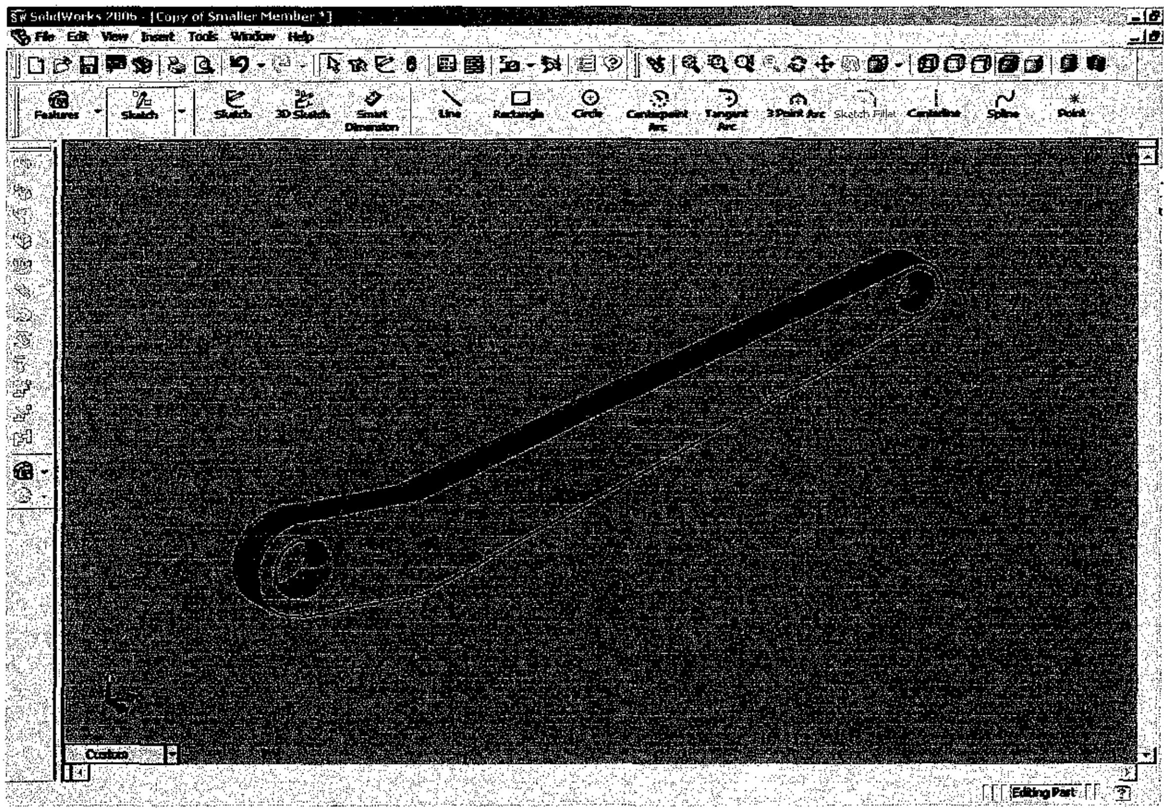


Figure A9: The Type C element of the retractable satellite dish structure

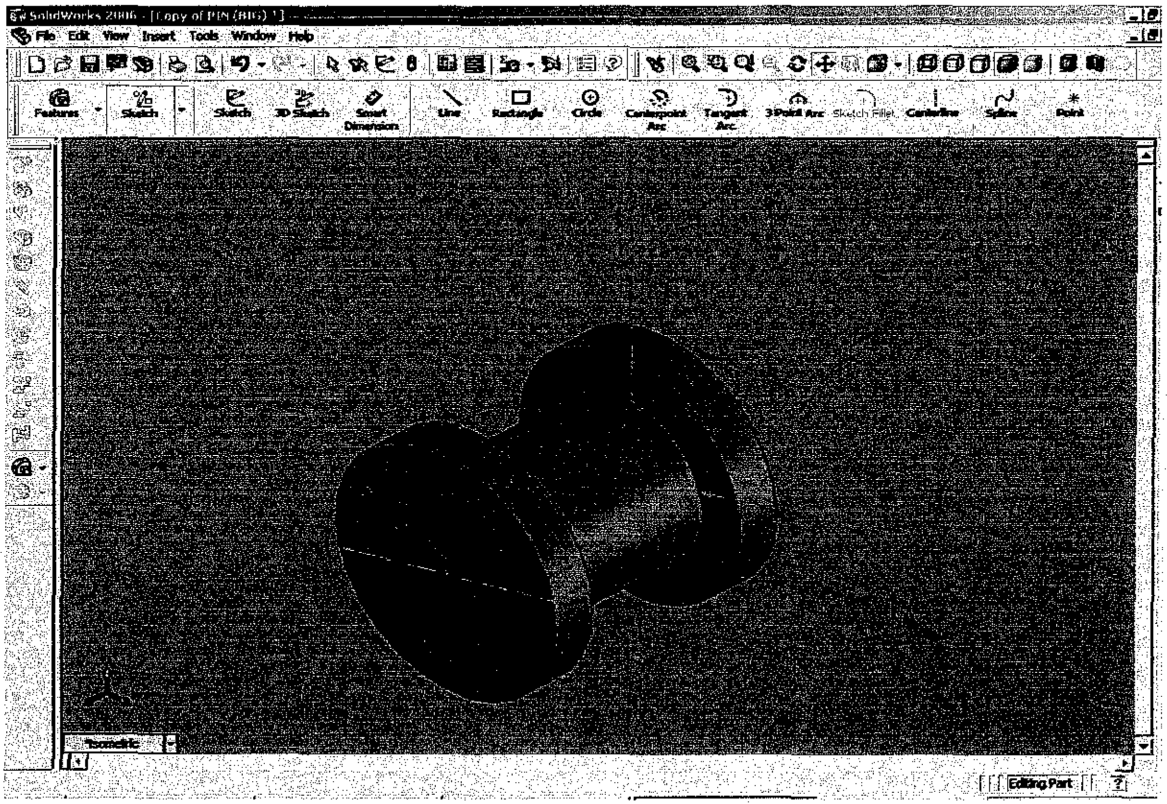


Figure A10: The Pin Connector of the retractable satellite dish structure.

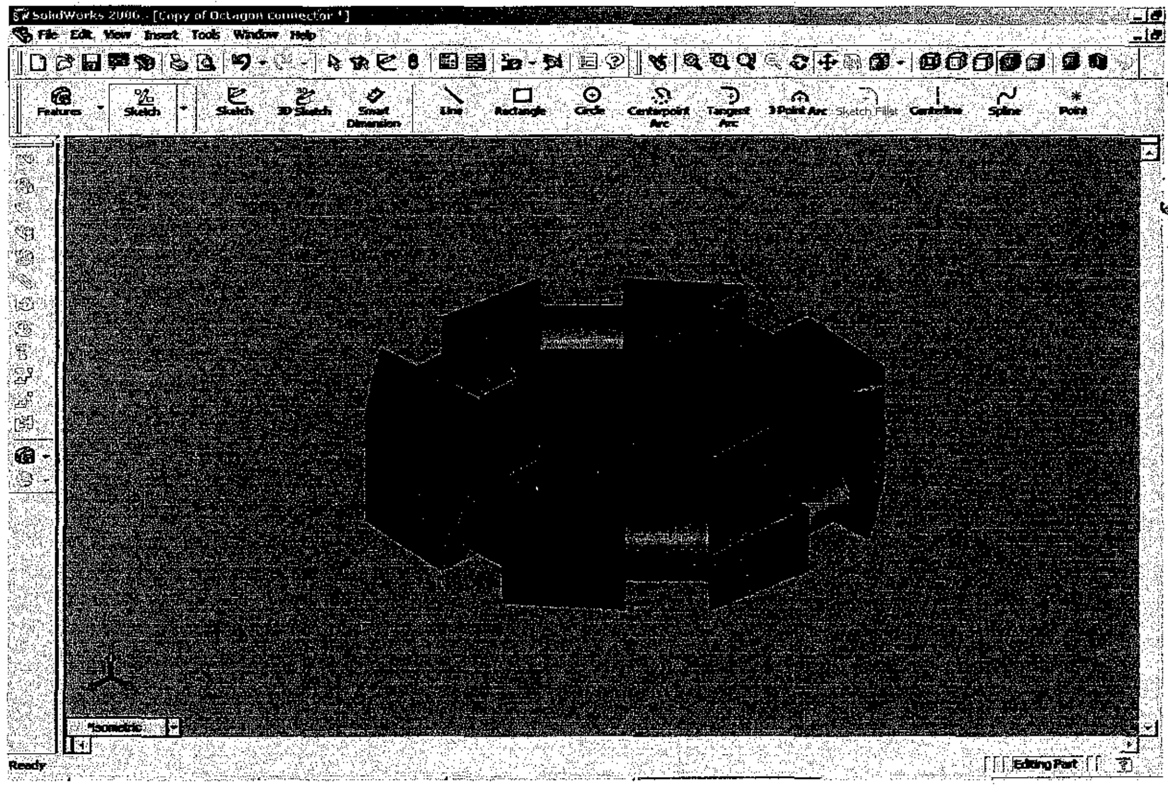


Figure A11: The Octagonal Connector of the retractable satellite dish structure

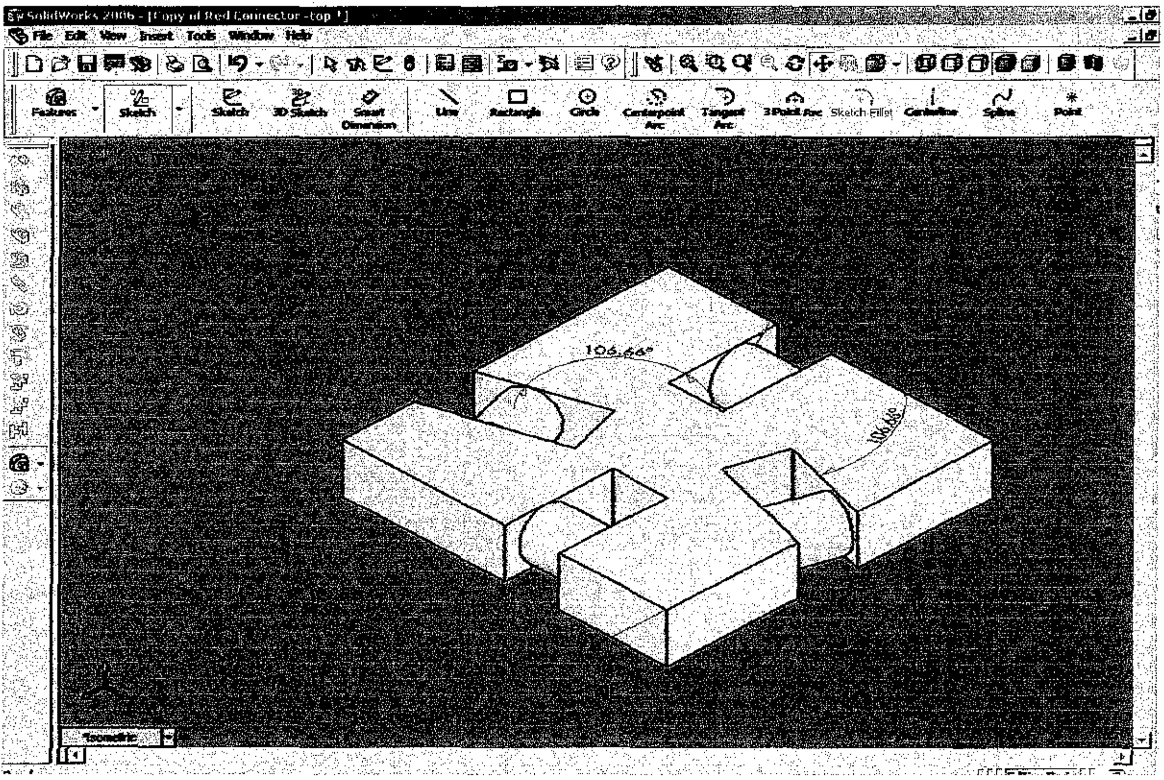


Figure A12: The Upper Connector of the retractable satellite dish structure.

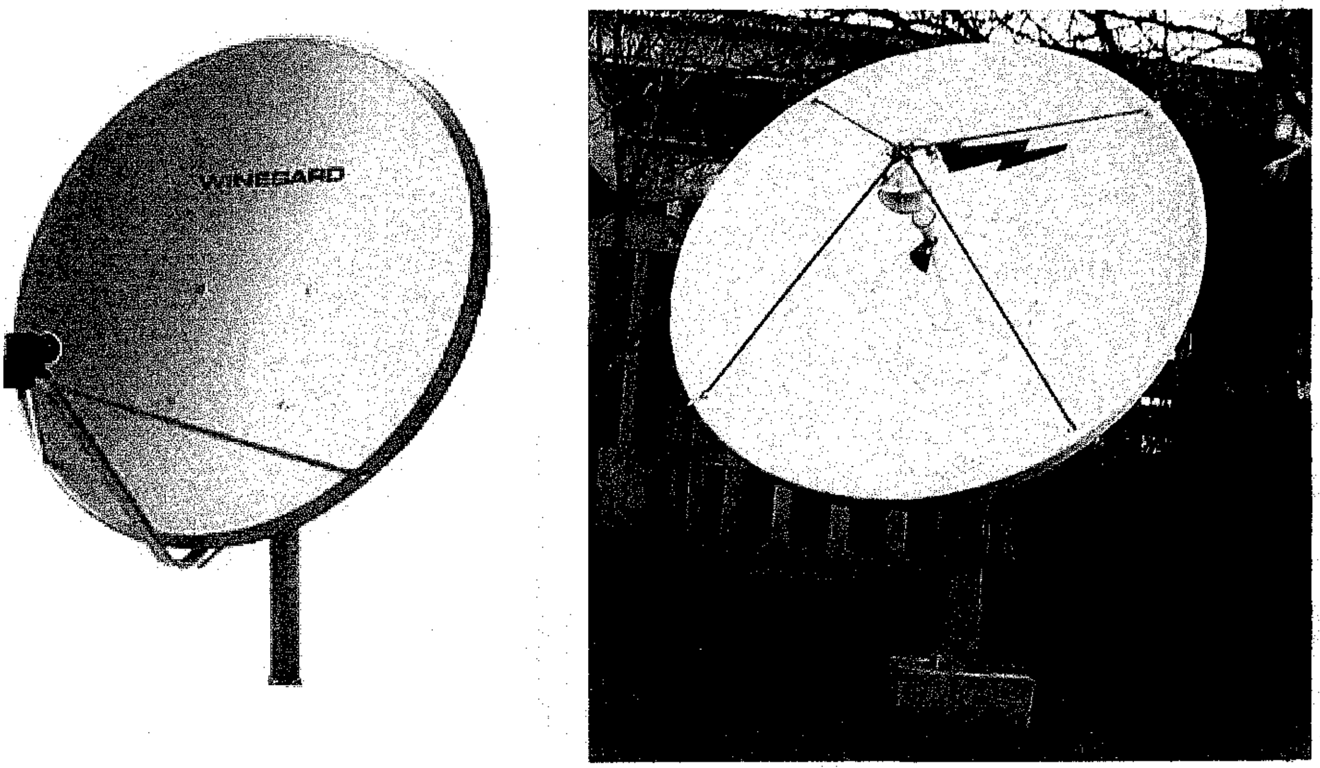


Figure A13: Typical one-piece solid satellite dish.