INTERIM REPORT
STUDY OF THERMAL CONDUCTIVITY REQUIREMENTS
VOL. II
MULTIPLE DOCKING ADAPTER (MDA) THERMAL MODEL

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

N 70 24179

HREC-1347-2
LMSC/HREC D148611-II

NASA CR 102603

LOCKHEED MISSILES & SPACE COMPANY

HUNTSVILLE RESEARCH & ENGINEERING CENTER

HUNTSVILLE RESEARCH PARK

4800 BRADFORD BLVD., HUNTSVILLE, ALABAMA

INTERIM REPORT

STUDY OF THERMAL CONDUCTIVITY REQUIREMENTS

VOL. II

MULTIPLE DOCKING ADAPTER (MDA) THERMAL MODEL

December 1968

Contract NAS8-21347

Prepared for George C. Marshall Space Flight Center
National Aeronautics and Space Administration

by

R.O. Hedden

APPROVED BY: ______________________
J.S. Farrior
Resident Director

FOREWORD

This document presents the results of work performed by Lockheed's Huntsville Research & Engineering Center while under contract to the Propulsion & Vehicle Engineering Laboratory of NASA-Marshall Space Flight Center. This task was conducted as partial fulfillment of Contract NAS8-21347, "Study of Thermal Conductivity Requirements." Technical Monitors of this contract were Mr. John Austin and Mr. E. Haschal Hyde of the Propulsion & Vehicle Engineering Laboratory at NASA-Marshall Space Flight Center.

The interim report for "Study of Thermal Conductivity Requirements" consists of two volumes as follows:

Vol. I:	High Performance Insulation Thermal Conductivity Test Program
Vol. II:	Multiple Docking Adapter (MDA) Thermal Model

SUMMARY

This report describes mathematical models of the Apollo Applications Program's Multiple Docking Adapter that were developed by Lockheed's Huntsville Research & Engineering Center. Two models, for use in detailed thermal analyses of the Multiple Docking Adapter, were developed and checked out. These were:

- Multiple Docking Adapter Thermal Model, and
- Apollo Applications Program Cluster Thermal Model.

These models were written for use with two existing computer programs:

- The Lockheed Heat Rate Computer Program, and
- The Lockheed Mark 5C Thermal Analyzer.

These two programs provide the capability for complete thermal analyses of the Multiple Docking Adapter in any of its many planned orbital configurations.

A modified version of the Incident Orbital Heat Flux computer model developed under Contract NAS8-21003 provides the capability for calculating the heat fluxes (solar, albedo and planetshine) incident to the Multiple Docking Adapter taking into account the effects of blockage and reflections from the orbiting cluster. These heat fluxes are used as input for the Multiple Docking Adapter and Apollo Applications Program Cluster Thermal Models. The Multiple Docking Adapter Thermal Model and the Apollo Applications Program Cluster Thermal Model provide the capability for determining the steady-state and/or the transient temperature distribution throughout the Multiple

Docking Adapter for a completely realistic set of boundary conditions. The effect of module rearrangements, surface finish changes, solar panel and module configuration changes can be evaluated. Also, internal heat load changes, experiment surface finish changes, structural changes, as well as most of the other changes which affect the Multiple Docking Adapter temperature distributions can be evaluated using these computer models. Details of the mathematical models and their use in the thermal evaluation of the Multiple Docking Adapter are presented in this report.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Section 1
INTRODUCTION

The purpose of this study was to develop a complete thermal model of the Multiple Docking Adapter (MDA) which can be utilized to verify the adequacy of the MDA thermal design. Two mathematical models were developed, utilizing existing Lockheed computer programs, which provide a capability for the complete thermal analysis of the MDA. These models and a modified version of the Incident Orbital Heat Flux Model developed under Contract NAS8-21003 are used in the thermal evaluation. The modifications, which involve the MDA, include the removal of two ports, the extension of the radiator section, and the matching of the nodal network breakdown to the mechanical interfaces. These models perform the following functions: (1) the Incident Orbital Heat Flux Model calculates the incident orbital heat fluxes to the vehicle; (2) the MDA Thermal Model calculates the temperature distribution of the MDA; and (3) the Apollo Applications Program (AAP) Cluster Thermal Model calculates the boundary temperatures for the MDA Thermal Model.

<u>Incident Orbital Heat Flux Model</u>: The Incident Orbital Heat Flux Model, as its name implies, was developed to obtain the incident orbital heat fluxes to the MDA. These heat fluxes consist of solar, albedo and planetshine radiant energy and are dependent on the orientation of the surface with respect to the Earth and Sun and the surface finish. In addition to the preceding factors, the total incident orbital heat fluxes must include the radiant energy which is reflected from other surfaces of the orbiting configuration and account for the possible blockage of radiant energy by these surfaces. Therefore, the Incident Orbital Heat Flux Model consists of the complete orbiting cluster model. The model was developed so that modules can easily be docked at any of the MDA docking ports or eliminated if they do not exist on the mission being investigated. The surface view factors are calculated and then used in the calculation

of the effective, or $\mathscr{F}$, view factors which account for multiple reflections and different surface emissivities. The $\mathscr{F}$ are punched as RADK on data cards in a format suitable for use in the MDA Thermal Model and the AAP Cluster Thermal Model. The next step is to calculate the incident orbital heat fluxes which are also punched on data cards for use in the thermal models. Note the three steps:

- View factor calculations
- RADK calculations
- Heat flux calculations

can be accomplished in a single computer run. The step-by-step approach was taken so that the results of each step can be checked before proceeding to the next step, and because of the difficulty in obtaining sufficient Univac 1108 computer time to make a complete run.

MDA Thermal Model: The MDA Thermal Model was developed for use in evaluating the internal heat loads and temperature distributions on the MDA. The thermal model consists of an equivalent electrical resistor-capacitor network with variable boundary conditions. Solutions can be obtained for both the steady-state and transient cases. External heat loads are supplied in data card form by the Incident Orbital Heat Flux Model. The thermal model takes into account all types of heat paths (conduction, radiation and/or convection) from the external skin to inner conditioned "air." Radiant energy exchange between the MDA and other surfaces of the orbiting cluster as well as radiant energy losses to outer space are taken into account. Each experiment is modeled as a separate node having an internal heat source which can be turned on or off. An internal radiation network is included in the thermal model which simulates the radiant energy exchange between experiments. (The inner wall is also included in this simulation.) The thermal model is set up using a boundary temperature of -45°F for the MDA radiator section. A technique for establishing the initial temperature distribution is contained in the model.

AAP Cluster Thermal Model: The AAP Cluster Thermal Model was developed to obtain boundary temperatures (surface temperatures of the entire cluster) for use in the MDA Thermal Model. Similar in operation to the MDA Thermal Model, the AAP Cluster Model takes into account conduction, radiation and convection in all of the AAP Cluster modules. Since only the surface temperatures of the modules are to be used, an extremely detailed model of each module is neither feasible nor necessary; however, the modules contain sufficient detail to make the resultant surface temperatures meaningful.

These models provide a capability for evaluating the external heat fluxes incident to the MDA, the internal heat loads and the temperature distributions.

Section 2

TECHNICAL DISCUSSION

As mentioned previously, the Multiple Docking Adapter (MDA) Thermal Model consists of three basic models: (1) the Incident Orbital Heat Flux Model for calculating the incident orbital heat fluxes; (2) the MDA Thermal Model for calculating the internal heating and transient temperature distribution for the MDA; and (3) the AAP Cluster Thermal Model for calculating the boundary temperatures for the MDA Thermal Model.

A discussion of the combined models is presented in Section 2.1 to show how the individual models are used to produce a complete model for evaluating the thermal environment of the MDA. Several important aspects of the models are discussed briefly in Section 2.1 and discussed fully in Sections 2.2, 2.3 and 2.4. The reader may find it helpful to re-read Section 2.1 after reading Sections 2.2, 2.3 and 2.4.

2.1 COMBINED MODELS

The objective in developing the MDA Thermal Model was to provide tools for easily evaluating the thermal environment of the MDA for the various missions and configurations that will be encountered during the Apollo Applications Program. A large number of different configurations must be thermally evaluated as a result of the many missions, as well as probable mission and design changes that are anticipated. These studies are required in order to provide designers with thermal data necessary for developing satisfactory designs. Since the configuration and flight profiles will be changing, probably until the launch date, the models must be flexible and easy to modify. The computer cost associated with evaluating these changes must also be kept in mind.

From the preceding discussion, one might conclude that one model, not three, would be the solution to the flexibility-cost problem. In the following discussion, factors that were considered which led to the development of three models are discussed.

External incident orbital heat fluxes are required for the prediction of structural temperatures. These heat fluxes consist of solar, albedo and planetshine radiant energy and are dependent on the orientation of the external surfaces with respect to the Earth and Sun and the surface finish. In addition, the total incident heat fluxes must include the radiant energy which is reflected from other surfaces of the orbiting configuration and account for the possible blockage of radiant energy by these surfaces. Since these are total heat fluxes, the energy radiated from the surface is accounted for in the thermal analyzer models; they are not affected by changes in the internal design of the MDA. This eliminates the costly computer time required to recalculate incident heat fluxes when internal design changes occur.

In order for the Incident Orbital Heat Flux Model to account for the blockage and multiple reflections from adjacent surfaces, the model consists of the complete orbiting configuration. The exterior surfaces of the orbiting configuration are described as to surface type, thermal radiation properties and orientation. Each exterior surface is divided into nodes (i.e., finite areas) which are assigned an identification number. These identification numbers provide a means of correlating the heat flux model and the thermal analyzer models.

During calculation of the total incident orbital heat fluxes, several other parameters are calculated which are required by the thermal analyzer program. An output program was developed to punch onto data cards all the information available that is required by the thermal analyzer. This reduces the effort required of the user and greatly reduces the chance of error.

The MDA Thermal Model, using the heat fluxes generated by the Incident Orbital Heat Flux Model, calculates the transient temperature distributions of the MDA. Unfortunately, there is no computer large enough to analyze economically the entire orbiting cluster in the detailed manner required for the MDA. The approach taken was to model the MDA in detail, using the same surface nodes as used in obtaining heat fluxes to the MDA. The heat transferred by conduction between the modules docked on the MDA and the MDA ports will be small and is partially neglected. However, the energy exchange by radiation may not be small. This energy exchange was accounted for by modeling all the surfaces of the orbiting cluster, except the MDA, as boundary nodes. The temperatures of these boundary nodes are input into the model as known temperatures. (Determination of these boundary temperatures will be discussed later.) The exterior nodes of the MDA are radiatively connected to the boundary nodes and thus account for the radiant energy exchange between all modules. Heat transfer paths (conduction, convection and radiation) are described by equivalent resistors, and equivalent capacitors are used to account for the thermal capacitance of the structure and experiments. Internal heat loads are accounted for in this model.

Since the initial temperatures are not known for the MDA they must be established. This is accomplished by using the time integrated average orbit heat rates and then calculating the steady-state temperatures. After the "average" temperatures are calculated, the heat rate time histories are used to calculate the transient temperatures. It may be necessary to calculate these temperatures over a period of several orbits in order to obtain a repetitive temperature cycle.

The AAP Cluster Thermal Model, using the heat fluxes generated by the Incident Orbital Heat Flux Model, calculates the boundary temperatures for the MDA Thermal Model. These boundary (or sink) temperatures are used in the radiation interchange network of the MDA Thermal Model. The "average" temperatures calculated by the AAP Cluster Thermal Model are used in the MDA Thermal Model as boundary temperatures. These boundary temperatures are based on the time-integrated average orbital heat rates. It would be possible, however, to use the transient temperatures calculated by the AAP Cluster

Thermal Model based on the cyclic orbital heat rates as boundary temperatures if sufficient computer core storage was available.

When changes occur, each model must be considered to determine whether or not a particular model is affected. In most cases a change in the model used for calculating the heat fluxes will necessitate changing and/or re-running the thermal analyzer.

2.2 INCIDENT ORBITAL HEAT FLUX MODEL

The Incident Orbital Heat Flux Model (Ref. 1), also referred to as the heat rate* model, was developed for use with the Lockheed Heat Rate Computer Program (Refs. 2 and 3). This model is used to calculate heat fluxes that the MDA receives from the Sun directly (solar) and those that are reflected back via the Earth's surface and atmosphere (albedo) and from the Earth directly (planetshine). The total heat flux incident to the MDA must also include the radiant energy that is reflected from other surfaces of the orbiting configuration and account for the possible shading or blockage of radiant energy by these surfaces. Since the effects of reflective energy and blockage by adjacent surfaces can significantly alter the heat fluxes incident to the MDA, the Incident Orbital Heat Flux Model includes the entire orbiting AAP Cluster as is shown in Figs. 1 through 3.

A cluster heat rate model, developed by Lockheed in fulfillment of another AAP task (Ref. 4), was used as the basis for the MDA heat rate model. This developed model was modified to reflect design changes and to provide more nodes for the MDA. As a result of the changes and additions, the original nodal assignment for the entire cluster was redistributed in order to provide the required MDA nodes. As a result of this necessary redistribution, the node identification numbers no longer follow a logical sequence. The MDA heat flux model node allocation is shown in Table 1. The complexity of the heat rate model precludes showing all nodes on a single figure. Therefore, the external node distribution of each module is shown on a separate figure as listed on the following page:

---

*When changing from heat flux to heat rate, an area multiplication is implied.

- Orbital Workshop (S-IVB), Fig. 4
- Saturn LM Adapter (SLA) and Airlock Module (AM), Fig. 5
- Multiple Docking Adapter (MDA), Fig. 6
- Command and Service Module (CSM), Fig. 7
- Lunar Module (LM), Fig. 8
- Apollo Telescope Mount/Rack (ATM/RACK), Fig. 9.

The heat rate model describes all of the external surfaces with respect to a surface coordinate system which is subsequently rotated and translated to coincide with the control coordinate system. The description of each surface includes the rotations and translations, surface dimensions, surface finish characteristics (emittance, absorptance and transmittance), nodal distribution and identification, whether the surface can shade or be shaded, and the division of nodes into smaller elements. The input data are described in detail in Ref. 2.

The central coordinate system was originally defined with the origin at the center of the MDA docking ports, with the +X axis toward the S-IVB nozzle and the LM/ATM on the +Z axis; however, the MDA ports were moved toward the S-IVB by 24 inches but the origin remained as previously defined (Fig. 1). An intermediate coordinate system is used to identify all nodes of a module to provide the capability of moving or relocating an entire module by simply moving or relocating the intermediate coordinate system with respect to the central coordinate system.

The Incident Orbital Heat Flux Model is set up as three separate runs which are submitted in sequence as follows:

Run 1: Calculates the radiation view factors
Run 2: Reduces the number of elements and calculates the radiation resistor constants. (Reduction in the number of elements reduces the computer run time considerably without seriously affecting the results of Runs 2 and 3.)
Run 3: Calculates the heat rates.

The reasons for following the run sequence are listed below:

- Computer time for three "short" runs is easier to obtain than for one long run.
- Each step can be checked before proceeding to the next step. If errors are found, only that step has to be rerun or corrected.
- When changes pertaining to the orbit data are made, only Run 3 need be rerun.
- When changes pertaining to the surface finish data are made, only Runs 2 and 3 need be rerun.

It should be noted that the entire run can be set up as one run if the user is not concerned with long computer run times.

2.3 MDA THERMAL MODEL

The MDA Thermal Model was developed to calculate the steady-state and transient structural temperatures using the Lockheed Thermal Analyzer (Mark 5C) Computer Program (Ref. 5). The thermal model consists of equivalent electrical resistors and capacitors which represent the thermal resistances (conduction, convection and radiation) and thermal capacitances. The model uses the same model surface subdivision, or nodes, as the Incident Orbital Heat Flux Model (Ref. 1) modified by NASA personnel to conform to the latest design changes. The modifications reflect such changes as the removal of two ports, the extension of the radiator section, and the matching of the nodal network to the mechanical interfaces. Inner nodes are then established and the thermal resistances between nodes are calculated. Where applicable, internal heat loads were added. The heat rates and radiation resistance constants obtained using the Incident Orbital Heat Flux Model were applied to the external nodes. Since the initial temperatures are not known, they must be established. This is accomplished by using the time integrated average orbit heat rates and then calculating the steady-state temperatures. After the "average" temperatures are calculated, the heat rate-time histories are used to calculate the transient structural temperatures. The temperatures reflect the thermal properties of the structure, radiative heat losses to outer space and radiative exchange between nodal surfaces including multiple reflections.

The model checkout case was taken from the Mission B cold case with the interior atmosphere at 70°F. No power to the experiments was considered; however, the model is set up to accept heat inputs from the experiments by changing table values in the data section of the thermal model from 0.0 to 1.0 at the appropriate time to account for heat addition. The strip heater power input is included in the model. A temperature of 65°F was chosen as an on-off control for the heater power; however, any control temperature may be used. Presently, the model is set up to handle the heat flux to all exterior nodes on the MDA; however, boundary temperatures may be supplied to any of the nodes (especially the MDA radiators) by placing the appropriate temperature in the temperature block and removing the capacitance value from the capacitor block. The boundary temperatures for the model were calculated using the AAP Cluster Thermal Model and an average orbital heat rate to account for all radiation effects. Further discussion of the boundary temperature is presented in Section 2.4.

Figs. 10 through 14 show the nodal breakdown of the outer shell, the superinsulation and the inner shell, respectively. The outer shell is a constant thickness of 0.02-in. aluminum alloy 2219 T-87 while the inner shell (aluminum alloy 2219 T-87) varies from 0.076 to 0.25 in. The 0.25-in. thickness appears at points where the interior and exterior longerons attach to the inner shell. Between the inner and outer shells are several longerons of varying lengths with three Fiberglas standoff points each, several Fiberglas rings and a one-inch layer of superinsulation which is broken into three layers so the temperature profile through the high performance insulation may be obtained (Fig. 15). An effective resistance for the conduction path between the two shells was calculated using

$$\frac{1}{R_{\text{effective}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

Radiation between the outer shell and the outer layer of superinsulation was determined using

$$\epsilon_{\text{effective}} = \frac{1}{1/\epsilon_1 + 1/\epsilon_2 - 1} \quad .$$

Conduction through the superinsulation to the inner shell was taken into account. (See Table 2 for material properties.) Figures 15 through 19 show the general relationship between the inner and outer shells and the longerons for three sections along the MDA. A typical Fiberglas ring and longeron are shown in Fig. 20.

The docking ports were handled in a manner similar to the inner and outer shells. Figures 15 and 16 show typical ports and Table 3 shows the nodal breakdown for each port and cover plate. The Command and Service Module (CSM) is attached to the axial port and the Lunar Module (LM) is attached to the port pointing toward the Sun. The aft portion of the MDA is attached to the Airlock Module (AM).

The interior nodal network is shown in Fig. 21. The interior longerons tie the experimental packages (boxes) to the interior shell and are not continuous. Each longeron was considered as one node. In addition, the mounting bars and the boxes were each considered as one node. The nodal network selected serves two purposes: (1) the capacities of the nodes are kept at a value which will maintain a reasonable computer run time, thus allowing more orbits to be considered; and (2) the program is able to accommodate a larger system and compensate for all modes of heat transfer within this system and at the same time locate the major problem areas. In the problem areas, a more detailed model should be developed using this model to obtain boundary conditions.

The previously discussed longerons are assumed to be aluminum alloy 2219 T-87; their dimensions are shown on MSFC Drawing No. 10M12999, Sheets 1 through 9. Materials for the experimental packages were not given, therefore, aluminum alloy 2219 T-87 was assumed. Material properties used in this checkout case are given in Table 2.

Conduction resistances were determined for the longeron-box-bar network considering contact resistance across joints as well as resistance through the longerons, bars and boxes. Convection resistances were calculated for the interior of the inner shell and the internal boxes using a value of 0.05 Btu/hr-ft^2-^{o}F for the convective heat transfer coefficient.

Thermal capacities were determined for the longeron and mounting bar nodes using the appropriate value of specific heat. Capacities for the experimental packages (boxes) were determined using individual box weights and an assumed value of 0.225 Btu/lb-^{o}F for specific heat. Weight and power output of each experiment are given in Table 4.

An internal radiation network for the MDA thermal model was calculated using a modified version of the Lockheed Heat Rate Program (Ref. 2). The interior of the MDA was modeled as a cone-frustum-cylinder combination with a pair of discs, located top and bottom, providing complete closure. The individual experiments were modeled as boxes or cylinders and correspond in dimensions and location to MSFC Drawing No. 10M12999, Sheet 5. A value of 0.3 was used for both the emissivity and absorptivity of the participating surfaces. Since the modified Heat Rate Program has a 190-node limitation, selection of surfaces was made on the basis of size and amount of internally generated power that must be dissipated. Table 4 provides the nodal breakdown of the experiment boxes. The nodes and surfaces are further divided into elements for the view factor calculations and to check for shading.

The internal radiation resistance constants are independent of the orbit or mission, the internal temperature and the heat input. If surface properties (α and ϵ) of the experiments change or the experiments are moved to another location, the internal radiation network must be changed.

2.4 AAP CLUSTER THERMAL MODEL

Modeling of the radiant energy exchange between the MDA and the other surfaces of the orbiting cluster presents a problem with the limited size of today's computers. As stated previously, the approach taken was to model the surface nodes of all the modules except the MDA as boundary nodes.

In order to obtain the temperature histories of the boundary or sink nodes, it was necessary to model the entire AAP Cluster using the same exterior nodes as the Incident Orbital Heat Flux Model and the MDA Thermal Model (Figs. 4 through 10 and 22 through 30). Heat rate tables from the Incident Orbital Heat Flux Model can be used for both the thermal models. The boundary or sink temperatures can either be the orbit "average" temperatures based on the orbit "average" heat rates or the transient temperatures based on the cyclic orbital heat rates provided sufficient computer core storage is available.

Since the Incident Orbital Heat Flux Model presented in Ref. 1 was modified by NASA personnel to coincide with the latest design changes, these changes are also reflected in the exterior nodal breakdown of the MDA and AAP Cluster Thermal Models. The heat rates and temperature histories were calculated using the same procedures as described for the MDA. Radiation resistors were connected between all the surface nodes of the entire orbiting cluster.

2.5 COMPUTER PROGRAMS

The use of two computer programs is required to conduct the thermal evaluation of the MDA Thermal Model. The Lockheed Heat Rate Program, Ref. 2, is used to obtain the external heat rates on the entire orbiting cluster and the Lockheed Thermal Analyzer Program (Mark 5C), Ref. 5, is used to determine the AAP Cluster and the MDA temperature distributions and heat losses. Both of these computer programs are currently operational on the NASA/MSFC Univac 1108 computer.

The Heat Rate Program is capable of handling 140 nodes described by rectangles, discs, trapezoids, cylinders, parabaloids, cones and spheres or portions of these geometrical shapes. Each node can be divided into a number of smaller elements (up to a total of 3500 elements for all the nodes).

The Heat Rate Program calculates the heat rates for each element and averages these for each node; thus, the use of a number of elements per node provides good accuracy in calculation of the heat rates and view factors. The program accounts for all shielding and reflections from all the nodes and calculates all the view factors and radiation constants between nodes. The radiation constant calculations utilize the matrix solution of the equations developed by Poljak (Ref. 6) and include the total radiant energy exchange between nodes. All calculations assume perfectly diffuse radiation. The Heat Rate Program involves three specific operations conducted in sequence to first obtain shaded view factors for all the nodes, then calculate radiation constants, and finally calculate the total absorbed heat rates. The total absorbed heat rates are based upon the shaded view factors, the node surface finish characteristics, and all reflections.

The Heat Rate Program has the following capabilities (Ref. 2):

- Calculation of radiant view factors with card output
- Calculation of radiant interchange factors (RADKs) with card output
- Calculation of direct incident or total absorbed solar, albedo and planetshine heat rates with card output. The heat rates can be plotted on the SC 4020 plotter.

The Thermal Analyzer Control System (Ref. 5) is composed of two distinct programs: the Mark 5C Program (thermal analyzer program) and the Q24 Program (heat rate program). The MDA Thermal Operational Computer Model uses only the Mark 5C Program (thermal analyzer program). The thermal analyzer program solves transient and steady-state heat flow problems using a digital computer to obtain a finite difference solution for the analogous R-C electrical network.

2.6 USE OF THE MDA THERMAL MODEL

The MDA Thermal Model was developed to provide easy evaluation of the different orbital conditions and the docking (or removal) of modules at the various MDA ports. These modifications can be handled with a minimum of changes to the basic models. In order to evaluate other changes such as surface finish changes, major configuration changes, solar panel configuration, etc., a more involved procedure is required and will be outlined.

The models have been developed to handle the shifting of modules to any port on the MDA. The Cluster has been divided into four groups of modules: the basic or "fixed" group and three attached secondary "units." The fixed group includes the S-IVB Orbital Workshop, the Airlock Module and the Multiple Docking Adapter. The other Cluster modules are as follows: Unit 1 is the CSM, Unit 3 is the ATM/Rack combination and Unit 4 is the LM.*

Three ports are available on the MDA for docking the three units. Figure 1 illustrates the location of these ports with respect to the Cluster central coordinate system and also shows the present placement of the three units in the model. Any unit may be shifted to any of the three ports by redefining its position in the heat rate model and by making the proper conduction connections in the thermal model.

In the heat rate model, the position and orientation of each unit with respect to the central coordinate system of the model is specified by one transformation card at the end of the surface data input (Ref. 2). Only this card need be changed to dock a module at another port. The heat rate model will produce punched cards (radiation resistor constants, heat rate tables and function statements) which are inserted into the thermal analyzer models in place of the existing data cards.

In order to analyze changes other than module docking to the Cluster, considerably more data card changes are required which depend upon the change to be evaluated. Surface finish changes can be evaluated rapidly and only involve changing the surface identification cards in the Heat Rate Program input (Section 2.2, Run 2) to the new α and ϵ values. Once these have been changed, new radiation constants and heat rates can be obtained and inserted in place of

---

*Unit 2 no longer exists.

the existing data in the thermal analyzer models. The new temperatures can then be obtained and checked with the reference values to evaluate the effect of surface finish change or changes.

Where the configuration of a module or solar panel is changed, a more extensive effort will be required. New surface identification cards are required to define the desired configuration. When a module configuration change alters the location of other modules with respect to the central Cluster coordinate system, new surface identification cards will also be required for those modules in their revised location. All three heat rate runs are required and possibly additional changes to the thermal analyzer models. It will be necessary to re-evaluate the temperatures for the boundary nodes.

A multitude of configurations can be analyzed. When the changes are complex, the complete program should not be attempted without a series of small checkout runs of the heat rate model to ensure that the changes have been correctly made.

Section 3
CONCLUSIONS

Analytical tools were developed for use in performing thermal analyses of the MDA. These tools consist of three computer program models which were developed for use with existing Lockheed computer programs. These models are:

- The Incident Orbital Heat Flux (Heat Rate) Model (Ref. 1) which provides the capability for calculating the orbital heat fluxes to the MDA. These heat fluxes consist of solar, albedo and planetshine radiant energy and account for the effects of blockage by and reflected heat fluxes from other surfaces of the entire orbiting cluster. This model produces (in the form of punched data cards) transient and orbit averaged heat rate tables as well as functional statements which are required by the Thermal Analyzer Models.
- The MDA Thermal Model (Thermal Analyzer Model) which provides the capability for calculating the transient and/or steady-state temperature distribution of the MDA. Using an equivalent R-C network, the heat transfer paths (conduction, convection and radiation) from the outer skin to the inner compartment "air" are simulated. The internal heat generated by the experiments and the radiation energy exchange between the experiments are accounted for.
- The AAP Cluster Thermal Model (Thermal Analyzer Model) which provides the capability for calculating the steady-state and/or transient temperature distribution of the entire orbiting cluster. The AAP Cluster surface temperatures are used as boundary or sink temperatures in the MDA Thermal Model. The AAP Cluster Thermal Model uses the same general information and calculation procedures as the MDA Thermal Model.

These models were developed using the best available information for the AAP Cluster and MDA. In some areas assumptions were necessary because sufficient data were not available. These assumptions were based on the data which were available and/or good design practices. As more information is made available and as design changes occur, the models can easily be updated if necessary.

The models were designed so that changes could be made with a minimum of effort. For example, a completely different orbit can be evaluated by changing one data card in the Incident Orbital Heat Flux Model. Computer economy was also kept in mind. The models are programmed such that pertinent information is stored on magnetic tape for later use.

Section 4
FUTURE STUDIES

The design details for the MDA and the orbiting cluster are not firm. As design changes occur, they must be evaluated to determine their effects on the MDA Thermal Model. In many cases these design changes will necessitate changes in the models. Since the thermal models are detailed enough to be perturbed by seemingly minor design changes, these models should be continually updated to provide the best available thermal design data. Design changes such as variation in insulation thickness and modification of the radiators or vehicle structure will seriously affect the calculated results. The interior positioning of the experiments is based on a preliminary design configuration. Since a base line configuration was not available, it is anticipated that major changes will occur. These changes will necessitate a modification to the interior radiation and conduction networks.

There are many possible combinations of orbiting configurations and orbit conditions as well as the different ways the MDA experiments can be used. Since the evaluation of all these combinations will require a considerable amount of man/computer hours, a parametric analysis is in order. It is first necessary to establish a reference condition(s). The configuration can be bracketed by considering the complete orbiting Cluster and the gravity gradient storage mode. The extreme β angles of zero and 52 degrees with the Cluster both space oriented and Earth oriented can be used to establish reference orbit conditions. Using these results, the "hot" and "cold" reference cases can be established. During the remainder of the parametric study, orbit average values are recommended for the evaluation criteria since transient analyses will require more time for the evaluation and longer computer run times and would not add significantly to the overall evaluation. Some of the parameters which should be included in the parametric study are:

- Surface finishes
- Internal heat loads and duty cycles
- Compartment sink temperature
- Radiator sink temperature
- Internal insulation
- Surface finish of experiments.

As a better understanding of the model's response to changes is gained, the necessary type of runs can be altered so that additional parameters can be evaluated in less time.

REFERENCES

1. Lockheed Missiles & Space Company, "Final Report for Multiple Docking Adapter (MDA) Thermal Model," LMSC/HREC A842023, Huntsville, Ala., 6 July 1967.
2. Newby, T. S., "Heat Rate Computer Program," LMSC TXA 1954, Lockheed Missiles & Space Company, Sunnyvale, Calif., 26 October 1966.
3. Newby, T. S., "Revisions and Additions to the Heat Rate Computer Program User's Manual," LMSC TXA 1954-1, Lockheed Missiles & Space Company, Sunnyvale, Calif., 29 March 1967.
4. Yoshikawa, Y., et al., "Cluster Thermal Model," LMSC/A842205, Lockheed Missiles & Space Company, Sunnyvale, Calif., 1 May 1967.
5. Bible, A. E., et al., "Thermal Analyzer Control System for IBM 709-7090-7094 Computer Engineering Utilization Manual," LMSC 3-56-65-8, Lockheed Missiles & Space Company, Sunnyvale, Calif., 1 September 1965.
6. Jakob, M., Heat Transfer, Vol. 2, Chap. 31, Sections 8 and 10, Wiley, New York, 1957.

Table 1

INCIDENT ORBITAL HEAT FLUX MODEL, NODE ALLOCATION

Identification	Number of Nodes	Node Number
S-IVB:		
Nozzle	1	1
Nozzle Support	1	2
Aft Dome	1	4
Cylinder	12	5-16
Solar Panels	2	95, 96
SLA:		
Cylinder	4	29-32
AM Heat Shield	4	33-36
MDA:		
Radiator	4	37-40
Cylinder	24	142-165
Dock Ports	2	168, 173
Ports Open	2	171, 172
Cone	4	45-48
CSM:		
Cone	4	49-52
Cylinder	4	53-56
-X End	1	57
Nozzle	1	58
LM:		
Front End Sphere	1	73
Forward Cylinder	5	71, 75, 78-80
Right Box Cylinder	4	81, 82, 134, 76
Left Box Cylinder	4	84, 85, 133, 140
Center Box	8	101, 102, 131, 132, 87, 88, 97, 98
Aft Cylinder	3	135, 138, 139
ATM/RACK:		
Cylinder	4	59-62
Cylinder Bottom	1	3
+Z End	1	63
Rack Panels	4	64, 66, 68, 70
Rack Shields	2	72, 74
Solar Panels	4	103, 105, 107, 109

Table 2

MATERIAL PROPERTIES

Material	Conductivity, K (Btu/hr-ft-$^{\circ}$F)	Density, ρ (lb/ft^3)	Specific Heat, C_p (Btu/lb-$^{\circ}$F)
2219 T-87 Aluminum Alloy	72.0	176.3	0.23
6061-0 Tempered Aluminum	72.0	176.3	0.23
7075 T-6 Aluminum Alloy	72.0	176.3	0.23
Fiberglas (Epoxy Resin)	9.58×10^{-2}	102.0	0.305
Super Insulation (Aluminum-Mylar)	5.0×10^{-4}	1.5	0.315

Table 3

MDA PORT AND PLATE NODES

Port Position	Node					
	Exterior	Surface Insulation	Interior	Cap Cover Plate	Cover Plate Surface Insulation	Cover Plate Interior
Radial (-y axis)	168	396	188	172	193	195
Radial (+z axis)	173	395	187	171	192	194
Axial (-x axis)	174 175 176 177	178 179 180 181	182 183 184 185	198	199	399

Port Position	Node			
	Exterior Insulation	Interior Insulation	Cover Plate Exterior Insulation	Cover Plate Interior Insulation
Radial (-y axis)	332	336	349	353
Radial (+z axis)	331	335	348	352
Axial (-x axis)	338 339 340 341	342 343 344 345	354	355

Table 4

MDA EXPERIMENTS

Experiment	Node No.	Weight (lb)	Power (Btu/sec)
M509, ASMU	410	119	0.0758
D019, Mol Suit	411	45	
M487, Shower	412	35	
M487, Fecal Dryer	413	20	
M056, SMMD	414	14	0.00095
M056, SMMD	415	14	0.00095
M402	416	86	
M487, Fecal Collector	417	47	
T027, Photometer	418	45	0.0104
T025, Coronagraph Meas. Contamination	419	26.3	
T027, Sample Array	420	27	0.0038
M050, Helmet	421	9.25	
M053, Base Motor	422	90	0.1612
M058, BMMD	423	38	0.0019
M508, Litton Hard Suit	424	70	
M402	425	86.25	
M402	426	124.5	
ESS, M018	427	43.3	0.0474
M050, Gas Analyzer	428	40	0.0142
M050, Ergometer	429	35	
M050, Work Task Board	430	15	
D020, Mounting Hardware and Restraints	431	88.5	0.0265
M509, Propellant Tank	432	45	
M509, Gas Umbilical HHMU	433	56.75	
M487, Food	434	84	

Table 4 (Continued)

Experiment	Node No.	Weight (lb)	Power (Btu/sec)
M508, Restraints	435	46	
S018, Micrometeorite Collection	436	15.1	
M508, Work Task Board	437	100	
M487, Food Management	438	61	
Water Container	439	48.75	
Water Container	440	48.75	
D019, Sleep Restraints	441	35	
M487, Personal Equipment	442	58	
M402	443	228.9	
M051, LBNP	444	45	
M487, Personal Equipment	445	60.38	
M487, Personal Equipment	446	60.7	
M402	447	225	
M053, Chair	448	50	
M487, Sample and Bag Stowage, Personal Hygiene	449	61	
M053, Control Console	450	46	
M509, Propellant Tanks	451	90	
M487, Fire Extinguishers, M052, Medical Supplies, NASA Sleep	452	50	
T027, Glide Slope Ind.	453	10	
Camera			0.0161
Photo Lights			0.1138

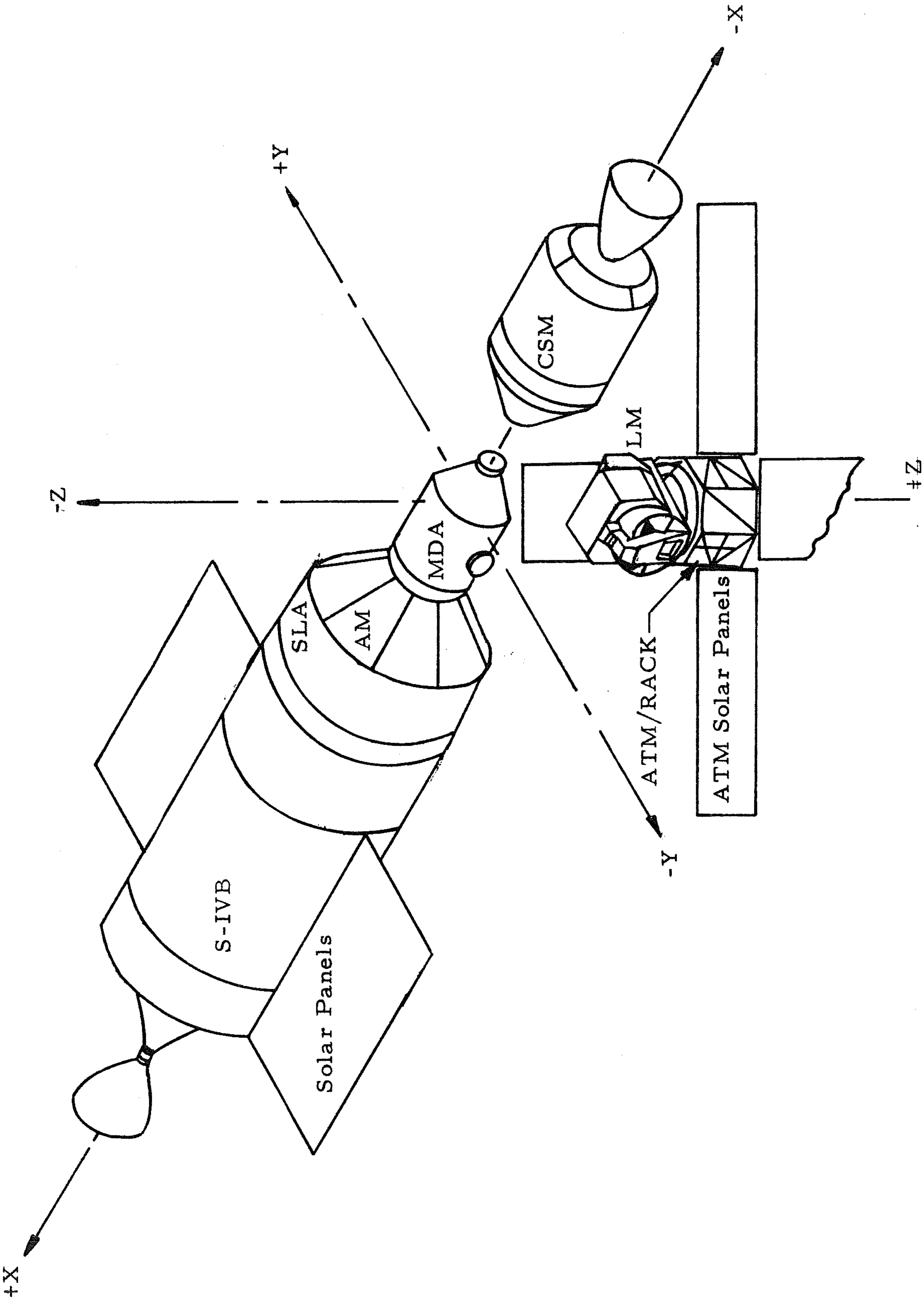


Figure 1 - Orbiting Cluster Configuration

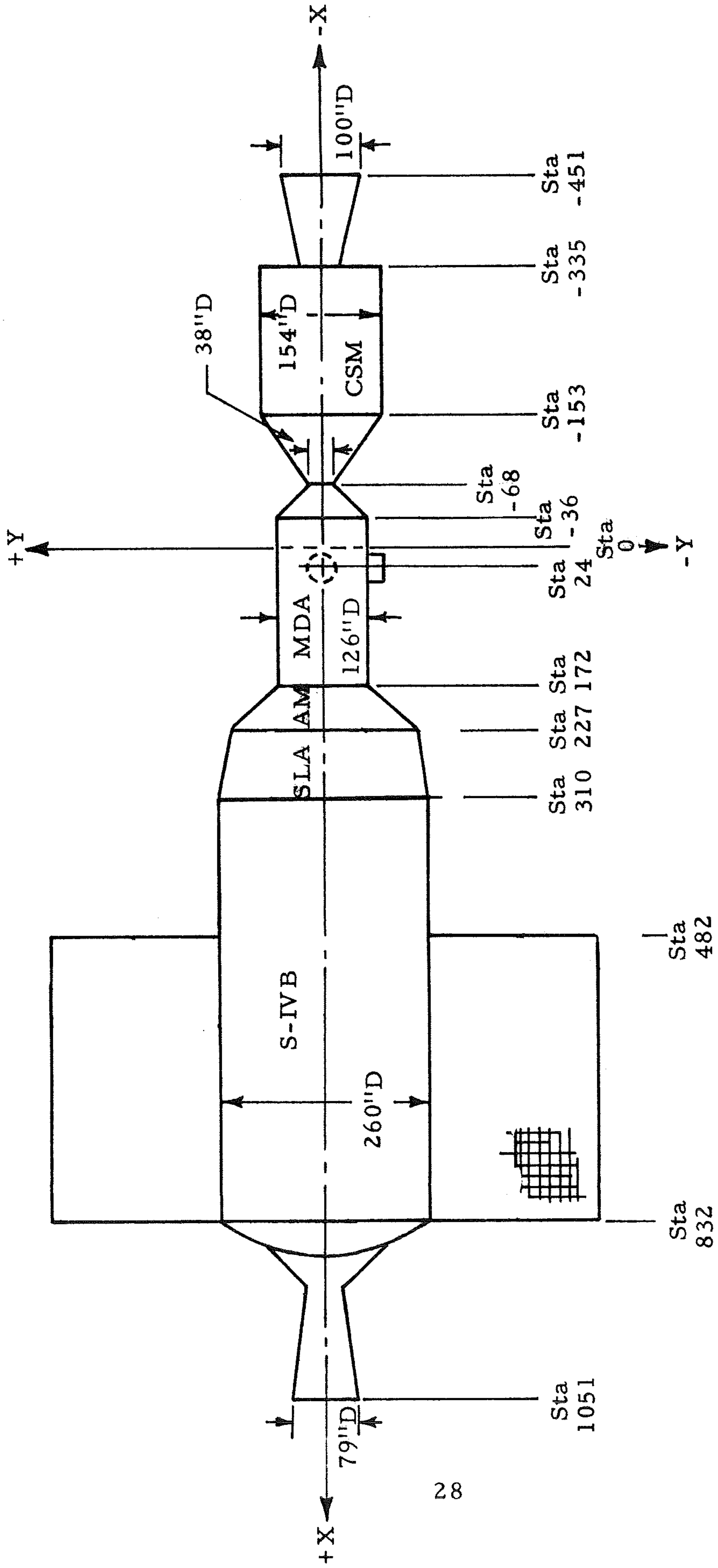


Figure 2 - Orbiting Cluster (X-Y Plane)

D = diameter

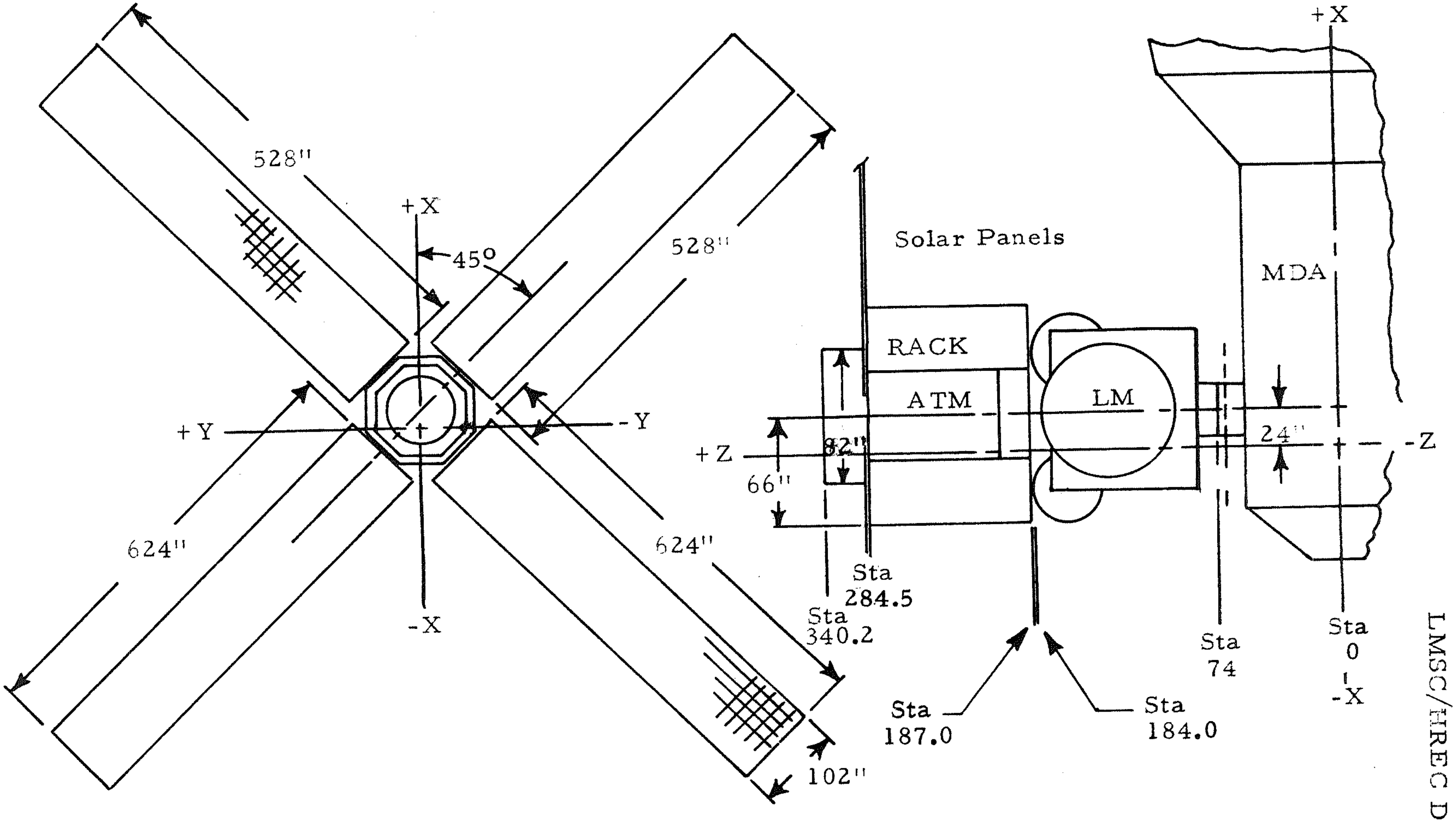
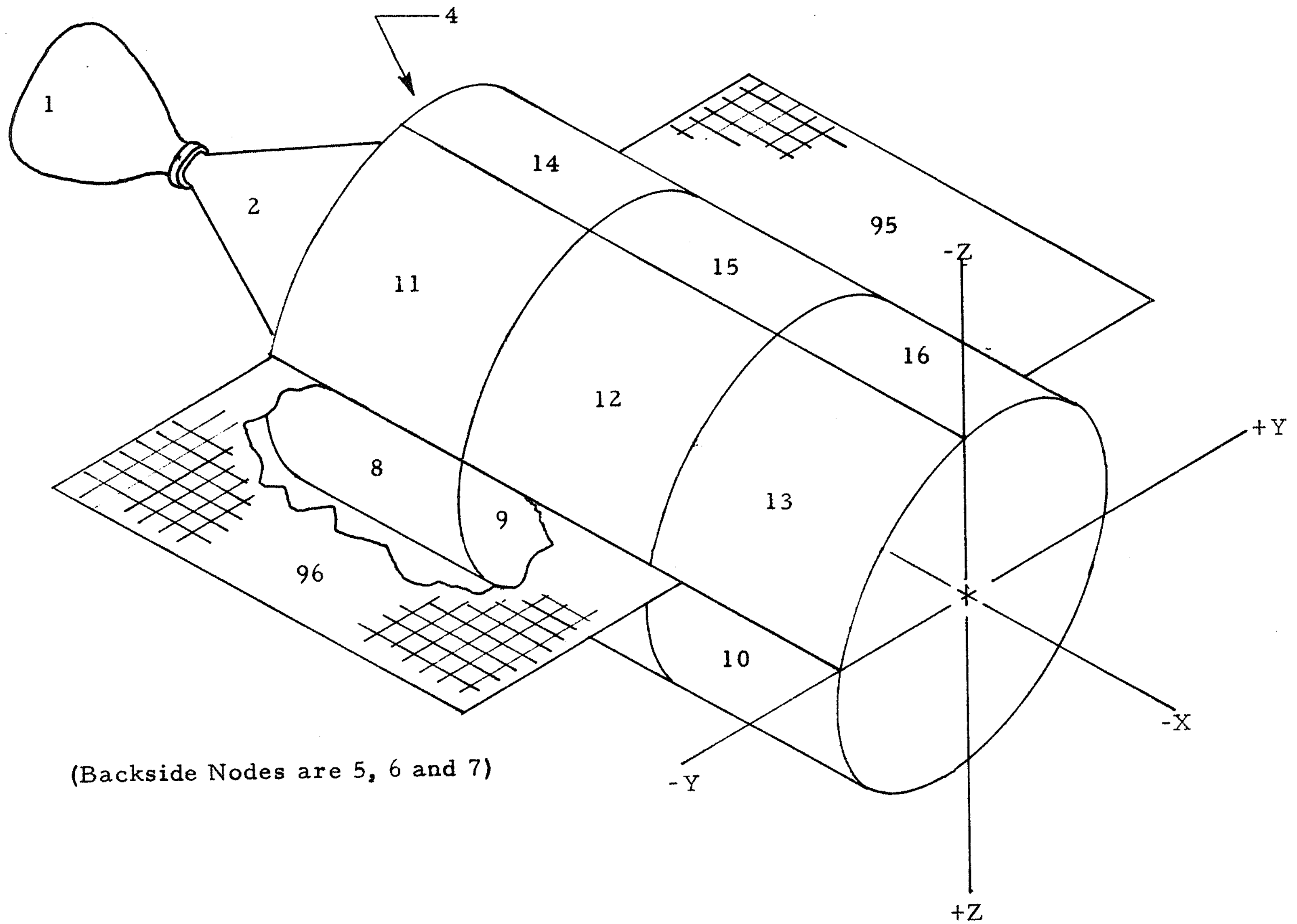
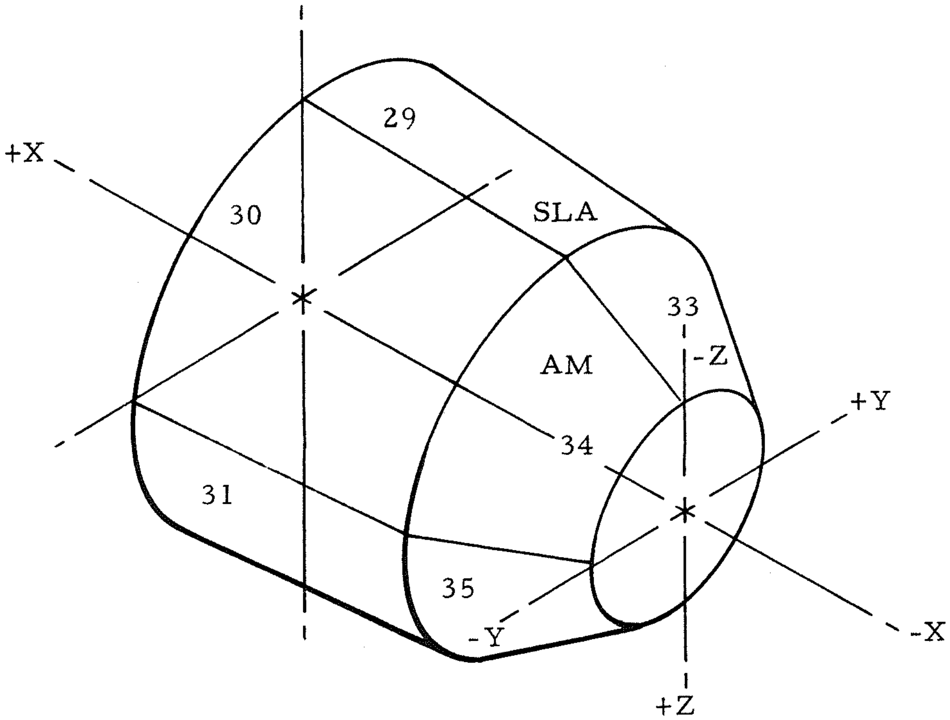


Figure 3 – Orbiting Cluster (X-Z Plane)



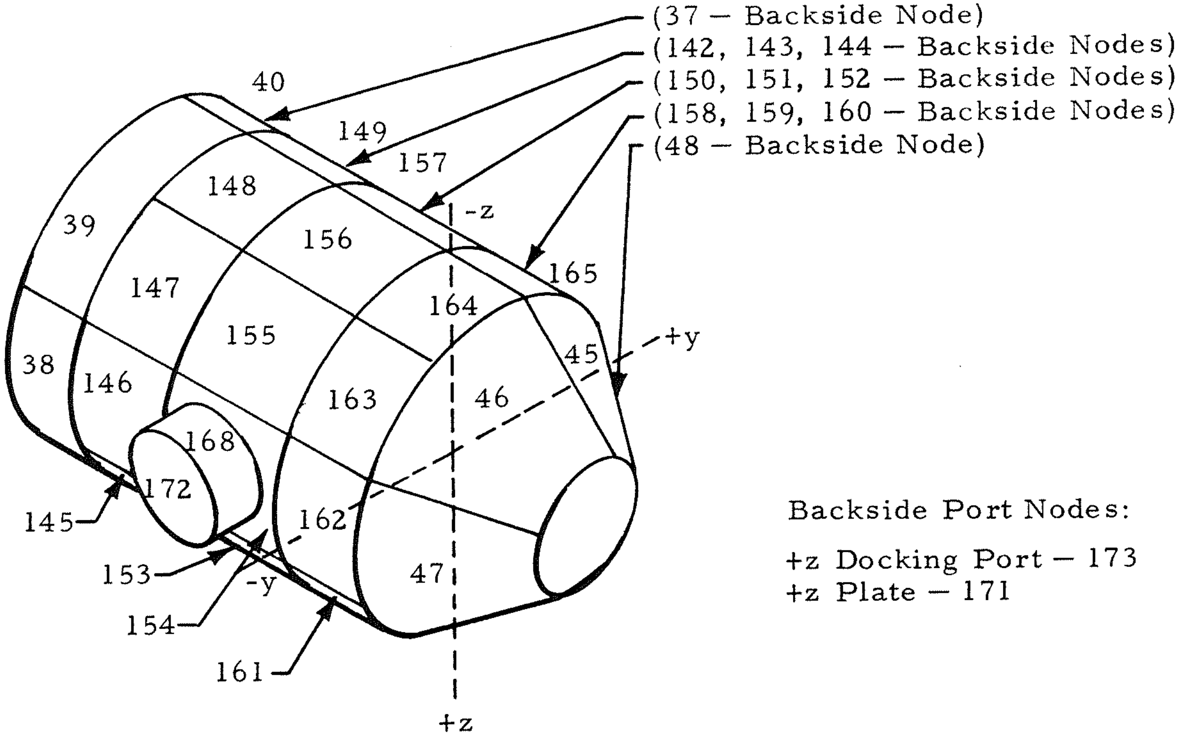
(Backside Nodes are 5, 6 and 7)

Figure 4 – S-IVB Orbital Workshop Nodal Network



(Backside SLA node is 32; backside AM node is 36)

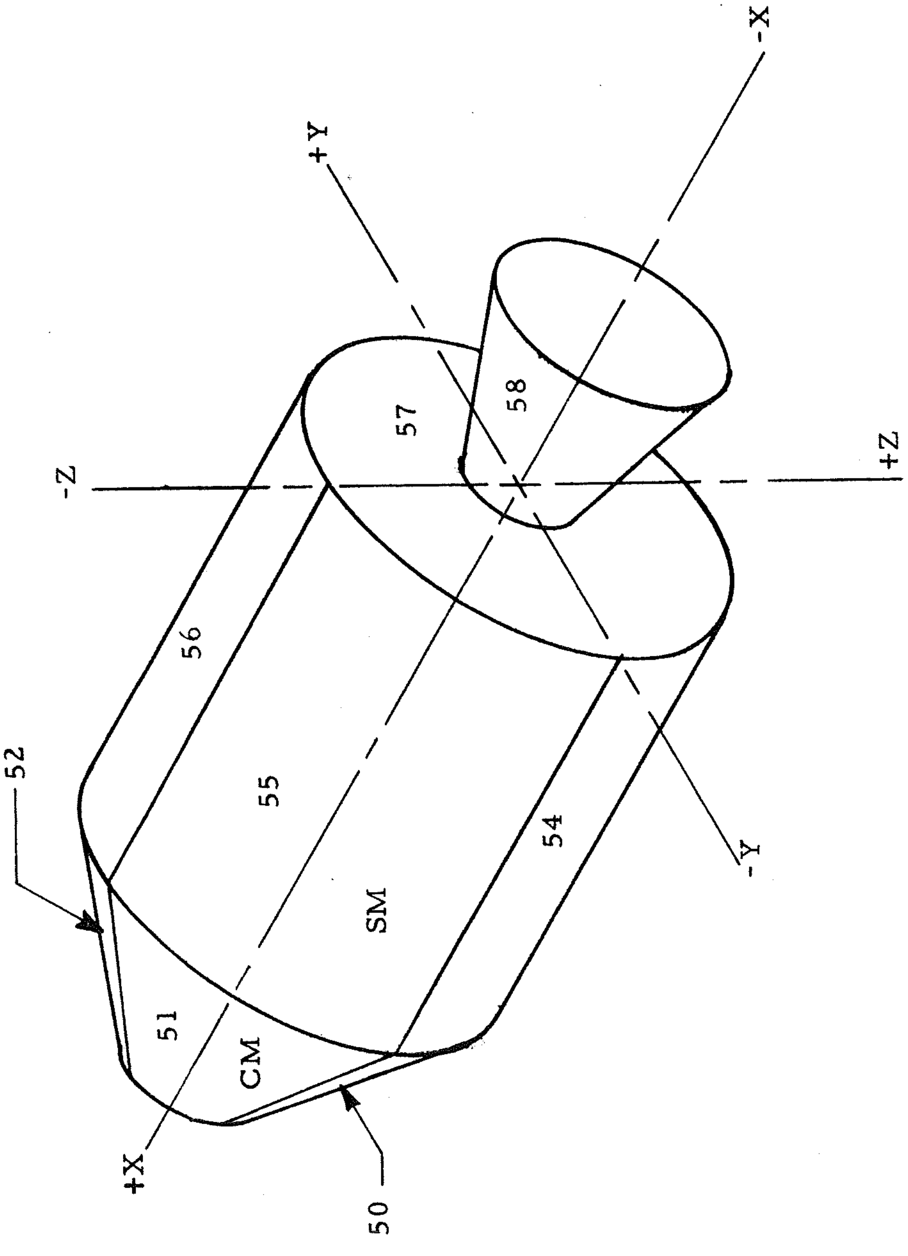
Figure 5 - SLA and AM Nodal Network



Backside Port Nodes:

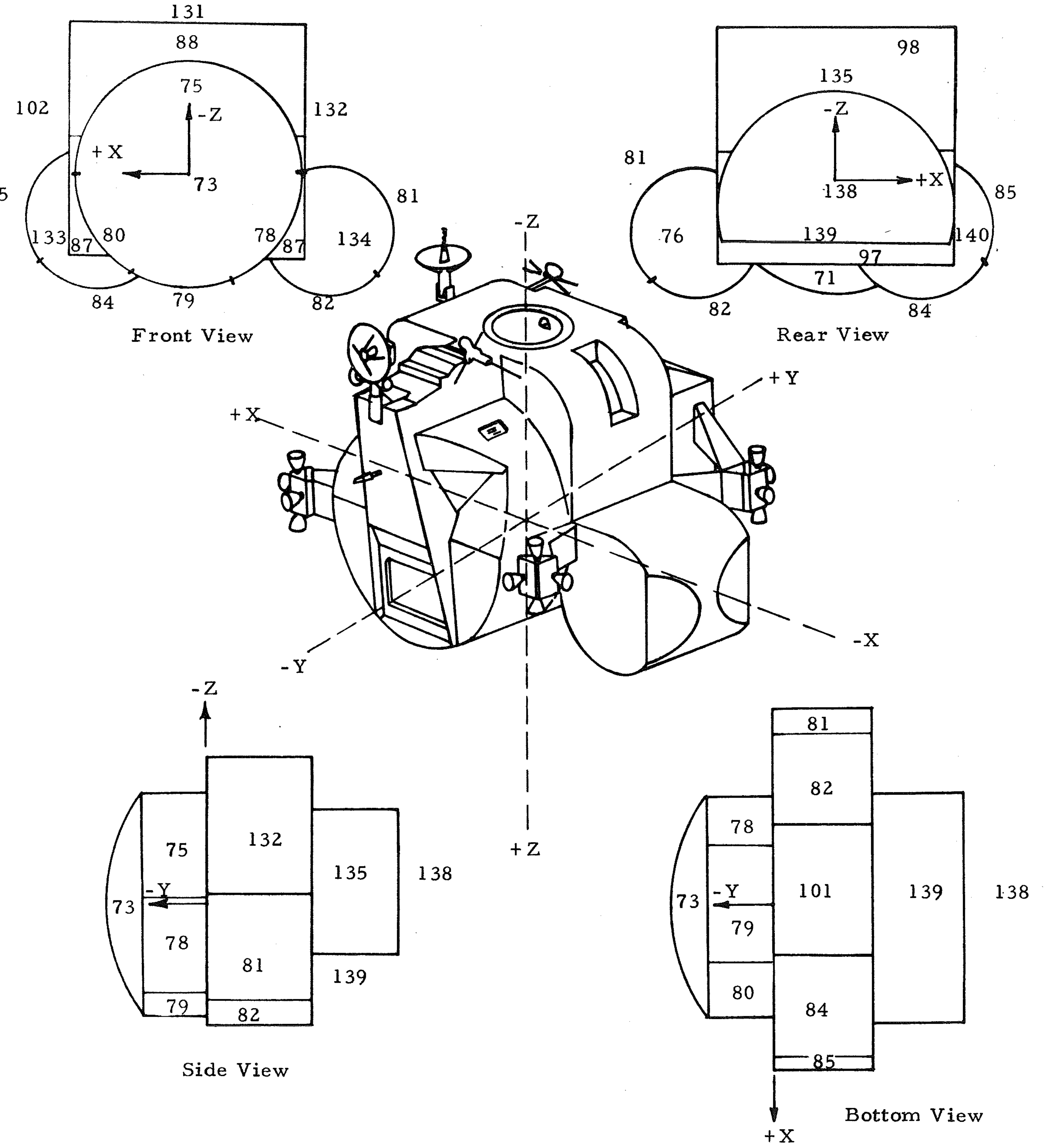
+z Docking Port — 173
+z Plate — 171

Figure 6 - Multiple Docking Adapter Nodal Network



(Backside node of cone is 49; backside node of cylinder is 53)

Figure 7 - CSM Nodal Network



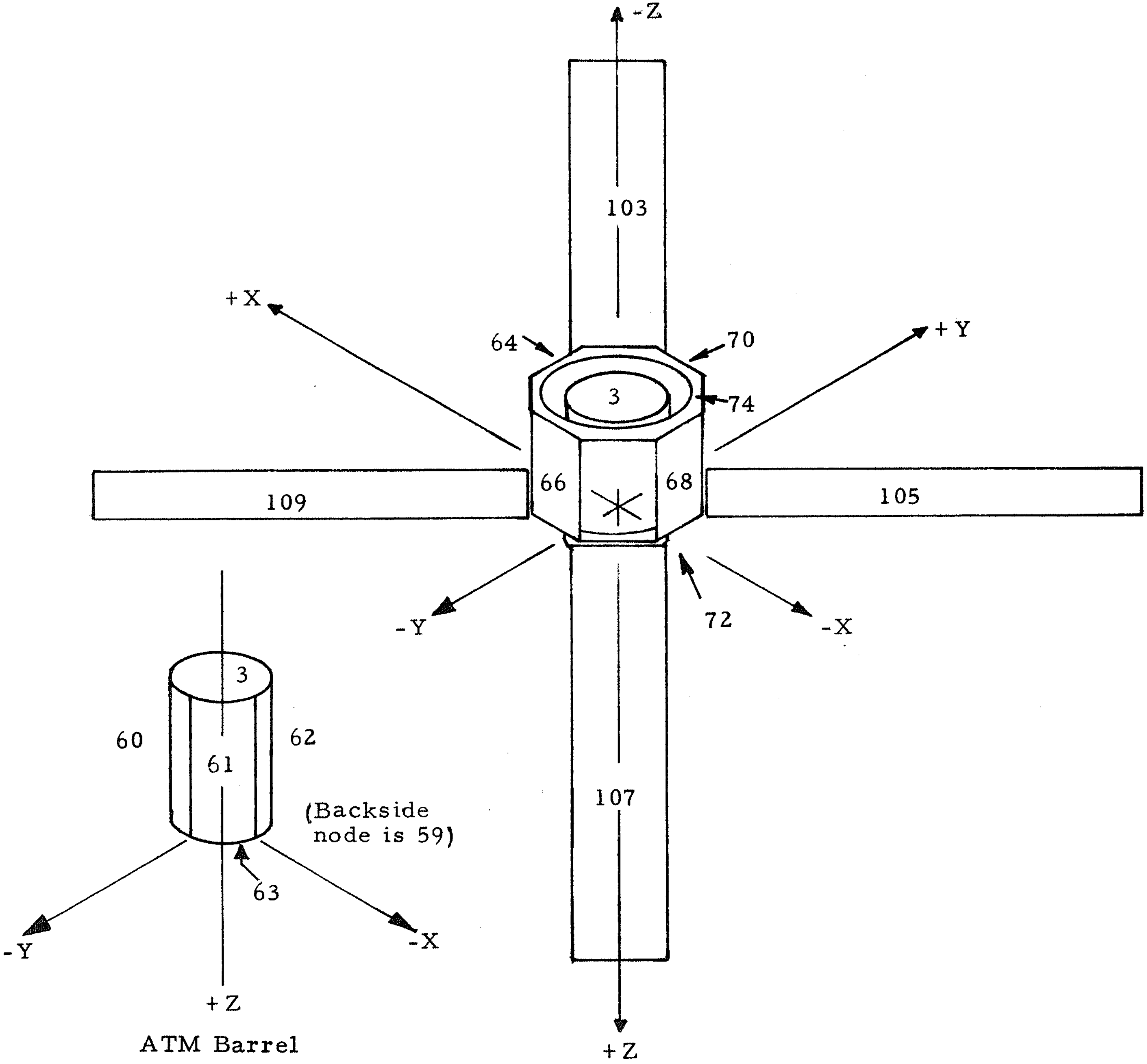
Front View

Rear View

Side View

Bottom View

Figure 8 – LM Nodal Network



ATM Barrel

Figure 9 – ATM/RACK Nodal Network

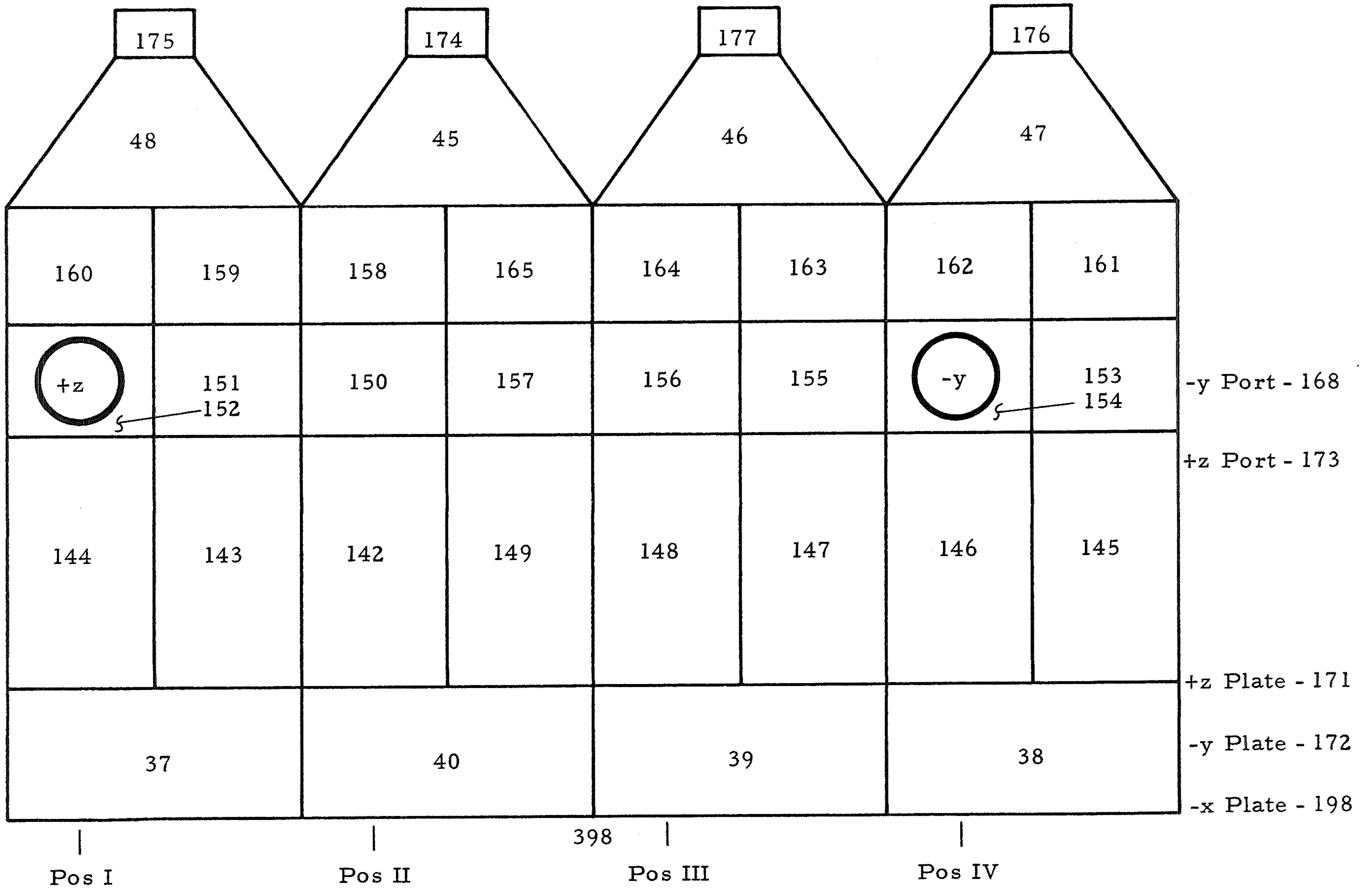


Figure 10 - Nodal Network for the Exterior Shell of the MDA

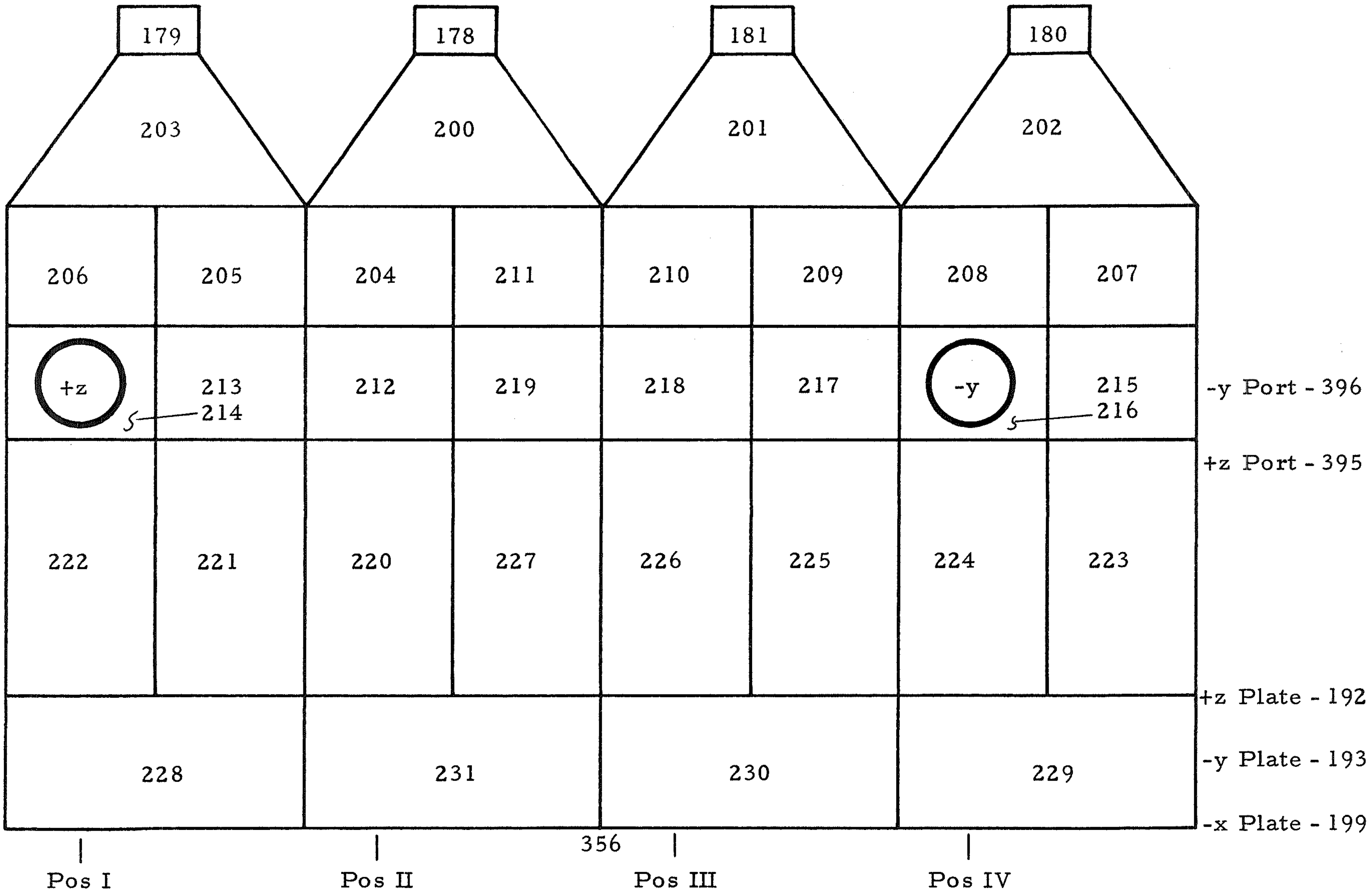


Figure 11 - Nodal Network for the Insulation Surface Nodes of the MDA

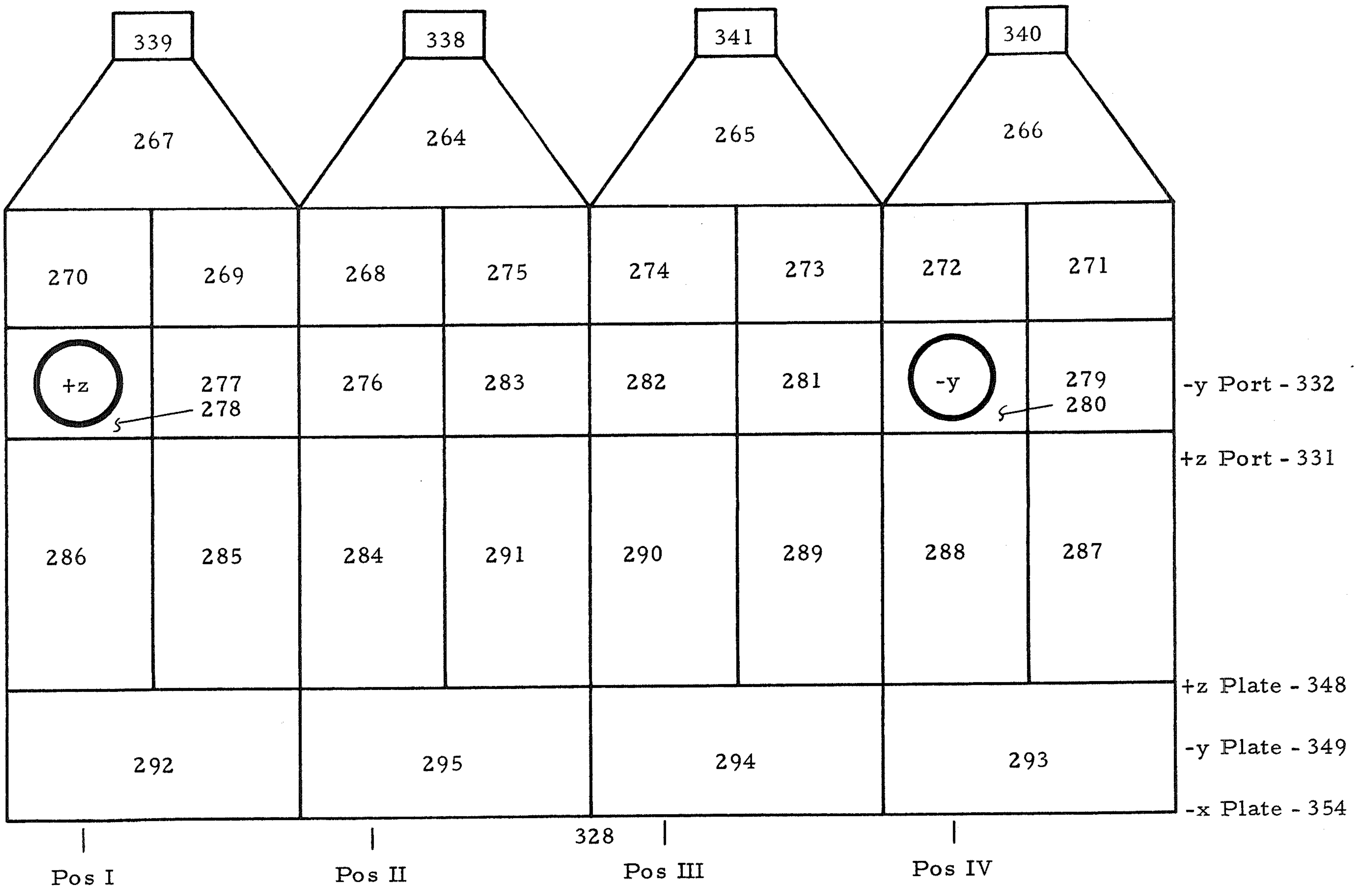


Figure 12 - Nodal Network for the Insulation Exterior Nodes of the MDA

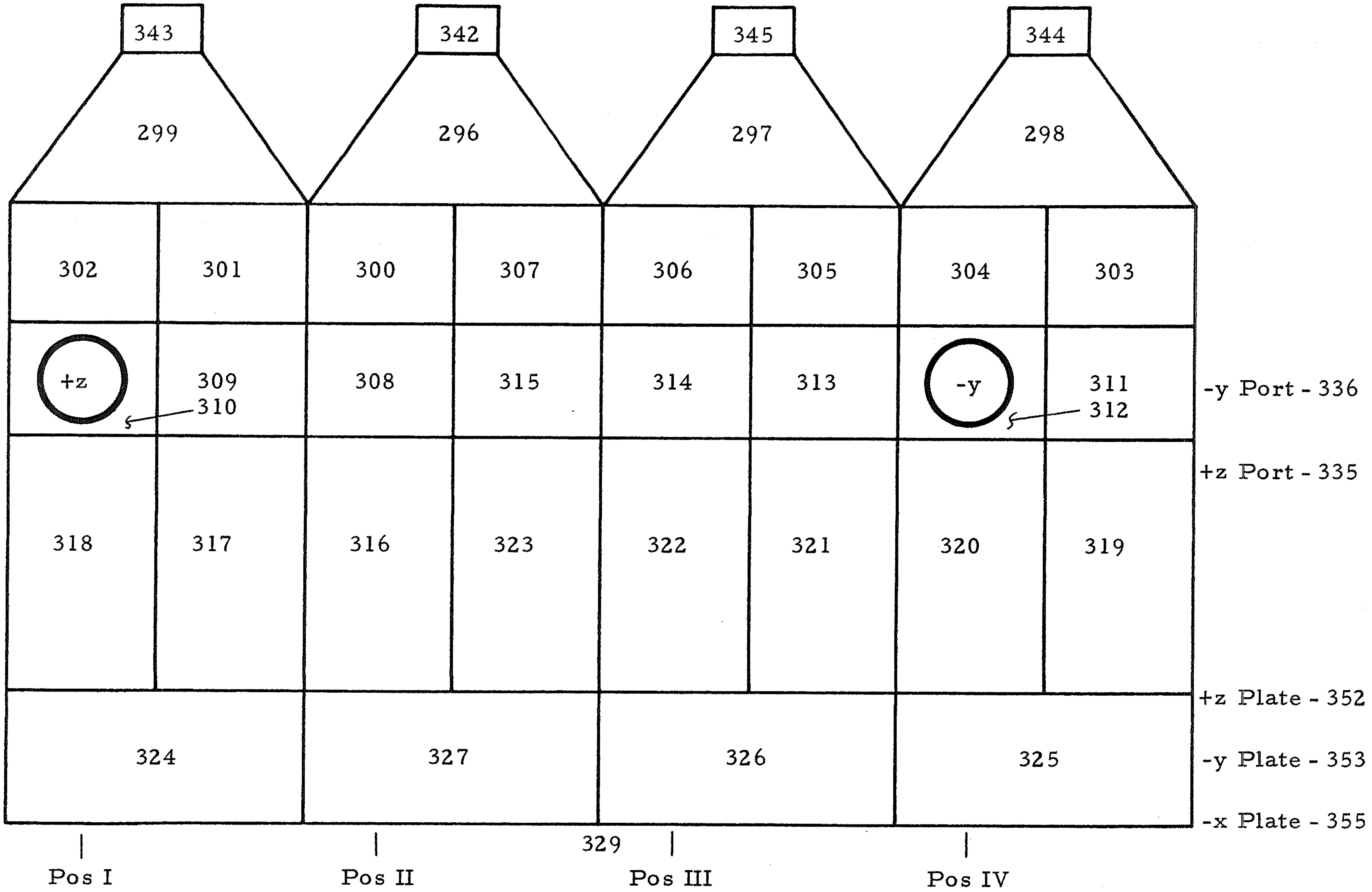


Figure 13 - Nodal Network for the Insulation Interior Nodes of the MDA

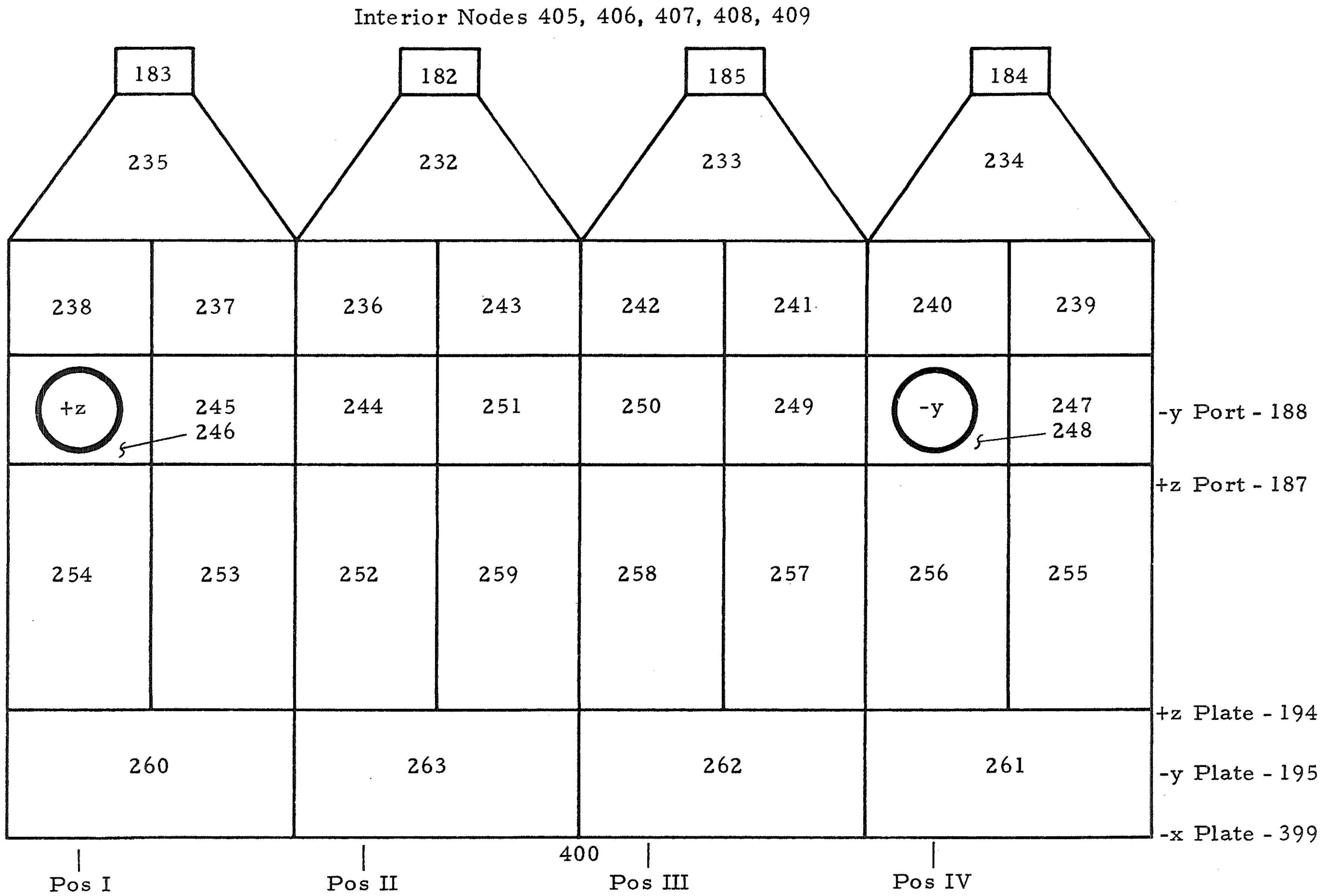
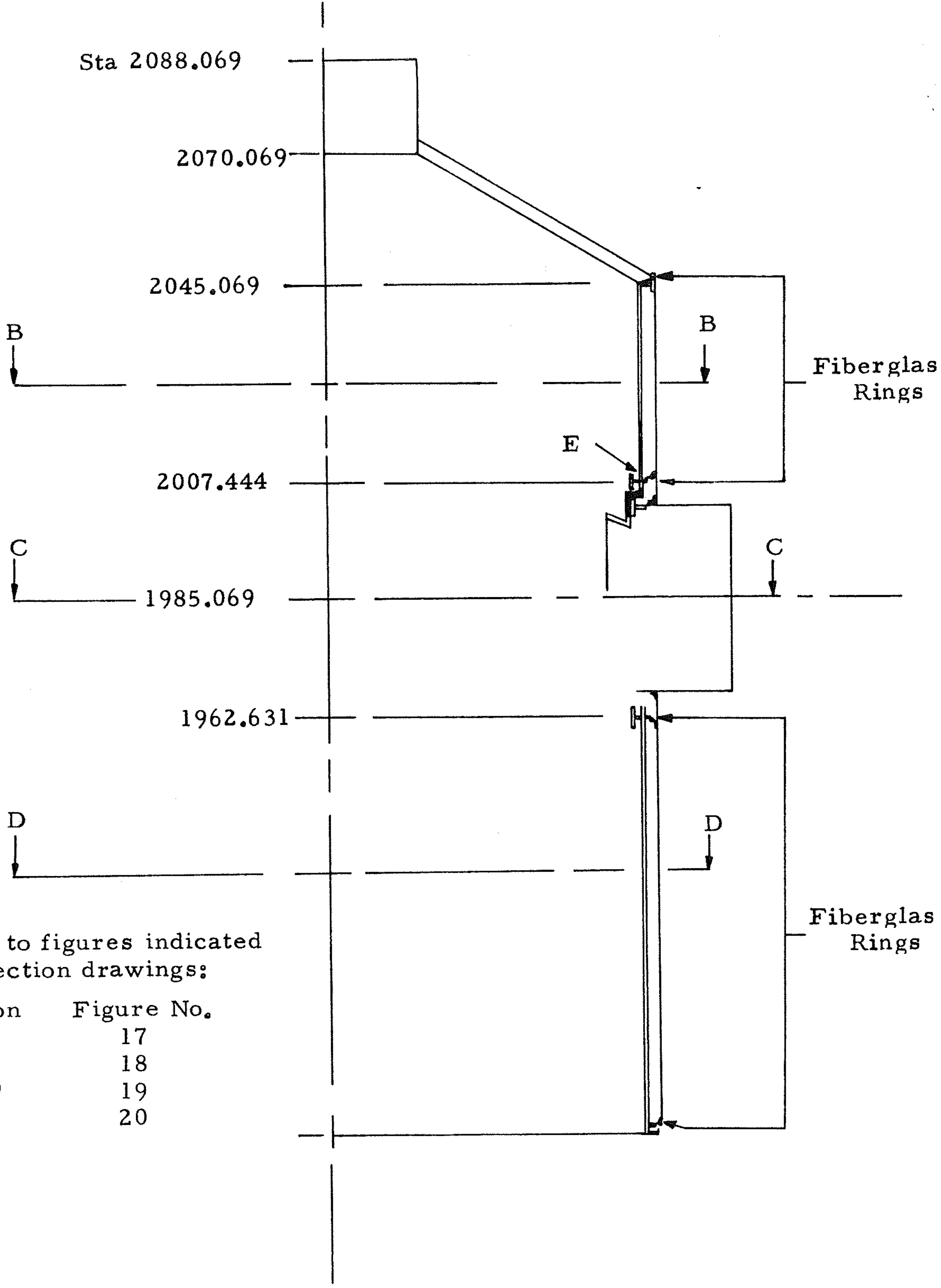


Figure 14 - Nodal Network for the Interior Shell of the MDA

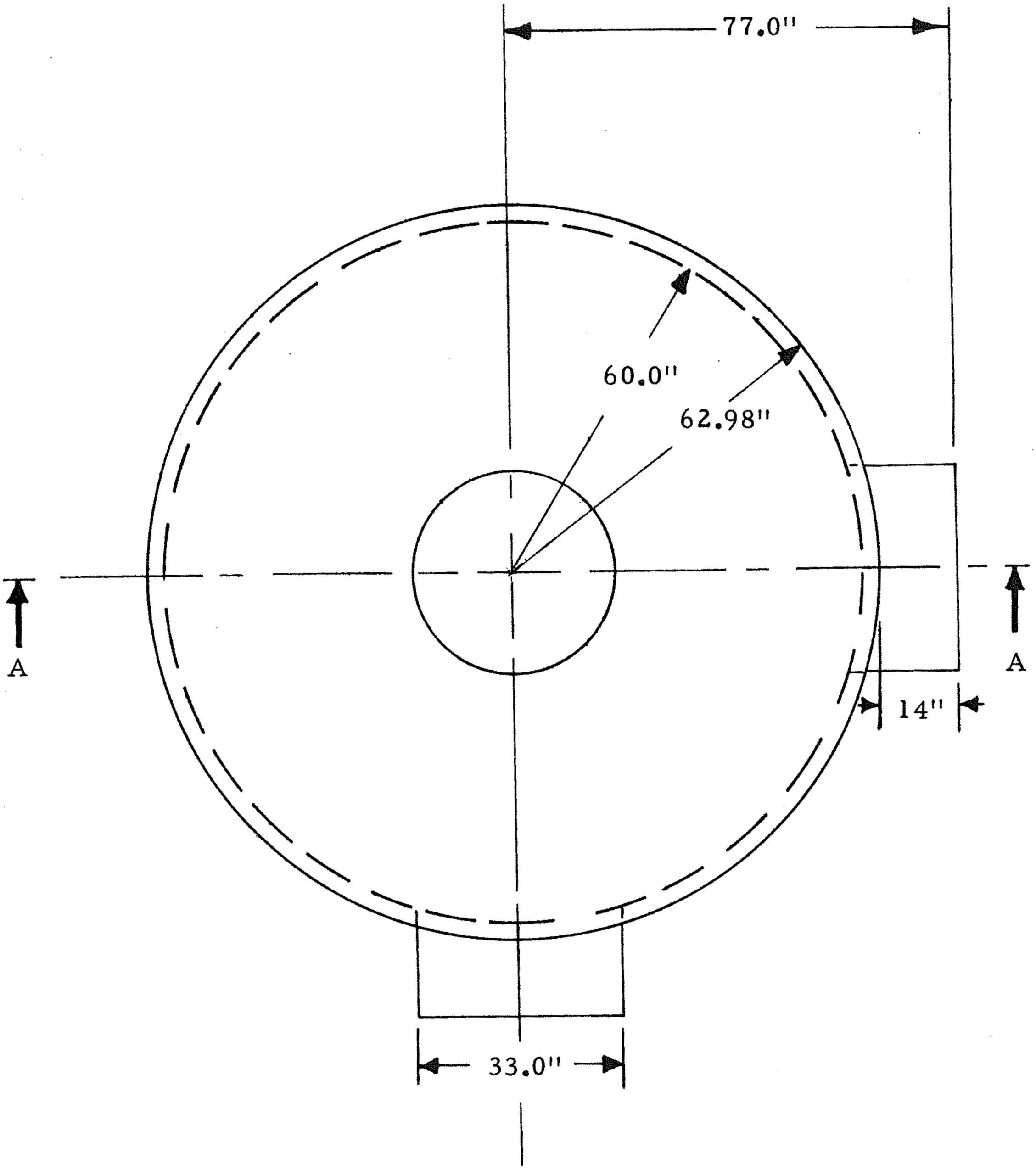


Refer to figures indicated for section drawings:

Section	Figure No.
B-B	17
C-C	18
D-D	19
E	20

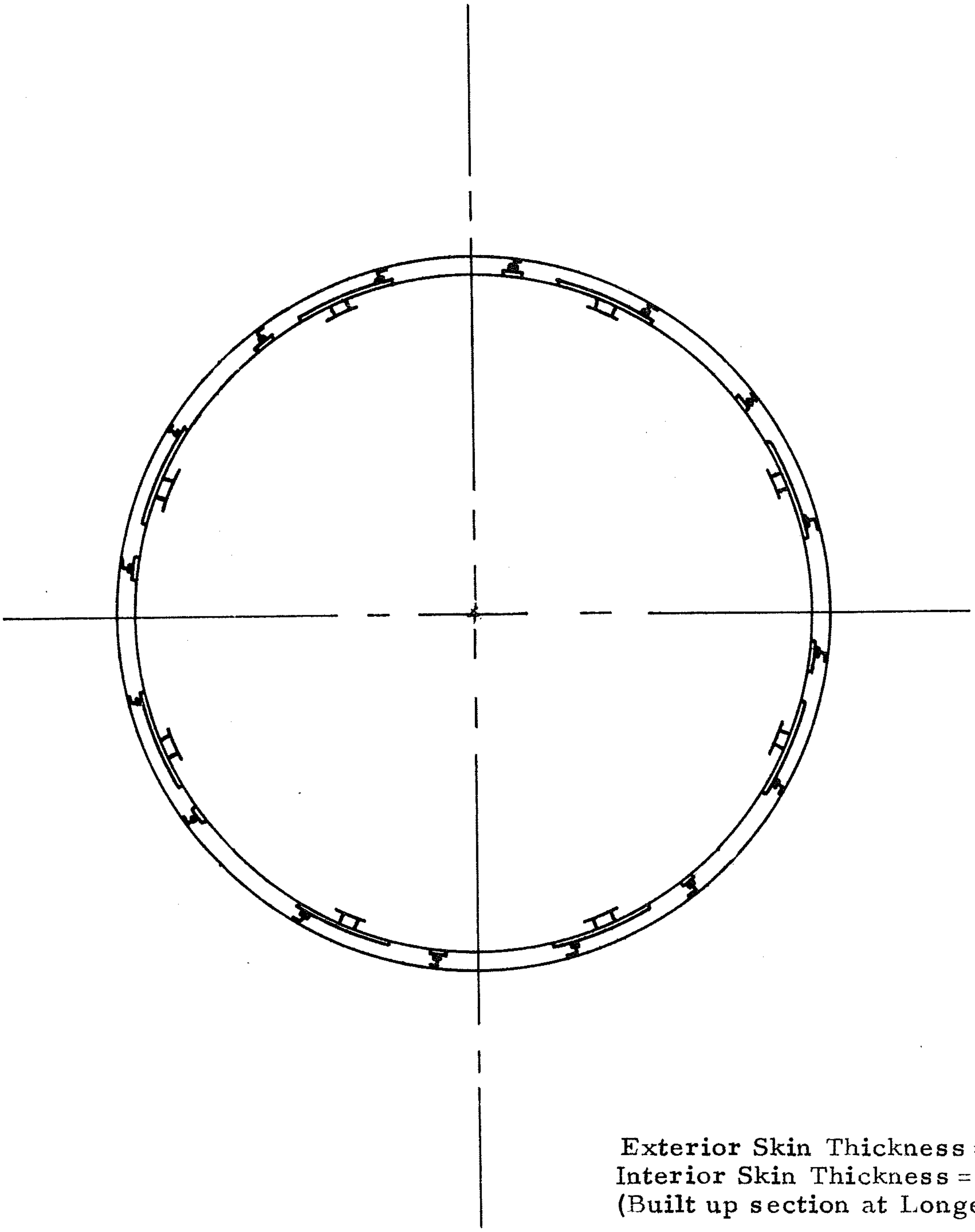
Section A-A (See Figure 16)

Figure 15 – Cross-Section of MDA Exterior and Interior Shells



(Section A-A shown in Figure 15)

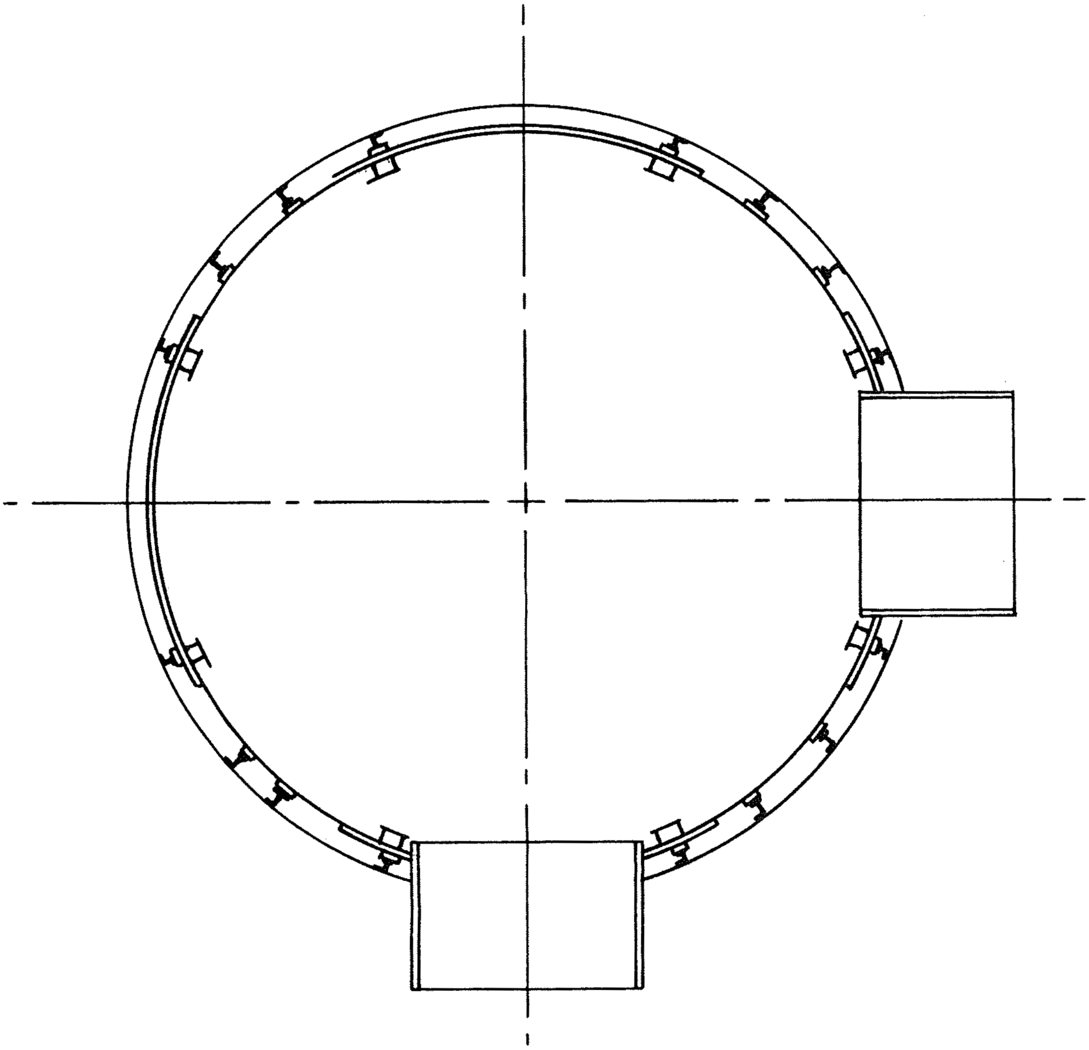
Figure 16 – Docking Ports



Exterior Skin Thickness = .020 in.
Interior Skin Thickness = .076 in.
(Built up section at Longerons, .25 in.)

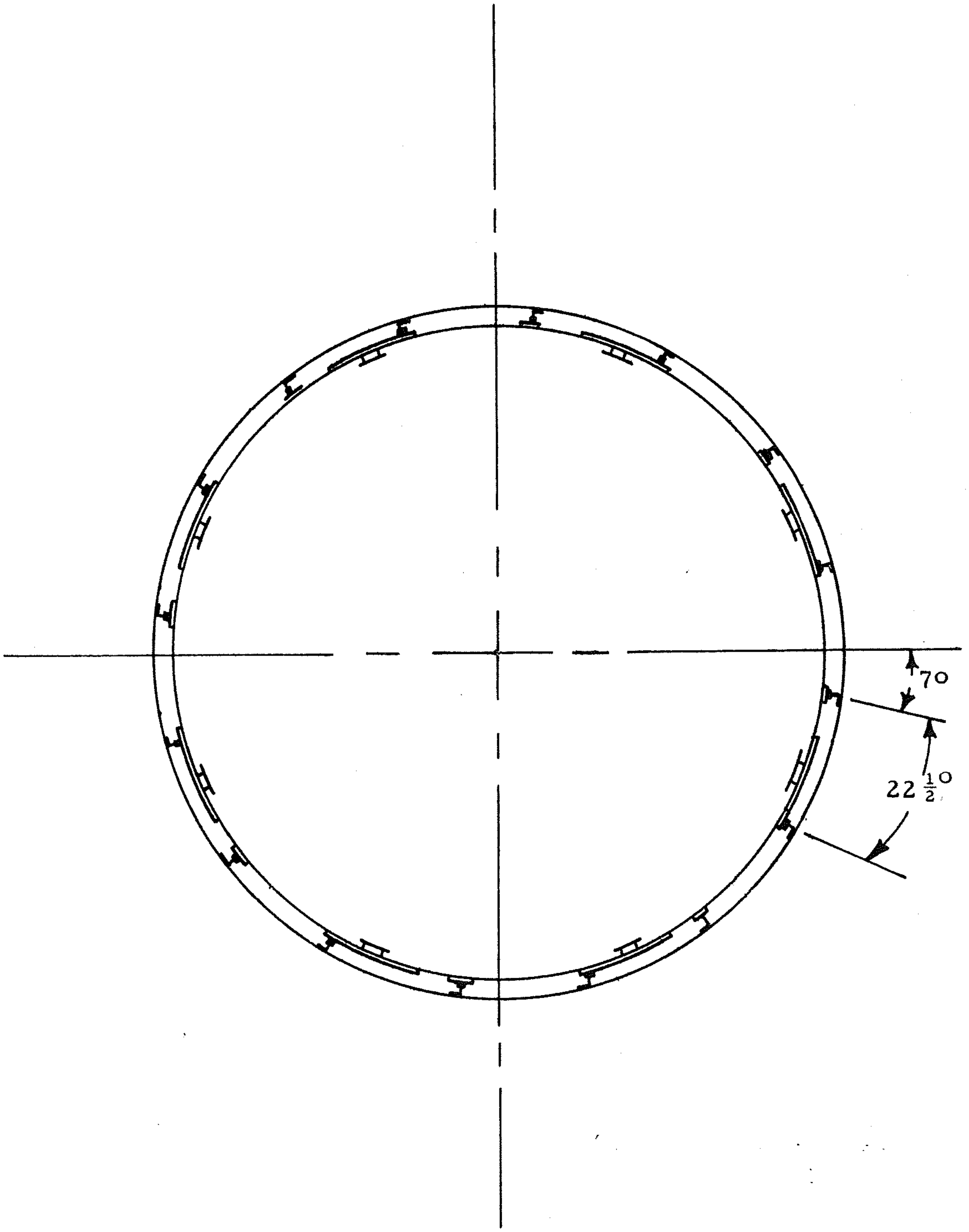
Section B-B

Figure 17 – Relationship Between Exterior and Interior Shells from Station 2007.444 to Station 2045.069



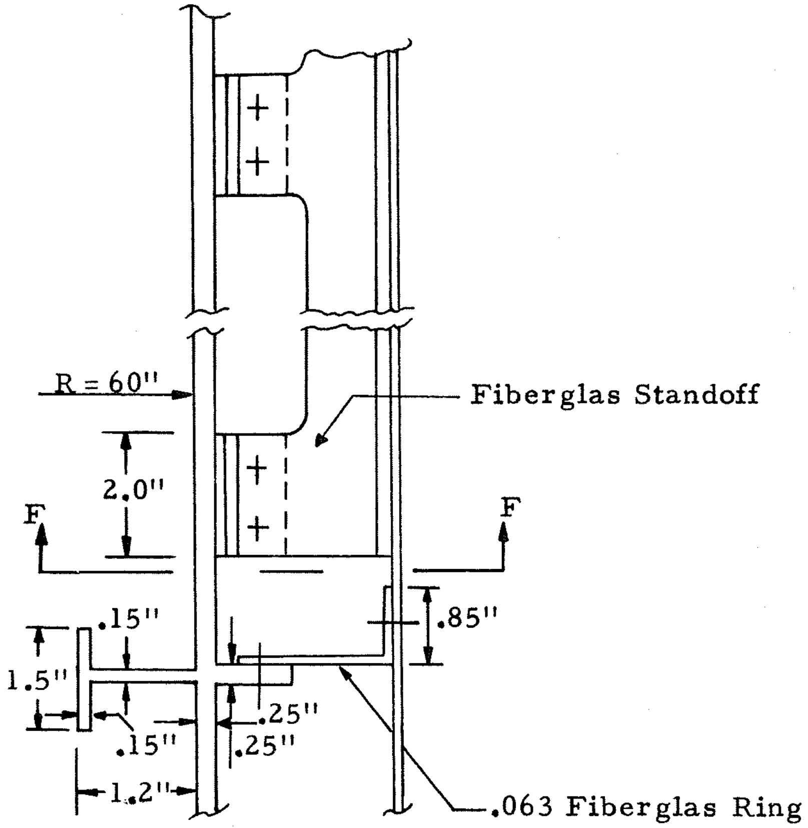
Section C-C

Figure 18 - Relationship Between Exterior and Interior Shells from Station 1962.631 to Station 2007.44

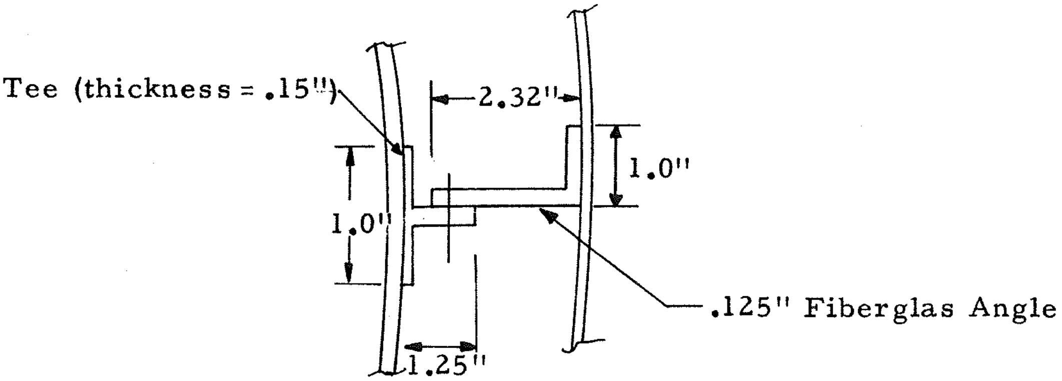


Section D-D

Figure 19 – Relationship Between Exterior and Interior Shells from Station 1882.069 to Station 1962.631



Section E



Section F-F

Figure 20 - Fiberglas Standoff Points and Rings

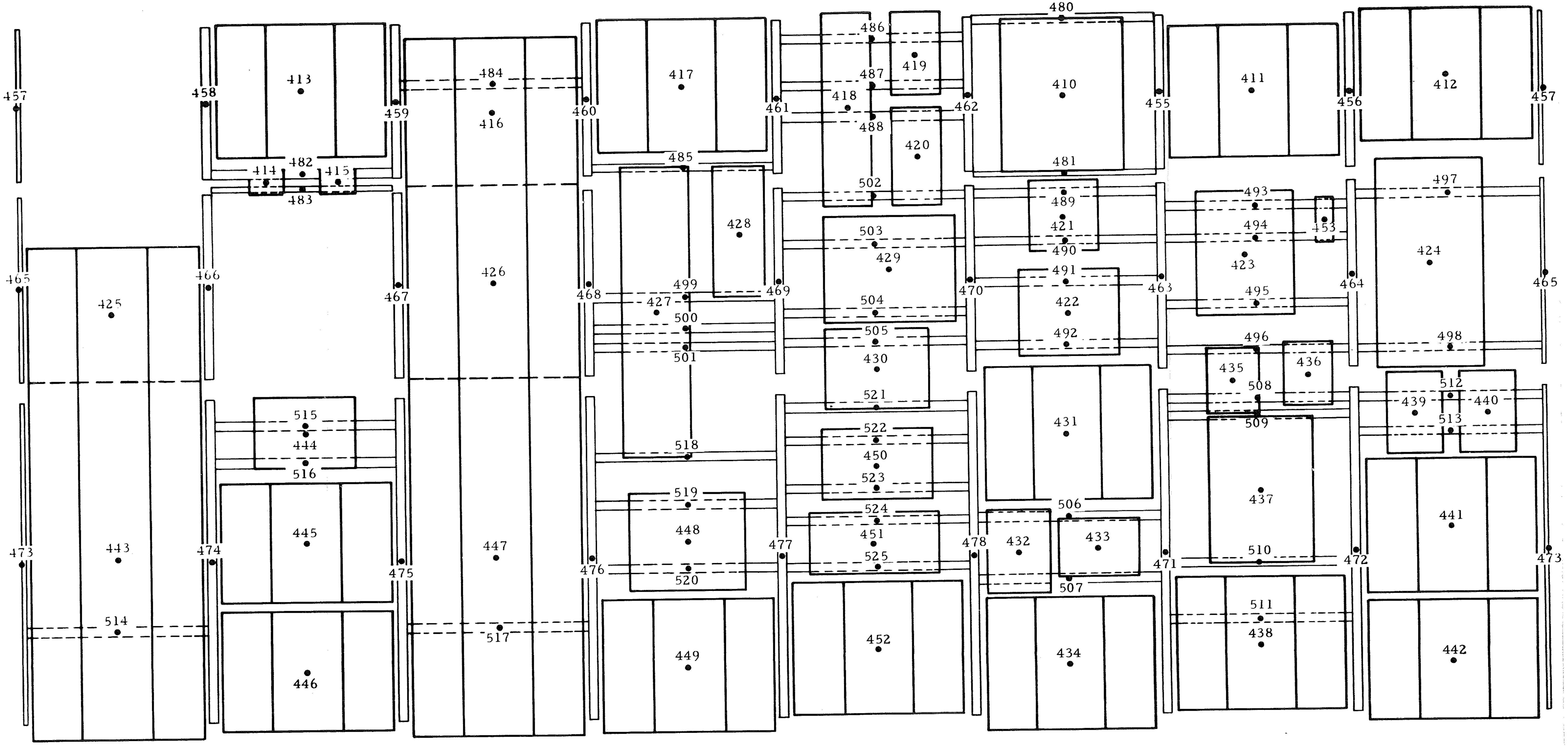
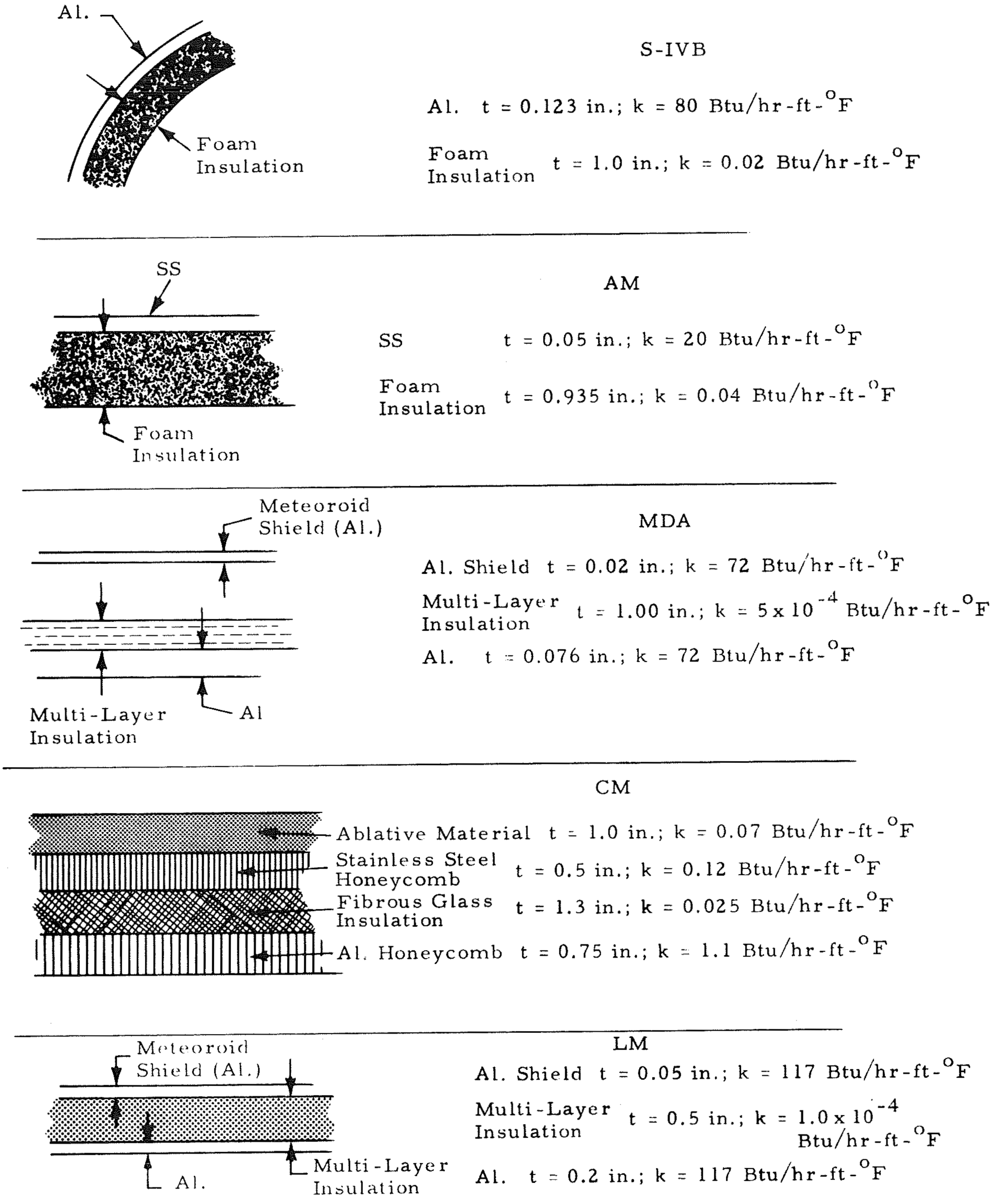


Figure 21

Nodal Breakdown for the Interior Longeron Network and Experiment Packages of the MDA



S-IVB

Al. t = 0.123 in.; k = 80 Btu/hr-ft-°F

Foam Insulation t = 1.0 in.; k = 0.02 Btu/hr-ft-°F

AM

SS t = 0.05 in.; k = 20 Btu/hr-ft-°F

Foam Insulation t = 0.935 in.; k = 0.04 Btu/hr-ft-°F

MDA

Al. Shield t = 0.02 in.; k = 72 Btu/hr-ft-°F

Multi-Layer Insulation t = 1.00 in.; k = 5×10^{-4} Btu/hr-ft-°F

Al. t = 0.076 in.; k = 72 Btu/hr-ft-°F

CM

Ablative Material t = 1.0 in.; k = 0.07 Btu/hr-ft-°F

Stainless Steel Honeycomb t = 0.5 in.; k = 0.12 Btu/hr-ft-°F

Fibrous Glass Insulation t = 1.3 in.; k = 0.025 Btu/hr-ft-°F

Al. Honeycomb t = 0.75 in.; k = 1.1 Btu/hr-ft-°F

LM

Al. Shield t = 0.05 in.; k = 117 Btu/hr-ft-°F

Multi-Layer Insulation t = 0.5 in.; k = 1.0×10^{-4} Btu/hr-ft-°F

Al. t = 0.2 in.; k = 117 Btu/hr-ft-°F

Figure 22 - Wall Cross-Section and Thermal Conductivities of AAP Cluster Modules

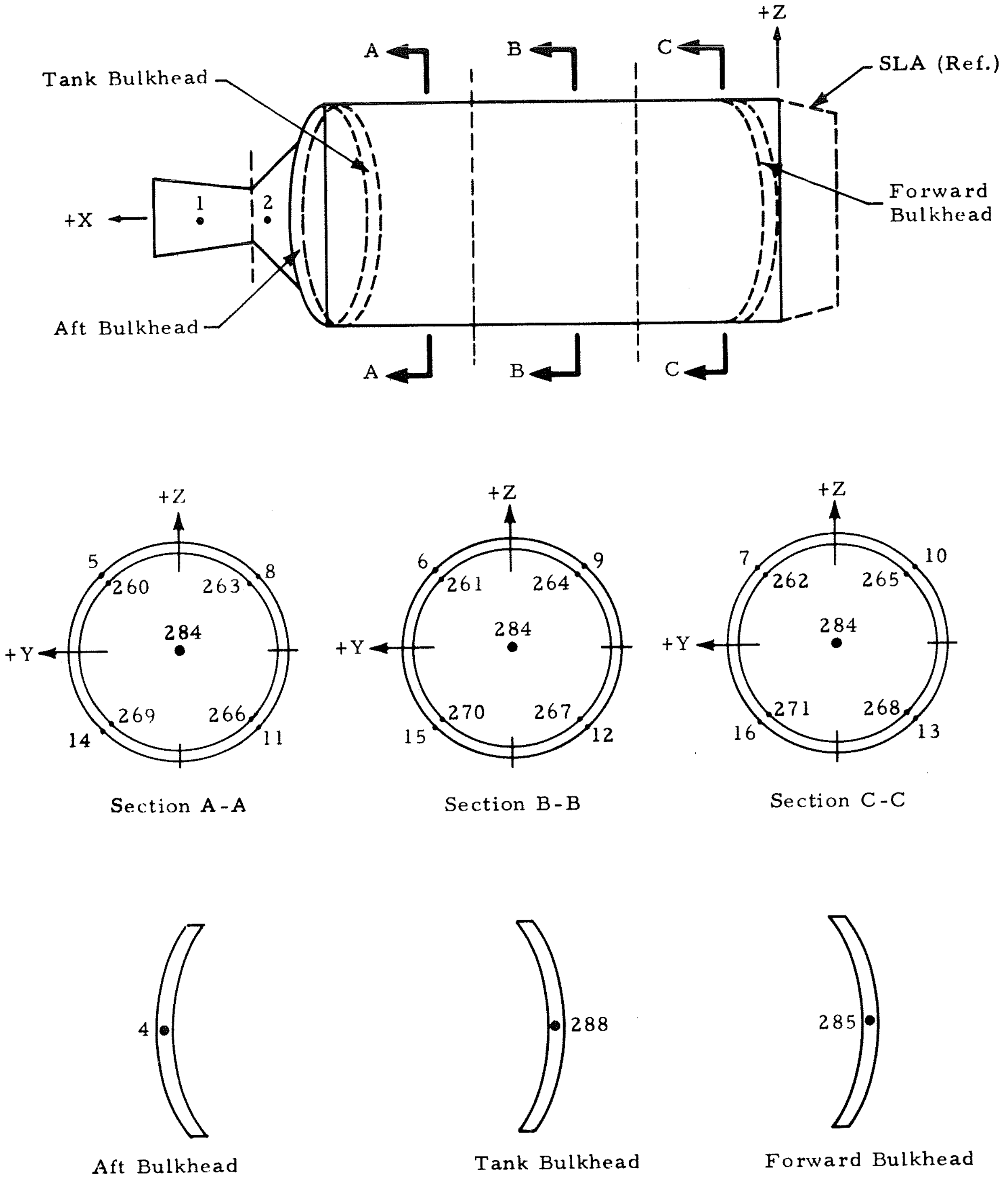
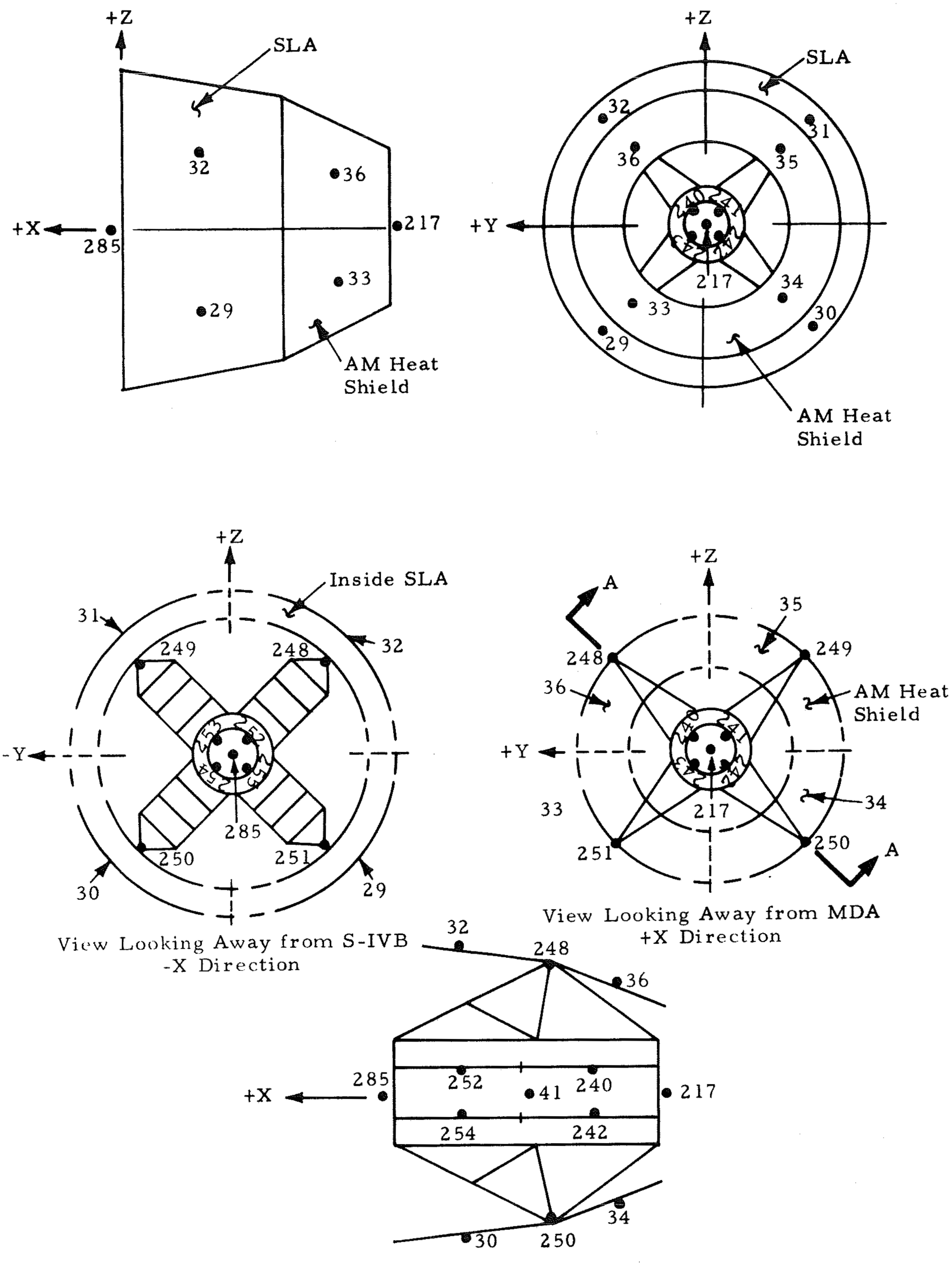


Figure 23 - AAP Cluster S-IVB Orbital Workshop Nodal Network



View Looking Away from S-IVB
-X Direction

View Looking Away from MDA
+X Direction

Section A-A

Figure 24 - AAP Cluster SLA and AM Nodal Network

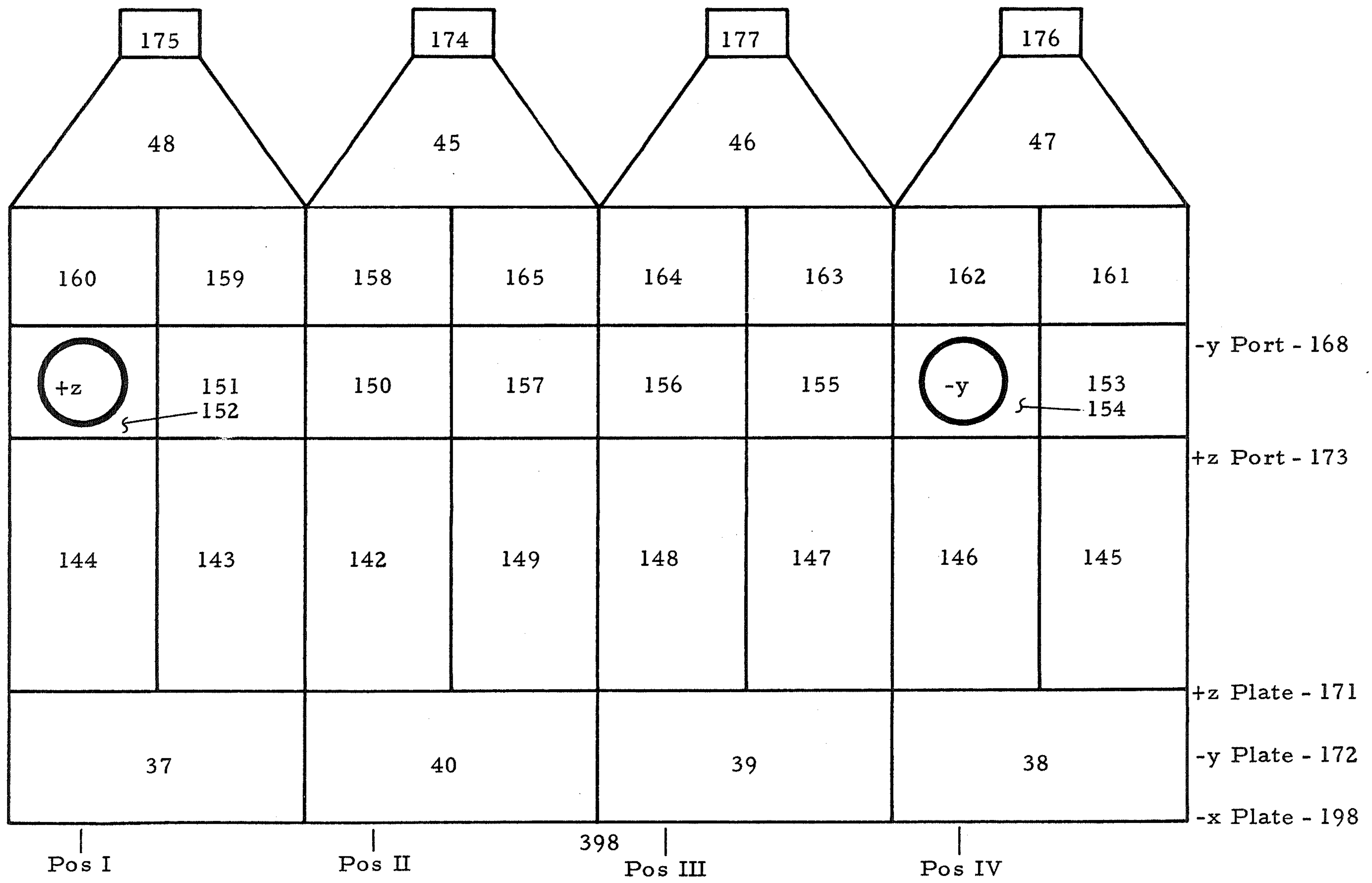


Figure 25 - AAP Cluster MDA Exterior Shell Nodal Network

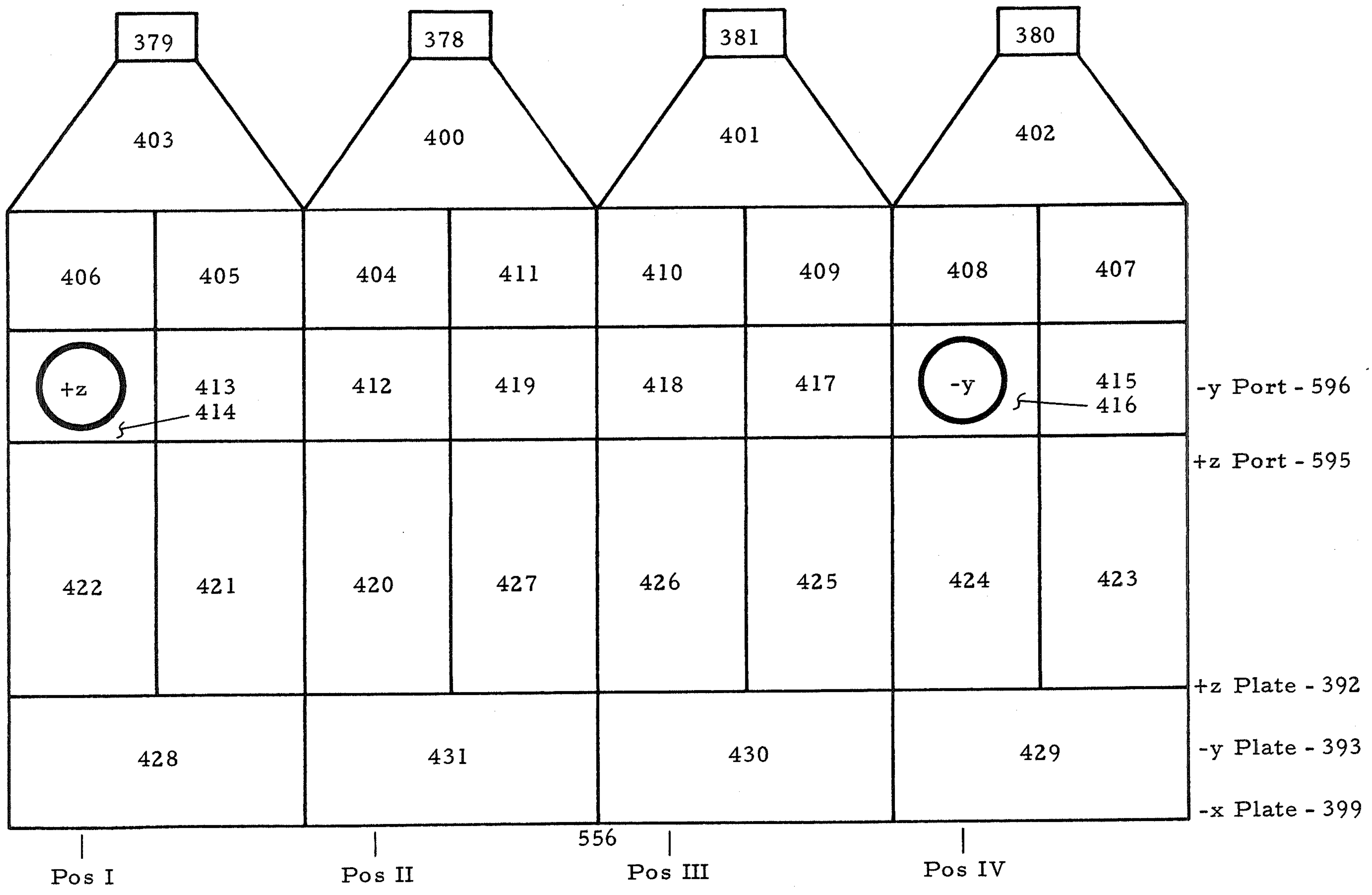


Figure 26 - AAP Cluster MDA Insulation Nodal Network

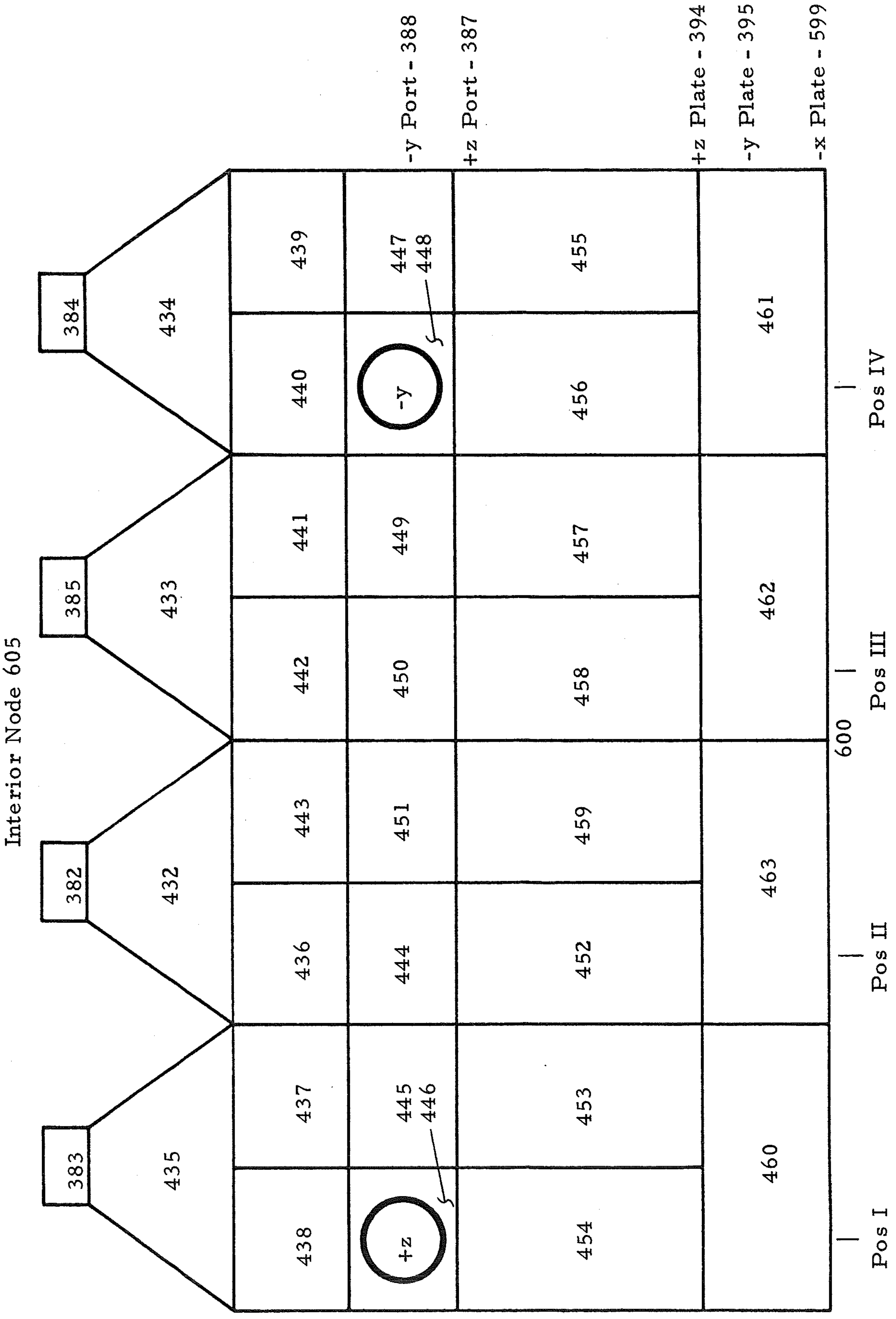


Figure 27 - AAP Cluster MDA Interior Shell Nodal Network

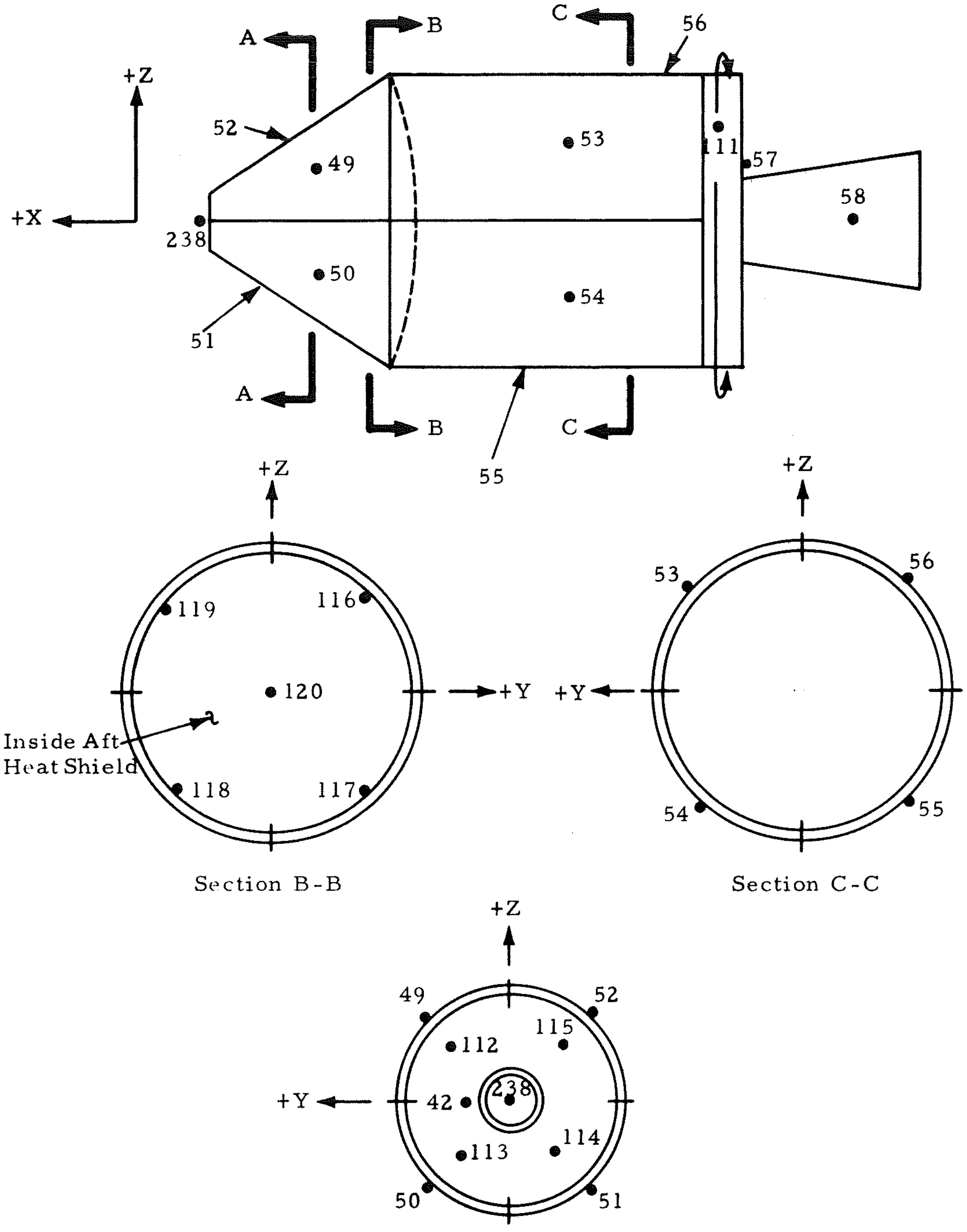
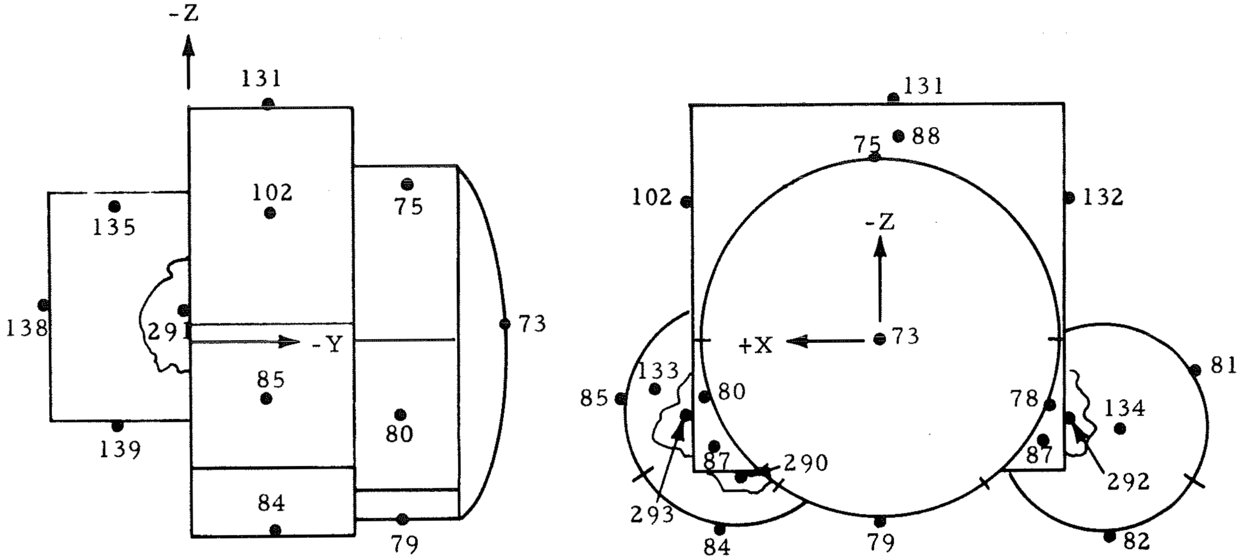


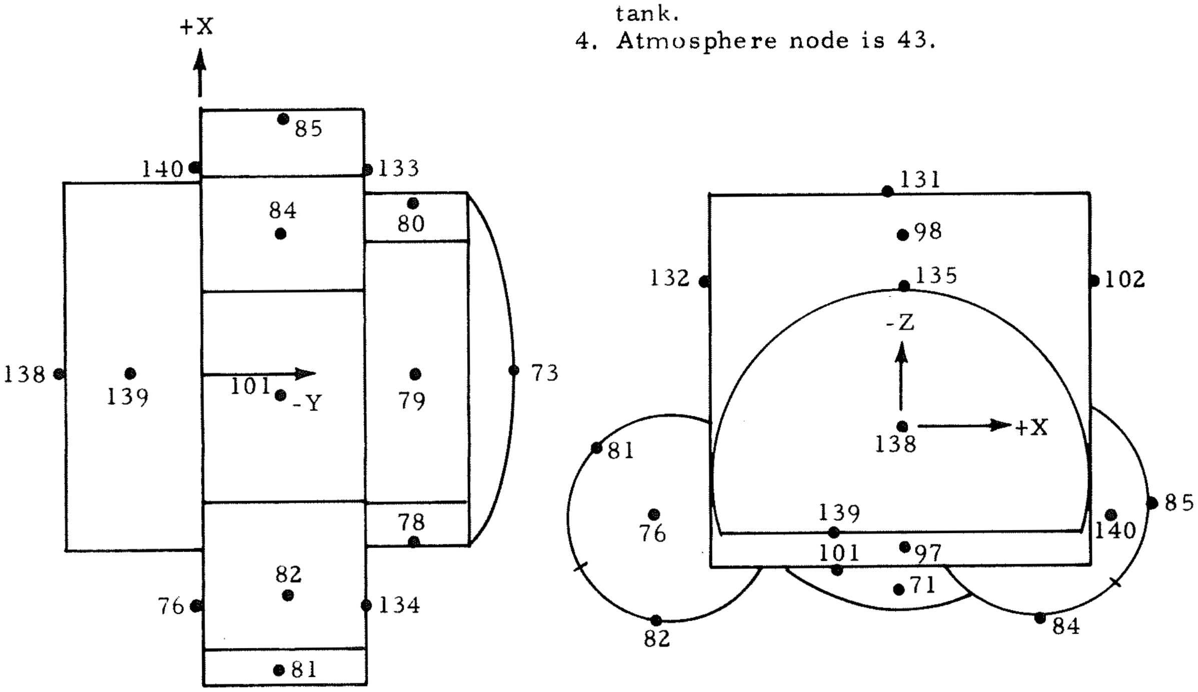
Figure 28 - AAP Cluster CSM Nodal Network



Side View

Front View

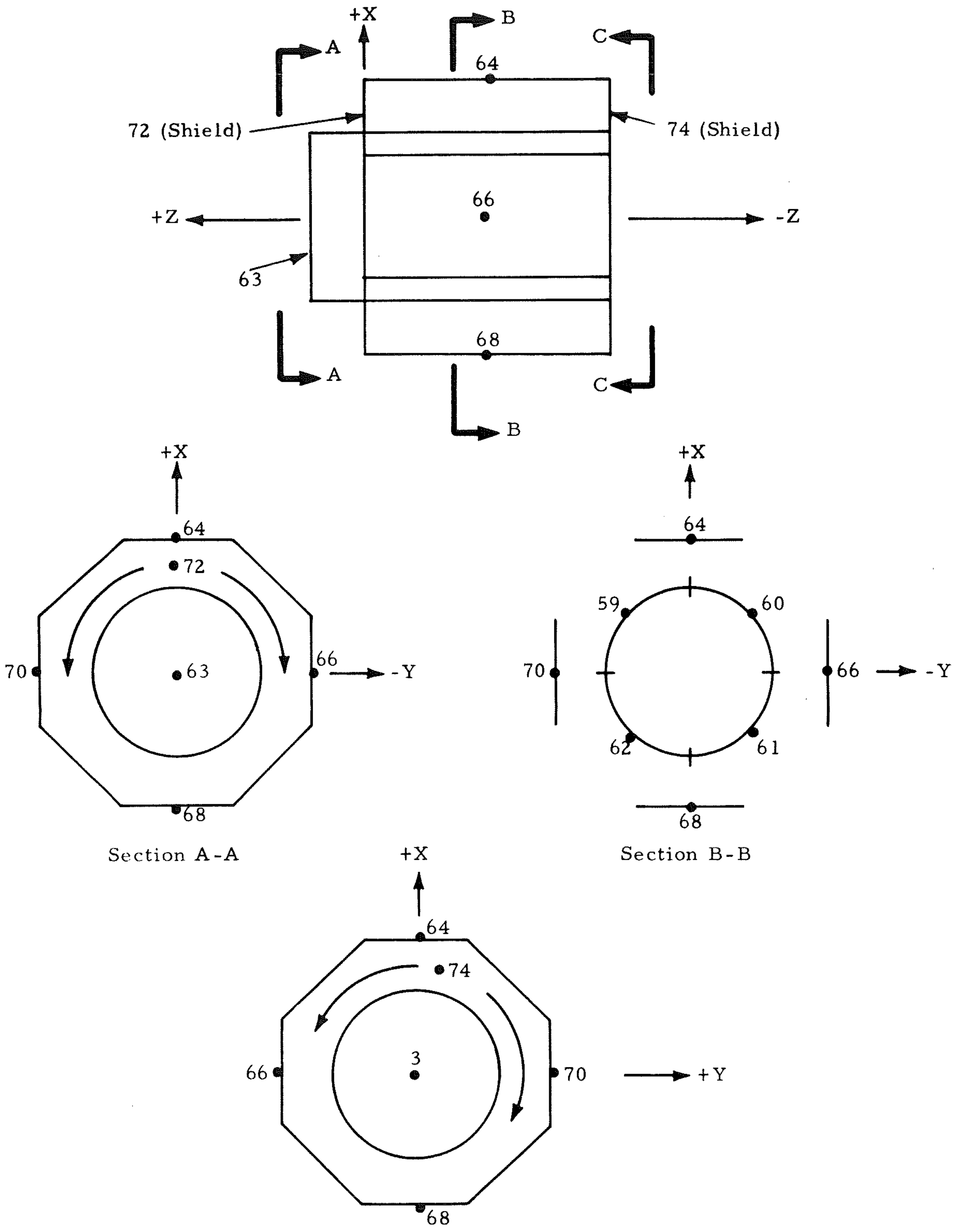
NOTES:
1. Node 291 is inside wall of +Y axis equipment mount.
2. Node 290 and Node 293 are inside walls of +X axis fuel tank.
3. Node 292 is inside wall of -X axis fuel tank.
4. Atmosphere node is 43.



Bottom View

Rear View

Figure 29 - AAP Cluster LM Nodal Network



Section A-A

Section B-B

Section C-C

Figure 30 - AAP Cluster ATM/RACK Nodal Network