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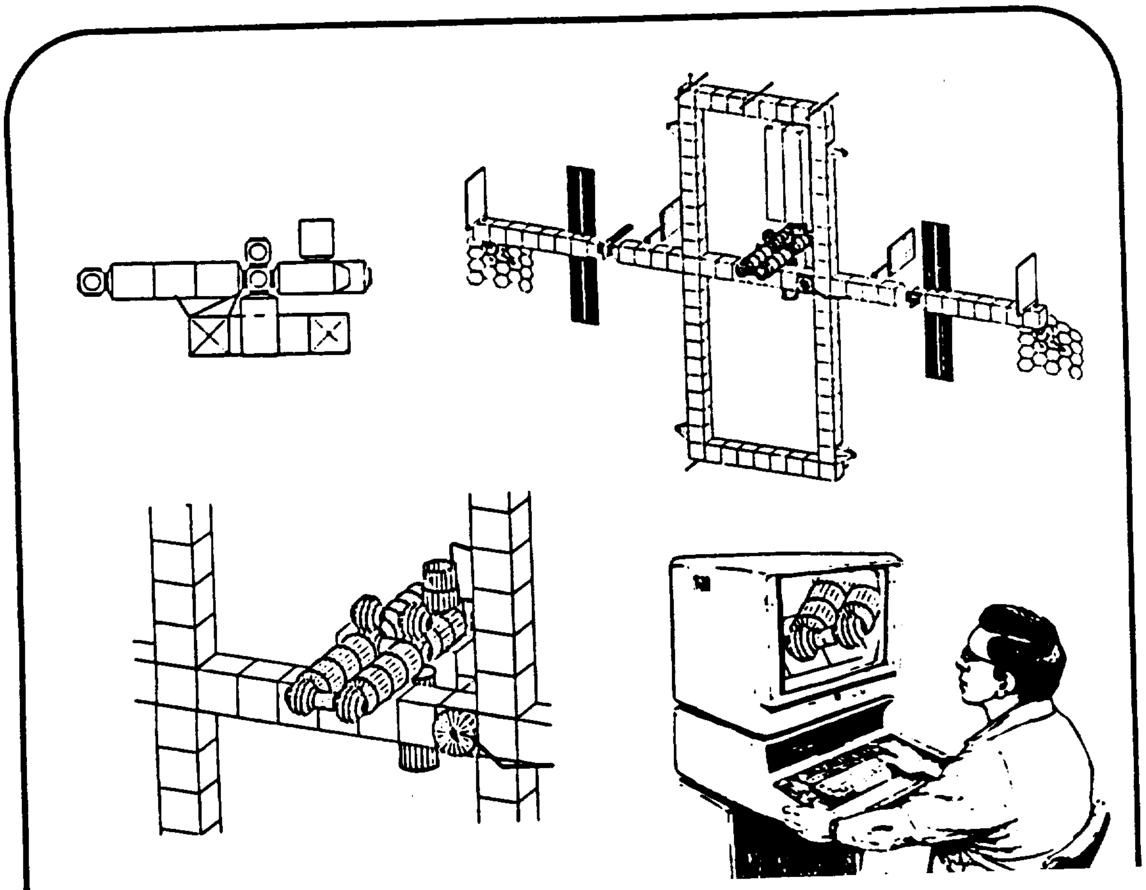
SSS 86-0133

# Space Station Structures Development

## NASA/MSFC CONTRACT NAS8-36421

## OCTOBER 1986



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Space Station Systems Division

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# Space Station Structures Development

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Submitted by

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## FOREWORD

This report describes the major achievements of the study entitled "Space Station Structures Development." The study consisted of three tasks:

- o Task 1: Development of Alternate Deployment Systems for Linear Truss
- o Task 2: Advanced Composite Deployable Truss Development
- o Task 3: Assembly of Structures in Space/Erectable Structures

Design drawings and a laboratory test report that supplement the report are included in the appendix.

The study was initiated on May 9, 1985 and was completed eighteen months later on October 31, 1986. Efforts on Task 1 were concluded on December 20, 1985. Efforts on Task 2 were concluded on October 31, 1985. Efforts on Task 3 were conducted for the entire length of the study.

This study was managed by Marshall Space Flight Center (MSFC) and was performed by the Space Station Systems Division personnel of Rockwell International Corporation located in Downey, California. The study COR was Mr. Erich E. Engler. The study manager was Mr. H. Stanley Greenberg. The deputy study manager was Mr. Paul H. DeWolfe until December 20, 1985. The deputy study manager for the balance of the study was Mr. Volker B. Teller.

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# INTRODUCTION

The study described in this report consisted of three interrelated tasks focused on deployable Space Station truss structures. Task 1, Development of Alternate Deployment Systems for Linear Truss, resulted in the preliminary design of an in-space reloadable linear motor deployer. This deployer was selected as the best alternative to the four-jackscrew deployer developed under NASA/MSFC contract NAS8-34677, Development of Deployable Structures for Large Space Platform Systems, and built under NASA/MSFC contract NAS8-34657, Ground Test Article for Deployable Space Structure Systems.

Task 2, Advanced Composites Deployable Truss Development, resulted in the testing and evaluation of composite materials for struts used in a deployable linear truss. Coupon tests were performed using P75S/934 graphite epoxy and a trade study was performed to determine the feasibility of molded composites for truss strut end fittings.

Task 3, Assembly of Structures in Space/Erectable Structures, resulted in the preliminary design of Space Station pressurized module support structures. An independent, redundant support system was developed for the common United States modules.

The scope of this study was originally much larger. Development and testing of prototype Space Station hardware was planned for all three tasks. A change in the focus of this study occurred largely as a result of the erectable truss construction selection as Space Station Program baseline in January 1986. The emphasis of the study was then limited to the structural attachment of the pressurized modules to the erectable truss.

Considering this background, the most significant result of this study is the preliminary design of Space Station pressurized module support structures. The development of operations and requirements, concept trade studies and design approaches leading to the preliminary design is described in section 3.0. The preliminary design is described in section 3.4.6. The most important aspect of Task 3 study efforts is the development of a flexible design approach that allows simple modifications to accomodate evolving Space Station configurations and requirements.

Recommendations for future work on the pressurized module support structure are 1) to incorporate the baseline Space Station configuration and examine related requirements and operations and 2) to continue development with design, fabrication and test of prototype hardware to demonstrate assembly techniques for future use in space. Continued work is necessary to achieve technology readiness in support of Space Station production and operation.

## 1.0 DEVELOPMENT OF ALTERNATE DEPLOYMENT SYSTEMS FOR LINEAR TRUSS

### 1.1 INTRODUCTION

Linear deployable trusses are an option for the strongback of NASA's Space Station and other future space structures. The key benefits such a truss offers are that (1) ground assembly and checkout of the structure and integrated systems is maximized and (2) extracurricular activity (EVA) requirements are minimized. A reliable and low cost method of deploying such a structure is necessary to make this type of assembly in space feasible. Task 1 of this contract, which was terminated in December 1985, consisted of:

- o Defining deployer requirements
- o Developing alternative deployer concepts
- o Performing a trade study for the concepts devloped
- o Completing a preliminary design of the selected concept

### 1.2 DEPLOYER REQUIREMENTS

Requirements for the truss deployer were established based on the key technical issues identified. The issues addressed include cost, reliability, deployer weight, root strength, EVA risk, development risk, suitability for reload, ease of ground demonstration, and manufacturing complexity. When evaluating deployer concepts cost, reliability and weight issues were considered most important; root strength and EVA risk were considered next. The other issues, although less important in comparison, are distinguishing characteristics of the concepts developed and are considered in the evaluation.

#### 1.2.1 Cost

Mechanical systems such as a linear truss deployer can be expensive to develop, design, qualify and build. Recognizing the importance of cost in the Space Station program, cost is the primary design driver in the selection of the deployer. The requirement to minimize cost is satisfied by developing each concept considered to a level of depth that minimizes estimating uncertainties.

#### 1.2.2 Reliability

The expense of launching the NSTS demands successful deployment of Space Station truss elements on each flight delivered. The lowest cost deployer may be much more expensive should a failure occur and additional launches be required. Known and proven technology is used where appropriate to incorporate maximum reliability into each concept. Where new technology is required, designs are pursued in sufficient depth for accurate reliability assessments.

#### 1.2.3 Deployer Weight

A minimum weight design is a major concern due to the limited payload capacity of the NSTS when flying to the Space Station orbital altitude. A minimum weight design can reduce launch costs by increasing payload packaging efficiency, resulting in fewer flights to deliver the Space Station to orbit. The weight and cost requirements are interrelated through the design approach, analysis and materials selected. As such, this iterative trade is critical for the selection of a deployer.

### 1.2.4 Root Strength

Root strength is defined as the structural strength of the truss at any time during deployment. The deployer must have sufficient root strength to maintain control of the deployed truss when subjected to a sudden load. Such a load could be the result of a reaction control thruster firing from the NSTS orbiter. Root strength is provided to a deployer by the deployment mechanism or a secondary support system that maintains structural continuity between the deployed or partially deployed truss and the truss housing.

### 1.2.5 EVA Risk

One obvious advantage a deployable truss has over an erectable truss is the reduced EVA requirements. Excessive use of EVA in the assembly of the Space Station is a major safety concern. One of the main objectives of the deployable truss is to minimize the EVA required to complete construction of the Space Station strongback. EVA operations required in using candidate deployers are identified for the trade study.

### 1.2.6 Development Risk

The development risk inherent in any new design is an issue because of the impact on deployer cost and development schedule. As described before, existing technology is used where applicable. The design must minimize development schedule risk so that the overall Space Station program schedule is not jeopardized.

### 1.2.7 Suitability for Reload

Reload is defined as the capability to place truss assemblies into a previously used truss deployer. Reload could occur in space or on the ground. Reload in space takes place when a deployer is delivered with the initial truss assembly and remains in orbit for later use. This approach results in less payload weight to orbit and fewer deployers required to assemble the Space Station. Reload on the ground occurs when the deployer is returned to earth after each flight in which truss is delivered. This approach also results in fewer deployers and eliminates the EVA required for in-space reload; however, it increases the payload weight delivered to orbit. The capability for reload is examined for all concepts developed. The EVA required for in-space reload and turnaround time for ground reload are also evaluated.

### 1.2.8 Ease of Ground Demonstration

Another factor in the development schedule of a truss deployer is the ease of ground demonstration. The relative cost, risk and complexity of ground verification is assessed for each concept.

### 1.2.9 Manufacturing Complexity

A primary component of the cost of the deployer is the degree of complexity in manufacturing and assembling deployer components. This factor is also used in assessing the risk involved in the development of each deployer concept.

## 1.3 ALTERNATE DEPLOYER CONCEPTS

Nine concepts were developed for inclusion in the deployer trade study. A 2.74-meter (9-foot) deployable truss was assumed. Five of the concepts utilize threaded shafts, or jackscrews for deployment of the truss. Three of the concepts use reciprocating mechanisms for deployment. The other concept evaluated relies solely on the EVA astronauts for deployment. The nine concepts developed are:

- Four-jackscrew deployer developed under contract NAS8-34677, Development of Deployable Structures for Large Space Platform Systems, and built under contract NAS8-34657, Ground Test Article for Deployable Space Structure Systems
- Four-jackscrew deployer with the jackscrews folding in a "card table" type configuration
- 2.74-meter (9-foot) folding two-jackscrew deployer
- 5.49-meter (18-foot), 180$^{\circ}$ folded two-jackscrew deployer
- 5.49-meter (18-foot), extendable two-jackscrew deployer
- DC power linear motor deployer with reciprocating deployer arms
- Reciprocating transporter assisted deployer
- Semi-manual tool deployer
- Two-man EVA assisted deployment

### 1.3.1 Four-Jackscrew Baseline Deployer

The four-jackscrew deployer was designed and built under two prior NASA/MSFC contracts as previously described. The detailed definition of this concept is the reason for its selection as baseline. The major components of this deployer are:

- A truss batten deployment jackscrew system which translates truss bays out of the housing one bay at a time
- A diagonal truss member latch unlocking system which unlocks telescoping diagonals from the stowed position
- A longeron truss member latch unlocking system which unlocks

folding longerons from the stowed position

- A jackscrew support frame assembly that supports the cantilevered jackscrews during truss deployment
- A programmed positioning controller to precisely regulate bay-by-bay truss deployment
- A spring-loaded precompression system to eliminate structure backlash

The baseline four-jackscrew is shown in Figure 1.3-1. A spline shaft at the rear of the deployer advances the jackscrews and jackscrew support frame out of the housing. Each batten frame contains a half nut at each of its four corners to which the jackscrews engage. The initial bay of truss engages and is driven out concurrent with the jackscrews and support frame. Subsequent truss bays engage the jackscrews and are driven out of the housing one at a time. The entire deployment process is controlled by a programmable position system and redundant drive motors.

The basic operation of all the jackscrew type deployers is the same. The main difference is in the number of jackscrews and their method of deployment.

### 1.3.2 Four-Jackscrew Card Table Deployer

The four-jackscrew card table deployer was modified from the baseline four-jackscrew deployer. The main difference in the design is the folding jackscrew system. This feature eliminates the need for a complex spline shaft system to deploy the jackscrews, as shown in Figure 1.3-2. On the other hand, a split jackscrew with matching threads is required for successful operation. The jackscrews are housed in a small frame and braced by telescoping struts for root strength. The intial truss batten frame is engaged on the jackscrew at the start of deployment. Subsequent truss batten frames are driven off the jackscrews one at a time until deployment is complete.

### 1.3.3 2.74-Meter Two-Jackscrew Deployer

The 2.74-meter (9-foot) two-jackscrew deployer was developed as a low weight alternative to the baseline four-jackscrew deployer. As shown in Figure 1.3-3, the jackscrews fold 90° against the truss housing when stowed and are supported by a frame and folding struts. Similar to the four-jackscrew card table deployer, the spline shaft system for deploying the jackscrews is not required. Half nuts are required for only two of the batten frame corner fittings. The motors used to drive out the jackscrews provide enough torque to deploy the truss using only two jackscrews.

### 1.3.4 5.49-Meter 180° Folded Two-Jackscrew Deployer

The 5.49-meter (18-foot) 180° folded two-jackscrew deployer was developed as a higher root strength alternative to the 2.74-meter two-jackscrew deployer. The jackscrews fold 180° against the truss

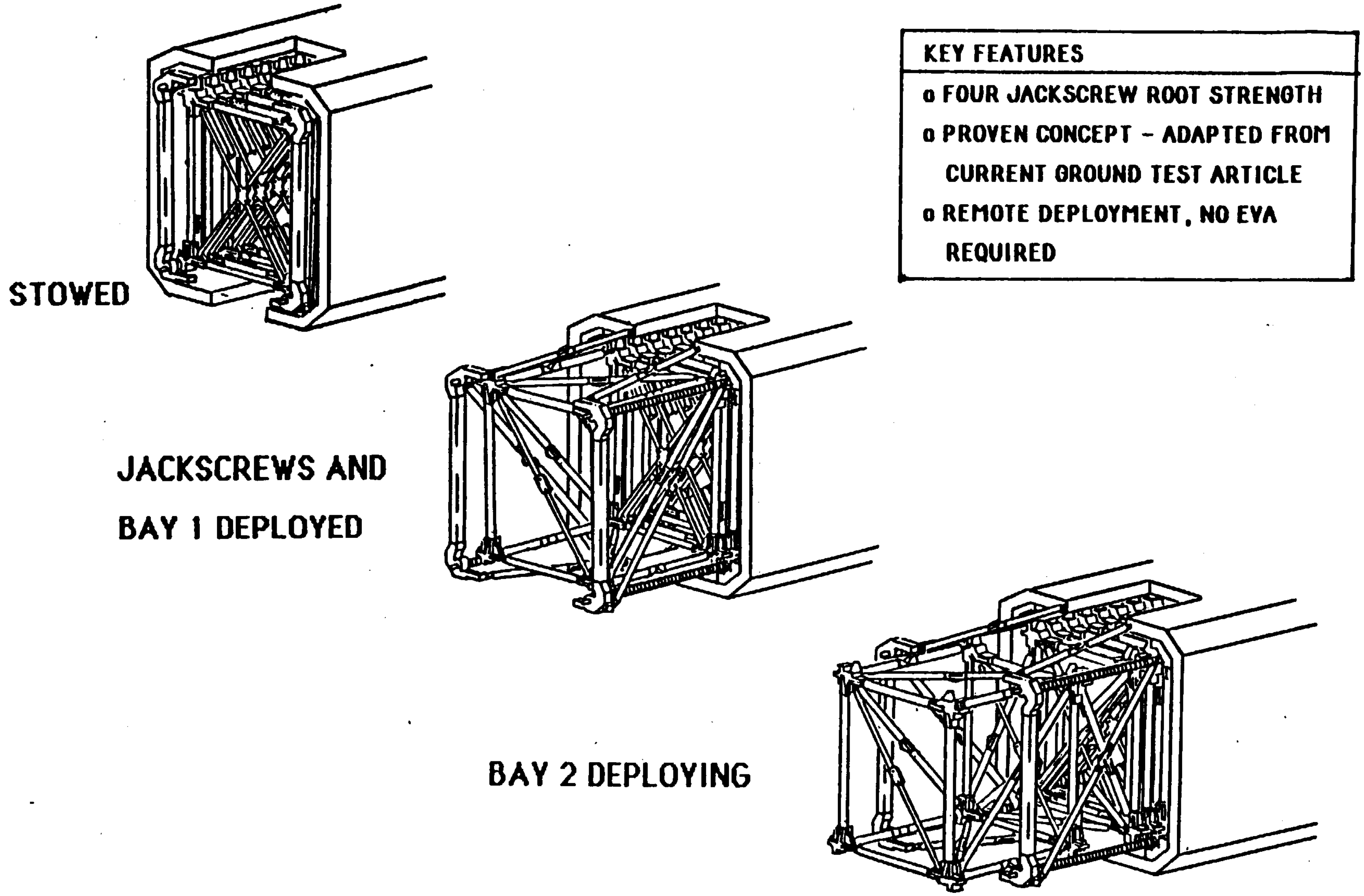



Figure 1.3-1. Baseline Four-Jackscrew Deployer

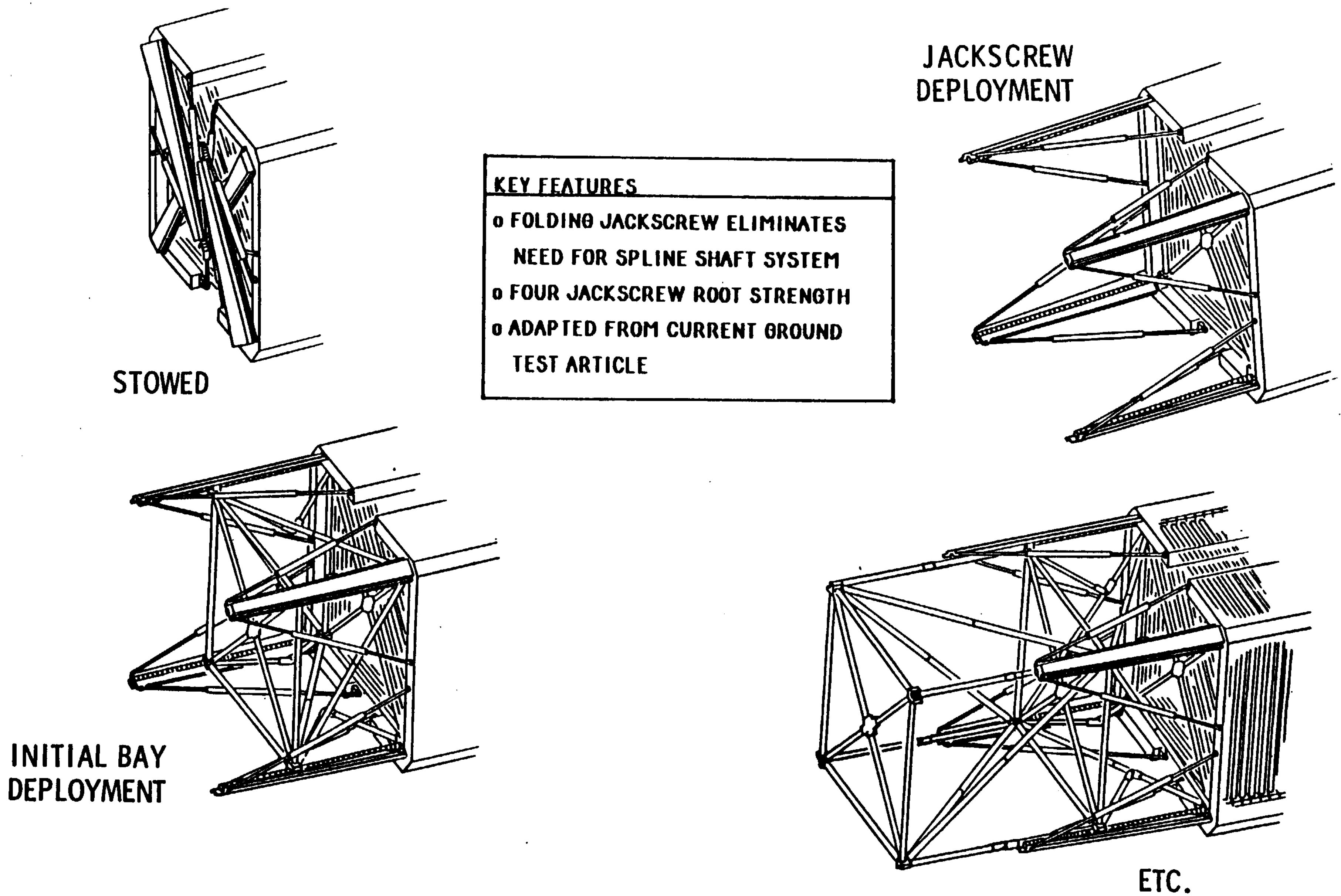



Figure 1.3-2. Four-Jackscrew Card Table Deployer

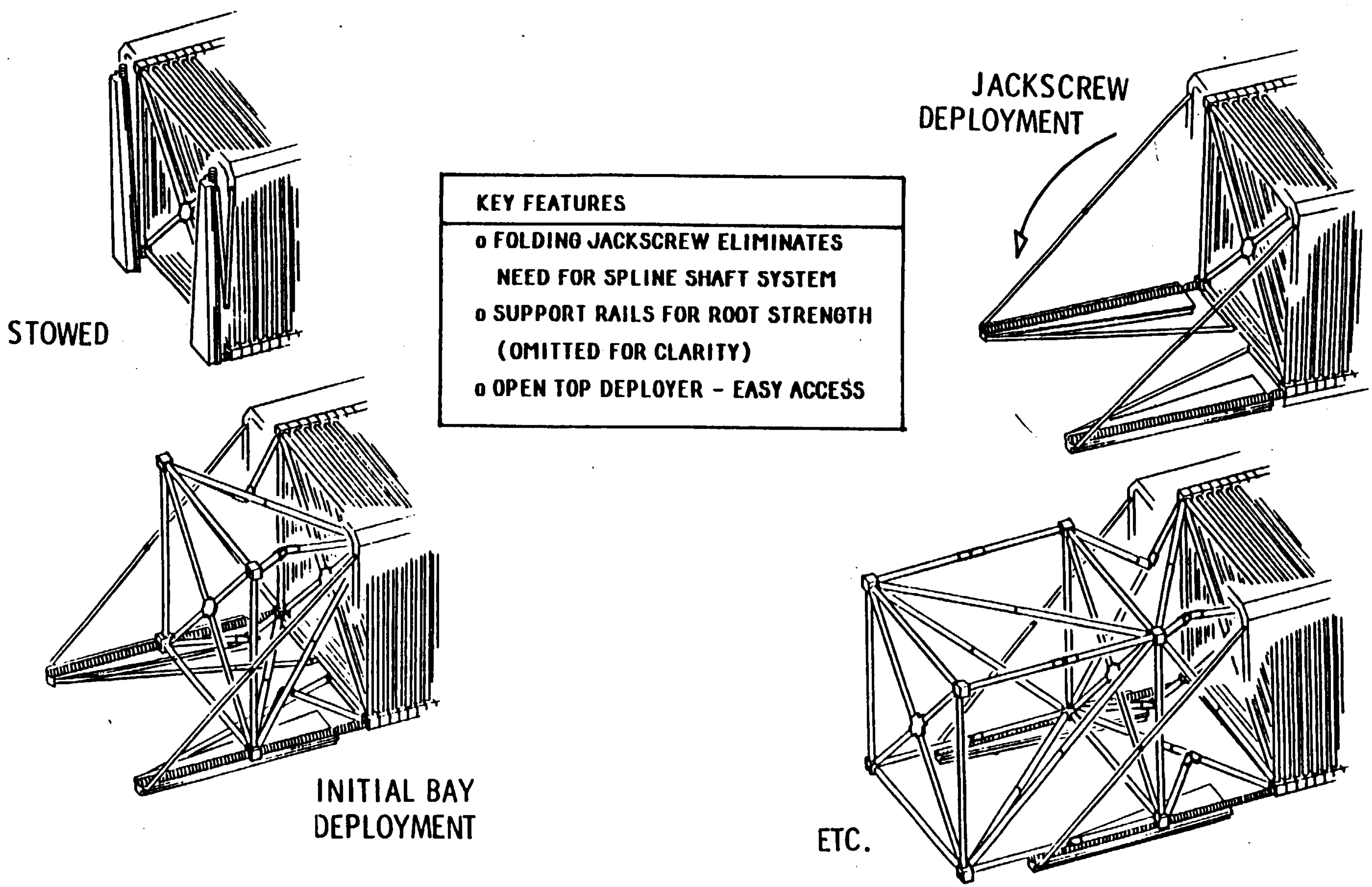



Figure 1.3-3. 2.74-Meter Two-Jackscrew Deployer

housing when stowed and unfold as the first part of the deployment process (see Figure 1.3-4). A spline shaft system is also not required for this concept; however, the jackscrews are split at several locations and the alignment of threads upon deployment is more difficult. Two bays of truss are on the jackscrew/rail structure until the last bay of truss is deployed providing better stability and root strength than the 2.74-meter two-jackscrew deployer.

### 1.3.5 5.49-Meter Extendable Two-Jackscrew Deployer

The 5.49-meter (18-foot) extendable two-jackscrew deployer was developed as an alternative to the 180° folded two-jackscrew deployer. This concept does not require a complex folded jackscrew but, instead drives out the jackscrew with a spline shaft system similar to the baseline four-jackscrew deployer. The root strength provided is identical to that of the 180° folded two-jackscrew deployer. The concept is shown in Figure 1.3-5.

### 1.3.6 Linear Motor Deployer

This concept utilizes four DC powered linear motors to drive reciprocating deployer arms. The arms grapple the outermost truss batten member and extend the batten frame until the truss bay locks in place. The deployer arms then release the batten and retract to grapple the next batten member. This process, as shown in Figure 1.3-6, repeats until the truss is deployed. Linear motor position is controlled to within .0025 mm (.0001 inch) to ensure accurate deployment of each truss bay.

### 1.3.7 Transporter Assisted Deployer

The transporter assisted deployer utilizes rails and a reciprocating platform system. The platform also doubles as a transporter for the Mobile Servicing Center (MSC) that traverses along the surface of the truss after deployment and services the Space Station. The first two bays are manually deployed in this concept. The transporter and rails are then attached to the outermost bay and subsequent bays are deployed as the transporter reciprocates (see Figure 1.3-7). Support rails attached to the truss housing provide root strength.

### 1.3.8 Semi-Manual Tool Deployer

The semi-manual tool deployer concept was developed as a low cost alternative to the linear motor deployer. It consists of a drive motor, a rail, a traveler, and a cable-and-pulley system to move the traveler. Two of these deployers are used in tandem to deploy the truss, as shown in Figure 1.3-8. The tool is first attached to the truss housing by EVA. The traveler engages the first batten frame and drives the initial bay of truss out of the housing. The traveler then releases the first batten frame and retracts to grapple the second batten frame. This process repeats until the truss is fully deployed. This tool is compact and can be left in space and re-used for truss assemblies delivered on subsequent flights.

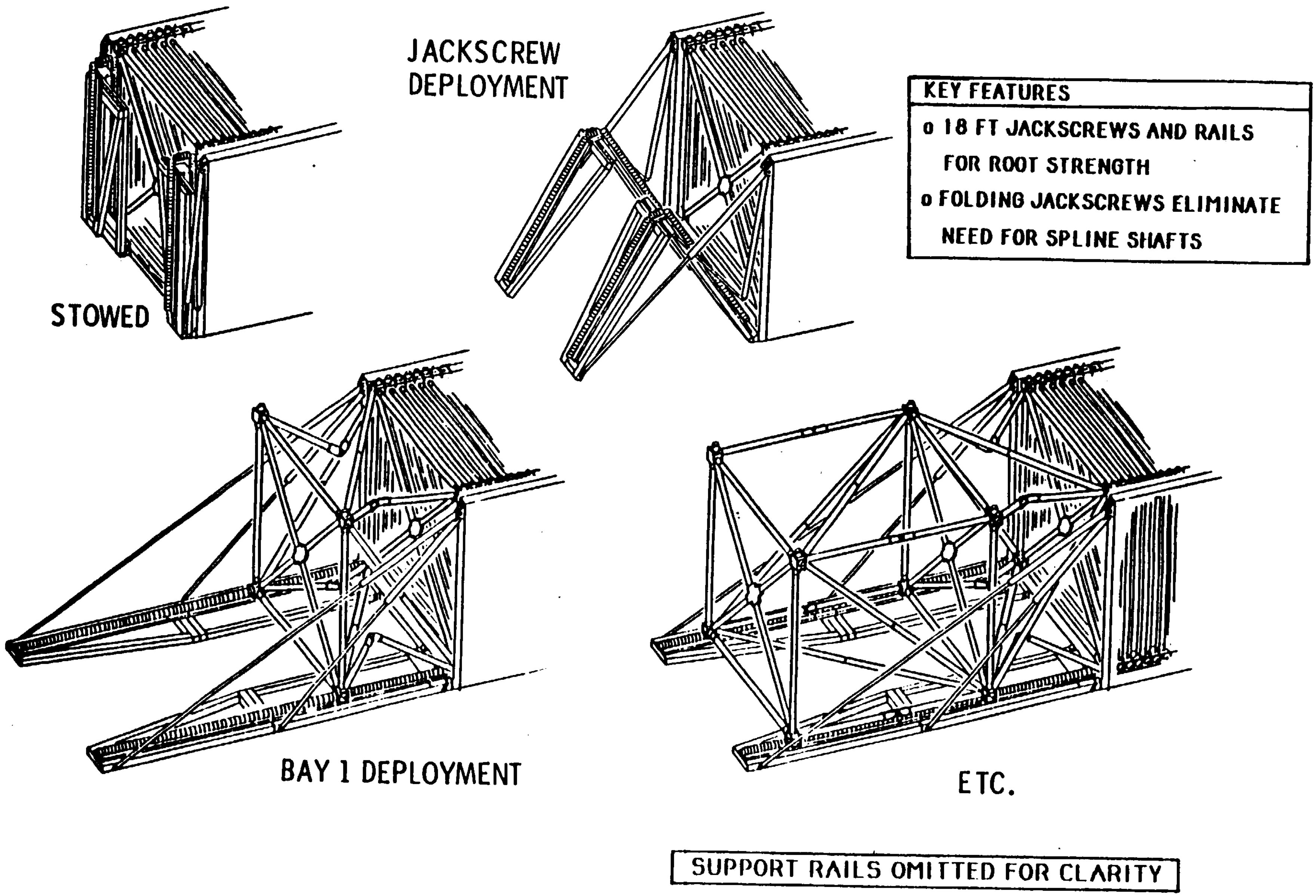



Figure 1.3-4. 5.49-Meter 180° Folded Two-Jackscrew Deployer

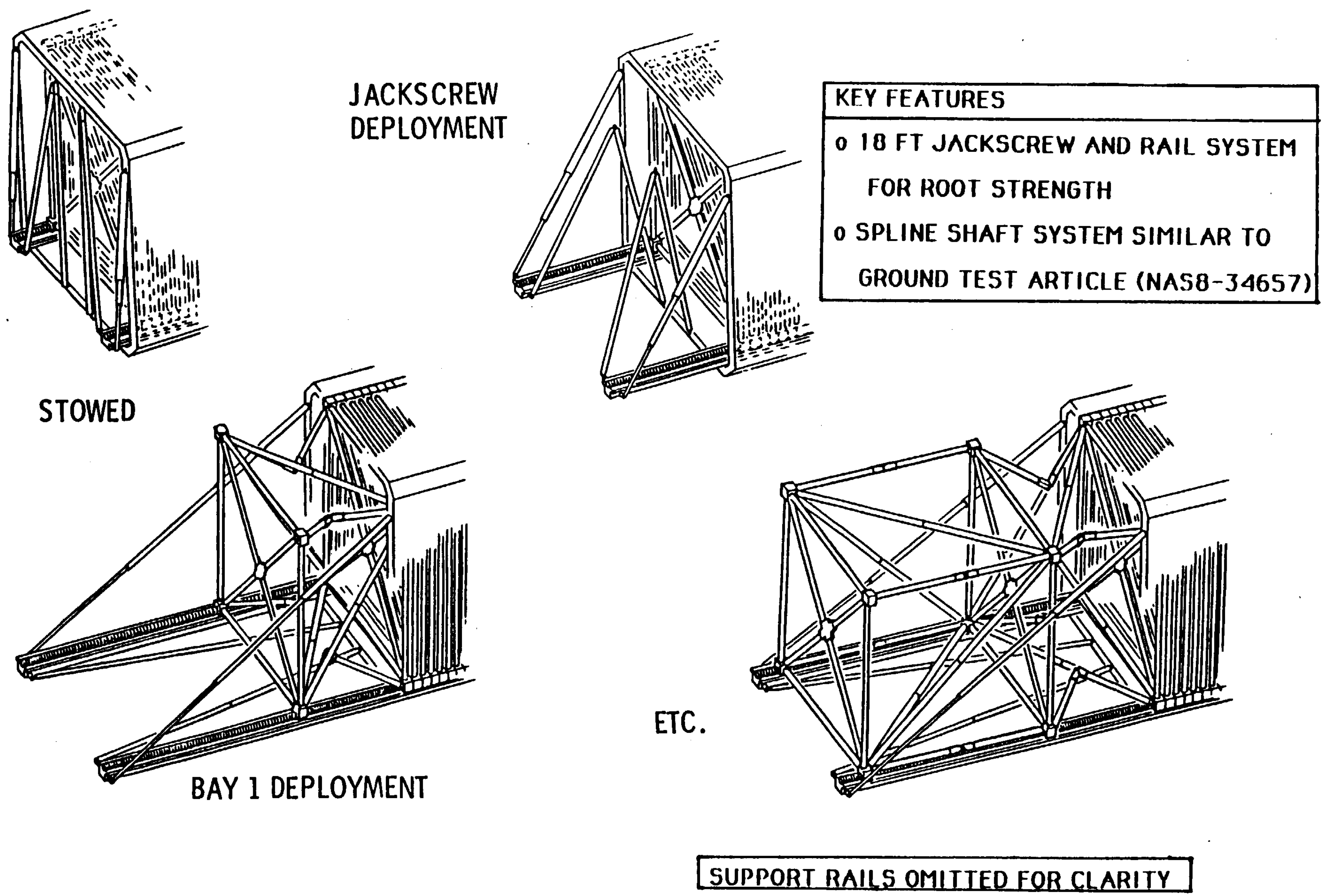



Figure 1.3-5. 5.49-Meter Extendable Two-Jackscrew Deployer

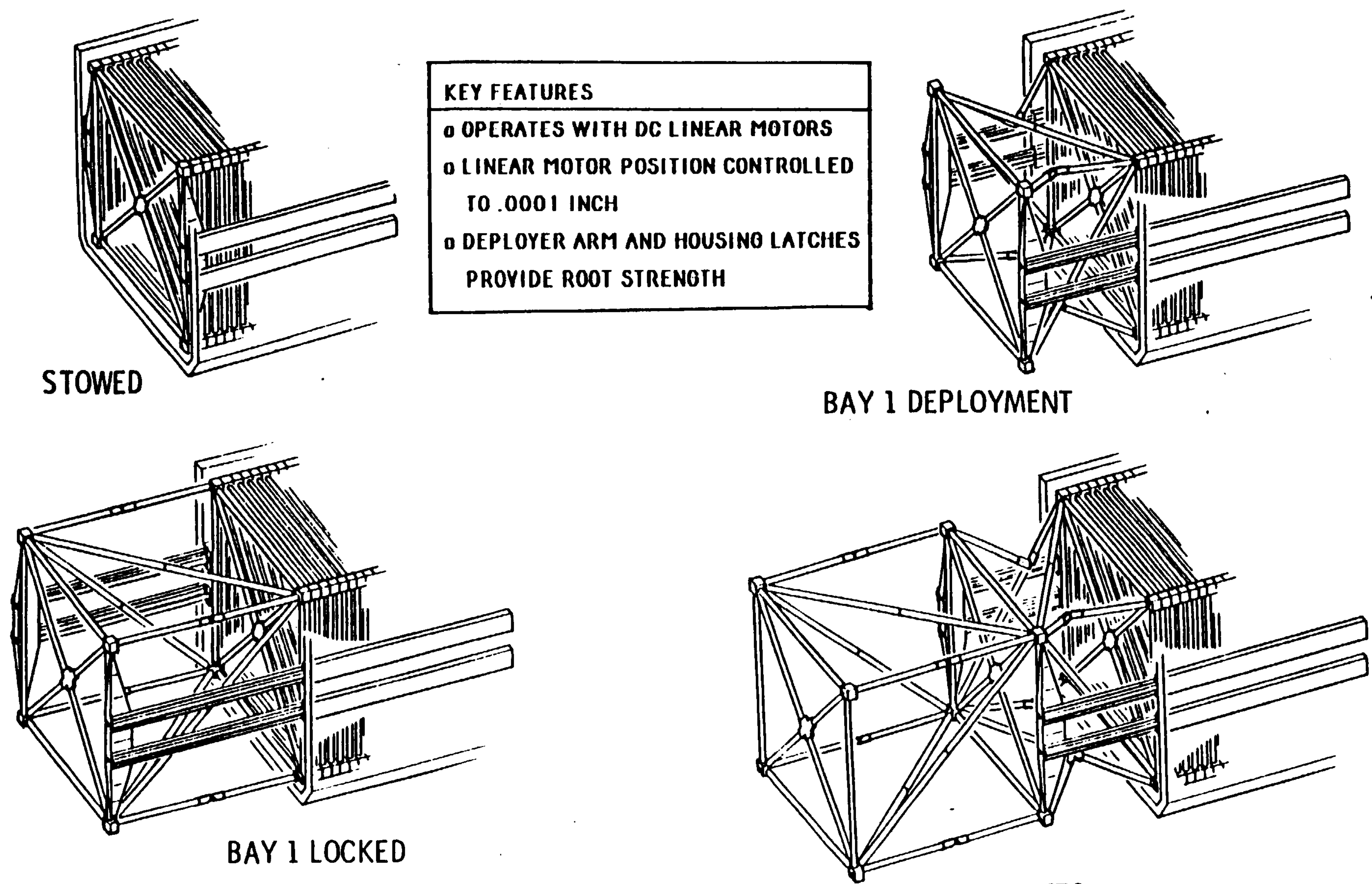



Figure 1.3-6. Linear Motor Deployer

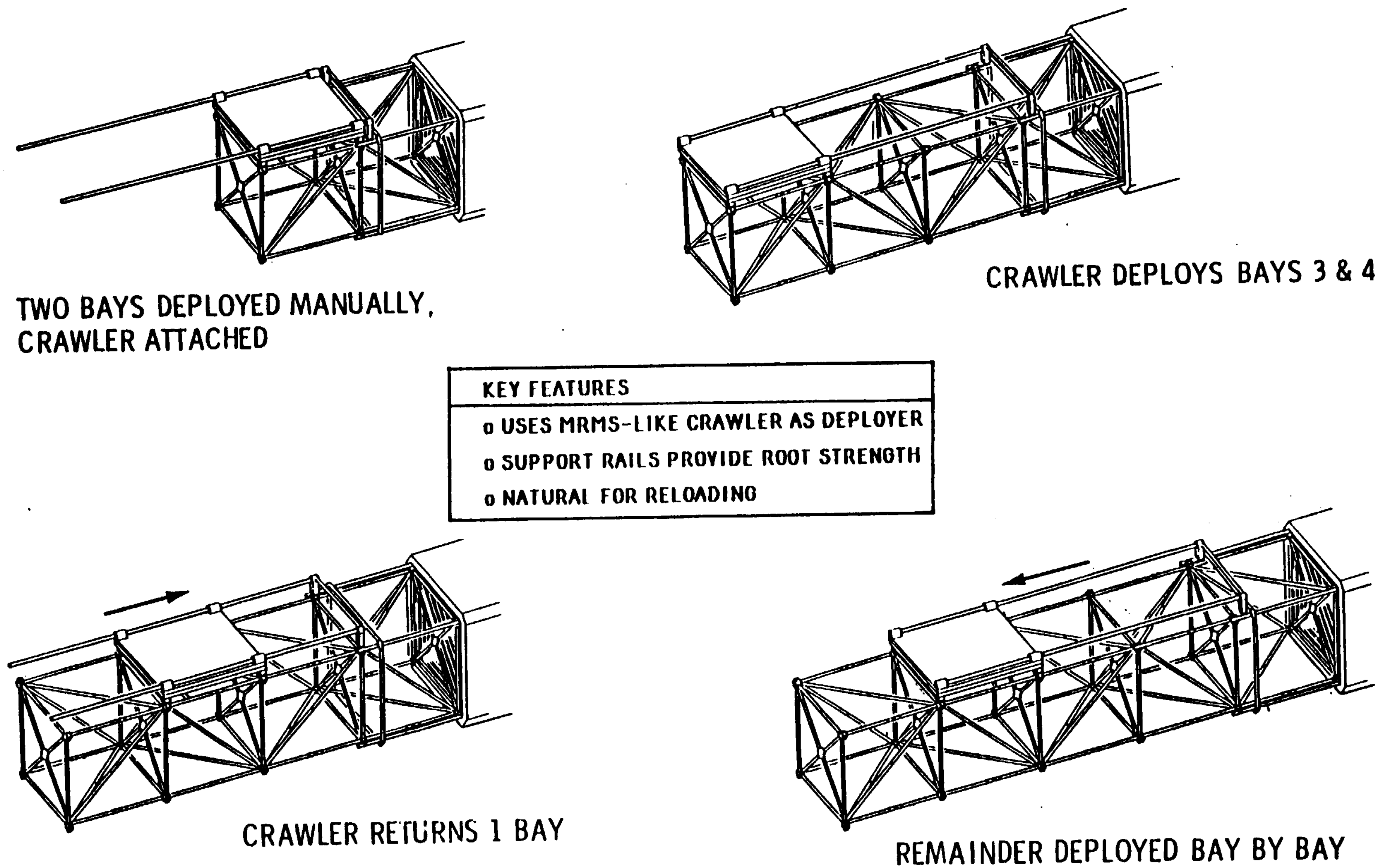



Figure 1.3-7. Transporter Assisted Deployer

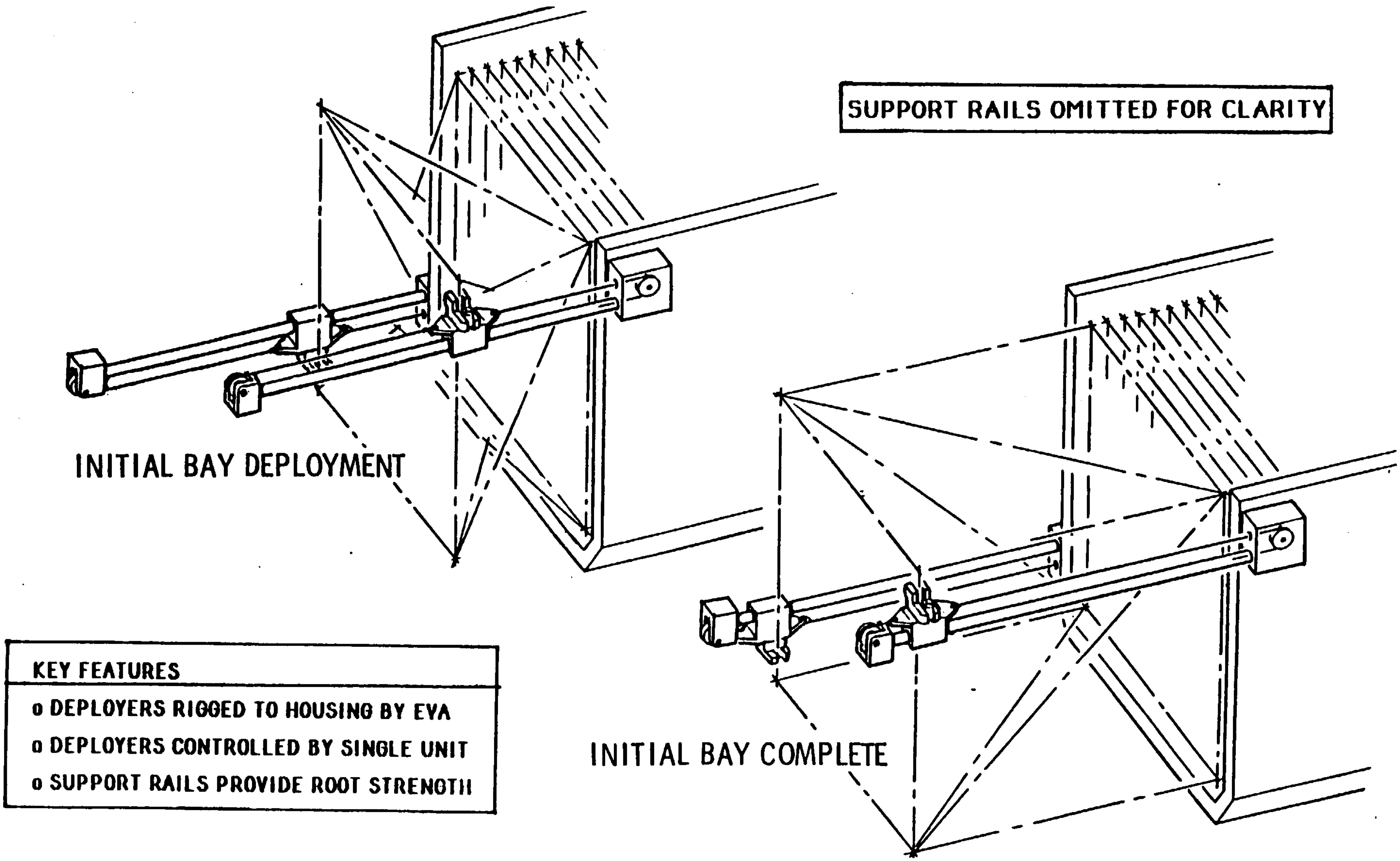



Figure 1.3-8. Semi-Manual Tool Deployer

### 1.3.9 Two-Man EVA Assisted Deployment

The two-man EVA assisted deployment concept was included in the design as a least cost alternative to the other concepts developed. The only hardware associated with this concept are two support rails that help guide the truss out of the housing and provide root strength during the deployment process. The concept obviously requires a great deal of exertion by the EVA astronauts, as depicted in Figure 1.3-9.

## 1.4 ALTERNATE DEPLOYER TRADE STUDY

A trade study was performed on the deployer concepts described in section 1.3 based on the requirements described in section 1.2. Conceptual design drawings were used as the basis for all evaluations. A summary of the trade study is shown in Table 1.4-1. A review of the results reveal three concepts that are superior to the rest. The four-jackscrew baseline deployer provides the best reliability, low EVA requirements and outstanding root strength. The linear motor deployer combines low relative cost, high reliability, low EVA requirements and good root strength. The semi-manual tool deployer has a very low relative cost, very low weight and low manufacturing complexity. An in-depth summary of the trade study follows.

### 1.4.1 Cost

Costs tabulated in Table 1.4-1 are referenced from the two-man EVA assisted deployment option. The two-man EVA assisted and semi-manual tool deployment options are obviously the lowest cost options. The relative cost of the rest of the concepts directly correspond to and were computed based on the amount of hardware required and the manufacturing complexity associated with each concept. Evaluation of these parameters resulted in the linear motor deployer as the lowest cost alternative of the hardware oriented concepts developed.

### 1.4.2 Reliability

Reliability data in Table 1.4-1 are based on a 200-point maximum. The four-jackscrew baseline deployer is deemed most reliable due to the detailed development, design, fabrication and proven operation performed under the previously mentioned NASA/MSFC contracts NAS8-34677 and NAS8-34657. The linear motor deployer is rated as next most reliable based largely on its space-proven usage on currently orbiting satellites and its design simplicity. The linear motor reliability rating could even have been higher had production drawings of existing space-rated hardware been available. The four-jackscrew card table deployer recieved its high rating based on similarity with the proven four-jackscrew baseline design.

### 1.4.3 Deployer Weight

Weights data in Table 1.4-1 include just the deployer mechanisms and structures and do not include the truss housing. Again, the two-man EVA assisted and semi-manual tool deployment options are obviously the least weight options. Of the other concepts, the

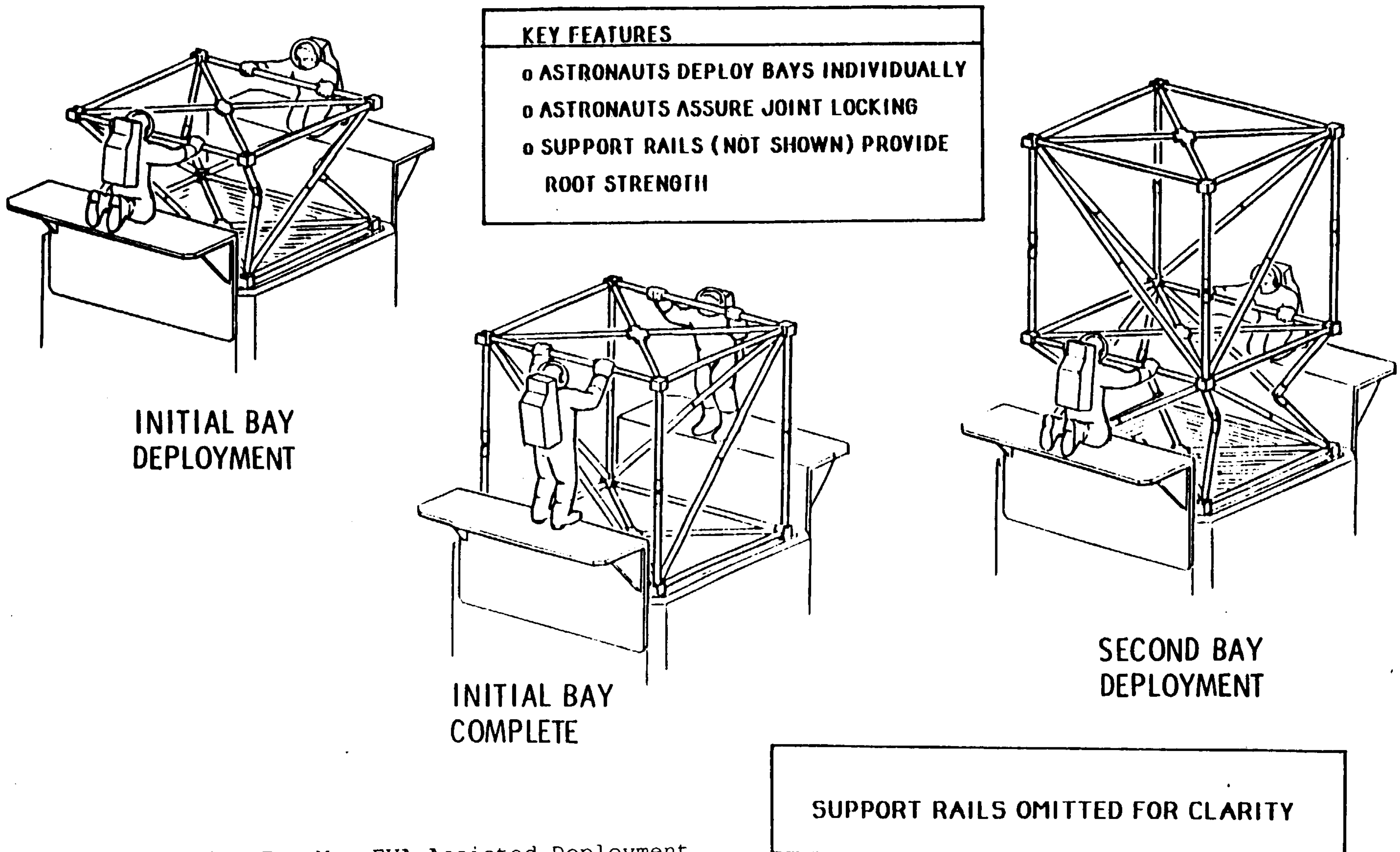



Figure 1.3-9. Two-Man EVA Assisted Deployment

Table 1.4-1. Trade Study Results Favor Linear Motor and Semi-Manual Tool Deployer Concepts

| Criteria / Concept | Four-Jackscrew GTA | Four-Jackscrew Card Table | Linear Motor | Two-Jackscrew 9 ft | Two-Jackscrew 18 ft, 180° | Two-Jackscrew 18 ft, Extended | Crawler Assisted | EVA Tool Assisted | EVA Manually Assisted |
|---|---|---|---|---|---|---|---|---|---|
| 1. Relative cost (least cost = 1) | 7 | 8 | 3 | 4 | 6 | 9 | 5 | 2 | 1 |
| 2. Deployer reliability (maximum = 200) | 125 | 95 | 100 | 70 | 55 | 70 | N/A | 45 | N/A |
| 3. Deployment mechanism weight | 1,823 lb | 2,050 lb | 950 lb | 833 lb | 1,333 lb | 1,355 lb | 1,938 lb | 112 lb | 100 lb |
| 4. Root strength | Best | Best | Good | Marginal | Marginal | Marginal | Marginal | Marginal | Marginal |
| 5. EVA requirements (1 = none, 10 = heavy) | 1 | 3 | 1 | 3 | 3 | 1 | 7 | 6 | 10 |
| 6. Technology requirements Development test requirements (0 = minimum development) | 0.88 | 1.00 | 0.73 | 0.99 | 0.96 | 0.93 | 0.89 | 0.91 | 0.73 |
| 7. Suitability for reload | Ground | Ground | Space | Ground | Ground | None | Space | Space | N/A |
| 8. Ease of ground demonstration | Good | Good | Good | Good | Good | Good | Good | Good | Best |
| 9. Manufacturing complexity (0 = simplest) | 1.00 | 0.80 | 0.30 | 0.65 | 0.80 | 1.00 | 0.40 | 0.25 | 0.15 |

2.74-meter (9-foot) two-jackscrew deployer is the least weight followed by the linear motor deployer. Other concepts are heavier by virtue of more and/or longer jackscrews, rails and supporting structure.

### 1.4.4 Root Strength

The best deployers for root strength are the two four-jackscrew deployer options. The four jackscrews, rails and supporting structures provide the best truss stability during deployment. The linear motor deployer arms provide good root strength as well which is impressive considering its relatively low-weight design. Other options featured relatively low weights; however, the fewer jackscrews, rails and supporting structures resulted in designs with marginal root strength.

### 1.4.5 EVA Risk

EVA risk was rated on a ten-point scale with one representing little or no EVA and ten representing heavy EVA. The four-jackscrew baseline, 5.49-meter (18-foot) extendable two-jackscrew, and linear motor deployers are all rated best in terms of EVA risk. All require little or no EVA to supervise the deployment of the truss. The other jackscrew deployer concepts involve folding jackscrews and require active EVA participation during the initial phase of deployment. The transporter assisted, semi-manual tool and two-man EVA assisted deployment options all require extensive EVA participation throughout the deployment process. Upon closer examination of the two-man assisted option, the EVA requirements are so large that it is eliminated by this criteria alone.

### 1.4.6 Development Risk

Development risk was assessed based on estimated test requirements for the various concepts. The rating was made on a scale from zero (minimum development required) to one. The ratings of all concepts are in a tight band. It is interesting to note that the linear motor deployer received the best rating although the four-jackscrew baseline deployer is considered more reliable. This indicates that considering the design drawings available without regard to proven usage of the technology results in lesser development risk for the linear motor deployer.

### 1.4.7 Suitability for Reload

Each concept was evaluated for reload capability in space or on the ground. In-space reload is preferred because only one deployer is required to assemble the entire Space Station truss structure (although a back-up would be considered). Reload on the ground requires at least two deployers to facilitate the NSTS flight schedule. Either capability is preferred to requiring a separate truss deployer for each truss assembly delivered to orbit.

The words provided in Table 1.4-1 indicate the reload capability of each option. The concepts capable of space reload can also be reloaded on the ground. The linear motor, transporter assisted and semi-manual tool deployers have in-space reload capability. Each of these concepts are readily attached to and removed from the truss housing using existing EVA tools. The five jackscrew deployer concepts each can be adapted to ground reload but would require extensive EVA or added complexity to allow in-space reload.

#### 1.4.8 Ease of Ground Demonstration

Evaluation of ground demonstration resulted in no significant discriminators between concepts. None of the concepts received an excellent rating due to the difficult nature of demonstrating hardware on the ground to simulate an operation that will take place in space. The two-man EVA assisted deployment option was deemed best simply because no complex mechanisms require ground evaluation.

#### 1.4.9 Manufacturing Complexity

Manufacturing complexity was rated on a zero (least complex) to one scale. All five jackscrew deployment concepts are judged the most complex. The addition of the spline shaft jackscrew deployment systems in the four-jackscrew baseline and 5.49-meter (18-foot) extendable two-jackscrew deployers resulted in the highest complexity rating given. The semi-manual tool deployer received the best rating (except for the two-man EVA assisted option) with the linear motor deployer close behind. The reciprocating mechanism deployment technique in general is considered much less complex than the jackscrew method of deployment.

#### 1.4.10 Summary

Based on the results of the trade study, the linear motor and semi-manual tool deployer concepts were recommended for development into a preliminary design. When simultaneously considering the key criteria of cost, reliability, deployer weight, root strength and EVA risk, these deployers demanded further consideration. Upon the completion of the preliminary designs, detail comparisons to the proven four-jackscrew baseline deployer can be conducted for a final recommendation.

It is interesting to note that a concept similar to the transporter assisted deployer developed under this contract is under consideration for assembling erectable trusses for the Space Station. The concept uses the transporter, which doubles as the MSC transporter, as part of the erection fixture located in the NSTS payload bay. The reciprocating transporter drives assembled truss bays out of the payload bay to allow subsequent truss assembly at a single location. This concept was recommended by the Critical Evaluation Task Force (CETF) at Langley Research Center.

### 1.5 PRELIMINARY DESIGN OF SELECTED CONCEPT

Shortly after the preliminary design of the linear motor deployer and semi-manual tool deployer was initiated, the idea of a single design that incorporates the advantages of both deployers was formulated. The strong points of the linear motor deployer are its low relative cost, high reliability, low EVA requirements and good root strength. The linear motor deployer is also in-space reloadable; however, the associated reloading operations as initially defined are cumbersome in comparison to the semi-manual tool deployer. Other strong points of the semi-manual tool deployer are its very low relative cost, very low weight and low manufacturing complexity. The weaknesses of the semi-manual tool deployer--primarily low reliability, marginal root strength and excessive EVA requirements--are formidable obstacles to its implementation.

Further study of the semi-manual tool deployer revealed the ease of attachment, removal and re-attachment as its best feature relative to other designs. The incorporation of this feature into the linear motor deployer provides the best deployer for comparison with the four-jackscrew baseline deployer. Figure 1.5-1 shows the reloading operation possible with this type of linear motor deployer. Recognizing the promise of this concept, the preliminary design proceeded without further consideration of the semi-manual tool deployer as initially developed.

### 1.5.1 Linear Motor Background

The force generating capability of DC linear motors was largely responsible for its selection over other types of linear motors (microstepping linear motors, for instance). Peak forces of up to 1000 pounds each can be generated by this in-space proven motor. This is more than adequate to overcome frictional forces existing in the stowed truss and mating surfaces of the deployer.

The force is generated by an electromagnetic flux (EMF) established between magnet and coil assemblies (see Figure 1.5-2 for location on the deployer). Depending on the polarity of the flux in the coil, the magnet assembly is repulsed in either of the two linear directions. The level of the EMF force is remotely controlled by a electronic amplifier and power supply. Relative positioning of the magnet and coil assemblies is also remotely monitored. A time history of this relative position can be programmed such that the electronic amplifier is adjusted in real time.

### 1.5.2 Linear Motor Operation

The linear motor deployer concept utilizes two reciprocating deployer "yokes" to deploy a stowed linear truss. The pre-packaged truss is stowed in a housing and carried in the NSTS orbiter payload bay to orbit. Two structural pallets attach to payload bay sill longeron and keel bridge fittings, as shown in Figure 1.5-3. The aft pallet reacts x- and z-direction loads while the forward pallet reacts x-, y- and z-direction loads.

In the first stage of deployment, the forward pallet is separated from the truss housing. The housing is then rotated to a vertical position with the forward pallet still in place (see Figure 1.5-4). The pallet to housing interface is angled to provide clearance during the rotation. Actual truss deployment begins as four grapple latches

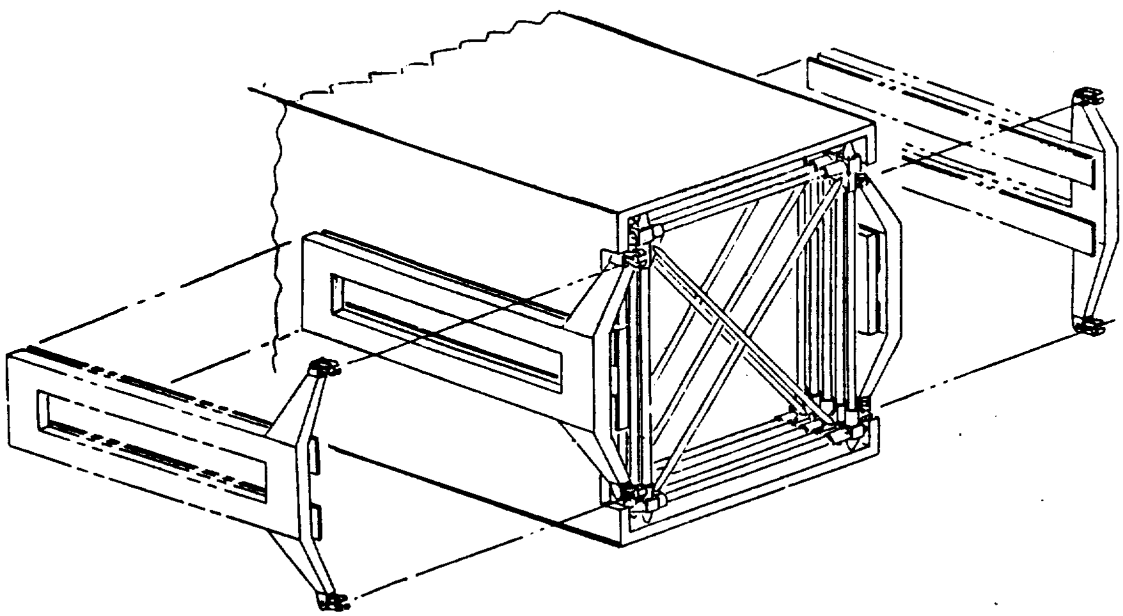


Figure 1.5-1. Reloadable Linear Motor Deployer

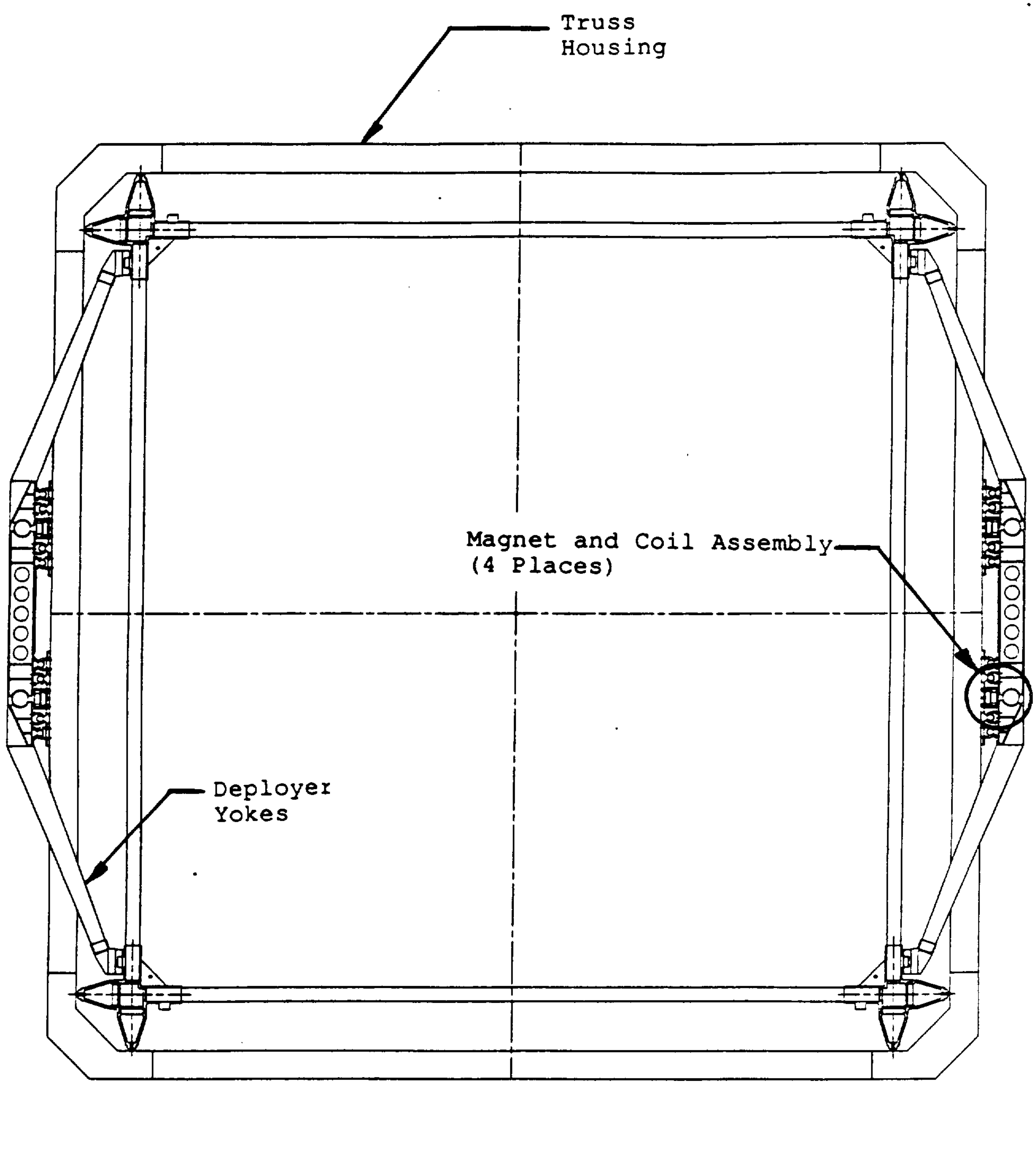



Figure 1.5-2. Linear Motors Located on Opposite Sides of Truss Housing

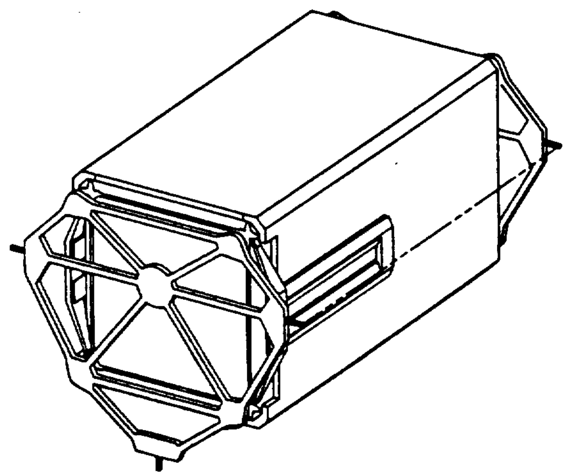


Figure 1.5-3. Structural Pallets Used to Attach Packaged Truss to NSTS Payload Bay

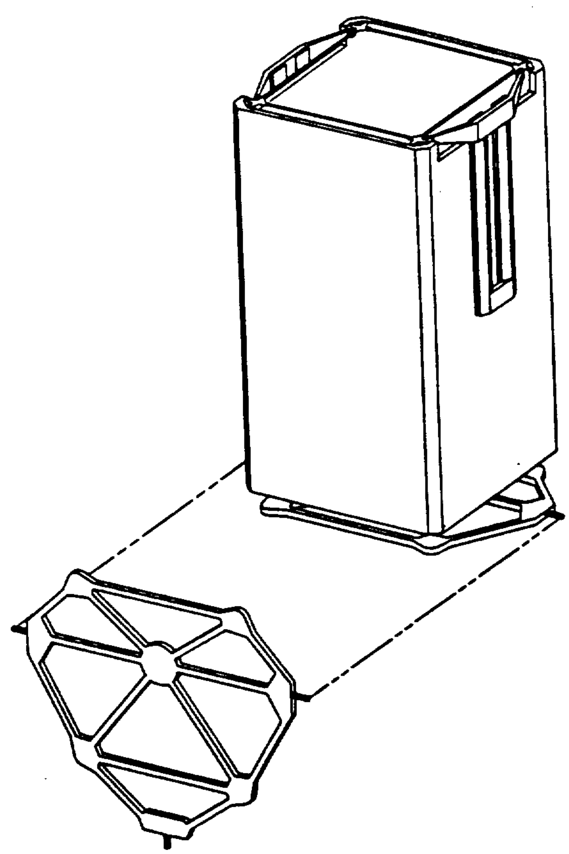


Figure 1.5-4. Truss Housing Rotated in Preparation for Deployment

at the extremities of the deployer yokes secure probes located on each of the four corners of the outermost batten frame. With positive capture confirmed, the deployer yokes begin linear travel outward from the housing. The two yokes are driven independently to accomodate potentially unbalanced loads during deployment. Deployment of a bay is complete when motor positioning data indicates full bay extension and current draw data indicates resistance to yoke motion. Overlap of the linear motion elements provides root strength during all phases of this operation. After successful deployment of a bay, the grapple latches release the batten corner fitting probes and the yokes are retracted to grapple the next batten frame which has been pulled into detents vacated by the first frame. This procedure is shown in Figure 1.5-5. The truss bays are repetitively extracted from the housing until deployment is complete.

### 1.5.3 Deployer Design

The linear motor assembly is attached to the sides of the truss housing. The forward portion of the housing is cut out to accomodate the deployer yoke interface with the truss batten frame. An end view of this assembly is shown in Figure 1.5-2 and an exploded view of all deployer components is shown in Figure 1.5-6. The deployer yoke (or carraige structure assembly), an interface plate, linear motor magnet assembly, guide rails and teflon coated linear bushings make up the reciprocating portion of the deployer. The linear motor magnet assembly, rigidly attached to the interface plate, is the moving part of the assembly. The linear motor electromagnetic coil/guide assembly, base platform, another set of guide rails and teflon-coated linear bushings comprise the assembly rigidly attached to the truss housing. The electromagnetic coils run the length of the coil guide and provide the flux that generates the linear force. A cross-section of the assembly rigidly attached to the truss housing is shown in Figure 1.5-7.

The deployer yokes are made of sheet metal and the spars, ribs, tubes and skins are made of machined aluminum. The completed assembly, minus the sheet metal skin, is shown in Figure 1.5-8. The interface plate, guide rails, teflon coated bushings and linear motor magnet assembly are rigidly attached to this structure.

The mechanical elements of the linear motor deployer developed as part of the linear motor design include:

- o Linear motor retention latches, guides and shear pins to clamp the deployer assembly to the truss housing, release the assembly when deployment is complete and transfer load from the deployer to the truss housing
- o Truss retention pins and latches to secure a truss bay prior to deployment and ensure the truss locks in place when deployed
- o Grapple latches that secure the truss to the deployer carraige yoke and provide root strength to the truss during deployment

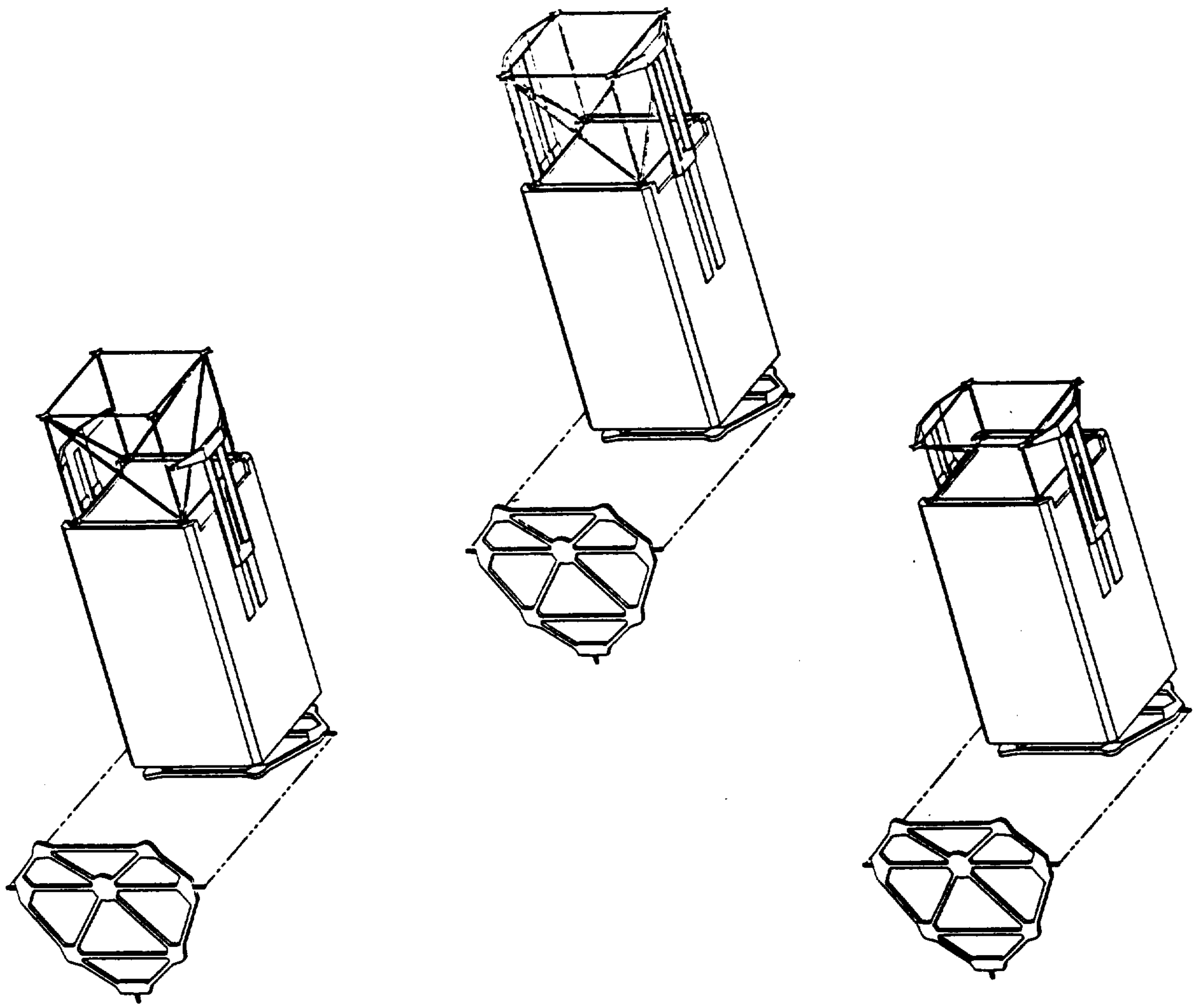


Figure 1.5-5. Linear Motor Deploys First Bay of Truss

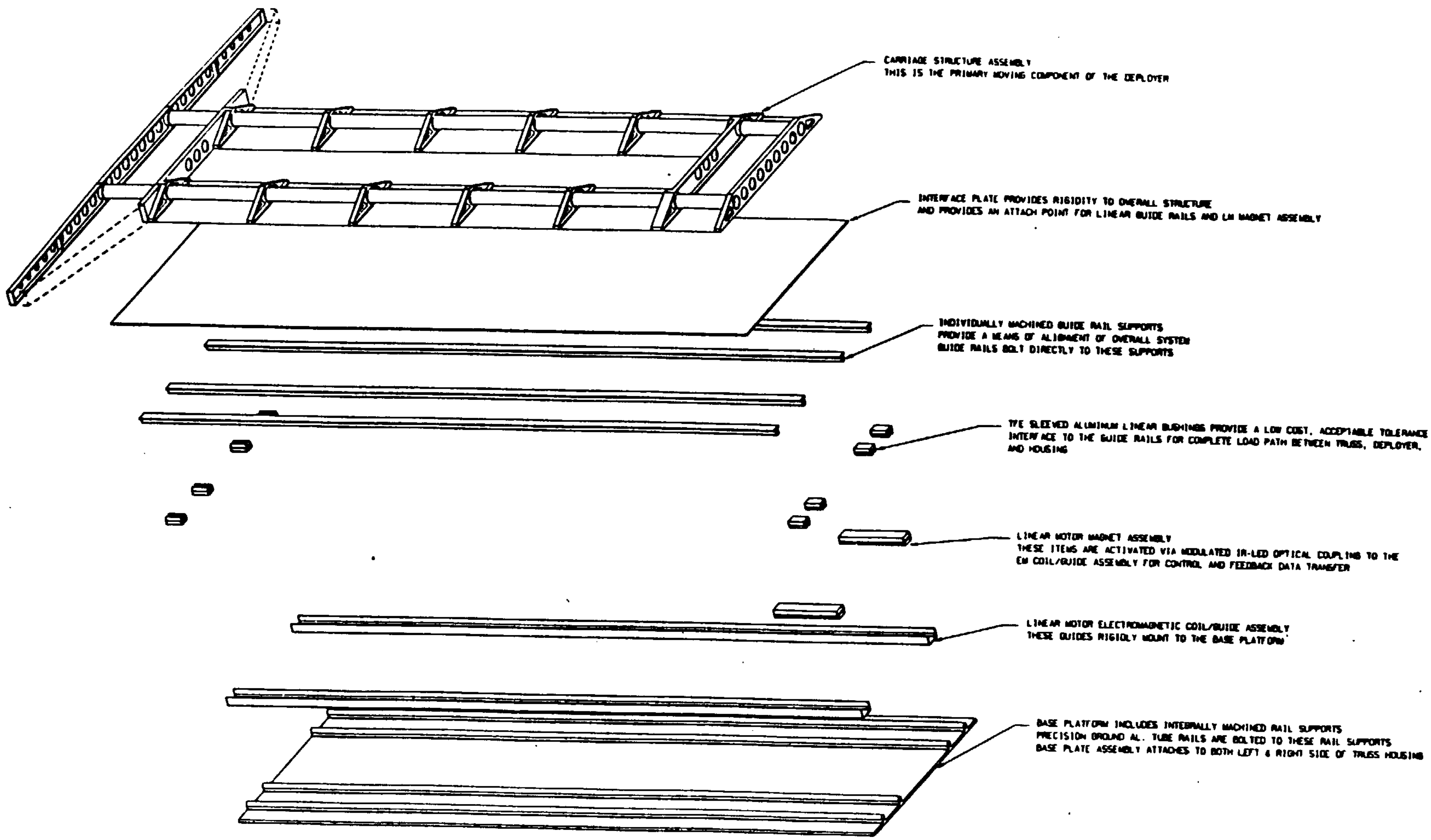



Figure 1.5-6. Exploded View of Linear Motor Deployer

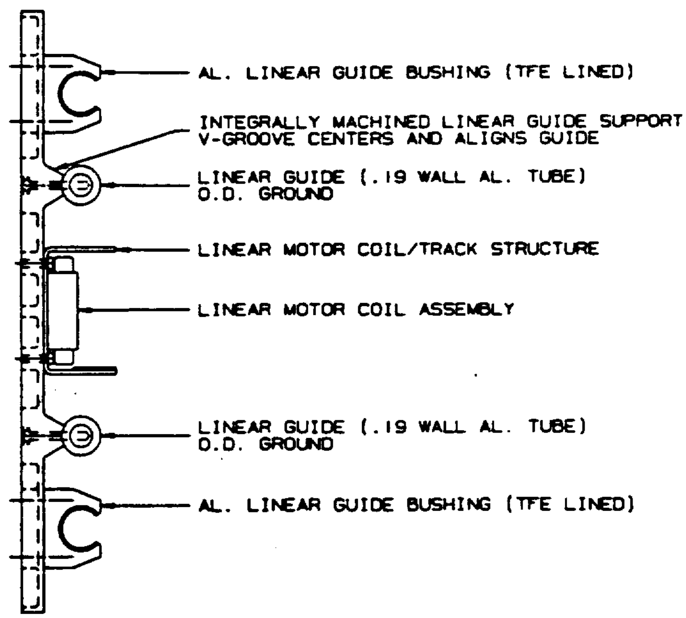



Figure 1.5-7. Linear Motor and Guide Assembly

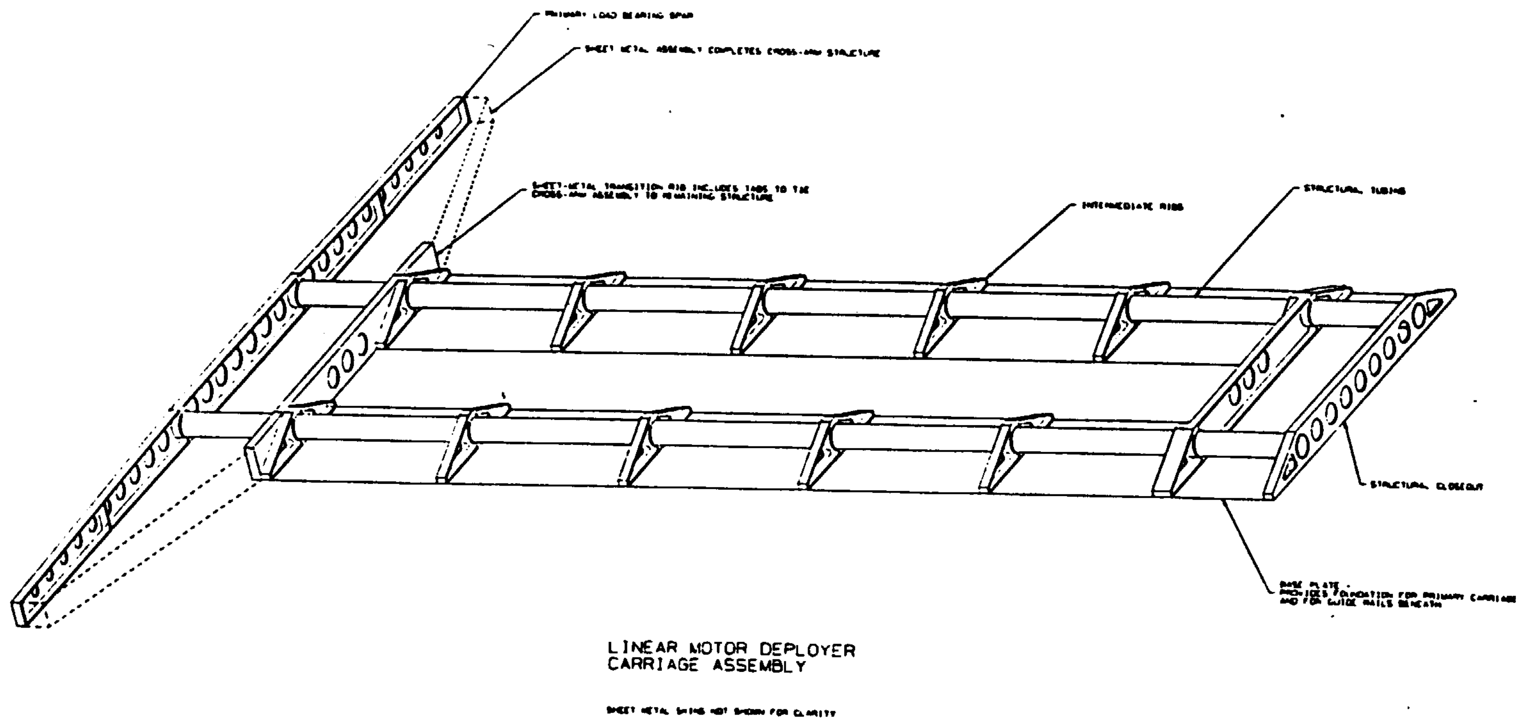



Figure 1.5-8. Linear Motor Carraige Assembly

The linear motor retention latches, guides and shear pins are depicted in Figure 1.5-9. The toggle clamp lever shown provides the reloadable feature by releasing the deployer from the truss housing when deployment is complete. When a subsequent loaded housing is delivered to space, the toggle clamp is used to secure the deployer to the housing. An alternate to this design not developed is a spring-loaded, remotely-actuated latch to replace the toggle clamp lever.

The truss retention pins and latches are shown in Figure 1.5-10. The unidirectional rotary latch and locking lever work in tandem to secure and release truss batten frames as they exit the housing.

The grapple latch is shown in Figure 1.5-11. A rotary solenoid is used to energize the grapple latch during deployment and de-energize the latch during yoke retraction and truss capture. An alternative concept investigated is a mechanical grapple latch. Such a latch reduces deployer power requirements but, as developed, has minimal root strength.

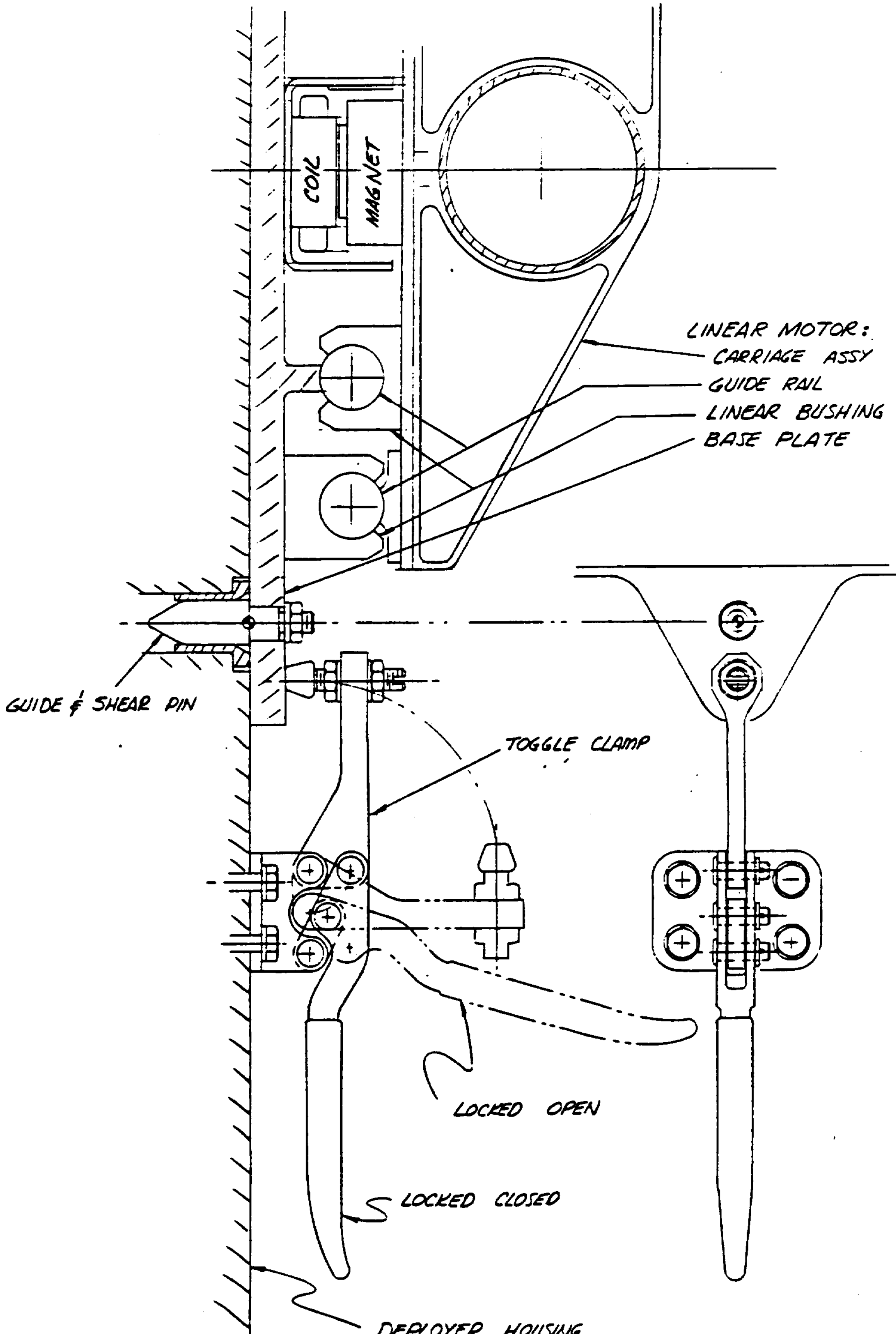



Figure 1.5-9. Deployer Latches, Guides and Shear Pins

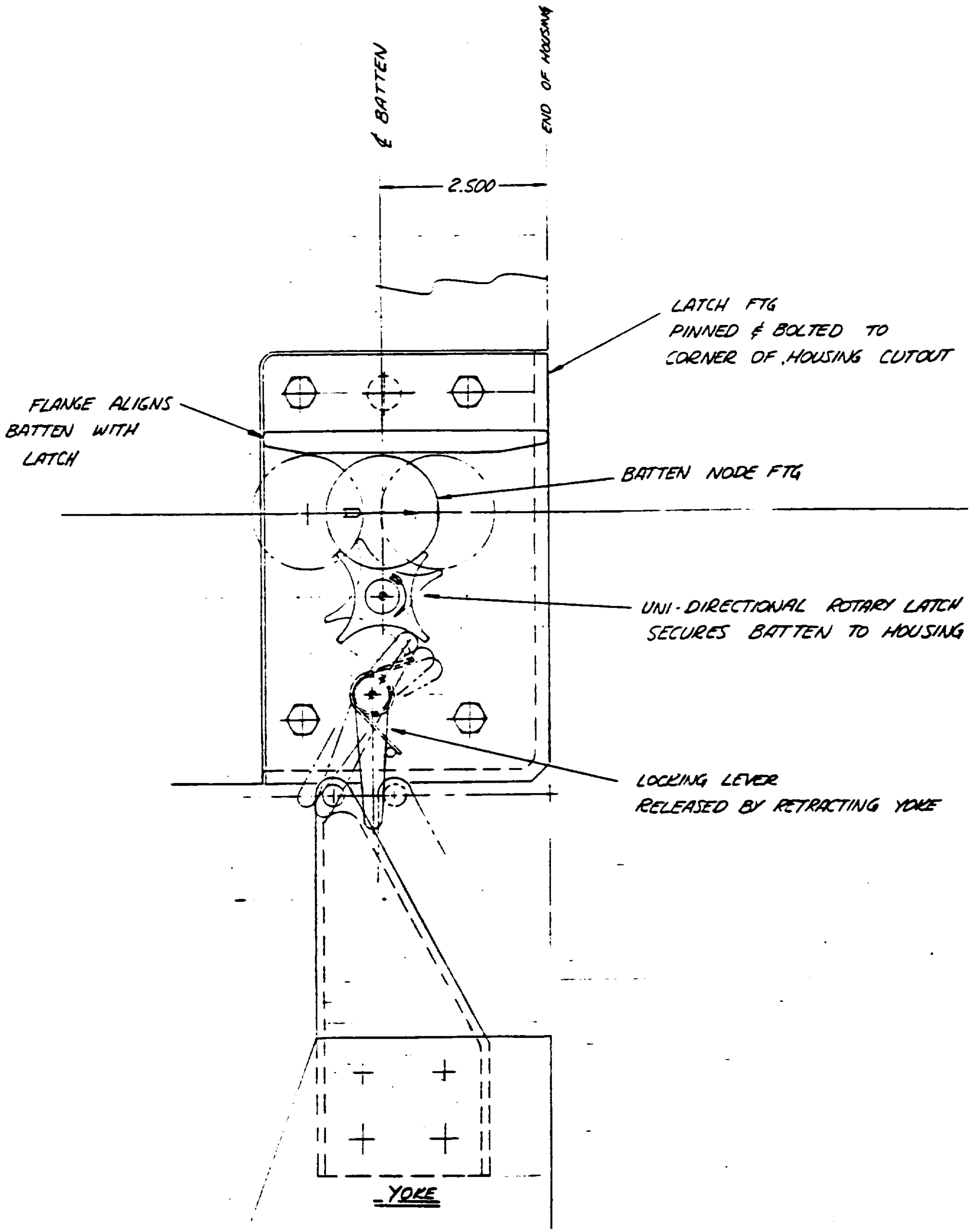



Figure 1.5-10. Deployer Retention Pins and Latches

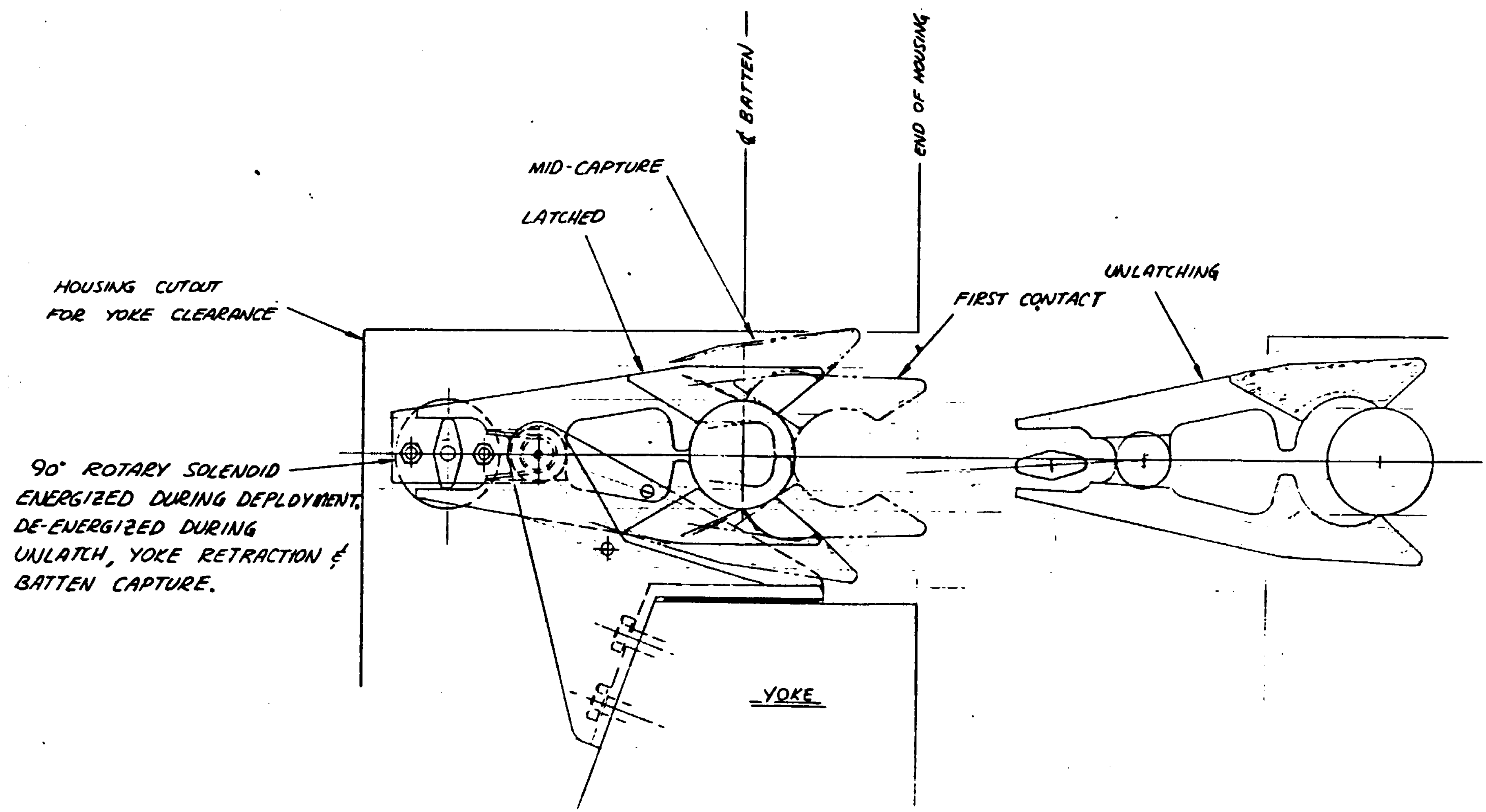



Figure 1.5-11. Truss Batten Frame Grapple Latch

# 2.0 ADVANCED COMPOSITES DEPLOYABLE TRUSS DEVELOPMENT

## 2.1 INTRODUCTION

The environment in which the Space Station will operate and the functional requirements imposed on its structure dictate the use of advanced composites for truss components. Truss struts are an obvious application for continuously reinforced graphite epoxy composites because of the material's thermal stability and high stiffness potential. Other deployable truss components, such as strut end fittings, are also candidates for composites. Task 2 of this contract, which was terminated in October 1985, consisted of:

- o Defining Space Station truss structure requirements
- o Material selection and coupon testing
- o Strut end fitting trade study

## 2.2 SPACE STATION TRUSS REQUIREMENTS

Major requirements were defined for the Power Tower Space Station configuration shown in Figure 2.2-1. This configuration was the NASA baseline in June 1985 when work on this contract began. A 2.74-meter (9-foot) cube is the basic building block of the deployable truss which also contains 3.88-meter (12.7-foot) diagonal members. The struts that make up the truss are tubular with end fittings that allow connection to adjacent members. Folding and telecoping center joints are used in members that are altered to facilitate the stowed position of the deployable truss. The requirements, shown in Table 2.2-1, address the individual struts that comprise the truss in this configuration. While the stiffness and strength requirements shown are unique to the Power Tower configuration, the other requirements are still applicable as are the following sections that summarize each of the major requirements.

### 2.2.1 Dimensional Stability

Dimensional stability is one of two key design drivers that dictates the use of low coefficient of thermal expansion (CTE) materials for the strut tubes. Due to their low weight, graphite epoxy composites are favored over Invar for the truss tubes when considering this requirement. While low CTE materials are also desirable for end fittings and center joints, there is less a need in that application since they comprise a small portion of the overall strut length. Satisfying this requirement ensures uniform deployment of the truss and maintains pointing and tracking accuracy of on-board experiments and power generation equipment during thermal exposure.

### 2.2.2 Axial Stiffness

Axial stiffness is the other key design driver affecting the selection of materials for the Space Station truss structure. An analysis of the overall structure flexural (EI) and torsional (GJ) stiffness requirements leads to a design governed by the product of

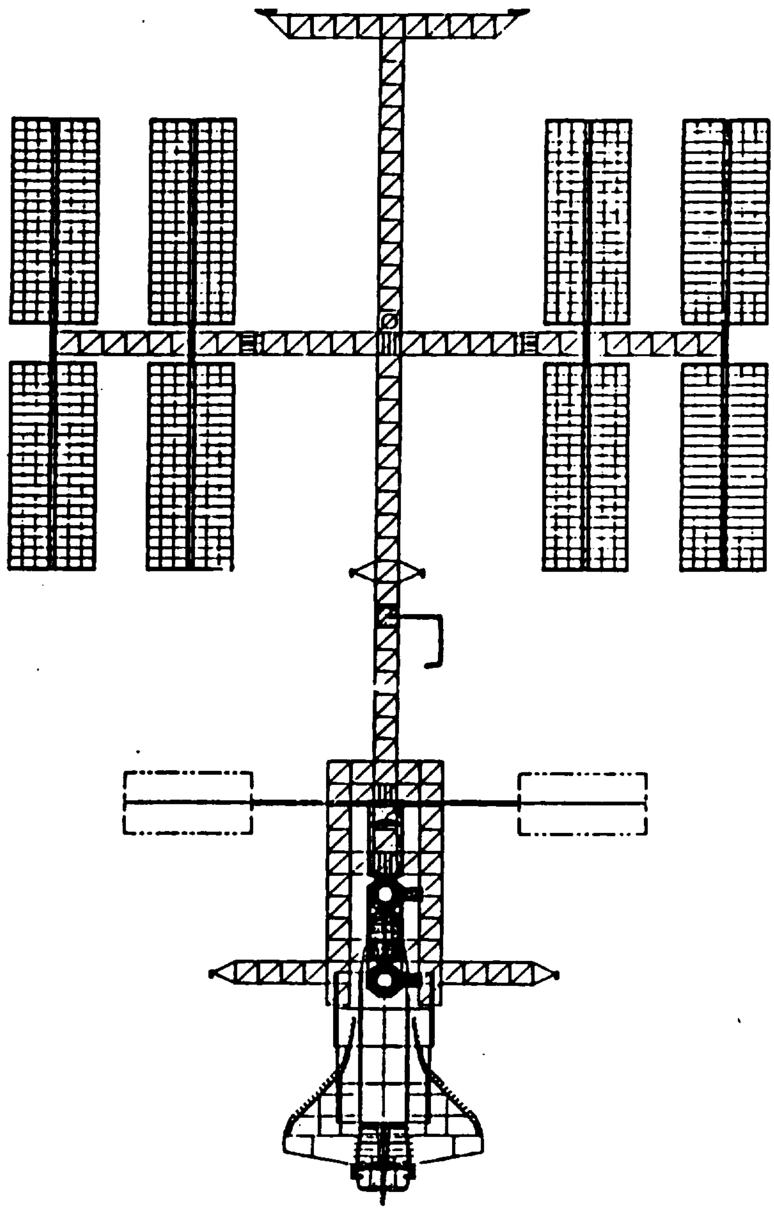


Figure 2.2-1. Power Tower Space Station Configuration

Table 2.2-1. Truss Requirements Dictate Use of Advanced Composites

| Type | Requirement | Rationale |
|---|---|---|
| Dimensional stability (coefficient of thermal expansion) | $-0.9 \times 10^{-6}$ to $0.9 \times 10^{-6}$ m/m-°C ($-0.5 \times 10^{-6}$ to $0.5 \times 10^{-6}$ in./in.°F) | Assures trouble-free deployment and maintains pointing and tracking accuracy during thermal exposure |
| Axial stiffness ($A_{tube} \times E_L$) | $38 \times 10^6$ N ($8.5 \times 10^6$ lb) | Provides sufficient stiffness for adequate frequency separation of structures and control systems |
| Strength (ultimate column loads, tension, and compression) | 11,600 N (2,600 lb)<br>5,800 N (1,300 lb) | Ultimate loads for longerons/battens and diagonals respectively during RCS maneuvers and berthing loads |
| Age life in space (atomic oxygen, thermal cycling, and UV radiation) | 30-year exposure 250-nautical mile orbit, -100°C to 90°C (-150°F to 200°F) | Degradation of composite resin, development of coating and "toughened" composite required |
| Damage resistance and repair | Handling loads during fabrication and on-orbit deployment, on-orbit debris impact | Resistance a function of material selection and fiber orientation, repair techniques required |

the cross-sectional area and longitudinal modulus of the strut tube as shown in Table 2.2-1. There are a number of materials and fiber orientations that satisfy this requirement with weight and cost the obvious trade-off. The end and center fittings again do not contribute significantly to the overall strut stiffness, but the design chosen for these components must not appreciably degrade from the performance of the strut.

### 2.2.3 Strength and Stability

Strength is of less concern for the Space Station due to the low operational loads expected. The areas of most interest are the transition regions between the composite tube and end or center joint fittings. Column stability is also a concern more because of the effect the end fittings and center joints have on end fixity than the magnitude of the loads involved. The design of the tube-to-fitting interface is the key to satisfying both requirements.

### 2.2.4 Age Life in Space

Age life in space is the major materials selection driver and creates a concern with the use of composites. Atomic oxygen and thermal cycling are the two most severe aspects of the low earth orbit environment. Atomic oxygen particles degrade the epoxy in a graphite epoxy system through kinetic energy and/or chemical reaction. Thermal cycling causes microcracks to form in the epoxy due to the CTE mismatch between the graphite fiber and epoxy resin. The development of "toughened" resins and protective coatings for the composite tubes is necessary to satisfy this requirement.

### 2.2.5 Damage Resistance and Repair

Damage resistance and repair are practical requirements necessary for the low cost implementation of composites to the Space Station. Damage resistance is a function of material selection, fiber orientation and external protection. Development of non-destructive test methods for damage detection is essential if composites are used. Development of repair techniques for damaged tubes and removed external protection is required to minimize strut replacement. The level of damage in which a repair is necessary must be established.

## 2.3 MATERIAL SELECTION AND COUPON TESTING

The material selected for coupon testing was P75S/934 graphite epoxy. P75S is a 517 GPa (75 MSI) modulus graphite fiber manufactured by AMOCO Performance Products, Inc. (formerly a product of Union Carbide). The fiber is procured by Fiberite and their 934 epoxy, a 177°C (350°F) cure temperature resin, is used to produce the completed prepreg. This selection, made due the high specific stiffness and low CTE of the material, was based on the requirements for the Power Tower Space Station truss configuration. The coupon tests were used to confirm the selection by verifying material properties. Further detail on material selection and coupon testing are described in the following sections.

### 2.3.1 Material Selection

A wide variety of composites were considered for the truss tube. The materials considered range from high strength, low modulus glass reinforced composites to moderate strength, high modulus graphite reinforced composites. Three materials were chosen for further scrutiny from those available; namely, T300/934, T50/934, and P75S/934. All of the products are Fiberite manufactured prepregs.

The T300/934 material features high strength and moderate to low modulus and has been extensively used on the NSTS payload bay doors and Orbital Maneuvering System (OMS) pods. It deserves serious consideration because of its large data base and impressive track record. The T50/934 material features intermediate strength and modulus. It deserves consideration due to an improvement in modulus and CTE properties compared to T300/934 and favorable cost compared to P75S/934. The P75S/934 material features the best modulus and CTE of the three composites considered; however, it is also the most costly. Higher modulus fiber systems, such as P100/934, were not considered due to their prohibitive cost and lack of track record.

The discriminating factors involved in selecting P75S/934 for the coupon tests are shown in Table 2.3-1. The CTE and specific stiffness properties of the material are significantly better than that of the T50/934 and T300/934 materials. The negative CTE value is desirable to offset positive CTE contributions from end fittings and center joints. The objective is to design a strut with an overall CTE as close to zero as possible. The specific strength of P75S/934, while lower than that of the other systems, is more than adequate for the lightly loaded Space Station truss structure. The applicable experience of P75S/934, while minimal in comparison to T300/934, does include currently orbiting satellites. Finally, even though P75S/934 has the least resistance to microcracking of the three systems evaluated, the material properties most critical to the Space Station truss are not affected.

### 2.3.2 Coupon Testing

The coupon tests were used to compare collected material property data with manufacturer supplied data and to verify the selection of P75S/934 as the baseline for the Space Station truss tubes. The following tests were performed:

- o Tension and compression tests at room temperature, -100°C (-150°F) and 90°C (200°F) for control and thermal cycling exposed specimens
- o CTE tests over a temperature range of -100°C to 121°C (-150°F to 250°F) for control, thermal cycling exposed and atomic oxygen exposed specimens
- o Thermal cycling tests over a temperature range of -100°C to 90°C with subsequent inspection for microcracking
- o Atomic oxygen exposure tests with subsequent inspection for

Table 2.3-1. P75S/934 Chosen for High Specific Stiffness and Low Thermal Expansion

| Requirement | Undirectional Material Properties | | |
|---|---|---|---|
| | P75S/934 | PAN50/934 | T300/934 |
| Thermal expansion (in./in.-°F) | $-0.7 \times 10^{-6}$ | $-0.4 \times 10^{-6}$ | $-0.3 \times 10^{-6}$ |
| Specific stiffness ($E/\rho$, in.$^5$) | $590 \times 10^6$ | $505 \times 10^6$ | $315 \times 10^6$ |
| Specific strength ($Ftu/\rho$, in.) | $1.6 \times 10^6$ | $2.7 \times 10^6$ | $3.6 \times 10^6$ |
| Application experience | Some spacecraft | Some aerospace | Widespread aerospace, aircraft |
| Microcracking sensitivity | Least resistance of systems considered, extensional properties unaffected, torsional properties reduced | No data | Highest resistance of systems considered |

resin and fiber damage

The results of the tension tests are shown in Table 2.3-2. The test specimen used is shown in Figure 2.3-1. The tests were all performed to failure. The location of most failures were in the grips; an indicator that the peak ultimate strengths were not obtained. The strengths achieved were all in excess of truss strength requirements and high enough to obtain good modulus data. The modulus values were measured at three different locations on the stress-strain curve because as the stress in the material increased, the slope of the curve increased. The three measurements--designated E1, E2 and E3 in Table 2.3-2--were taken as follows:

- o E1: initial linear portion of the stress-strain curve
- o E2: secant modulus between 20 and 50 percent of ultimate stress
- o E3: the upper-most linear portion of the stress-strain curve

The manufacturer's published data reveals a significant difference in the compression and tension modulus of P75S/934 (241 GPa or 35 MSI versus 310 GPa or 45 MSI). It can be surmised, then, that the modulus of the material at low stress levels may be in between the two extremes. Although the results shown in Table 2.3-2 do not approach the 310 GPa (45 MSI) stiffness level, the trend of lower modulus for lower stress levels is confirmed. The tension modulus of previously thermally cycled tension specimens are not appreciably different from the control specimens. The tension modulus of specimens tested at 90°C (200°F) are consistently higher than the room temperature or -100°C (-150°F) tests.

The results of the compression tests are shown in Table 2.3-3. The test specimen is shown in Figure 2.3-2. The specimen was loaded in four-point bending resulting in pure compression on the graphite epoxy face sheet. The tests were all performed to failure. All failures occurred when the composite face sheet delaminated. Lengths of the delamination are noted in Table 2.3-3. The modulus values obtained are less than published data, but seem to correspond to tension test data. The values are slightly less than the E1 tension modulus values as expected.

The results of the CTE tests are shown in Table 2.3-4. The test specimens were 12.7 mm (0.5 inch) by 76.2 mm (3.0 inches). The equipment used to obtain the data was a push rod dilatometer. The values obtained correspond well with published data. The CTE is not significantly affected by specimens previously exposed to thermal cycling or atomic oxygen.

The thermal cycle selected for testing is shown in Figure 2.3-3. The 32-minute cycle length, compared to the 90 minute earth orbit cycle, was selected to generate representative data at reduced cost. A total of 500 thermal cycles were performed with inspections occurring before exposure and at 25, 100, 200, 300, 400 and 500 cycles. A scanning electron microscope (SEM) was used to examine the

Table 2.3-2. Tension Test Results Verify Low Stress Modulus Trends

| SPEC NO. | ULTIMATE STRESS (KSI) | STRAIN TO FAILURE ($\mu$IN/IN) | MODULUS (KSI) $E_1$ | $E_2$ | $E_3$ | POISSON'S RATIO | TEST TEMP (F) | LOCATION OF FAILURE |
|---|---|---|---|---|---|---|---|---|
| IU2-1 | 97.92 | 2464 | 34.00 | 35.00 | 41.40 | 0.27 | 75* | in the grip |
| IU2-2 | 91.59 | 2560 | 34.00 | 37.80 | 38.00 | 0.31 | 75* | in the grip |
| IU2-3 | 116.50 | 3002 | 35.00 | 37.90 | 40.00 | 0.34 | 75* | gage area |
| AVG. | 102.00 | 2675 | 34.33 | 36.90 | 39.80 | 0.31 | 75* | --- |
| IU2-6 | 134.94 | 2694 | 36.00 | 38.90 | 40.9 | 0.30 | 75 | in the grip |
| IU2-7 | 116.88 | 2962 | 35.00 | 39.40 | 41.80 | 0.33 | 75 | in the grip |
| IU2-8 | 114.55 | 3137 | 30.00 | 35.20 | 39.90 | 0.27 | 75 | gage area |
| IU2-9 | 127.59 | 3169 | 35.00 | 39.10 | 41.80 | 0.32 | 75 | gage area |
| IU2-10 | 112.05 | 2646 | 39.00 | 40.40 | 44.00 | 0.39 | 75 | gage area |
| AVG. | 121.20 | 2876 | 35.00 | 38.6 | 41.48 | 0.32 | 75 | --- |
| IU2-11 | 72.66 | 2099 | 30.00 | 32.50 | 38.50 | 0.35 | -150 | in the grip |
| IU2-12 | 84.94 | 2055 | 32.00 | 43.60 | 42.00 | 0.39 | -150 | in the grip |
| IU2-13 | 82.15 | 2109 | 41.00 | 38.90 | 42.30 | 0.35 | -150 | in the grip |
| IU2-14 | 79.17 | 2378 | 33.50 | 34.00 | 36.90 | 0.34 | -150 | in the grip |
| IU2-15 | 96.36 | 2075 | 37.00 | 39.80 | 42.80 | 0.39 | -150 | in the grip |
| AVG. | 83.06 | 2143 | 34.70 | 37.76 | 40.50 | 0.36 | -150 | --- |
| IU2-16 | 82.70 | 1985 | 42.00 | 38.60 | 40.20 | 0.36 | 200 | in the grip |
| IU2-17 | 106.81 | 2548 | 39.00 | 41.40 | 44.00 | 0.33 | 200 | in the grip |
| IU2-18 | 103.05 | 2417 | 41.00 | 40.90 | 42.60 | 0.41 | 200 | in the grip |
| IU2-19 | 106.11 | 2516 | 40.00 | 41.20 | 45.00 | 0.31 | 200 | in the grip |
| IU2-20 | 85.76 | 2059 | 33.00 | 40.20 | 44.60 | 0.34 | 200 | in the grip |
| AVG. | 96.89 | 2305 | 39.00 | 40.46 | 43.28 | 0.37 | 200 | --- |

*Thermal Cycled Prior to Tensile Test

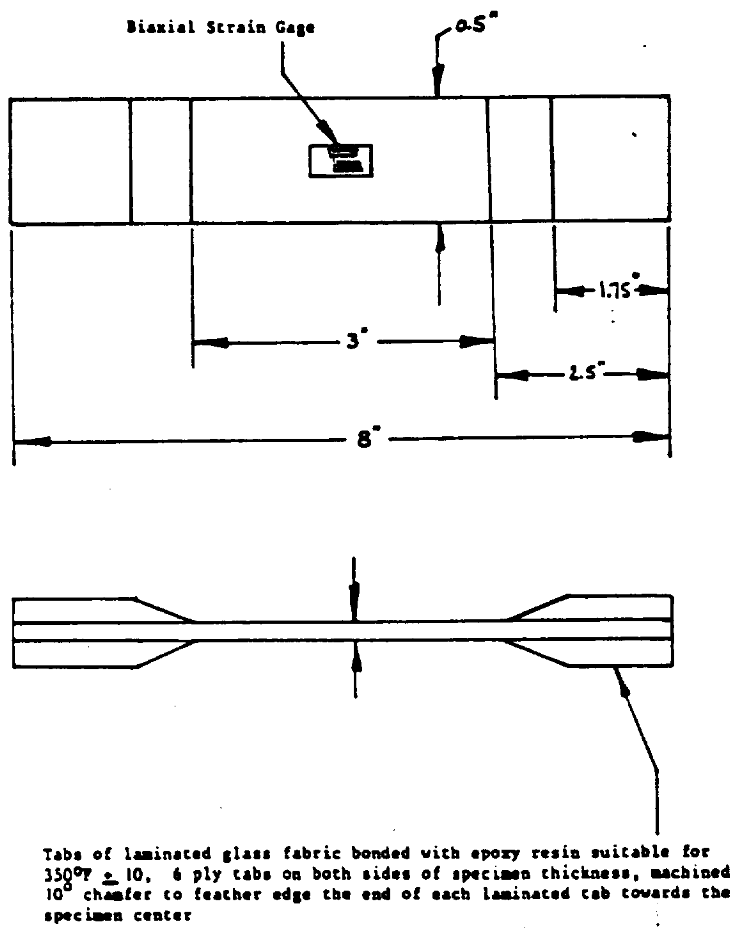
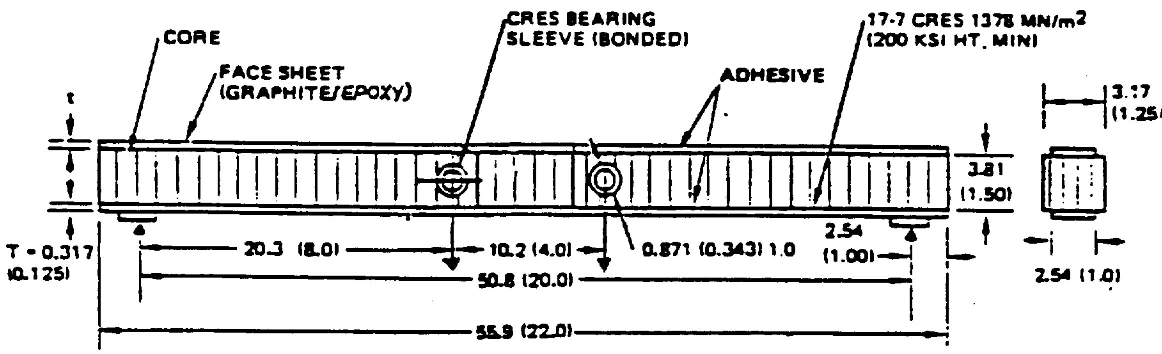



Figure 2.3-1. Tension Test Specimen

Table 2.3-3. Compression Test Results Verify Low Stress Modulus Trends

| SPECIMEN NO. | ULTIMATE STRESS (KSI) | STRAIN TO FAILURE ($\mu$IN/IN) | MODULUS KSI | TEST TEMP (F) | LENGTH OF DEBOND (INCH) |
|---|---|---|---|---|---|
| IU2-1 | 62.4 | 2194 | 35.2 | 75 | 6.5 |
| IU2-2 | 62.5 | 2304 | 36.2 | 75 | 10.5 |
| IU2-3 | 57.0 | 2022 | 35.3 | 75 | 9.5 |
| IU2-4 | 60.4 | 2208 | 32.9 | 75 | 10.0 |
| IU2-5 | 55.5 | 1955 | 32.9 | 75 | 8.5 |
| AVG. | 59.4 | 2137 | 34.2 | 75 | 9.0 |
| IU2-6 | 75.3 | 5837 | 32.0 | -150 | 10.6 |
| IU2-7 | 66.8 | 3069 | 29.0 | -150 | 10.0 |
| IU2-8 | 73.6 | 7280 | 32.0 | -150 | 16.0 |
| IU2-9 | 75.0 | 7934 | 32.0 | -150 | 12.7 |
| IU2-10 | 72.9 | 4344 | 34.0 | -150 | 11.5 |
| AVG. | 72.7 | 4633 | 32.0 | -150 | 12.1 |
| IU2-11 | 60.1 | 2084 | 35.0 | 200 | 4.0 |
| IU2-12 | 32.7 | 1036 | 33.0 | 200 | 8.0 |
| IU2-13 | 50.7 | 1648 | 34.0 | 200 | 4.0 |
| IU2-14 | 56.0 | 2062 | 33.0 | 200 | 2.0 |
| IU2-15 | 48.3 | 1562 | 34.0 | 200 | 5.0 |
| AVG. | 49.6 | 1679 | 33.8 | 200 | 5.4 |

FLEX SANDWICH BEAM TEST –
ULTIMATE COMPRESSION STRESS ON FACE SHEET




Specimen dimensions in centimeters & (inches)

Stress = 4P/( tW [ K+0.5(T+t) ] )

where:

P = Applied Load
W = Beam Width
K = Core Thickness
t = Compression Face Sheet Thickness
T = Tension Face Sheet Thickness

Figure 2.3-2. Compression Test Specimen

Table 2.3-4. Coefficient of Thermal Expansion Test Results Verify Published Data

| SPECIMEN NO. | TEMPERATURE RANGE (F) | MEAN CTE ($\mu$IN/IN-F) | | |
|---|---|---|---|---|
| | | CONTROLS | POST THERMAL CYCLING(2) | POST ATOMIC OXYGEN(5) |
| PARALLEL TO FIBER DIRECTION | | | | |
| IU1-1 | 75 TO -150 | -0.680 | -0.658 | -0.634 |
| | 75 TO 250 | -0.682 | -0.612 | -0.663 |
| IU1-2 | 75 TO -150 | -0.720 | -0.672 | -0.641 |
| | 75 TO 250 | -0.710 | -0.795 | -0.630 |
| IU1-3 | 75 TO -150 | -0.702 | -0.600 | NO TEST (4) |
| | 75 TO 250 | -0.622 | NO TEST (1) | " |
| AVERAGE | 75 TO -150 | -0.700 | -0.644 | -0.637 |
| | 75 TO 250 | -0.671 | -0.704 | -0.646 |
| TRANSVERSE TO FIBER DIRECTION | | | | |
| IU1-1 | 75 TO -150 | 12.60 | 12.61 | |
| | 75 TO 250 | 14.63 | 14.90 | |
| IU1-2 | 75 TO -150 | 12.82 | 12.60 | N/A |
| | 75 TO 250 | 15.06 | 14.66 | |
| IU1-3 | 75 TO -150 | 12.70 | NO TEST (3) | |
| | 75 TO 250 | 14.76 | " | |
| AVERAGE | 75 TO -150 | 12.71 | 12.60 | |
| | 75 TO 250 | 14.82 | 14.78 | |

NOTES:
(1) TEST MALFUNCTION
(2) CONTROL SPECIMEN THERMAL CYCLED (500 CYCLES)
(3) SPECIMEN DAMAGED IN HANDLING
(4) TEST SAMPLE TOO SMALL FOR THIRD SPECIMEN
(5) SPECIMEN TWO-INCHES IN LENGTH

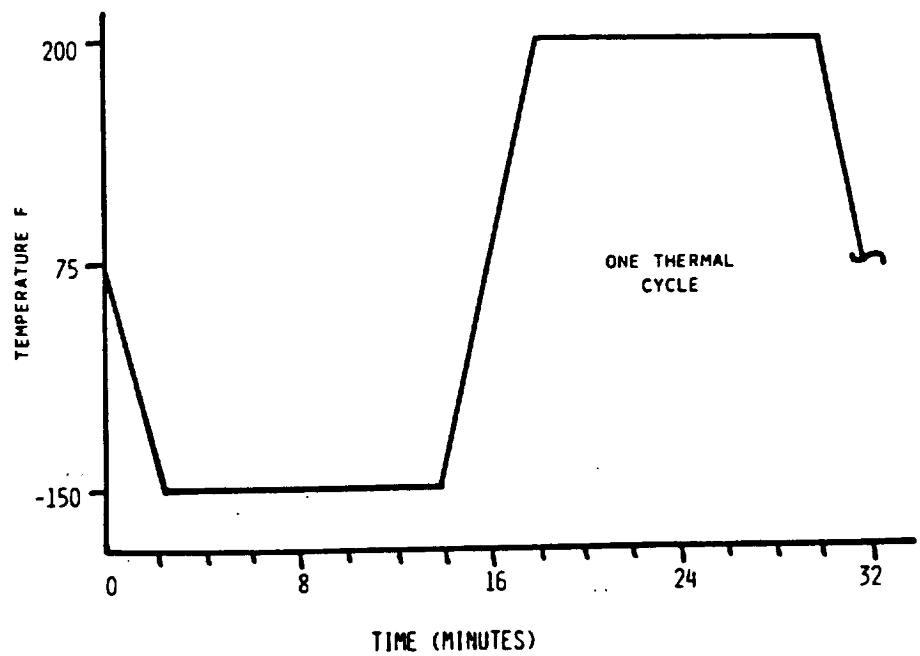



Figure 2.3-3. Thermal Cycle Chosen to Simulate Low Earth Orbit at Reduced Cost

specimens. One crack was observed prior to cycling and eight additional cracks were observed during the 400 cycle inspection. The cracks appeared to be insignificant and as previously described, did not adversely affect mechanical properties.

Low earth orbit atomic oxygen effects were simulated using a low temperature asher. The specimens exposed were 50.8 mm by 50.8 mm (2.0 inches by 2.0 inches) square. The specimens were prepared by covering all surfaces except a 38-mm by 44-mm (1.5-inch by 1.75-inch) area on one surface. The specimen was suspended in the chamber and exposed to 100 watts of RF power, 0.4 mm Hg and 55 cc/minute oxygen flow for various times. The results of the tests are shown in Figure 2.3-4. The plot shown indicates the loss of material thickness as a function of time. Both the resin and fiber were attacked in this environment as shown in Figure 2.3-5. The validity of the results is a subject of much debate. The process witnessed in these tests suggest a chemical reaction is the culprit for the material degradation--the material is eroded on all sides. Specimens returned from low earth orbit suggest a kinetic effect is present--the material is degraded only on one side apparently from the impact of atomic oxygen particles.

The complete laboratory test report on the coupon test program is provided in Appendix A.

## 2.4 STRUT END FITTING TRADE STUDY

The primary purpose of this trade study was to determine the best material and fabrication process for the end fittings of the truss struts. The secondary purpose of the trade study was to determine if composites are superior, or at least competitive, to metal in this application. The parameters evaluated included cost, weight and CTE of an overall strut (effects of composite tube and metal center joint included). Three basic concepts were evaluated in the trade study:

- Graphite epoxy or graphite polyetheretherketone (PEEK) composite molding

- Machined aluminum or titanium

- Investment-cast aluminum or titanium

Conceptual design drawings were completed for each type of fitting. The static analysis performed on each fitting assumed that the effective axial stiffness (the product of the cross-sectional area and the longitudinal modulus) of end fitting should be identical to that of the composite tube. The effective strut CTE was computed after the end fitting was sized.

The design for the molded composite fittings is shown in Figure 2.4-1. This end fitting is stiffened by three ribs and has a metallic insert in the end for interface with a rod end.

The design for the machined end fitting is shown in Figure 2.4-2. The end fitting chosen is similar to the end fitting designed for the Ground Test Article designed under contract NAS8-34677, Development of

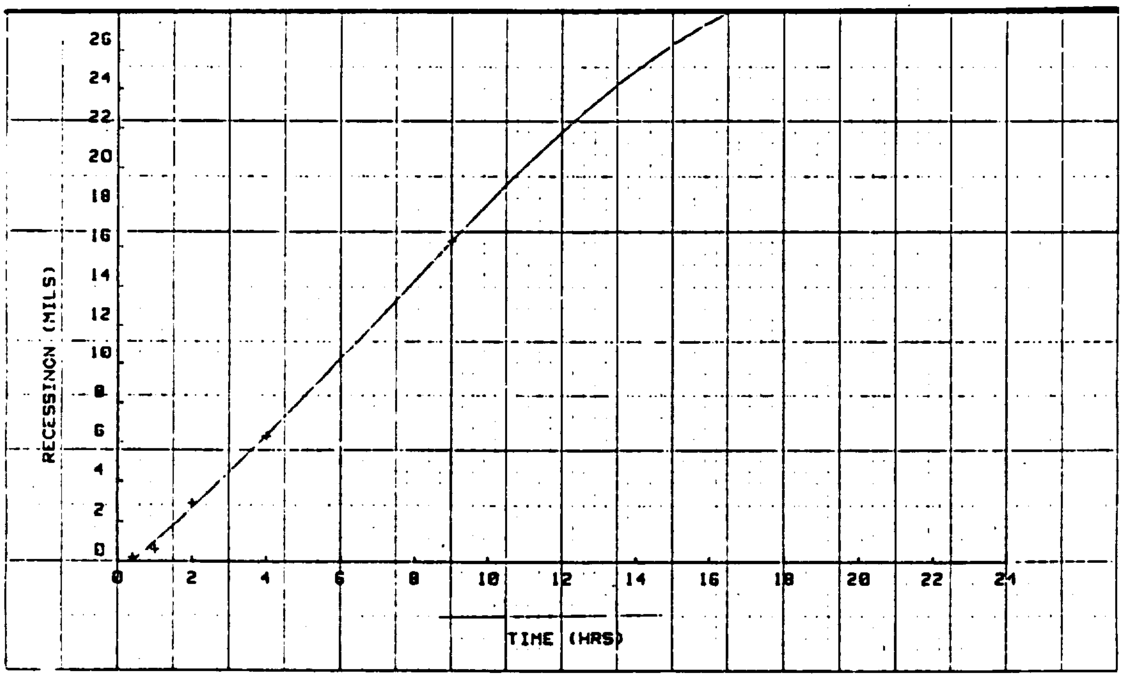
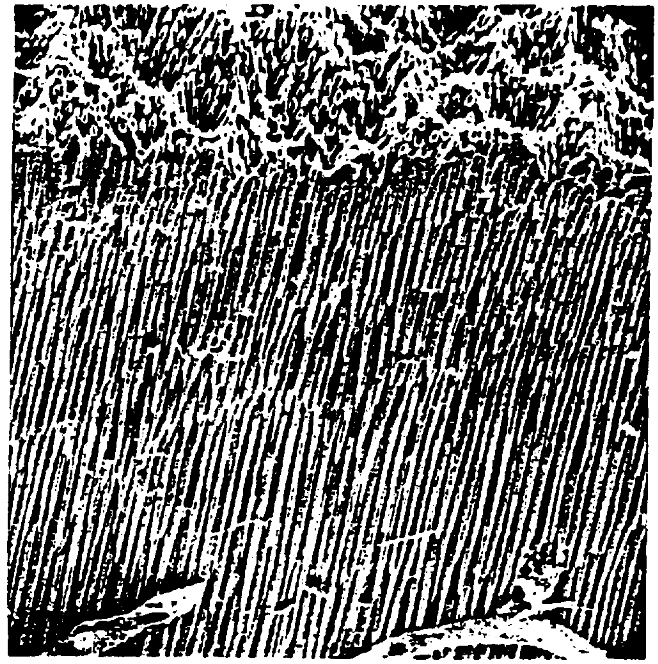



Figure 2.3-4. Atomic Oxygen Environment Degrades Material as Function of Time



85X

1000X

2000X

Figure 2.3-5. Graphite Fibers and Epoxy Resin Attacked by Atomic Oxygen

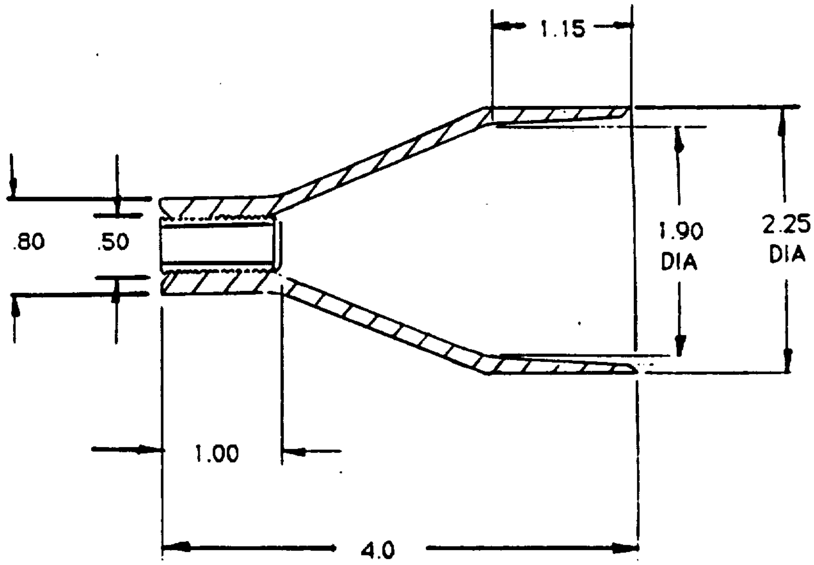



Figure 2.4-1. Molded Composite End Fitting

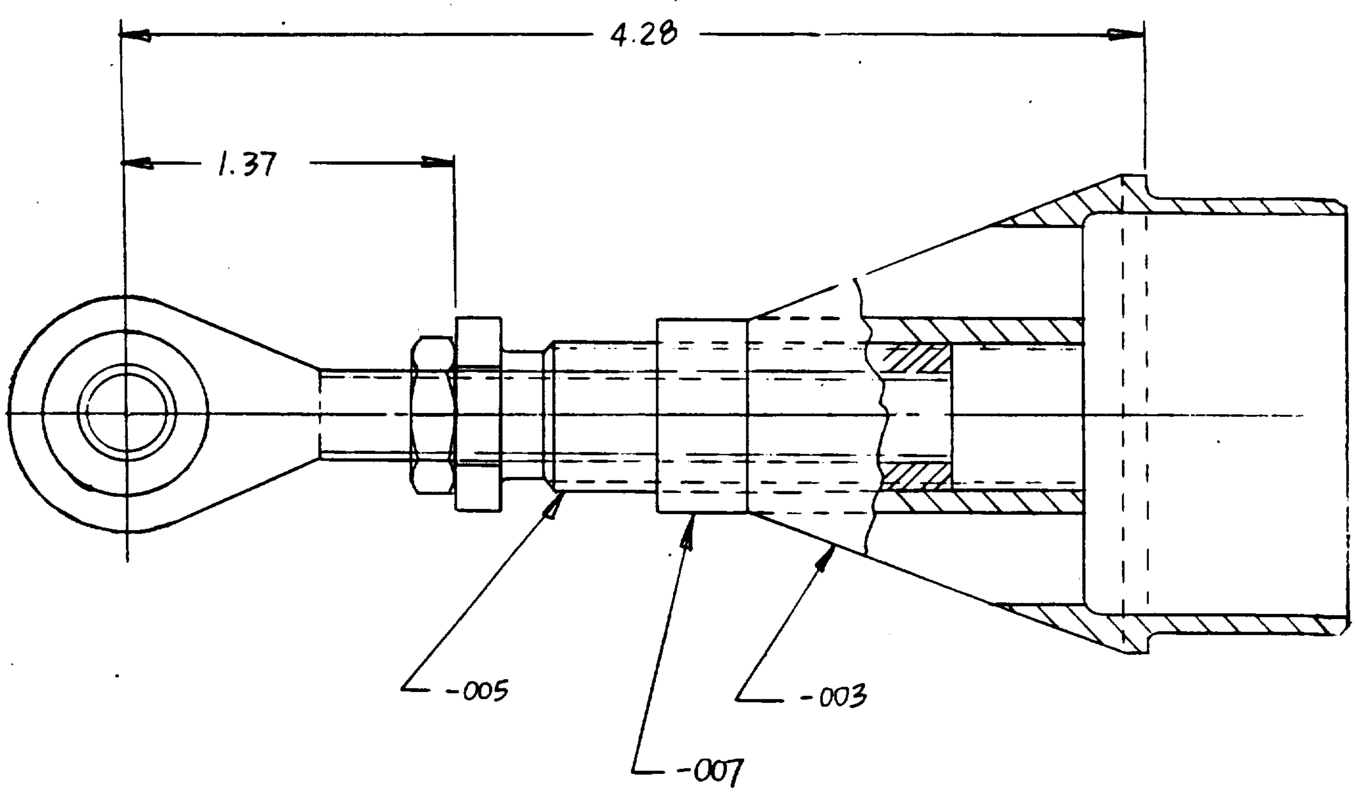



Figure 2.4-2. Machined Metal End Fitting

Deployable Structures for Large Space Platform Systems.

The design for the investment-cast fitting is shown in Figure 2.4-3. This end fitting is also stiffened by three ribs and is threaded in the end for interface with a rod end.

A summary of the trade study results is shown in Table 2.4-1. The costs were determined for two production quantities (168 units on the Ground Test Article and 1552 units on the Power Tower Space Station). Relative cost is shown in the Table based on the lowest-cost item (investment-cast aluminum). On the basis of these results, the investment-cast titanium is recommended for the strut end fittings. The investment-cast titanium fittings provide the lowest effective strut CTE and are weight and cost competitive to all other designs. Although the investment-cast aluminum fittings are the least cost, the effective strut CTE falls outside the $\pm 0.9 \times 10^{-6}$ m/m-$^{o}$C ($\pm 0.5 \times 10^{-6}$ in/in-$^{o}$F) requirement bandwidth. Further analysis is required to fully understand the consequences of this non-compliance.

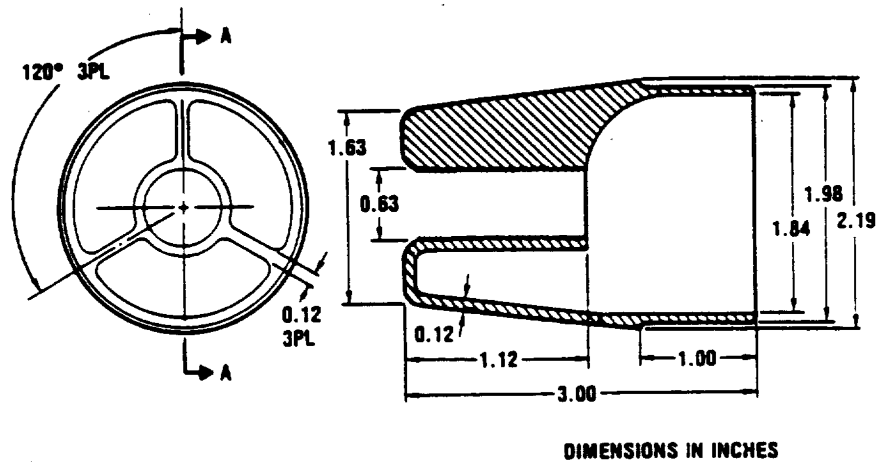



Figure 2.4-3. Investment-Cast Metal End Fitting

Table 2.4-1. Trade Study Indicates Investment-Cast Titanium is Best End Fitting

| Material Choice | Relative** Unit Cost GTA/Station | Unit Weight (lb) | Overall Strut CTE* |
|---|---|---|---|
| Graphite-epoxy chopped fibers | 26.0/17.0 | 0.50 | $0.70 \times 10^{-6}$ |
| Graphite/PEEK chopped fibers | 46.0/32.0 | 0.57 | $0.70 \times 10^{-6}$ |
| Titanium--machined | 37.0/30.4 | 0.27 | $0.68 \times 10^{-6}$ |
| Titanium--cast | 12.5/10.3 | 0.25 | $0.65 \times 10^{-6}$ |
| Aluminum--machined | 9.3/7.6 | 0.21 | $1.22 \times 10^{-6}$ |
| Aluminum--cast | 2.6/1.0 | 0.15 | $1.14 \times 10^{-6}$ |

*m/m-°C
**Relative cost calculated by dividing predicted cost of an item by the lowest-cost item (aluminum cast, station quantity)

Note: 168 units on GTA, 1,552 units on station

# 3.0 ASSEMBLY OF STRUCTURES IN SPACE/ERECTABLE STRUCTURES

## 3.1 INTRODUCTION

The development of techniques for the assembly of structures in space is critical to the success of NASA's Space Station Program. How to provide a variety of truss-to-truss, truss-to-subsystem and truss-to-commercial payload attachments is a critical issue for the assembly and operation of the Space Station. Work in Task 3 of this contract focused on the attachment of pressurized modules to the Space Station truss. The initial part of the effort focused on the "race track" module configuration (see Figure 3.1-1), which was NASA's baseline at the start of this contract. In December 1985, work began in earnest on the "figure eight" module configuration (see Figure 3.1-2), the new NASA baseline at that time. Subtle changes occurred to this baseline as time passed that affected the selection of the best design approach. In May 1986, after a quarterly review of this contract at Marshall Space Flight Center, it was decided to "freeze" the configuration and proceed with a preliminary design. This section of the final report is a chronological record of this work with emphasis on the "frozen" configuration. Work done prior to the configuration freeze was important in the selection of the design approach for the preliminary design. Specifically, this section of the final report consists of:

- o Defining operations and requirements
- o Performing a trade study for the attachment of the race track pressurized module configuration to the truss
- o Developing the attachment of the figure eight pressurized module configuration to the truss into a preliminary design

## 3.2 OPERATIONS AND REQUIREMENTS

The definition of operations and requirements is key to the development of pressurized module-to-truss structure attachments. Two fundamental operations approaches were defined that apply to either the race track or figure eight module configuration. Designs were developed that utilize each operations approach. Evaluation of the operations was key to the final design recommendation.

An equally fundamental aspect of the pressurized module-to-truss structure attachment design is the definition of requirements. Basic requirements remained the same throughout this design effort; however, specific requirements, such as module configuration, module size and module location relative to the truss changed as work on Task 3 progressed.

### 3.2.1 Operations

The operations related to the pressurized module support structure are divided into assembly, maintenance and removal procedures. Most of the effort in this contract focused on assembly operations; however, ease of maintenance and accomodation for module

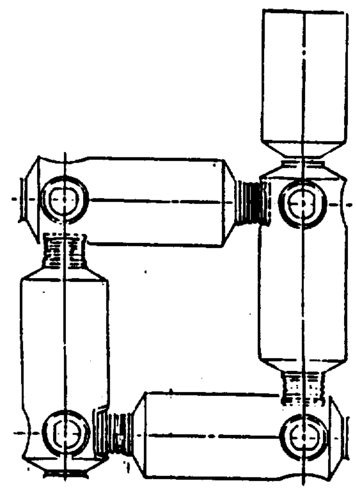


Figure 3.1-1. Race Track Pressurized Module Configuration

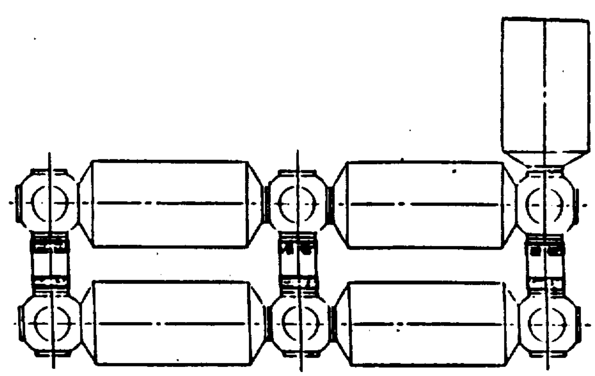


Figure 3.1-2. Figure Eight Pressurized Module Configuration

removal are also important aspects considered in the design.

Two fundamental approaches to assembling the modules were established at the outset of the design effort:

- o Erectable attachment option: attach the support structure to the truss, then position the pressurized module on the attachment points and secure the attachment

- o Pallet-mounted attachment option: attach the support structure to the pressurized module, then position the module/support structure assembly on the truss and secure the attachment

Subsequently delivered modules are assembled similarly. Flexible interconnect tunnels are then used in either approach to link the modules into the desired pattern, as shown in Figure 3.2-1.

Detailed assembly operations listings were initiated for the race track module configuration and evolved as the figure eight module configuration became baseline. The scenarios developed assume mobile servicing equipment (manipulator and transporter) is available for the assembly of the pressurized modules. The completed listing of assembly operations for the erectable attachment option is as follows:

1. EVA astronaut number one (EV1) traverses to and checks Mobile Servicing Center (MSC) at its control station

2. MSC grasps module support structure stowage container

3. EVA astronaut number two (EV2) releases the latches securing the module support structure stowage container to the NSTS payload bay

4. MSC removes and transports module support stowage container from the NSTS payload bay to assembly location on the truss

5. EV2 traverses from NSTS payload bay to assembly location

6. EV1 traverses from MSC control station to assembly location

7. EV1 and EV2 retrieve strut assembly from stowage container and traverse to specific attachment location

8. EV1 and EV2 unfold strut assembly and attach struts to existing truss corner fittings

9. EV1 or EV2 checks and prepares module attachment fitting

10. EV1 and EV2 traverse to stowage container and repeat steps 7 through 9 until support structure completely erected

11. EV1 traverses to MSC control station

12. MSC grasps module support structure stowage container and

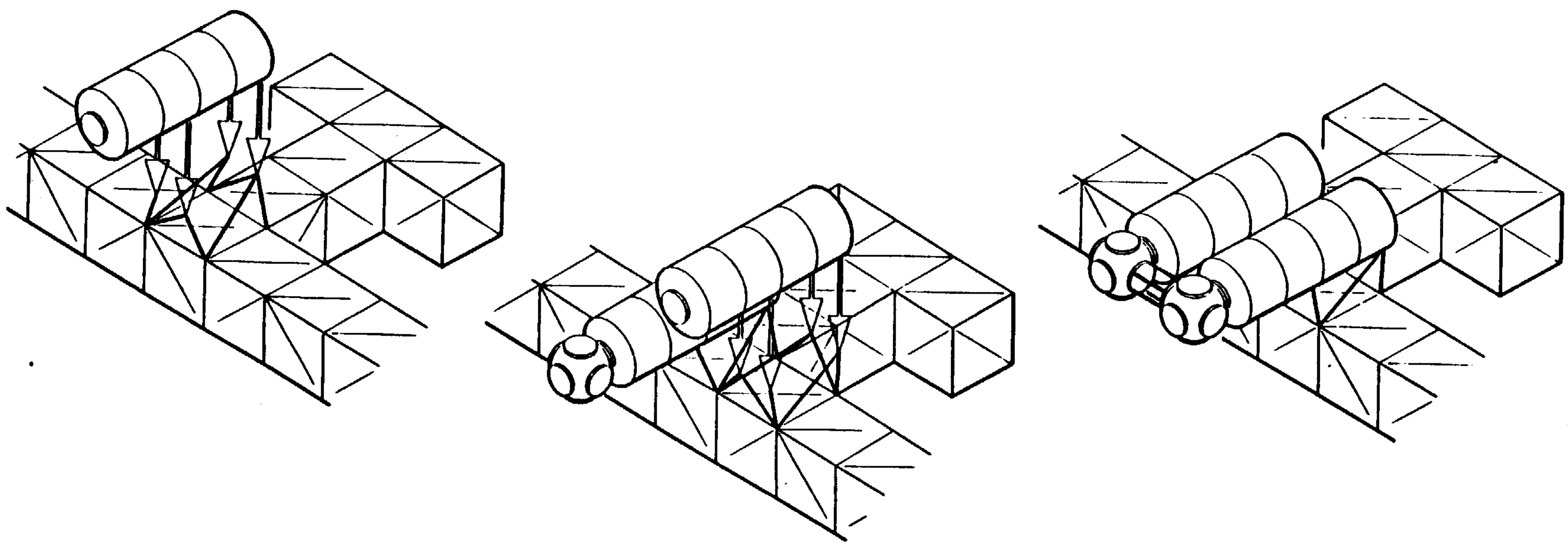



Figure 3.2-1. Assembly Sequence Provides for Simple Installation

transports it to the NSTS payload bay

13. EV2 traverses to NSTS payload bay and secures stowage container

14. MSC grasps pressurized module in NSTS payload bay

15. Module NSTS payload bay attachment latches are automatically released by Intravehicular astronaut number one (IV1) at the request of EV1

16. MSC removes pressurized module from NSTS payload bay

17. EV2 removes dedicated module support trunnion from stowage container, secures feet to NSTS RMS foot restraint, traverses to the pressurized module with assistance of IV1, and installs the trunnion on the module (repeated for four trunnion fittings)

18. EV2 releases from NSTS RMS foot restraint and traverses to erected support strut location

19. MSC positions pressurized module over erected struts and lowers module to align trunnions and module support struts

20. MSC inserts pressurized module into support fittings directed/ guided by EV2

21. EV2 secures pressurized module to support struts with latches

22. EV2 traverses to NSTS payload bay

23. MSC releases pressurized module and moves to storage location

24. EV1 leaves MSC control station and traverses to NSTS payload bay

The above procedure is estimated to consume 6 hours 15 minutes of EVA time. This constitutes the bulk of the EVA time expended since little other hardware is delivered on an NSTS assembly flight of this type. Therefore, the procedure appears well within maximum EVA time allocations for one flight.

A procedure was also developed for the pallet-mounted attachment option. The procedure developed appears to be within the 6 hour 15 minute EVA time estimate for the erectable attachment option. The main differences are:

- Entire module support structure is deployable and can be assembled with minimal EVA traversing

- Support structure is deployed early in the assembly sequence; the pallet is fastened to the pressurized module before translation to the truss attachment location

- Pressurized module, with support structure attached, is removed from NSTS payload bay, located over truss, and final attachment is made at the truss interface

Pressurized module removal, if required, is essentially a reversal of the assembly procedure. Removal is easier than assembly because the most difficult procedure during assembly is very simple. Guiding and securing the pressurized module into the module attachment fittings (erectable attachment option) or guiding and securing the pressurized module/deployed support strut assembly into the truss corner fittings (pallet-mounted attachment option) are critical, time-consuming procedures. During pressurized module removal, however, a release of latches and separation with the aid of the MSC manipulator provide a simple operation.

Maintenance operations on the support structure are also performed with relative ease. The arrangement of the supports allows the performance of repair procedures without removal of damaged members. If parts are damaged such that replacement is necessary, simple procedures are available. If a composite strut requires replacement, the same "snap-in" attachment fitting as used on the Space Station truss structure provides for easy removal (see Figure 3.2-2). Replacment of other components are facilitated by the "snap-in" fitting as well since detachment of a strut is part of the procedure for removing a module support or truss corner fitting.

3.2.2 Requirements

The requirements used to govern the design of the pressurized module support structure include those imposed on the Space Station by NASA and those derived as a result of design studies. Key requirements as specified by NASA are as follows:

- o Design-to-cost (minimize cost)
- o Commonality (use common hardware where feasible to minimize cost)
- o Standard interfaces for structure and utilities
- o Fail-safe design to preclude catastrophic failure or significant degradation of stiffness
- o Flexural and torsional stiffness characteristics compatible with control systems, pointing requirements and construction operations
- o Dimensional stability compatible with pointing requirements and construction operations
- o Strength to accomodate Space Station operations (NSTS berthing/docking and reaction control system thrust maneuvers)
- o Durable materials (acceptable for end-of-life properties)
- o Microgravity accelerations less than $1 \times 10^{-5}$ g
- o Scheduled and unscheduled maintenance and servicing

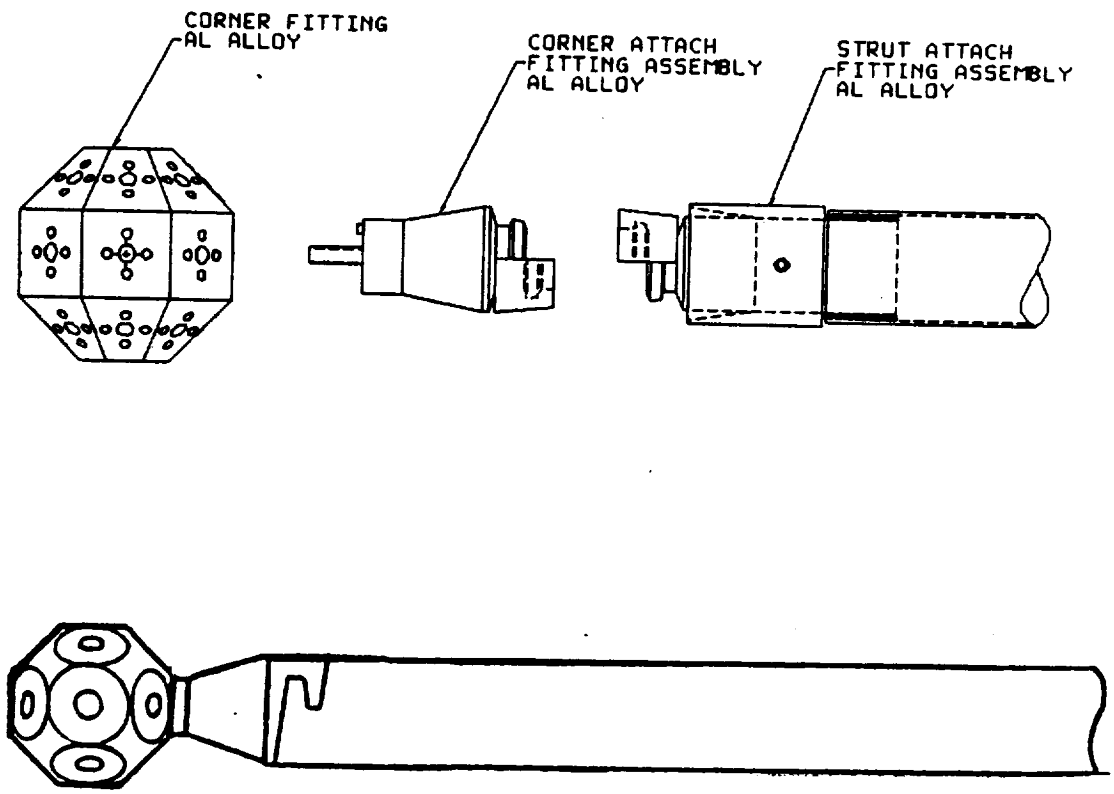



Figure 3.2-2. Snap-In Attachment Allows Easy EVA Assembly

- o Indefinite life with maintenance
- o NSTS transportable attachment provisions
- o EVA compatible (assembly time and capability)
- o Accomodation of module-to-module misalignments (manufacturing and assembly tolerances)

Additional requirements derived during the course of Space Station study efforts are:

- o NSTS berthing/docking clearance (to ensure NSTS clearance from Space Station structures)
- o MSC travel clearance (to ensure no interference with MSC as it travels on forward face of truss and on auxiliary trusses)
- o Minimize use of fixtures and tools during EVA assembly
- o Allow for removal of any one module without compromising structural integrity
- o Minimum of 1.52 mèters (5 feet) clearance between modules for EVA
- o Design to consider thermal contingency (fire in any one module)

As work on this task progressed, several key requirements initially driving the design changed. The baseline Space Station truss structure at the outset of the contract was a 2.74-meter (9-foot) deployable Power Tower truss (see Figure 2.2-1); a 5-meter (16.4-foot) erectable Dual Keel truss (see Figure 3.2-3) is used on the final design. The initial module pattern used was the race track; the figure eight is used on the final design. A 10.82-meter (426-inch) common module length was initially used (race track configuration); after several changes, a 13.28-meter (523-inch) is used on the final design (figure eight configuration).

Utilities interface requirements never solidified during the contract. The final design features a method for routing utilities from the truss structure to the common module assuming an end cone penetration location. The design developed is flexible to future changes in requirements.

## 3.3 RACE TRACK MODULE CONFIGURATION TRADE STUDY

Four structural support arrangements were developed for the race track module configuration. The differences in the four arrangements are the method of attachment to the module (side trunnions, keel trunnions, or dedicated attachment as shown in Figure 3.3-1), the type of attachment structure used (pallet-mounted or erectable struts) and the type of latches used on the module attachment fittings (automatic or manual). These differences resulted in a trade study of the twelve

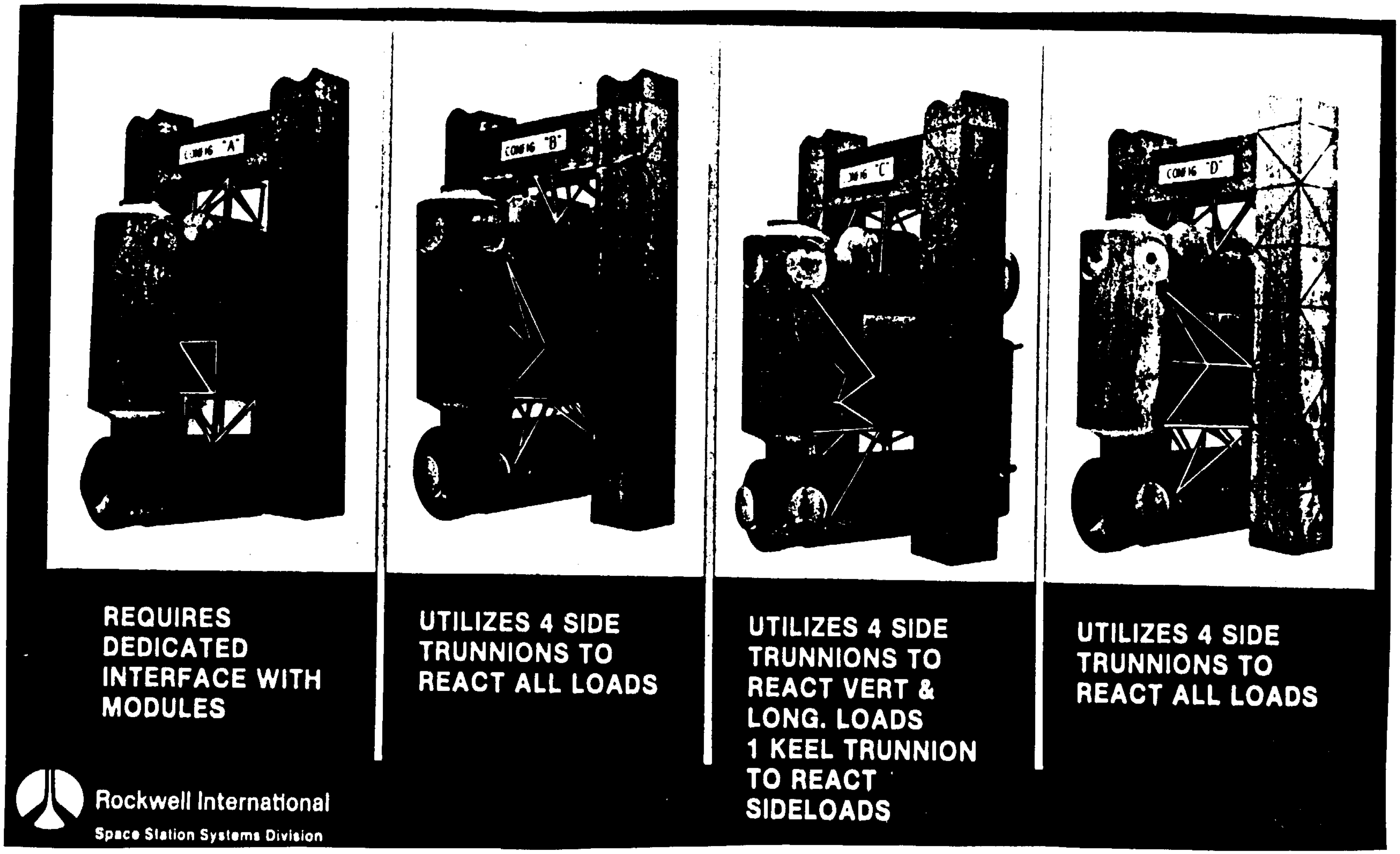



Figure 3.3-1. Four Structural Arrangements Used for Race Track Module Configuration Trade Study

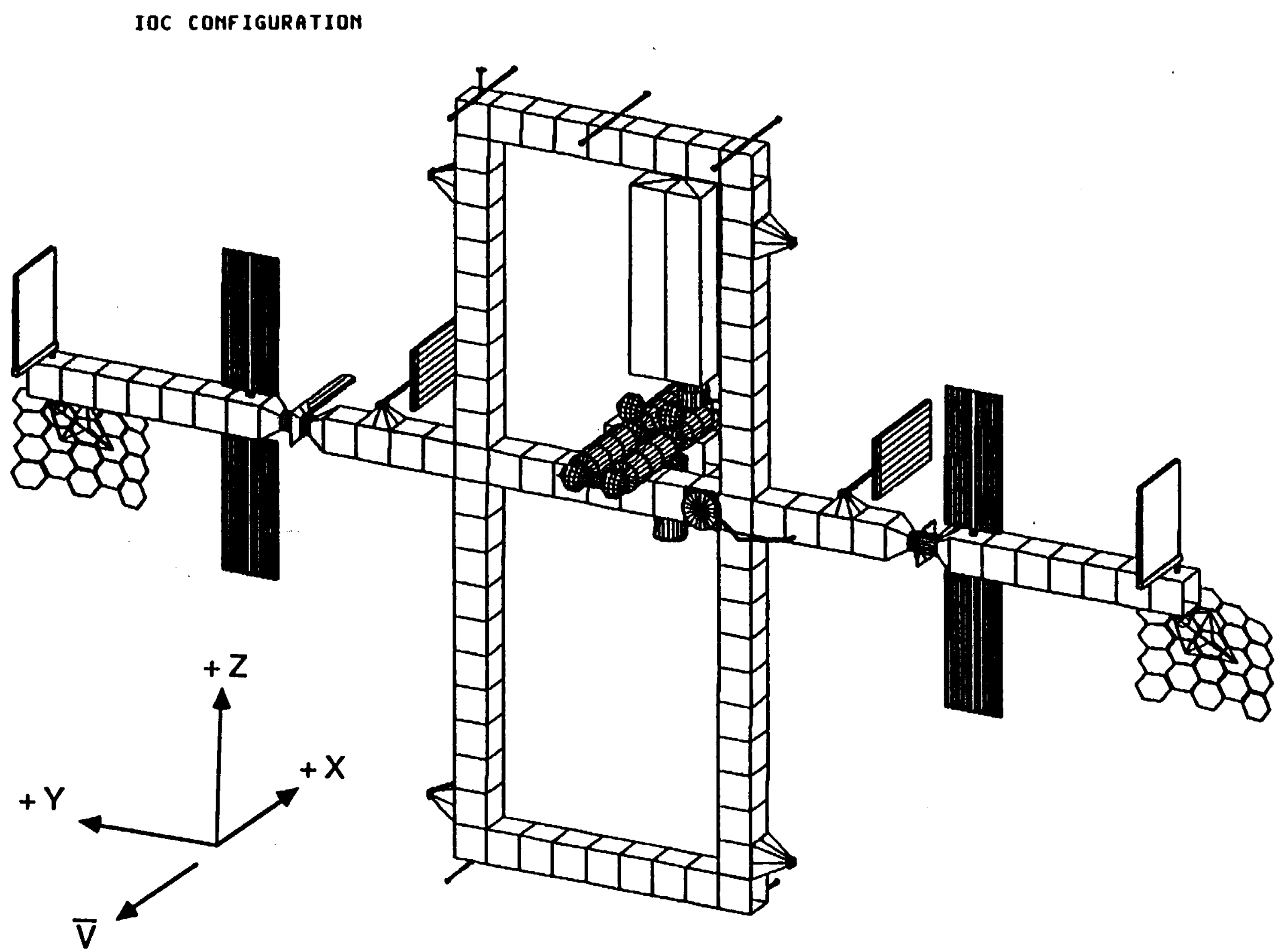



Figure 3.2-3. Dual Keel 5-Meter Erectable Truss Configuration

designs as summarized in Table 3.3-1. Nine criteria were identified for the trade study:

- o Weight
- o Producibility
- o EVA assembly operations
- o Cost (using complexity factor from producibility analysis and EVA assembly operations analysis)
- o Product assurance (safety, maintainability and reliability)
- o Risk
- o Commonality
- o Growth
- o Technical readiness

Of the nine criteria, only five provided discriminators used in the trade study. Risk is not a discriminator since all configurations utilize state-of-the-art materials and processes. Commonality is not a discriminator because the struts, strut end fittings and pallet assemblies are all common between designs. Growth is not a discriminator since all configurations are adaptable to the addition of modules at a later date. Technical readiness is not a discriminator due to the uniform development requirements for all designs. The results of the trade study for the five criteria evaluated is summarized in the following sections.

### 3.3.1 Weight

The summary of the support structure weights is shown in Table 3.3-2. Design A3 utilizing erectable support struts and manual module attachment latches is the least weight design for three reasons. First, the pallet-mounted designs are inherently heavier than the erectable strut designs. Second, the use of dedicated attachment results in shorter support struts and therefore less weight. Finally, manual latches are lighter than automatic latches.

### 3.3.2 Producibility

The producibility analysis considered five parameters in determining a complexity factor for each design:

- o Number of detail components
- o Complexity of strut fabrication
- o Complexity of fitting fabrication
- o Module attachment complexity

Table 3.3-1. Twelve Designs Evaluated in Race Track Configuration Trade Study

| ELEMENTS | CONFIGURATIONS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ |
| PALLET-MOUNTED TRUSS | X | X | | | X | X | X | X | | | | |
| ERECTABLE TRUSS | | | X | X | | | | | X | X | X | X |
| MANUAL LATCHES | X | | X | | X | | X | | X | | X | |
| AUTOMATIC LATCHES | | X | | X | | X | | X | | X | | X |

Table 3.3-2. Weight Analysis Favors Design A3

| DESCRIPTION | CONFIGURATION | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ |
| MAIN TRUSS/STRUT ATTACHMENT | 132.6 | 132.6 | 20.0 | 20.0 | 132.6 | 132.6 | 132.6 | 132.6 | 20.0 | 20.0 | 37.0 | 37.0 |
| STRUTS | 73.2 | 73.2 | 73.2 | 73.2 | 267.8 | 267.8 | 162.4 | 162.4 | 167.2 | 167.2 | 287.4 | 287.4 |
| MODULE/STRUT ATTACHMENT | 18.4 | 242.0 | 18.4 | 242.0 | 139.2 | 257.2 | 127.9 | 245.9 | 127.9 | 245.9 | 139.2 | 247.2 |
| ATTACHING PARTS | 11.2 | 11.2 | 5.6 | 11.2 | 27.0 | 32.9 | 21.1 | 27.0 | 15.8 | 21.7 | 23.2 | 28.6 |
| MARGIN | 33.6 | 69.0 | 16.8 | 69.0 | 80.4 | 98.5 | 63.0 | 81.1 | 47.1 | 65.2 | 69.2 | 85.8 |
| TOTAL* | 269.0 | 528.0 | 134.0 | 415.4 | 647.0 | 789.0 | 507.0 | 649.0 | 378.0 | 520.0 | 556.0 | 868.0 |

*WEIGHT IN POUNDS

- Complexity of ground pre-assembly

Each parameter was weighted for the analysis based on an estimate of its contribution to the overall complexity factor. Design A3 was chosen as the baseline and used as the reference to which all other designs were compared. As shown in Table 3.3-3, design A3 is the least complex of all designs evaluated closely followed by design A4.

### 3.3.3 EVA Assembly Operations

EVA assembly time estimates are summarized in Table 3.3-4. Design A4 results in the lowest assembly time followed closely by design A1. All one module EVA time totals are within single flight EVA allocations. Two conclusions drawn from the evaluation are:

- Pallet-mounted designs result in lower EVA times

- Automatic latches do not significantly reduce EVA time

### 3.3.4 Cost

Hardware and EVA costs were estimated for each of the twelve designs. A summary of relative design costs is shown in Table 3.3-5. The costs are referenced to the lowest cost design. The A1 design is the least expensive by an estimated 14 percent over designs A3 and B1. Hardware costs are based on complexity factors developed in the producibility evaluation. EVA costs are assumed equal to $103,000 per hour for this evaluation.

### 3.3.5 Product Assurance

A summary of product assurance analysis is shown in Table 3.3-6. Three factors were assessed including safety, maintainability and reliability. Twelve criteria were established with ease of EVA featured for safety, ease of assembly and repair operations featured for maintainability, and material life and structural design integrity featured for reliability. Each of the twelve criteria were rated on a ten point scale. Design A1 rated the best among all designs with design A2 closely following. Dedicated attachment designs (those identified with an A) are judged superior to designs utilizing module trunnions for attachment.

### 3.3.6 Summary

Although no clear cut favorite design is evident, options A1 and A3, the pallet-mounted and erectable dedicated attachment options, show the greatest promise. Both designs rated consistently high in all five trade areas. The two designs ranked first and second in the critical cost and weight evaluations.

The recommendation of this study was to develop concepts A1 and A3 into preliminary designs for further evaluation. At the time this portion of Task 3 concluded, however, the baseline Space Station configuration changed to the Dual Keel with a figure eight module pattern. Although this change required a repeat of much of the

Table 3.3-3. Producibility Evaluation Favors Design A3

| PARAMETER | ** COST DRIVER | CONFIGURATIONS | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_1$ | | $A_2$ | | $A_3$* | | $A_4$ | | $B_1$ | | $B_2$ | | $C_1$ | | $C_2$ | | $C_3$ | | $C_4$ | | $D_1$ | | $D_2$ | |
| | | LATCHES | | | | | | | | LATCHES | | | | LATCHES | | | | | | | | LATCHES | | | |
| | | MAN | | AUTO | | MAN | | AUTO | | MAN | | AUTO | | MAN | | AUTO | | MAN | | AUTO | | MAN | | AUTO | |
| | | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC | EVAL | DEV FAC |
| NUMBER OF DETAIL COMPONENTS | 0.30 | 324 | 0.40 | 324 | 0.40 | 240 | 0.30 | 240 | 0.30 | 372 | 0.46 | 372 | 0.46 | 344 | 0.43 | 344 | 0.43 | 324 | 0.40 | 324 | 0.40 | 296 | 0.37 | 296 | 0.37 |
| COMPLEXITY OF STRUT FABRICATION | 0.15 | 10 | 0.15 | 10 | 0.15 | 10 | 0.15 | 10 | 0.15 | 12 | 0.18 | 12 | 0.18 | 13 | 0.19 | 13 | 0.19 | 13 | 0.19 | 13 | 0.19 | 14 | 0.21 | 14 | 0.21 |
| COMPLEXITY OF FITTING FABRICATION | 0.20 | 12 | 0.24 | 13 | 0.26 | 10 | 0.20 | 11 | 0.22 | 17 | 0.34 | 18 | 0.36 | 15 | 0.30 | 16 | 0.32 | 14 | 0.28 | 15 | 0.30 | 17 | 0.34 | 18 | 0.36 |
| MODULE ATTACHMENT COMPLEXITY | 0.15 | 10 | 0.15 | 10 | 0.15 | 10 | 0.15 | 10 | 0.15 | 3 | 0.04 | 3 | 0.04 | 5 | 0.07 | 5 | 0.07 | 4 | 0.06 | 4 | 0.06 | 3 | 0.04 | 3 | 0.04 |
| COMPLEXITY OF GROUND PREASSEMBLY | 0.20 | 8 | 0.16 | 9 | 0.18 | 10 | 0.20 | 11 | 0.22 | 16 | 0.32 | 17 | 0.34 | 12 | 0.24 | 13 | 0.26 | 14 | 0.28 | 15 | 0.30 | 25 | 0.50 | 26 | 0.52 |
| SUM EQUALS CONFIG. COMPLEXITY FACTOR | — | -- | 1.10 | -- | 1.14 | -- | 1.0 | -- | 1.04 | -- | 1.34 | -- | 1.38 | -- | 1.23 | -- | 1.27 | -- | 1.21 | -- | 1.25 | -- | 1.46 | -- | 1.50 |

*Baseline Configuration. **Cost driver value determined as it is judged to impact total fabrication hours.

$$\frac{E}{BE} CD = \text{COMPLEXITY FACTOR}$$

E = Evaluation for each configuration
BE = Baseline evaluation
CD = Cost driver

Table 3.3-4. Design A4 Uses Least EVA Assembly Time

| EVA ASSEMBLY TIMES (HOURS) | CONFIGURATION | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ |
| ONE MODULE | | | | | | | | | | | | |
| ELAPSED TIME | 3.9 | 3.7 | 5.2 | 5.1 | 4.3 | 4.2 | 5.0 | 4.9 | 5.6 | 5.5 | 5.6 | 5.6 |
| TOTAL EVA TIME | 7.8 | 7.4 | 10.4 | 10.2 | 8.6 | 8.4 | 10.0 | 9.8 | 11.2 | 11.0 | 11.2 | 11.2 |
| FOUR MODULES | | | | | | | | | | | | |
| ELAPSED TIME | 15.6 | 14.8 | 20.8 | 20.4 | 17.2 | 16.8 | 20.0 | 19.6 | 22.4 | 22.0 | 22.4 | 22.4 |
| TOTAL EVA TIME | 31.2 | 29.6 | 41.6 | 40.8 | 34.4 | 33.6 | 40.0 | 39.2 | 44.8 | 44.0 | 44.8 | 44.8 |

Table 3.3-5. Cost Analysis Favors Design A1

| CONFIGURATION | RELATIVE HARDWARE COST | RELATIVE EVA COST | RELATIVE TOTAL COST |
|---|---|---|---|
| A1 | 1.20 | 1.05 | 1.00 |
| A2 | 3.23 | 1.00 | 1.62 |
| A3 | 1.00 | 1.41 | 1.14 |
| A4 | 3.04 | 1.38 | 1.78 |
| B1 | 1.44 | 1.16 | 1.14 |
| B2 | 3.55 | 1.14 | 1.80 |
| C1 | 1.37 | 1.35 | 1.23 |
| C2 | 3.39 | 1.33 | 1.86 |
| C3 | 1.15 | 1.51 | 1.26 |
| C4 | 3.20 | 1.49 | 1.89 |
| D1 | 1.42 | 1.51 | 1.34 |
| D2 | 3.46 | 1.51 | 1.99 |

Table 3.3-6. Product Assurance Evaluation Favors Design A1

| CRITERIA | FACTOR | CONFIGURATION | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $B_1$ | $B_2$ | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $D_1$ | $D_2$ |
| SAFETY | | | | | | | | | | | | | |
| LEAST COMPLEX FOR EVA ERECTION | 10 | 8 | 9 | 6 | 7 | 5 | 6 | 4 | 5 | 2 | 3 | 1 | 2 |
| EVA ACCESSIBILITY FOR ERECTION | 10 | 4 | 4 | 5 | 5 | 3 | 3 | 5 | 5 | 6 | 6 | 6 | 6 |
| ERECTION METHOD, MIN. EVA TRAVEL, MIN. EVA HAND. | 10 | 9 | 10 | 7 | 8 | 6 | 7 | 5 | 6 | 4 | 5 | 3 | 4 |
| LEAST COMPLEX FOR ASSY MISMATCH/ALIGNMENT | 10 | 7 | 6 | 8 | 7 | 3 | 2 | 4 | 3 | 5 | 4 | 2 | 1 |
| TOTAL | 40 | 28 | 29 | 26 | 27 | 17 | 18 | 18 | 19 | 17 | 18 | 12 | 13 |
| MAINTAINABILITY | | | | | | | | | | | | | |
| EASE OF REPAIR | 10 | 10 | 8 | 7 | 6 | 8 | 7 | 10 | 8 | 9 | 7 | 7 | 6 |
| EASE OF ACCESS TO MODULE OUTER SHELL. | 10 | 10 | 10 | 10 | 10 | 7 | 7 | 7 | 7 | 7 | 7 | 8 | 8 |
| SIMPLIFY MAN-MACHINE INTERFACE | 10 | 9 | 10 | 9 | 10 | 7 | 10 | 7 | 10 | 7 | 10 | 7 | 10 |
| EASE OF MISALIGNMENT ADJUSTMENT | 10 | 10 | 10 | 10 | 10 | 8 | 8 | 10 | 10 | 10 | 10 | 8 | 8 |
| TOTAL | 40 | 39 | 38 | 36 | 36 | 30 | 32 | 34 | 35 | 33 | 34 | 30 | 32 |
| RELIABILITY | | | | | | | | | | | | | |
| STRENGTH/STIFFNESS | 10 | 4 | 3 | 4 | 3 | 6 | 6 | 7 | 7 | 7 | 7 | 8 | 8 |
| RESISTANCE TO DAMAGE | 10 | 8 | 8 | 7 | 7 | 4 | 4 | 7 | 7 | 7 | 7 | 5 | 5 |
| LIFE | 10 | 7 | 6 | 7 | 6 | 5 | 4 | 6 | 5 | 6 | 5 | 5 | 4 |
| REDUNDANCY | 10 | 4 | 4 | 4 | 4 | 7 | 7 | 4 | 4 | 4 | 4 | 8 | 8 |
| TOTAL | 40 | 23 | 21 | 22 | 20 | 22 | 21 | 24 | 23 | 24 | 23 | 26 | 25 |
| GRAND TOTAL | 120 | 90 | 88 | 84 | 83 | 69 | 71 | 76 | 77 | 74 | 75 | 68 | 70 |

initial work in developing an attachment design, some of the key results of the trade study are applicable to the new configuration. The differences noted between the use of manual and automatic latches, pallet-mounted and erectable support structures, and trunnion and dedicated module attachment locations are similar for the figure eight module pattern.

## 3.4 FIGURE EIGHT MODULE CONFIGURATION ATTACHMENT TO TRUSS

The Power Tower truss/race track module pattern to Dual Keel truss/figure eight module pattern configuration change made in October 1985 necessitated the development of a new design approach. Whereas the race track module pattern is surrounded by a 2.74-meter (9-foot) truss in the Power Tower configuration (see Figure 3.3-1), the figure eight module pattern is positioned above a single transverse boom in the Dual Keel Configuration. The size of the truss and type of construction (deployable or erectable) was not baselined until January 1986 but the basic design problem was established at the outset. The balance of the effort on Task 3 focused on the Dual Keel/figure eight configuration. This work consisted of:

- Development of design approach
- Definition of design concepts
- Analysis of design concepts
- Selection of concept for preliminary design
- Definition of utility interfaces with modules
- Preliminary design

Space Station program changes within the figure eight pattern were incorporated as the study progressed including the selection of the 5-meter (16.4-foot) erectable truss as baseline, the replacement of two common modules with two international modules, and the relocation of modules relative to the truss. These changes had a significant effect on the preliminary design but did not void the groundwork established at the outset of the Dual Keel/figure eight effort.

### 3.4.1 Development of Design Approach

Four options were developed and evaluated in order to select a design approach for supporting the figure eight arrangement of pressurized modules. The options ranged from a minimum number of support struts for the four-module assembly to an independent, redundant support system for each module. In addition to the number and arrangement of support struts, a key structure in the design is the flexible interconnect tunnel (see Figure 3.4-1). The arrangement of the twelve tension struts in the tunnel determine its load-carrying capability. If all the tension struts are attached straight across the tunnel, only axial loads are carried. If the tension struts on opposite sides of the tunnel are angled, shear in one direction and

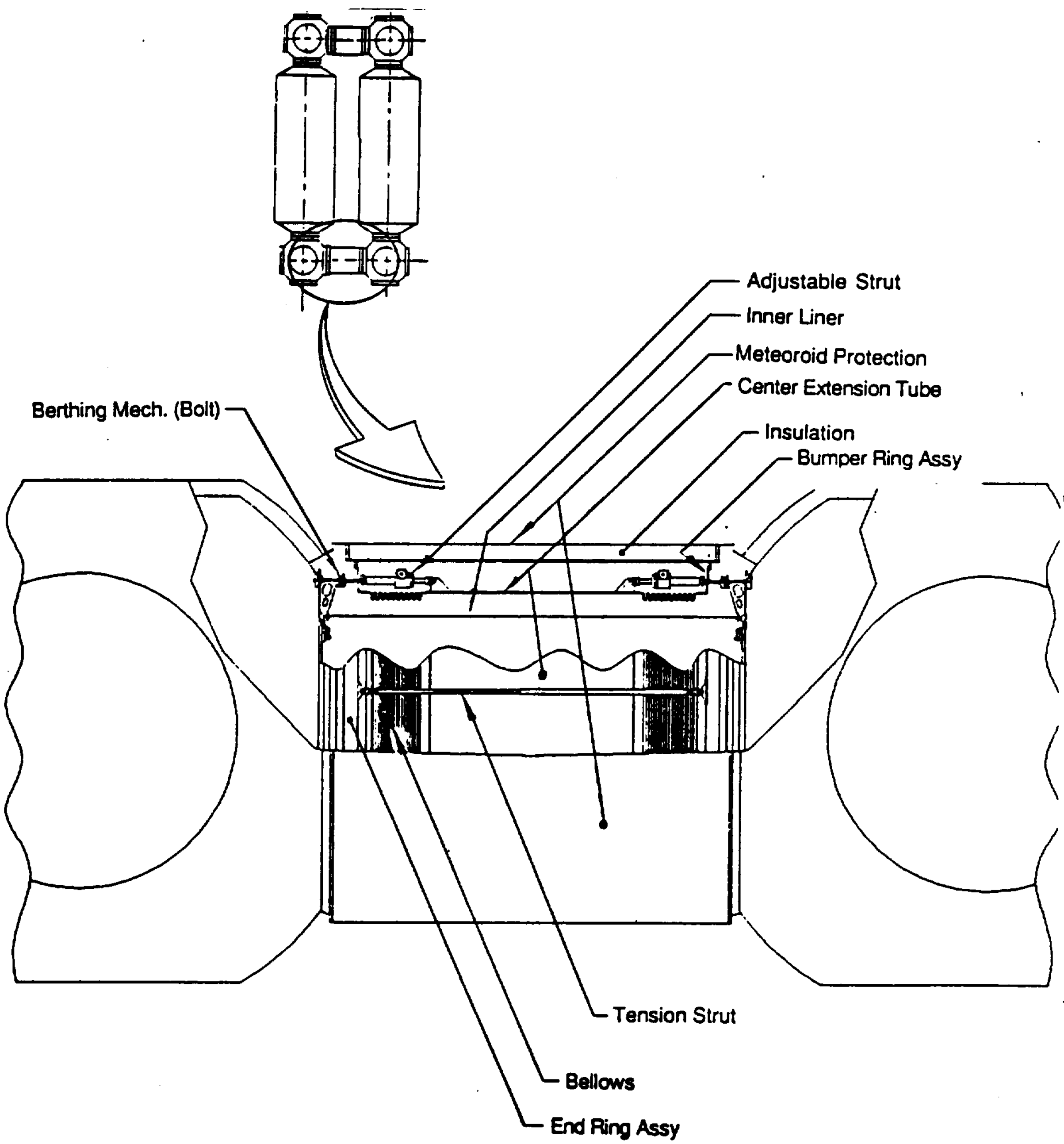



Figure 3.4-1. Flexible Interconnect Key to Pressurized Module Assembly

axial loads are carried. If all tension struts are angled, all shear and axial loads are carried. Fewer module support struts are required as the shear capability of the interconnect tunnels increase.

Three considerations that influenced the development and evaluation of the design approach options are:

- o Removal of any one strut without compromising structural integrity
- o Removal of any one module without compromising structural integrity
- o Thermal contingency (fire in any pressurized element)

The determination of strut location and interconnect tunnel load-carrying capability is based on these considerations with no more than one occurring at a time.

Figures 3.4-2 and 3.4-3 describe the design approach options. The numbers 1 through 4 on the modules indicate the order of assembly. The x, y and z notations indicate 1) the load directions reacted at the module supports and 2) the load carrying capability (axial and shear) of the interconnect tunnels.

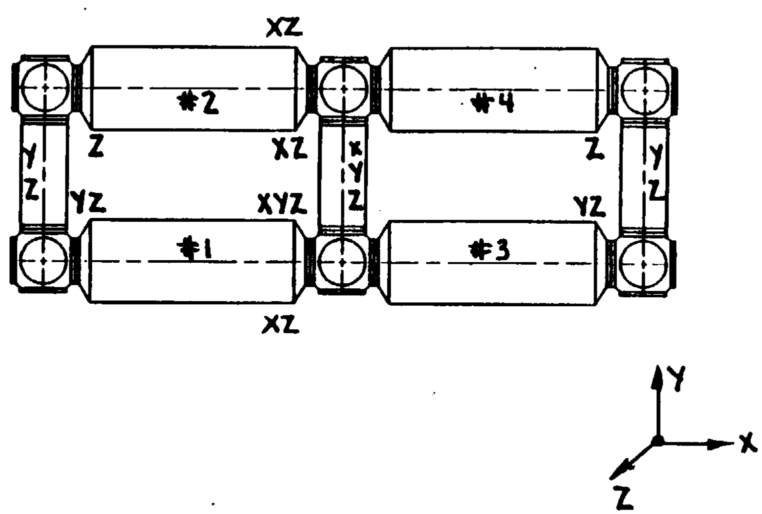
Option 1 is an approach using the minimum number of struts to support the pressurized modules (see Figure 3.4-2). Three planes of fixity are established from which thermal growth occurs. The x-direction plane of fixity is located across modules 1 and 2. The y-direction plane of fixity is located along modules 1 and 3. All of the module supports are assumed in the same z-direction plane. This approach allows thermal growth without introducing the associated loads into the support struts.

The center interconnect tunnel has full shear capability in the event a berthing/docking operation takes place at the node attached to module 3 or 4 with module 1 or 2 removed. The outer interconnect tunnels have z-direction shear capability to react berthing/docking loads in the event a z-direction support strut fails or is damaged. The x-direction shear capability is intentionally left off the outer interconnect tunnels to allow unrestricted module thermal growth.

Option 2 is an approach similar to option 1 except that common interconnect tunnels are used (see Figure 3.4-2). All three tunnels have axial and z-direction load carrying capability. In this case, x-direction loads carried across the center interconnect tunnel (which occurs only in the event of a berthing/docking operation at the node attached to module 3 or 4 with module 1 or 2 removed) are reacted by an additional set of support struts. A design to activate these struts only in this load case could be used to maintain the planes of fixity as described for option 1.

Option 3 is an approach in which the interconnect tunnels have only axial load carrying capability (see Figure 3.4-3). Additional supports are required in this case to react all z-direction loads

Option 1

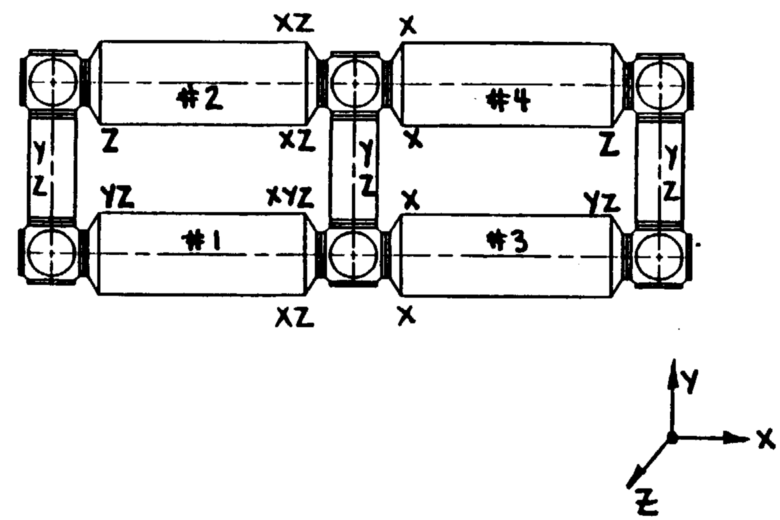



0 MINIMUM NUMBER OF STRUTS

0 FULL SHEAR CAPABILITY IN CENTER TUNNEL, "Z" SHEAR CAPABILITY IN OUTSIDE TUNNELS

0 PRIMARY ADJUSTMENT IN TUNNELS

Option 2

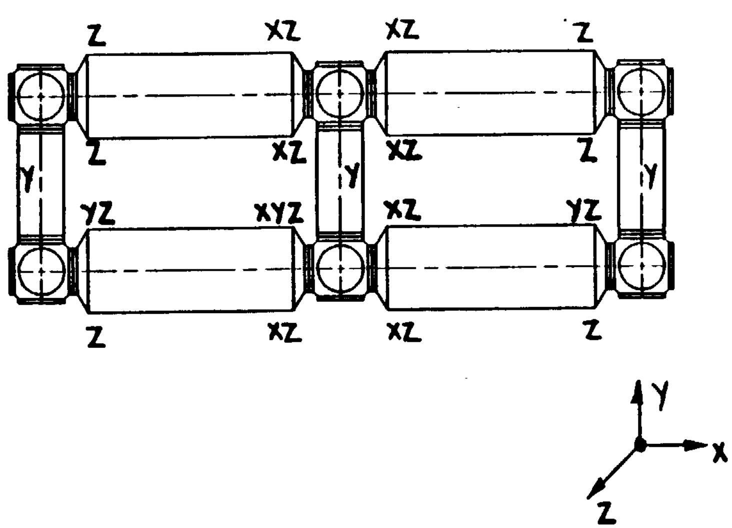



0 COMMON TUNNEL DESIGN, ALL HAVE "Z" SHEAR CAPABILITY

0 PRIMARY ADJUSTMENT IN TUNNELS

Figure 3.4-2. Designs With Minimum Number of Supports Require Load-Carrying Interconnect Tunnels

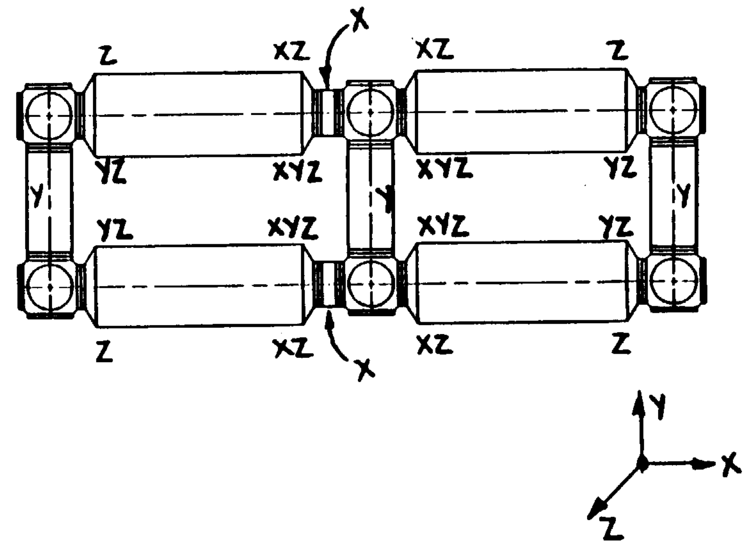
Option 3




0 AXIAL CAPABILITY ONLY
IN TUNNELS

0 PRIMARY ADJUSTMENT
IN SUPPORT STRUTS

Option 4




0 AXIAL CAPABILITY ONLY
IN TUNNELS

0 COMPLIANT INTERCONNECT
USED FOR ASSEMBLY/
ADJUSTMENT

0 INDEPENDENT SUPPORT
SYSTEM FOR EACH MODULE

Figure 3.4-3. Redundant Designs Maximize Operational Flexibility which were carried by the interconnect tunnels in options 1 and 2. Many of the additional supports are required only in the event of failure or damage of a strut, pressurized module removal, or docking/berthing operations at an alternate berthing port. These struts, similar to the extra struts required in option 2, can have activate/de-activate features to maintain planes of fixity.

Option 4 is an approach in which all pressurized modules are independently supported (see Figure 3.4-3). The redundant support system for each module allows complete operational flexibility during all phases of assembly and afterwards. Flexible compliant interconnect tunnels are used to accomodate assembly tolerances. Unless elaborate activate/de-activate features are included many of the supports will carry thermal expansion loads in addition to Space Station operational loads.

An evaluation of each design approach option indicates option 1 the superior method of support. Criteria in this evaluation include:

- o Cost (supports and interconnect tunnels)
- o Weight (supports and interconnect tunnels)
- o Assembly time
- o Operational flexibility
- o Design complexity

A summary of the empirical evaluation is shown in Table 3.4-1. Option 1 is consistently ranked first and second among the approaches and for the criteria in which it is ranked third, the interconnect tunnel weight difference compared to options 2 and 3 is small. The cost, weight and assembly time of each option is a function of hardware quantities. Designs are fundamentally more complex for options with additional supports since the number of attachment locations on the truss is fixed. Further, if activate/de-activate devices are used to accomodate thermal growth in options 2, 3 and 4, extra complexity is added to the design.

A recommendation of design approach is dependent not only on the requirements, but also the interpretation of requirements. For instance, if the requirement to remove any one module without compromising structural integrity applies during all phases of assembly, option 1 as presented is ruled out. If the requirement to remove any one module is interpreted to include all pressurized elements (modules, nodes and interconnect tunnels), an independent support system for each module is mandatory.

For the purposes of this design effort, the worst case interpretation of the requirements governed the design approach selection. As such, an independent support system for each pressurized module is the selected design approach. If a relaxed interpretation of requirements is realized in the future, modifications to the design developed can be easily made.

Table 3.4-1. Design Approach Evaluation Favors Option 1

| | OPTION 1 | OPTION 2 | OPTION 3 | OPTION 4 | COMMENTS |
|---|---|---|---|---|---|
| COST<br>SUPPORTS | 1 | 2 | 3 | 4 | OPTIONS WITH SOME TUNNEL SHEAR CAPABILITY REQUIRE FEWER SUPPORTS |
| INTERCONNECT TUNNELS | 2 | 1 | 1 | 3 | FULL SHEAR TUNNELS AND COMPLIANT INTERCONNECT OPTIONS MORE COSTLY |
| WEIGHT<br>SUPPORTS | 1 | 2 | 3 | 4 | OPTION 1 HAS FEWEST SUPPORTS, OPTION 4 REQUIRES INDEPENDENT SUPPORT SYSTEM FOR EACH MODULE |
| INTERCONNECT TUNNELS | 3 | 2 | 1 | 4 | LESS SHEAR CAPABILITY REDUCES TUNNEL WEIGHT, OPTION 4 HAS MORE TUNNELS |
| ASSEMBLY TIME | 1 | 2 | 3 | 4 | ASSEMBLY TIME CORRESPONDS TO HARDWARE QUANTITY IN VARIOUS OPTIONS |
| OPERATIONAL FLEXIBILITY | 2 | 2 | 2 | 1 | COMPLIANT INTERCONNECT MOST FLEXIBLE FOR MODULE INSTALLATION AND REMOVAL |
| DESIGN COMPLEXITY | 1 | 2 | 3 | 4 | ADDED COMPLEXITY WITH MORE SUPPORTS DESIGN FOR THERMAL CONDITIONS COMPLEX WITH MORE SUPPORTS |
| TOTALS | 11 | 13 | 16 | 24 | |

### 3.4.2 Definition of Design Concepts

A number of concepts were developed for the pressurized module support structure from which a candidate for preliminary design was selected. Designs were initiated for 2.74-meter (9-foot) deployable truss, 3.05-meter (10-foot) erectable truss, and 5-meter (16.4-foot) erectable truss configurations. The smaller trusses provide an improved attachment pegboard for the modules and simplifies the support strut geometry (see Figure 3.4-4). Shortly after the development of design concepts began, the 5-meter (16.4-foot) erectable truss was selected as baseline for the Space Station. Therefore, all subsequent efforts were directed at this configuration.

The baseline control lengths of the common module used in the design effort changed during the development of design concepts. The initial module used had a 13.06-meter (514-inch) berthing port-to-berthing port dimension; the module used in the final design has a 13.28-meter (523-inch) berthing port-to-berthing port dimension. The common module used in the final design is shown in Figure 3.4-5.

A matrix of support configurations considered for the pressurized modules is shown is Table 3.4-2. The primary options use auxiliary "bridge" or "center" truss structures as shown in Figures 3.4-6 and 3.4-7 respectively. A variety of attachment arrangements were studied for both options; including the use of longeron trunnion fittings only, longeron and keel trunnion fittings, dedicated attachment fittings, and a structural pallet. The method of growth from four modules to eight modules provides additional options. Growth can occur along side the initial set of four modules (the "raft" pattern shown in Figure 3.4-8) or above the intial set of four modules (the "stack" pattern shown in Figure 3.4-9).

The main advantage of the bridge truss structure design is that it allows minimum spacing of modules (6.1 meters or 20 feet) and thus minimum length interconnect tunnels. The weight and cost of the interconnect tunnels are minimized as well. The advantage of the 10.5-meter (34.4-foot) module spacing is that module trunnions are accessible for attachment. The additional weight and cost of interconnect tunnels required to provide this advantage is excessive compared to the solutions available for the minimum spacing design. Besides, the center truss support option uses the 10.5-meter (34.4-foot) separation distance with far less auxiliary truss requirements.

Of the bridge truss structure attachment designs, option 1 in Table 3.4-2 was selected for further development and analysis. Access to the module trunnions--the best and most logical place for support strut attachment--is restricted when minimum module spacing is used. This forces the use of 1) an intermediate pallet which significantly adds weight and EVA assembly time (Figures 3.4-10 and 3.4-11), 2) curved beams to clear module mold lines which raise structural load path, thermal expansion and commonality concerns (Figure 3.4-12), or 3) dedicated attachment hardware which adds weight and EVA assembly time (Figure 3.4-13). Of these three solutions, the dedicated attachment approach is clearly the best. It provides the best structural load path and does not require excessive EVA assembly time.

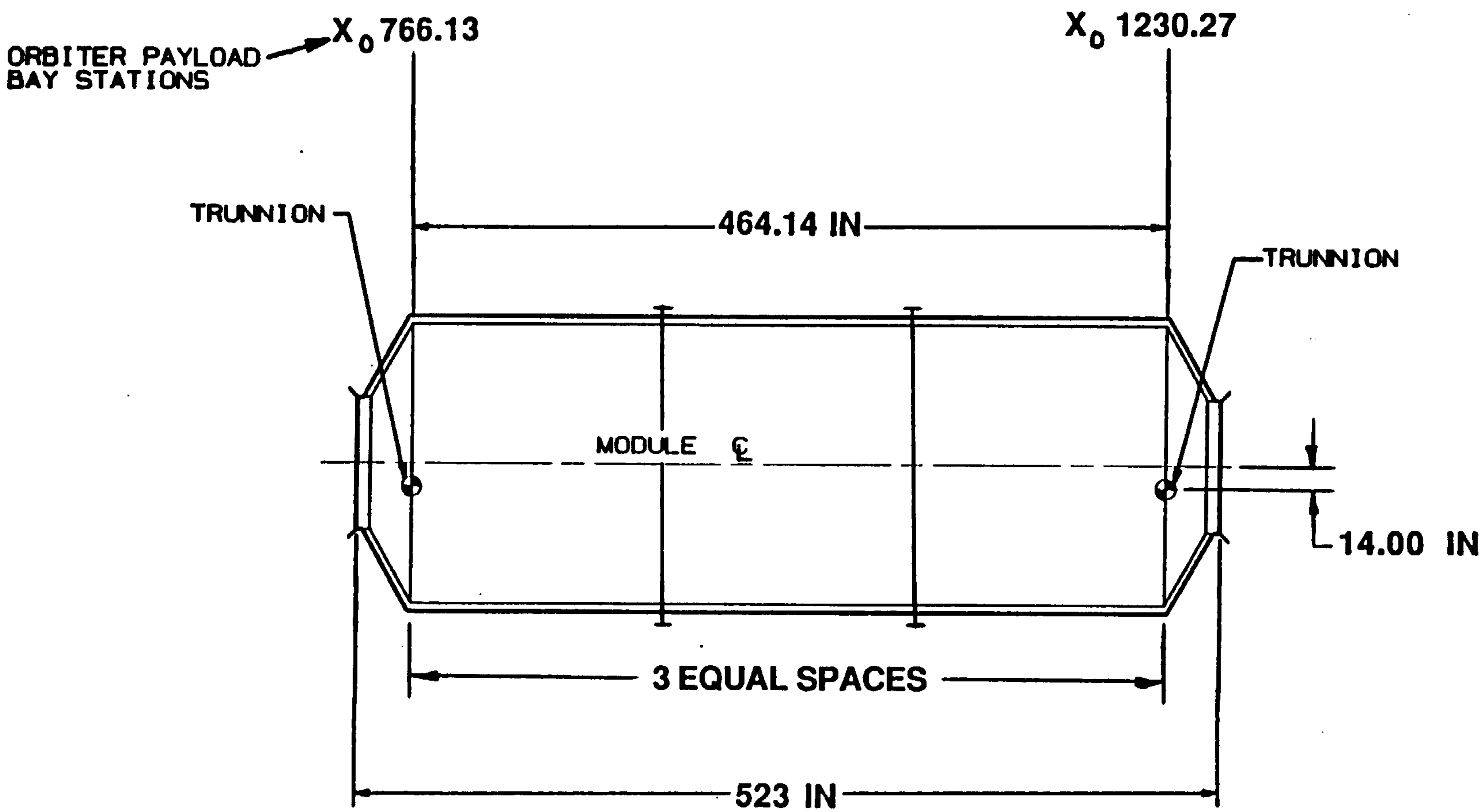



Figure 3.4-5. Module Control Lengths Establish Attachment Locations

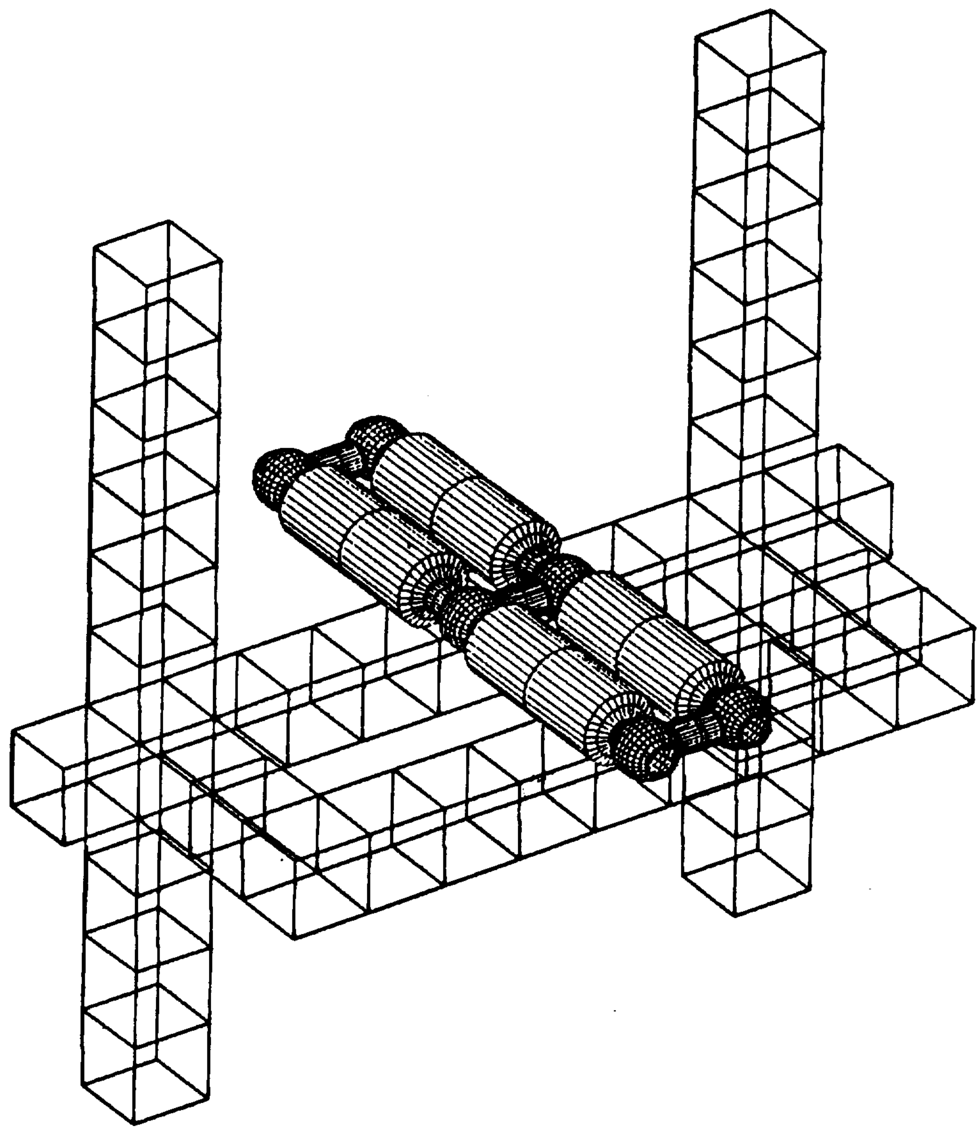


Figure 3.4-6. Auxiliary Bridge Truss Structure Option

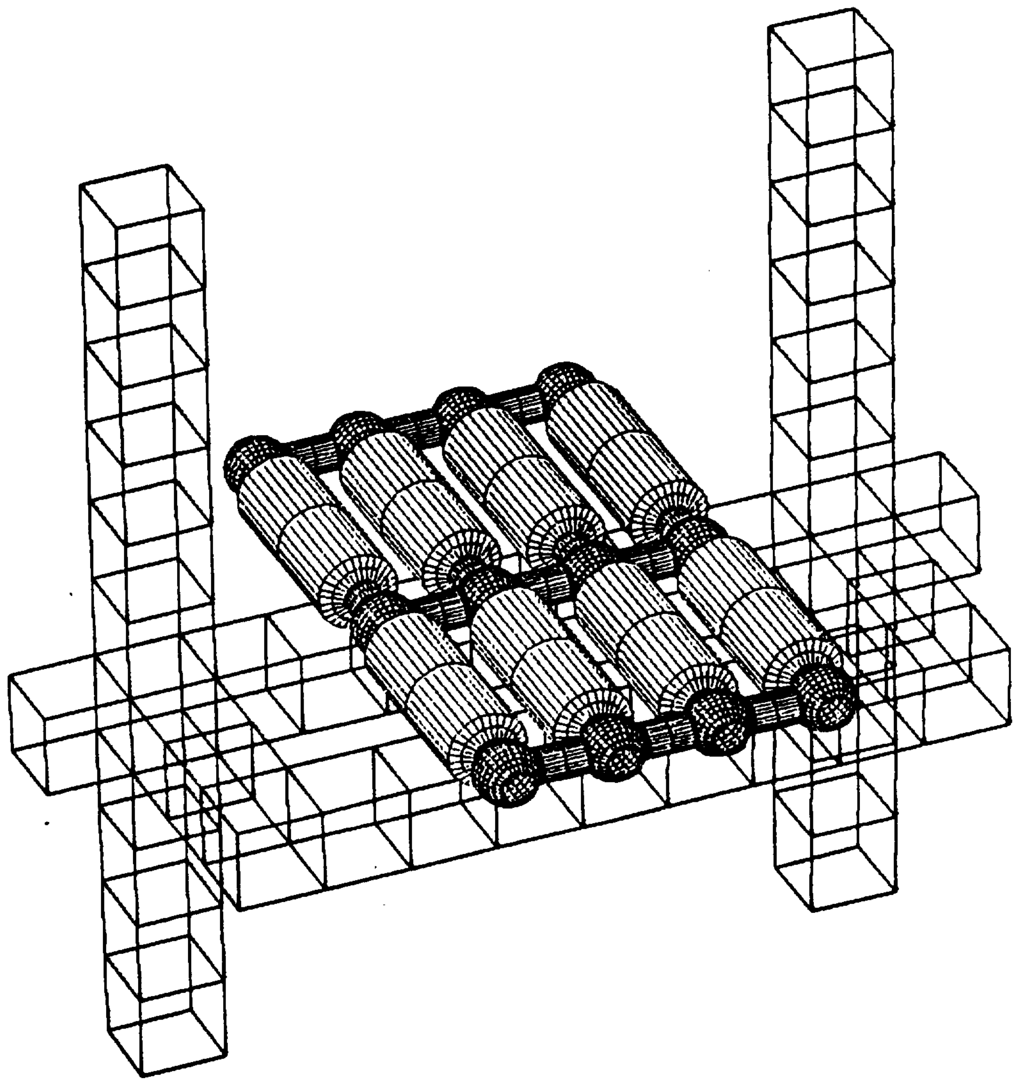


Figure 3.4-8. Growth Modules Added in Raft Pattern

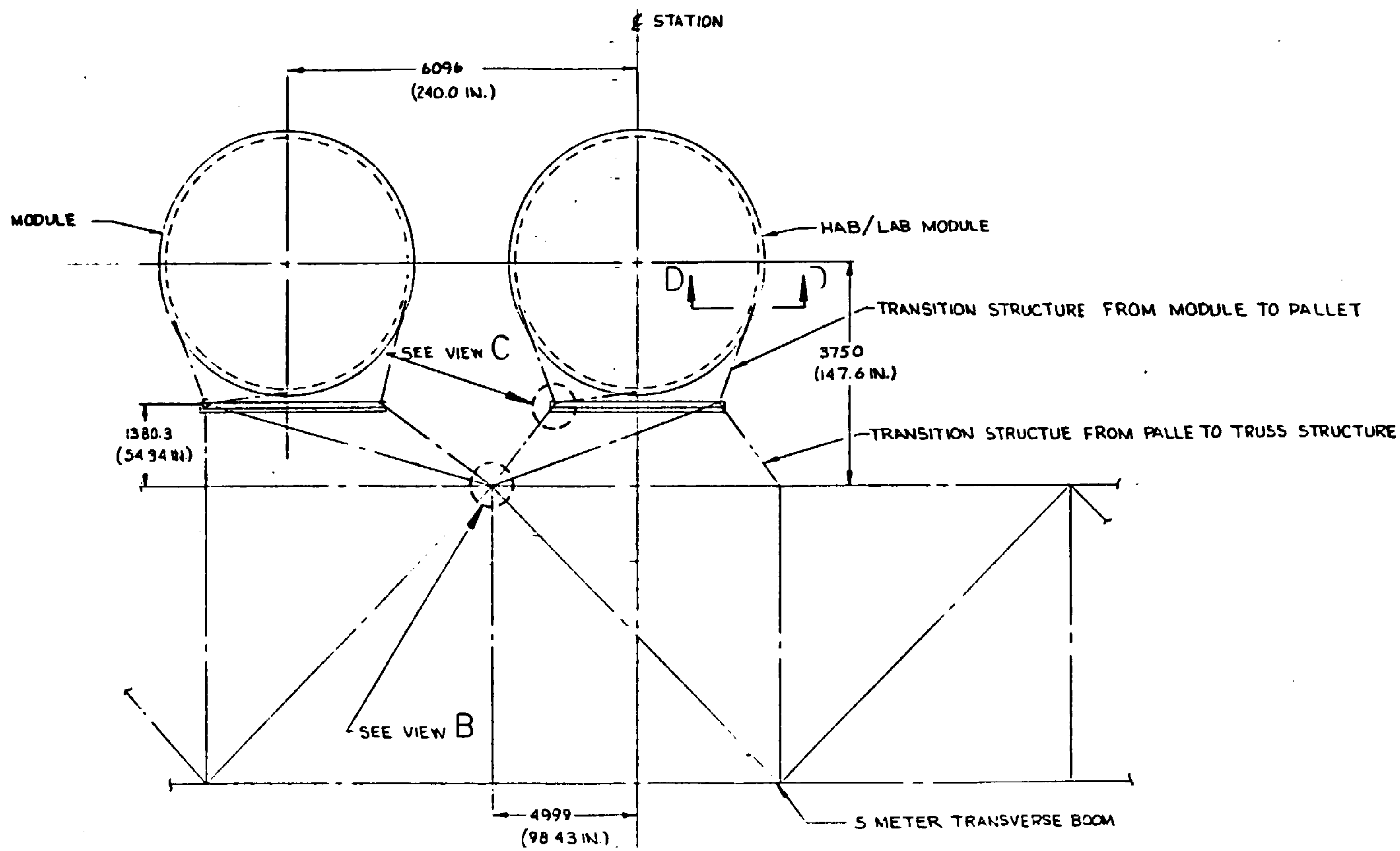



Figure 3.4-10. Intermediate Pallet Allows Trunnion Attachment

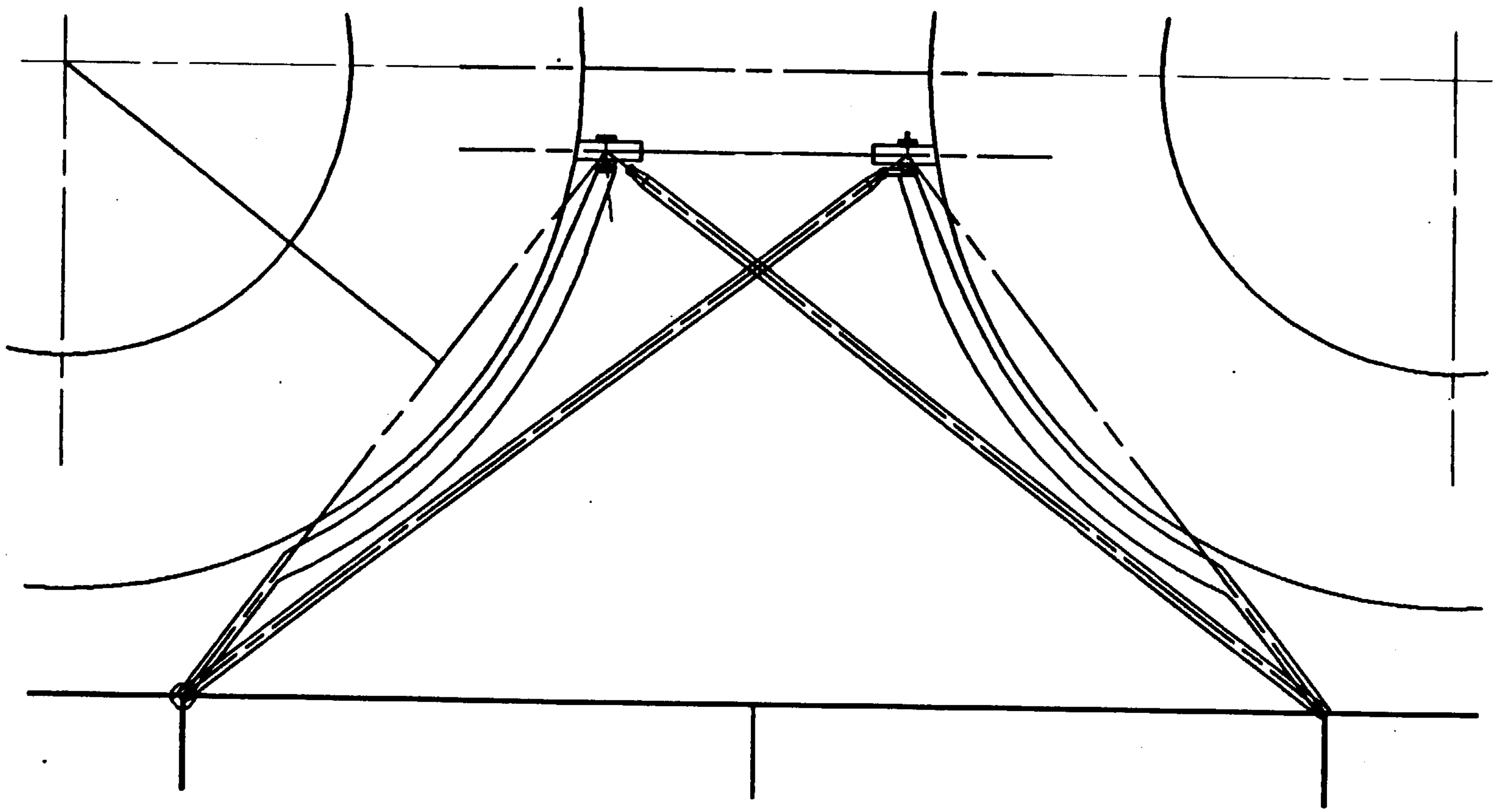


**Figure 3.4-12.** Curved Beams Allow Direct Attachment From Module Trunnions to Truss

The main advantages of the center truss structure designs are the reduction in the quantity of auxiliary truss structures and the direct attachment of support struts to the module trunnion fittings. Further, assembly tolerances are less of a concern for the center truss since it is an open structure cantilevered from the center of the transverse boom. The bridge truss is a closed structure with the possibility of tolerance build-up between the two attach locations on the transverse boom. Module longeron and keel trunnion fittings are required to interface with the NSTS payload bay during delivery to orbit. Use of these fittings eliminates the need for dedicated attachment hardware for module interface. Access to the trunnion fittings is a function of module spacing. The 10.5-meter (34.4-foot) spacing is required for the center truss design to enable a logistics module--attached to the lower port of a center node module--to clear the auxiliary truss.

Of the center truss structure attachment designs option 6 in Table 3.4-2, which utilizes both longeron and keel trunnion fittings on the modules, was selected for further development and analysis. Dedicated or palletized attachment concepts are undesireable if direct attachment to module trunnions is possible. Both options require extra hardware and EVA assembly time. Keel trunnion fittings, used to react y-direction loads during launch of the NSTS, are ideal for the same application on the Space Station.

The two requirements that most drive the module support design are the NSTS berthing/docking clearance and the MSC travel clearance. A distance of 10.67 meters (35 feet) is established from the forward face of the truss structure to the face of the primary berthing port. As shown in Figure 3.4-14, this distance avoids interference of the NSTS vertical stabilizer with the forward face of the truss structure. Truss structure is actually not present in the area of interference, but the area is reserved for satellite servicing. The MSC travels on the forward face of all the dual keel truss structure as well as the auxiliary truss structures upon which the modules are attached. Normal travel as well as plane change operations are considered.

The design developed for the bridge truss structure is shown in Figure 3.4-15. Each module is supported with a statically determinant six strut per module arrangement. Dedicated attachments are made on the module ring frames; one on an end ring frame and the other two-thirds the cylindrical length away on an intermediate ring frame (see Figure 3.4-5 for reference). One module attachment location reacts loads in the x, y and z directions. A second reacts loads in the x and z directions. The third attachment location reacts loads only in the z direction.

The design developed for the center truss structure is shown in Figure 3.4-16. Each module is supported with a seven strut arrangement. On one end of each module, two sets of x- and z-direction supports are attached to the longeron trunnions. A y-direction support is attached to the keel trunnions at the same end. The other end of each module is supported by a pair of struts that react z-direction loads. Two struts are necessary here due to the poor location of trunnion and truss attachment points. One of these

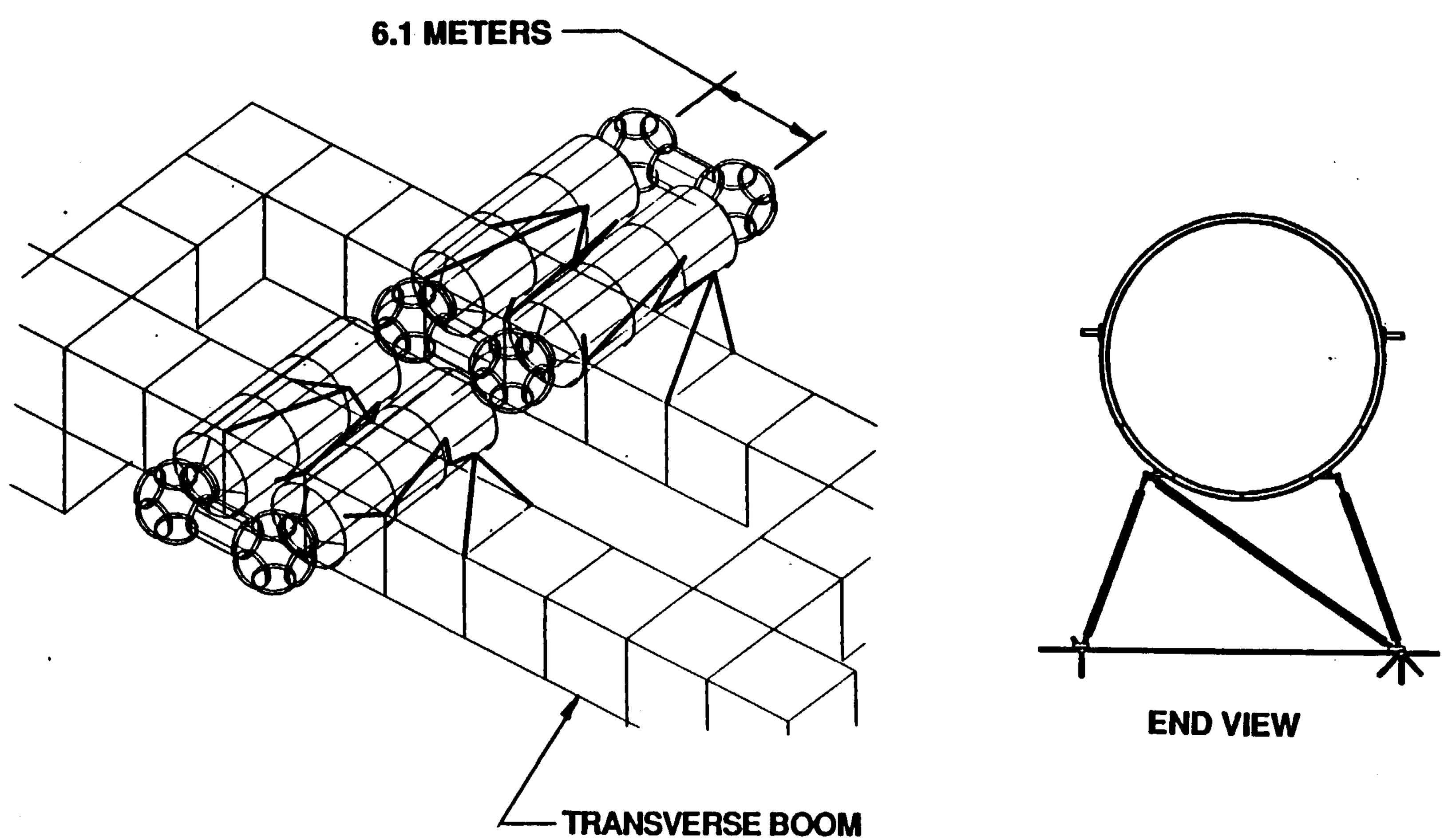



Figure 3.4-15. Dedicated Attachment Design Selected for Bridge Truss Structure

struts is attached to a partial truss bay assembled above the center bay of the transverse boom.

### 3.4.3 Analysis of Design Concepts

Loads analysis was performed for option 1 (bridge truss structure, dedicated module attachment--Figure 3.4-15) and option 6 (center truss structure, longeron and keel trunnion module attachment--Figure 3.4-16). Loads were determined for the support struts and the interconnect tunnels for NSTS docking (without attenuation) and six thermal contingency conditions.

The first step in determining the loads is the modeling of the entire Dual Keel Space Station structure. The stiffness of the structure directly influences the way in which loads are transferred to the struts and throughout the pressurized elements. The pressurized modules, support struts and load conditions are added to this model in preparation for the finite element analysis. Support struts are assumed common with those of the primary truss structure in the initial model. The tube has a 51-mm (2-inch) outside diameter, a 1.5-mm (0.060-inch) wall thickness and is made of P75S/934 graphite epoxy composite. The analysis is iterated when support strut loads are determined to arrive at a required wall thickness. Column stability controls the design.

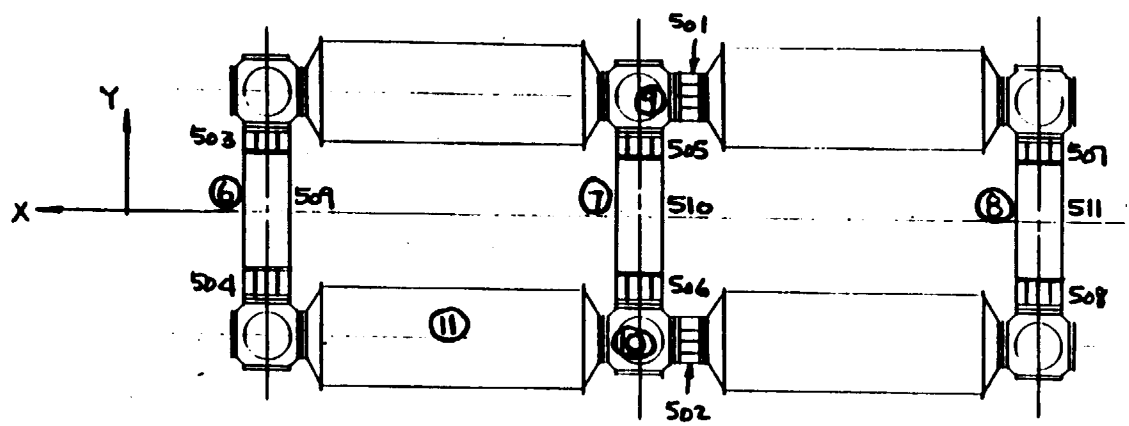
Parameters used for NSTS docking in the analysis are a maximum approach velocity of 0.03 meters per second (0.1 feet per second) in either the x-, y-, or z-direction coupled with a maximum approach rotation of 0.1 degrees per second. The range in temperature originally assumed for the thermal contingency analysis is 21°C to 93°C (70°F to 200°F). Later analysis performed used a more modest 21°C to 41°C (70°F to 104°F) temperature range. This drastic change is the result of detailed thermal analysis of an internal fire in a common module.

Hydrogen is used as the fuel in the thermal analysis since it has a high ratio of higher heating value to air fuel ratio (HHF/AFR) as compared to other fuels used on the Space Station. Therefore, a fire caused by hydrogen represents the worst case thermal contingency condition. The combustion process is limited by the amount of air available in the module. The analysis assumes a 22 percent oxygen, 78 percent nitrogen air content at 14.7 psia. Combustion is assumed complete when the oxygen content drops below 15 percent. The analysis also assumes normal operation of fire suppression equipment.

Analysis results for the bridge truss structure, dedicated module attachment design are shown in Tables 3.4-3 and 3.4-4. The loads in the support struts are shown in Table 3.4-3. Thermal conditions are fires occurring in pressurized elements (see Figure 3.4-17) using the 21°C to 93°C (70°F to 200°F) temperature range. Docking controls the design of the support struts in most cases. The tube thickness and diameter are driven by column stability. In most cases, the strut design used for the primary truss structure is inadequate for the module supports. Docking with attenuation must be addressed if struts common to those in the primary truss structure are used in this

Table 3.4-4. Interconnect Tunnel Thermal Loads Summary for Bridge Truss Structure Option

| BEAM ID | MAX. MOMENT IN-LBS | CASE ID | MAX. SHEAR LBS | CASE ID | MAX. AXIAL LBS | CASE ID | MAX. TORQUE IN-LBS | CASE ID |
|---|---|---|---|---|---|---|---|---|
| 501 | 288743. | 11 | 476. | 10 | -2117. | 9 | -44777. | 9 |
| 502 | 179957. | 10 | 622. | 11 | -2261. | 10 | 46431. | 10 |
| 503 | 96674. | 11 | 1730. | 11 | -317. | 6 | -16486. | 11 |
| 504 | 79834. | 11 | 1730. | 11 | -317. | 6 | -16486. | 11 |
| 505 | 85813. | 9 | 689. | 11 | -1684. | 7 | -33545. | 11 |
| 506 | 90202. | 10 | 689. | 11 | -1684. | 7 | -33545. | 11 |
| 507 | 114076. | 8 | 421. | 10 | -861. | 8 | 20147. | 9 |
| 508 | 111318. | 8 | 421. | 10 | -861. | 8 | 20147. | 9 |
| 509 | 77363. | 6 | 1730. | 11 | -317. | 6 | -16486. | 11 |
| 510 | 79490. | 7 | 689. | 11 | -1684. | 7 | -33545. | 11 |
| 511 | 113223. | 8 | 421. | 10 | -861. | 8 | 20147. | 9 |



design.

The results shown in Table 3.4-4 are the worst case thermal contingency loads in the interconnect tunnels due to a fire in pressurized elements as shown in the accompanying figure. The controlling thermal case analyzed is noted in the table. The results indicate the loads due to thermal contingencies are insignificant compared to normal operating pressure loads even though a high temperature range is used in the thermal load analysis for this design.

Analysis for the center truss structure, trunnion module attachment design are shown in Tables 3.4-5 and 3.4-6. The loads in the support struts are shown in Table 3.4-5. Thermal conditions are fires occurring in pressurized elements (see Figure 3.4-18) using the 21°C to 93°C (70°F to 200°F) temperature range. Docking controls the design of support struts in all cases even though the temperature range assumed in the thermal load analysis is greater than now expected. The tube thickness and diameter results indicate the strut design used for the primary truss structure is inadequate for this design. Docking with attenuation must be addressed if struts common to those in the primary truss structure are used in this design.

The results shown in Table 3.4-6 are the worst case thermal contingency loads in the interconnect tunnels due to a fire in pressurized elements as shown in the accompanying figure. The controlling thermal case analyzed is noted in the table. The data in the last two columns of the table are the percent increase of loads in tunnel struts (<u>not</u> module support struts) and tunnel cylindrical sections due to thermal contingencies compared to normal operating pressure loads. For example, the maximum tunnel strut loads in element 504 (upper compliant interconnect tunnel in the accompanying figure) due to a fire in any pressurized element are only 2.0 percent higher than the normal operating pressure loads in the tunnel struts. The results indicate that the loads due to thermal contingencies are insignificant compared to normal operating pressure loads.

### 3.4.4 Selection of Concept for Preliminary Design

At the time all previous design and analyses was in review to determine a recommendation for the pressurized module support structure, a NASA baseline configuration for the Initial Operating Capability (IOC) pressurized modules was established. The configuration consists of two United States (common) modules instead of four and also includes two international modules--the European Space Agency (ESA) module and the Japanese Experiment Module (JEM) (see Figure 3.4-19). The modules are still arranged in a figure eight pattern; however, if and how the international modules are attached to the truss was still an open issue.

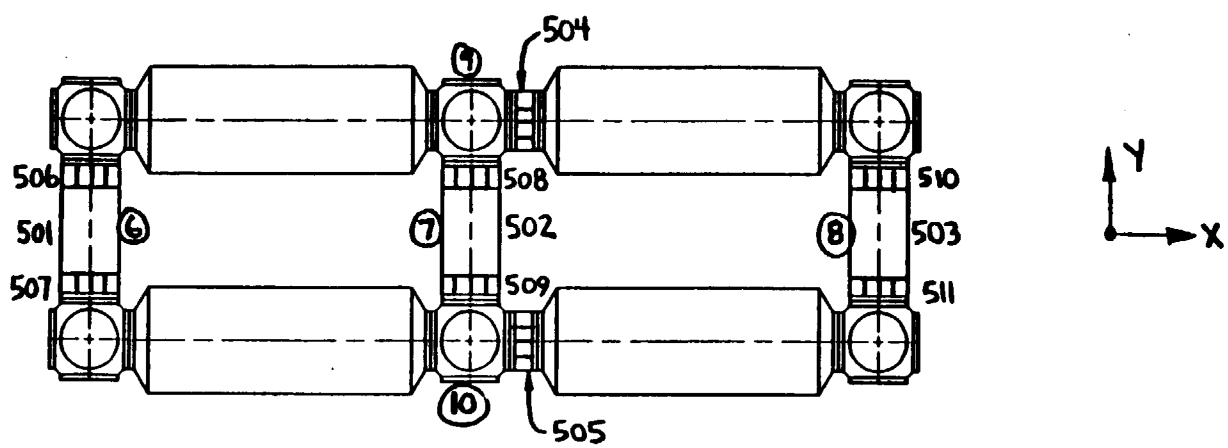
The recommendation for preliminary design presented to NASA/MSFC during the quarterly review at Marshall Space Flight Center in May 1986 is shown in Figure 3.4-20. The design consists of:

- o Module spacing and location relative to the Space Station

Table 3.4-6. Interconnect Tunnel Thermal Loads Summary for Center Truss Structure Option

| TUNNEL ID | MAXIMUM MOMENT (IN-LBS) | THERMAL CASE ID | MAXIMUM SHEAR (LBS) | THERMAL CASE ID | MAXIMUM AXIAL (LBS) | THERMAL CASE ID | MAXIMUM TORQUE (IN-LBS) | THERMAL CASE ID | %INCREASE STRUT LOAD | %INCREASE TUNNEL LOAD |
|---|---|---|---|---|---|---|---|---|---|---|
| 501 | 49479 | 6 | 22 | 7 | -230 | 6 | -477 | 7 | -- | 1.5 |
| 502 | 35088 | 6 | 59 | 10 | -1243 | 7 | 284 | 7 | -- | 1.1 |
| 503 | 58017 | 8 | 13 | 10 | -261 | 8 | 2583 | 10 | -- | 1.8 |
| 504 | 64241 | 8 | 795 | 7 | -674 | 9 | 12337 | 7 | 2.0 | -- |
| 505 | 61258 | 8 | 808 | 7 | -672 | 10 | -15094 | 7 | 1.9 | -- |
| 506 | 49481 | 6 | 22 | 7 | -230 | 6 | -477 | 7 | 1.5 | -- |
| 507 | 49461 | 6 | 22 | 7 | -230 | 6 | -477 | 7 | 1.5 | -- |
| 508 | 35114 | 6 | 59 | 10 | -1243 | 7 | 284 | 7 | 1.1 | -- |
| 509 | 34853 | 6 | 59 | 10 | -1243 | 7 | 284 | 7 | 1.1 | -- |
| 510 | 57957 | 8 | 13 | 10 | -261 | 8 | 2583 | 10 | 1.8 | -- |
| 511 | 58023 | 8 | 13 | 10 | -261 | 8 | 2583 | 10 | 1.8 | -- |

NOTE: STRUT LOAD UNDER NORMAL PRESSURE (32 PSI) IS 13,400 LBS ULTIMATE
TUNNEL LOAD UNDER NORMAL PRESSURE (32 PSI) IS 4,390 PSI ULTIMATE



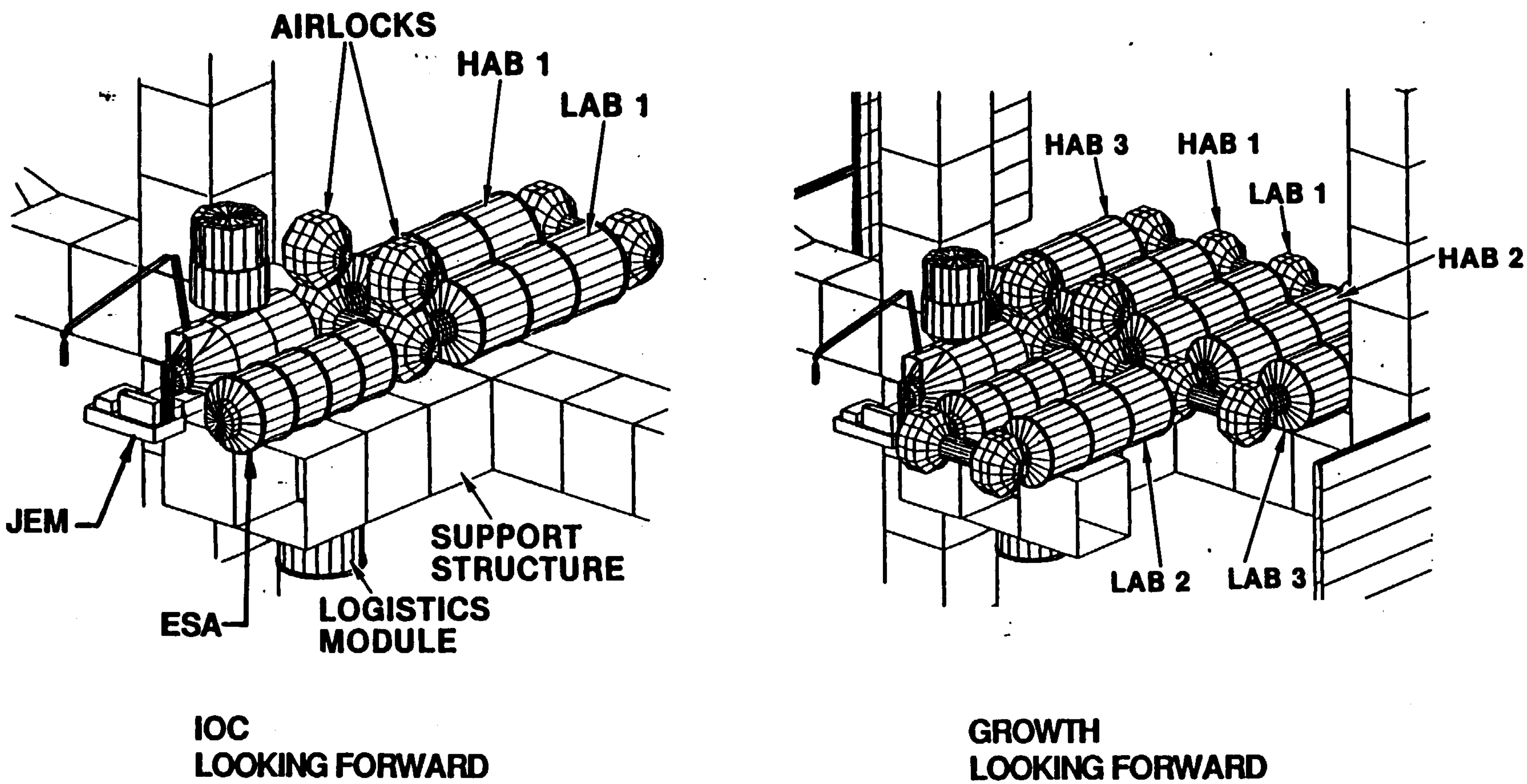



Figure 3.4-19. Pressurized Module Configuration for Preliminary Design

truss as derived in design studies

- o Dedicated attachments at module end ring frame and center of the cylindrical section
- o Cantilevered international modules
- o Independent, redundant eight-strut per module support system
- o Attenuated berthing ports for NSTS mating

The minimum 6.1-meter (20-foot) module-to-module spacing is used in the baseline configuration. The location of the modules relative to the truss is changed from previous configurations. The first common module delivered to orbit is centered over the bay of truss at the midpoint of the transverse boom. The minimum distance of the modules above the truss, though not specified in the NASA baseline, is 4.6 meters (181.1 inches). This distance is driven by the miscellaneous equipment located on the lower side of the JEM (see Figure 3.4-19). This module arrangement is the "frozen" configuration referred to in section 3.1, the introduction to Task 3. Other changes occurred subsequent to the May 1986 quarterly review, but were not incorporated into the preliminary design.

Dedicated module attachment is the best approach when minimum module-to-module spacing is used. As described in section 3.4.2, definition of design concepts, this approach provides the best structural load path and does not require excessive EVA assembly time. Further, upon review of the strut loads described in section 3.4.3, analysis of design concepts, it is obvious that shorter strut lengths are desired because of the column stability concern. Strut lengths are reduced significantly for the dedicated attachment approach as compared to the trunnion attachment approach.

Attachment of the dedicated fittings at the module ring frames is preferable. The recommended design has one set of attachments at the center of the module cylindrical section. If the cylinder is divided into four parts, an intermediate ring frame is located at the center of the module. If, however, the cylinder is divided into three parts, the intermediate ring frames are located at the one-third points. A layout of a module support design using the forward-located one-third ring frame for attachment indicates an interference with the MSC transporter. Use of the aft one-third ring frame results in poor load paths. When the center of the cylindrical section is used for attachment, there is no MSC interference (see Figure 3.4-21). Both three- and four-part module cylindrical section designs are under consideration by NASA/MSFC. If a three-part module cylindrical section is used, an intercostal structure is recommended to accomodate a center attachment location. A four-part cylindrical section is assumed for the preliminary design.

The recommendation for cantilevered international modules is based on analysis and the lack of a requirement for attachment to the truss in the midst of ongoing negotiations with the international partners. The analysis investigated microgravity accelerations in the

cantilevered modules due to crew disturbances. Assuming an electromagnetic isolation system at the base of an experiment, transient response levels are well within the $1 \times 10^{-5}$ g requirement (see Figure 3.4-22).

An independent, redundant support system is preferred for the baseline pressurized module support structure. The design must allow for the removal of one common module at IOC. Thus, if the international modules are cantilevered, an independent support system for each module is mandatory. This approach is also the most operationally flexible, allowing removal of any pressurized element during all phases of assembly and growth without compromising structural integrity of the module support system. Only six struts are required to provide a statically determinant support for a module. Eight struts are recommended to provide redundancy. If any one strut fails, no degradation occurs in the module support structure.

Attenuated berthing ports for NSTS mating are recommended based on the analysis described in section 3.4.3, analysis of design concepts. Attenuated berthing ports may also be required to reduce loads in the primary truss structure. The excessive tube wall thicknesses for the non-attenuated design are undesireable from a weight standpoint. In addition, a 51-mm (2-inch) diameter tube is the maximum desired based on EVA astronaut handling requirements. Grasping tubes of larger diameter is difficult with existing EVA gloves. Commonality with primary truss structure tubes is an attractive by-product of this design.

The recommendations for preliminary design were approved at the quarterly review. In addition to the development of the design as presented, the following efforts are included:

- o Development of concepts for supporting utilities from the primary truss to the module end cones
- o Consideration of ground-attachable dedicated module attachment fittings
- o Consideration of module insulation and meteoroid bumper penetration

### 3.4.5 Definition of Utility Interfaces

To define the pressurized module utility interfaces, an investigation of the routing and quantity of utilities was initiated. This design effort was conducted in January to April 1986 and thus reflects Space Station requirements at that time. The design is driven by four major requirements:

- o Provide redundancy for all utility systems
- o Minimize routing of utilities through pressurized nodes and interconnect tunnels
- o Isolate utility supports from primary truss structure load

path

- Provide adequate separation of utility connectors on pressurized module umbilical panel for EVA access

Utilities servicing the pressurized modules were divided into six systems for this design effort:

- Power management and distribution
- Active thermal control
- Data and communication
- Environmental control and life support water and waste
- Environmental control and life support gases
- Fluid servicing

Of these six systems, three are provided by permanently installed Space Station hardware and are routed to the pressurized modules via the truss structure (power management and distribution, active thermal control and data and communication). The other three systems are provided by the periodically resupplied logistics system (environmental control and life support water and waste, environmental control and life support gases, and fluid servicing). Water used in the active thermal control system is also furnished by the logistics system. Penetration of the utility systems is made on the module end cones. This location is consistent with internal utility routing schemes planned for the modules.

The routing of the power management and distribution system is shown in Figure 3.4-23. Main busses (400 volts alternating current) routed from the power generating subsystems (solar voltaic and solar dynamic) arrive at a utility distribution center depicted in the figure as a resource service center (RSC). From this center, redundant pairs of local busses are routed in parallel to the individual modules; 400 VAC to the common and international modules and 200 VAC to the airlocks and logistics modules. This method of routing, used for all the systems, minimizes utility routing through the module-to-module berthing ports.

The routing of the active thermal control system is shown in Figure 3.4-24. Ammonia lines are routed in parallel from the truss to heat exchangers located on common, international and logistics module end cones. Water used in the system is furnished by the logistics system and is looped throughout the system.

The routing of the data and communication system is shown in Figure 3.4-25. Fiber optic bundles are routed in parallel from the RSC to the common, international, logistics and airlock modules.

The routing of the environmental control and life support water and waste system is shown in Figure 3.4-26. The potable water lines

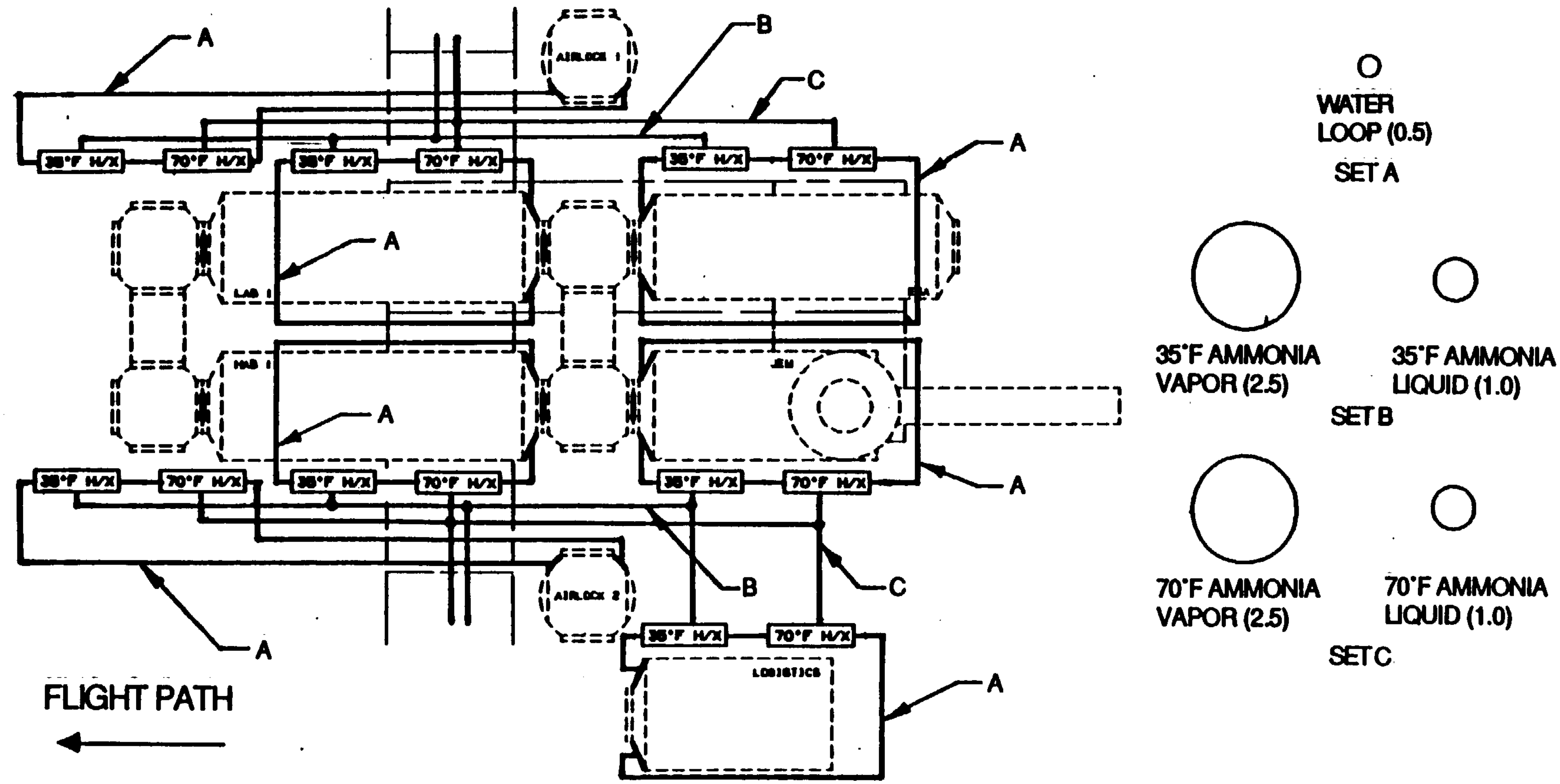



Figure 3.4-24. Routing for Active Thermal Control System

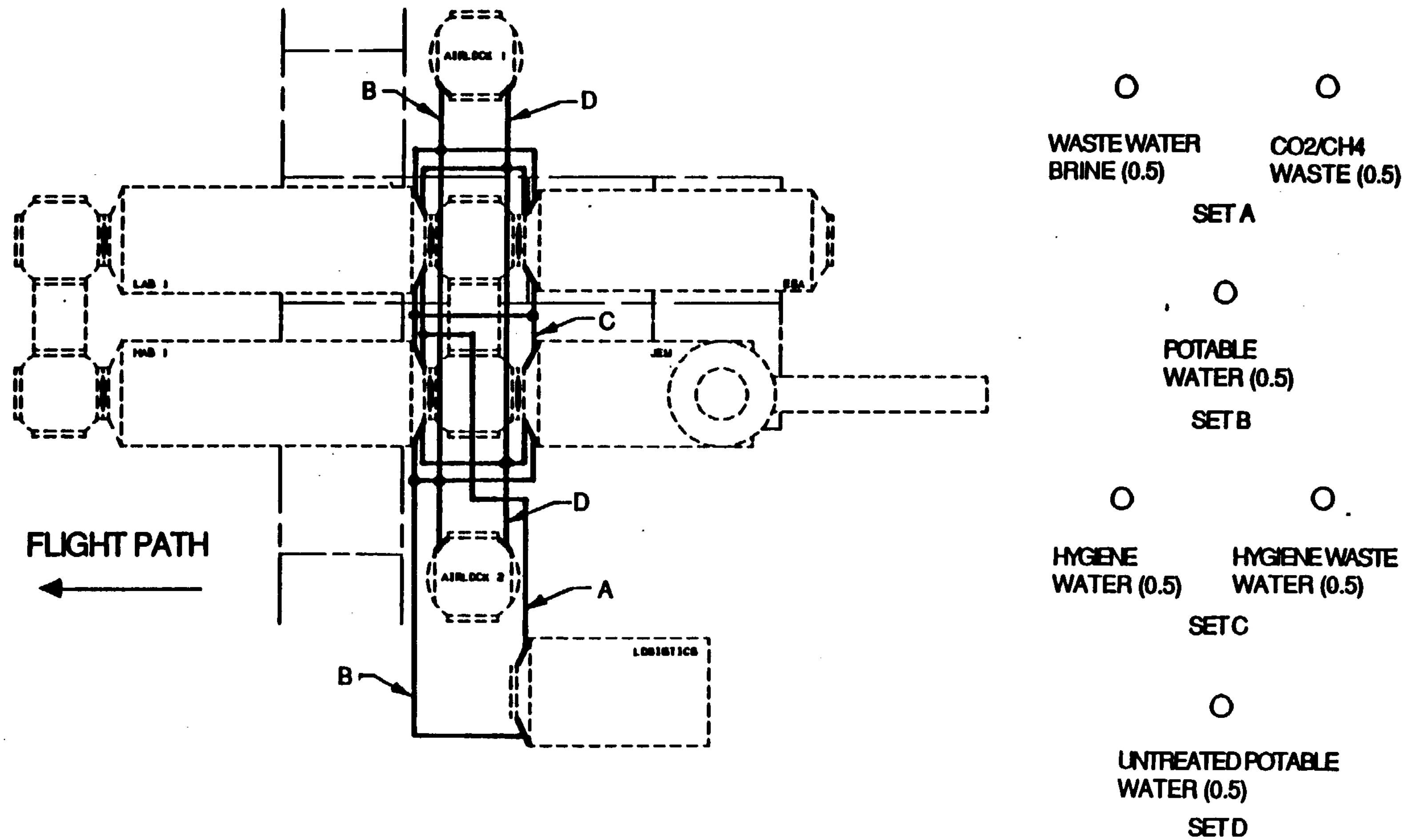
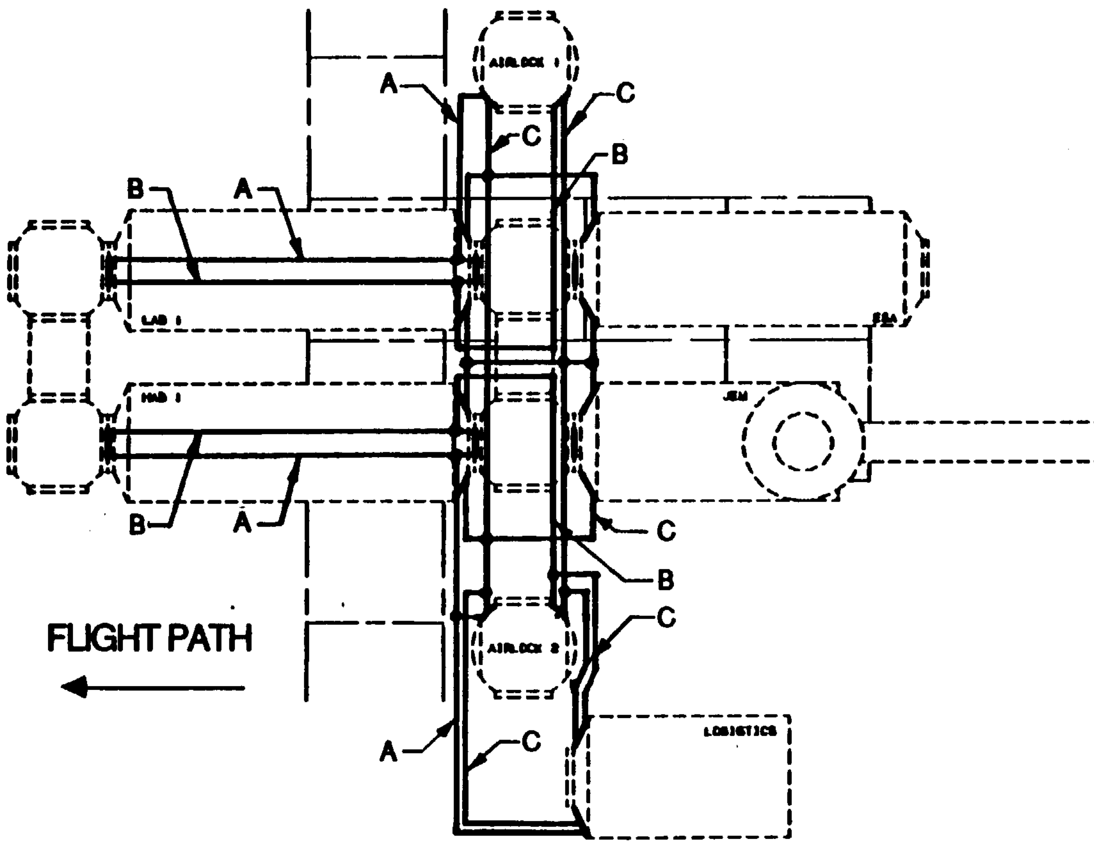



Figure 3.4-26. Routing for Environmental Control and Life Support Water and Waste System



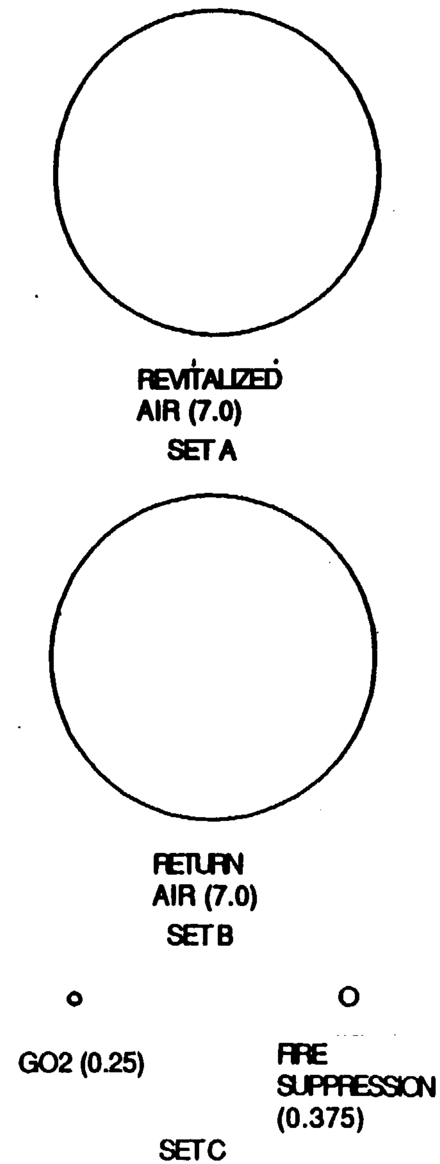
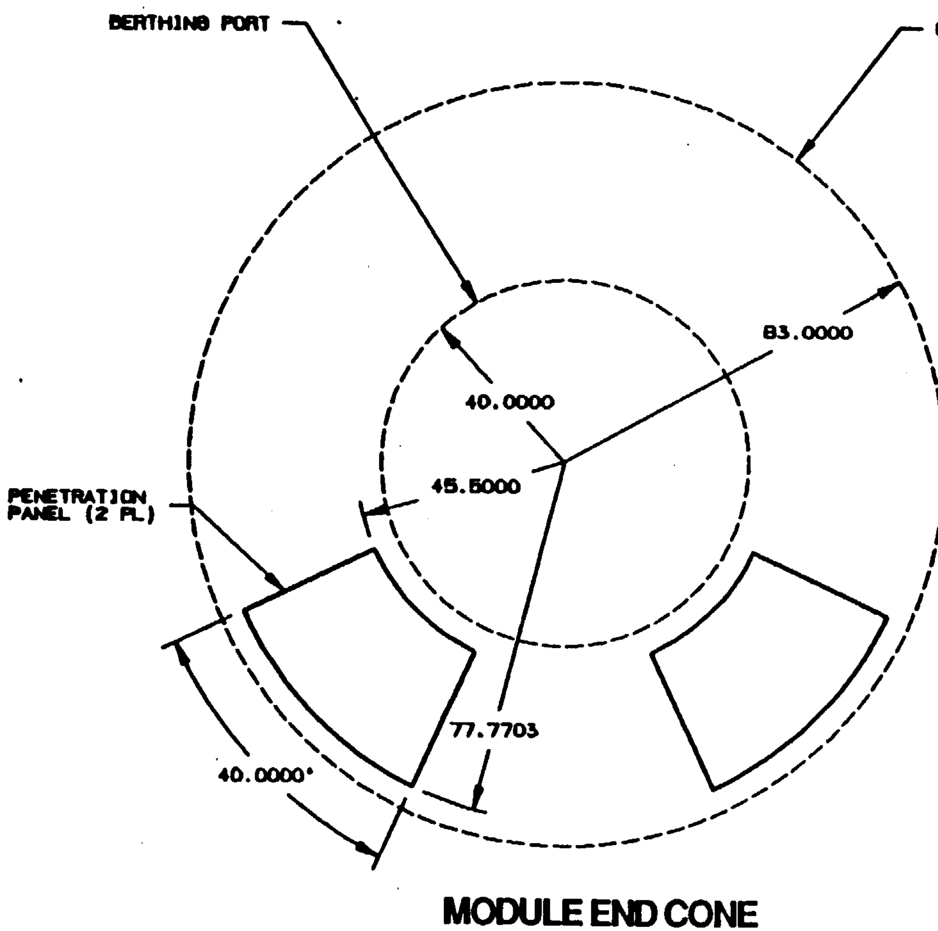
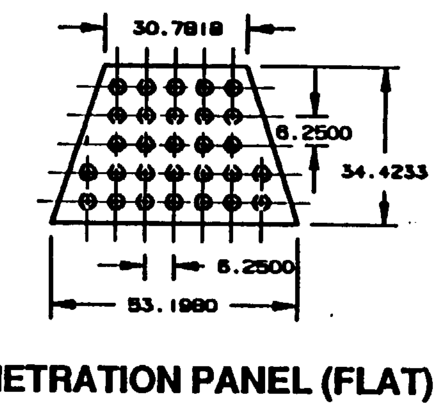




Figure 3.4-27. Routing for Environmental Control and Life Support Gases System




**PANEL SIZED FOR:**

**0 29 CONNECTORS**

**0 0.75 INCH O.D. QUICK DISCONNECTS**

**0 MINIMUM 3.0 INCHES BETWEEN CONNECTORS FOR EVA GLOVES**

Figure 3.4-29. Concept for Penetration Panel Connectors

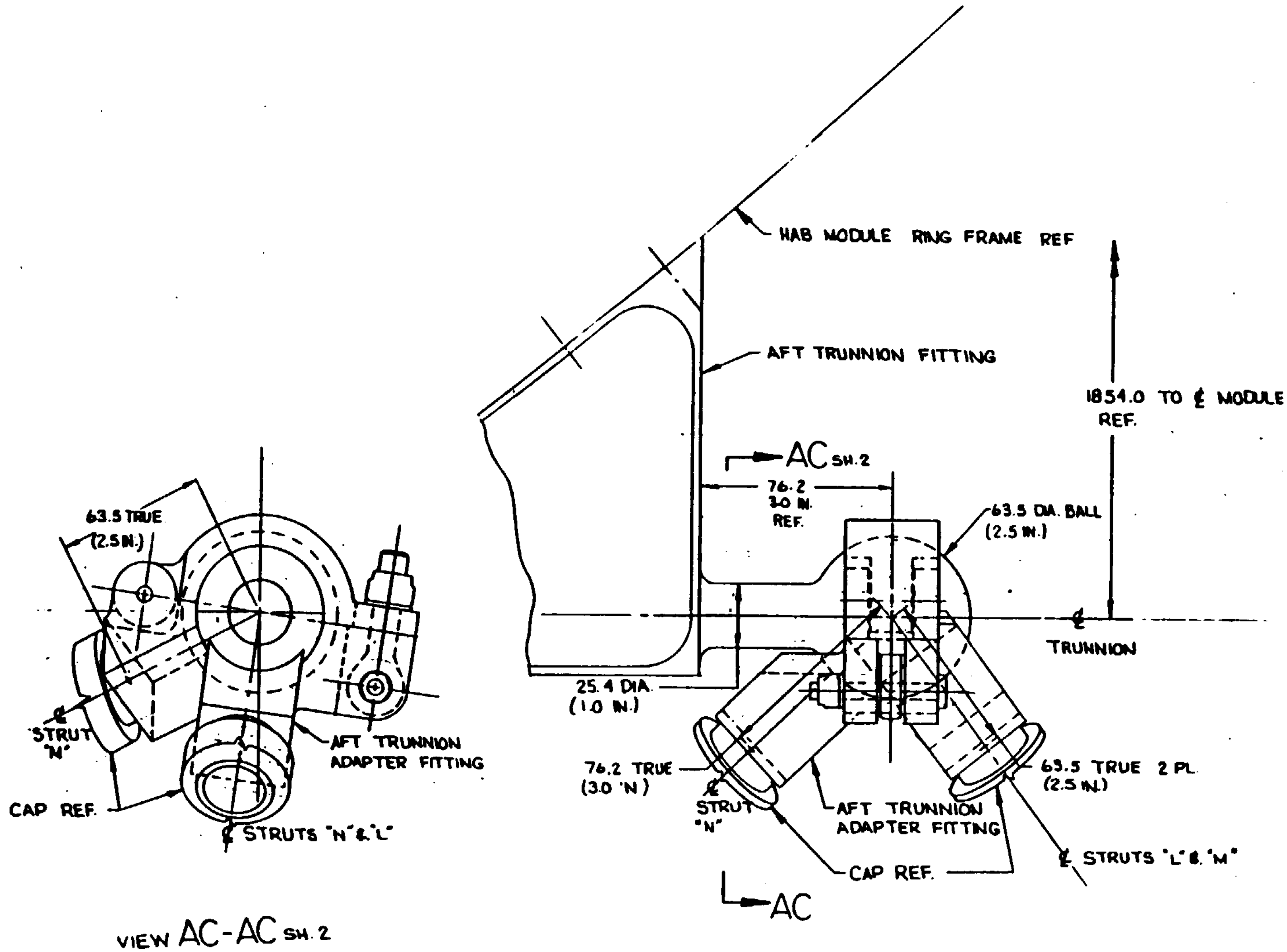



Figure 3.4-30. Maintenance and Assembly EVA Minimized by Clam-Shell Module Attachment Fitting

Module-to-module misalignments due to manufacturing and assembly tolerances are accomodated by the flexible interconnect tunnels and adjustable support struts. The interconnect tunnels each have two sets of three adjustable tie rods and the module support struts have axial adjustment capability. These features guarantee pressurized module support structure assembly despite the thermal environment present in low earth orbit.

Most of the requirements derived during the course of this study are satisfied as a result of addressing the NASA requirements and using the NASA baseline module configuration (see Figure 3.4-19). Derived requirements not specifically defined in the NASA baseline at the start of the preliminary design effort concern module spacing and location relative to the truss. The features of the preliminary design addressing these requirements include (see Figure 3.4-20):

- o 10.67-meter (35-feet) from forward face of primary truss structure to forward face of primary berthing port to provide NSTS berthing/docking clearance

- o Forward support struts attach to center of pressurized module cylindrical section to provide MSC travel clearance

- o 6.1-meter (20-feet) module-to-module spacing to provide clearance between modules for EVA

- o 4.6-meter (181.1-inch) upper face of truss to module centerline spacing to allow clearance for JEM external equipment

3.4.6.2 <u>Analysis</u>. Loads analysis performed on the preliminary design of the pressurized module support structure (Figure 3.4-20) is summarized in Tables 3.4-7 and 3.4-8. Attenuation is assumed for the berthing ports in the analysis. A stiff berthing port (assumed in previous analyses) has an estimated $6.39 \times 10^9$ newtons per meter ($3.65 \times 10^7$ pounds per inch) stiffness coefficient in the axial direction. An attenuated berthing port, though, has only an estimated 20,136 newtons per meter (115 pounds per inch) stiffness coefficient in the axial direction. This difference in stiffness softens the impact of the NSTS orbiter which approaches the berthing port at 0.03 meters per second (0.1 feet per second) coupled with a maximum rotation of 0.1 degrees per second (see section 3.4.3 for further description).

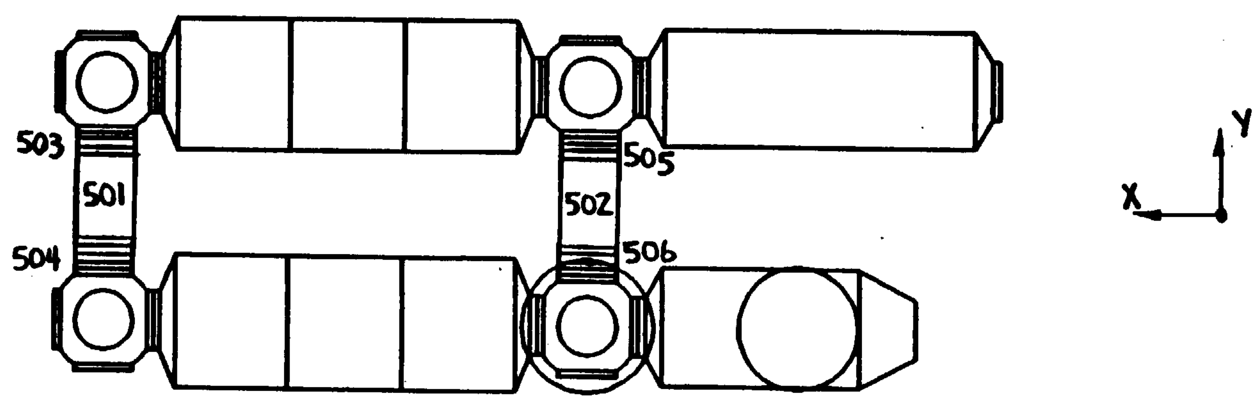
The loads in the support struts are shown in Table 3.4-7. The thermal conditions are fires occurring in pressurized elements (see Figure 3.4-31) using a 21°C to 41°C (70°F to 104°F) temperature range (see previous description in section 3.4.3). Strut identification numbers are shown in the figure as well. Docking loads control the design of all but one strut. The standard 51-mm (2-inch) diameter used for the primary truss structure can also be used for the module support structure. Furthermore, only two of the composite tubes require greater than the standard 1.5-mm (0.060-inch) wall thickness.

The results shown in Table 3.4-8 are the worst case thermal contingency loads in the interconnect tunnels due to a fire in

Table 3.4-8. Thermal Contingency Loads Insignificant Compared to Normal Operating Pressure Loads

| TUNNEL ID | MAXIMUM MOMENT (IN-LBS) | THERMAL CASE ID | MAXIMUM SHEAR (LBS) | THERMAL CASE ID | MAXIMUM AXIAL (LBS) | THERMAL CASE ID | MAXIMUM TORQUE (IN-LBS) | THERMAL CASE ID | % INCREASE STRUT LOAD | % INCREASE TUNNEL LOAD |
|---|---|---|---|---|---|---|---|---|---|---|
| 501 | 39198 | 7 | 1431 | 7 | -174 | 3 | 3428 | 7 | -- | 1.2 |
| 502 | 23855 | 4 | 664 | 7 | -308 | 4 | 4590 | 7 | -- | 0.7 |
| 503 | 72398 | 7 | 1431 | 7 | -174 | 3 | 3428 | 7 | 2.2 | -- |
| 504 | 73531 | 7 | 1431 | 7 | -174 | 3 | 3428 | 7 | 2.3 | -- |
| 505 | 34511 | 7 | 664 | 7 | -307 | 4 | 4590 | 7 | 1.1 | -- |
| 506 | 33129 | 4 | 664 | 7 | -307 | 4 | 4590 | 7 | 1.0 | -- |

NOTE: STRUT LOAD UNDER NORMAL PRESSURE (32 PSI) IS 13,400 LBS ULTIMATE
TUNNEL LOAD UNDER NORMAL PRESSURE (32 PSI) IS 4,390 PSI ULTIMATE



pressurized elements as shown in the accompanying figure. The controlling thermal case is noted in the table. The last two columns in the table indicate the percent increase of loads in the tunnel struts (not the module support struts) and tunnel cylindrical sections due to thermal contingencies compared to normal operating pressure loads. As in previous analyses (see section 3.4.3), the loads due to thermal contingencies are insignificant compared to normal operating pressure loads.

3.4.6.3 Module and Truss Attachment Fitting Design. The struts used in the pressurized module support structure are duplicates of those used in the primary truss structure with the exception of length and wall thickness in several instances (see Figure 3.4-32). Fittings are required to attach these standard components to the Space Station transverse boom and the common modules.

Two types of module attachment fittings were developed during the preliminary design. The preferred design, shown in Figure 3.4-33, utilizes a clam-shell attachment fitting and trunnion attachment fitting. The upper half of the clam-shell fitting opens to accept the trunnion fitting during assembly of the modules to the truss. A pivoting rod end with a nut is used to secure the upper half of the fitting when the trunnion fitting is seated. The upper portion of the fitting and the pivoting rod end are common for all clam-shell fittings.

The lower half of the clam-shell fitting is designed for each application. In the eight strut per module arrangement used in the preliminary design (refer to Figure 3.4-20), one fitting is designed to accept three struts (forming a tripod), two fittings are designed to accept two struts (forming bipods), and the fourth fitting is designed to accept one strut. The geometry of the lower portion of the fitting also differs between the two common modules supported and will further vary when designing for growth modules. Standard interfaces with the support struts are used at each location.

The trunnion attachment fitting shown in Figures 3.4-33 and 3.4-34 is fastened directly to the common module ring frames on orbit prior to assembly. This in-space assembly operation is not desired, but the NSTS payload bay envelope leaves little room to accomodate a ground-installed trunnion fitting of this type. An alternate design which eliminates this operation is described later. A longeron frame on the common module is required for the aft two trunnion fittings to transfer x-direction loads (those along the length of the module) into the stiffened skin of the module (see Figure 3.4-34). The end of the trunnion features a sphere that interfaces with the clam-shell fitting. The spherical interface allows rotation of the clam-shell fitting (and therefore the module support struts) to accomodate manufacturing and assembly tolerances that otherwise would inhibit module installation.

The second type of module attachment fitting eliminates the in-space attachment of a trunnion fitting to the common module ring frame (see Figure 3.4-35). The module ring frame in the vicinity of the attachment is altered to accept the fitting. As the NSTS payload bay

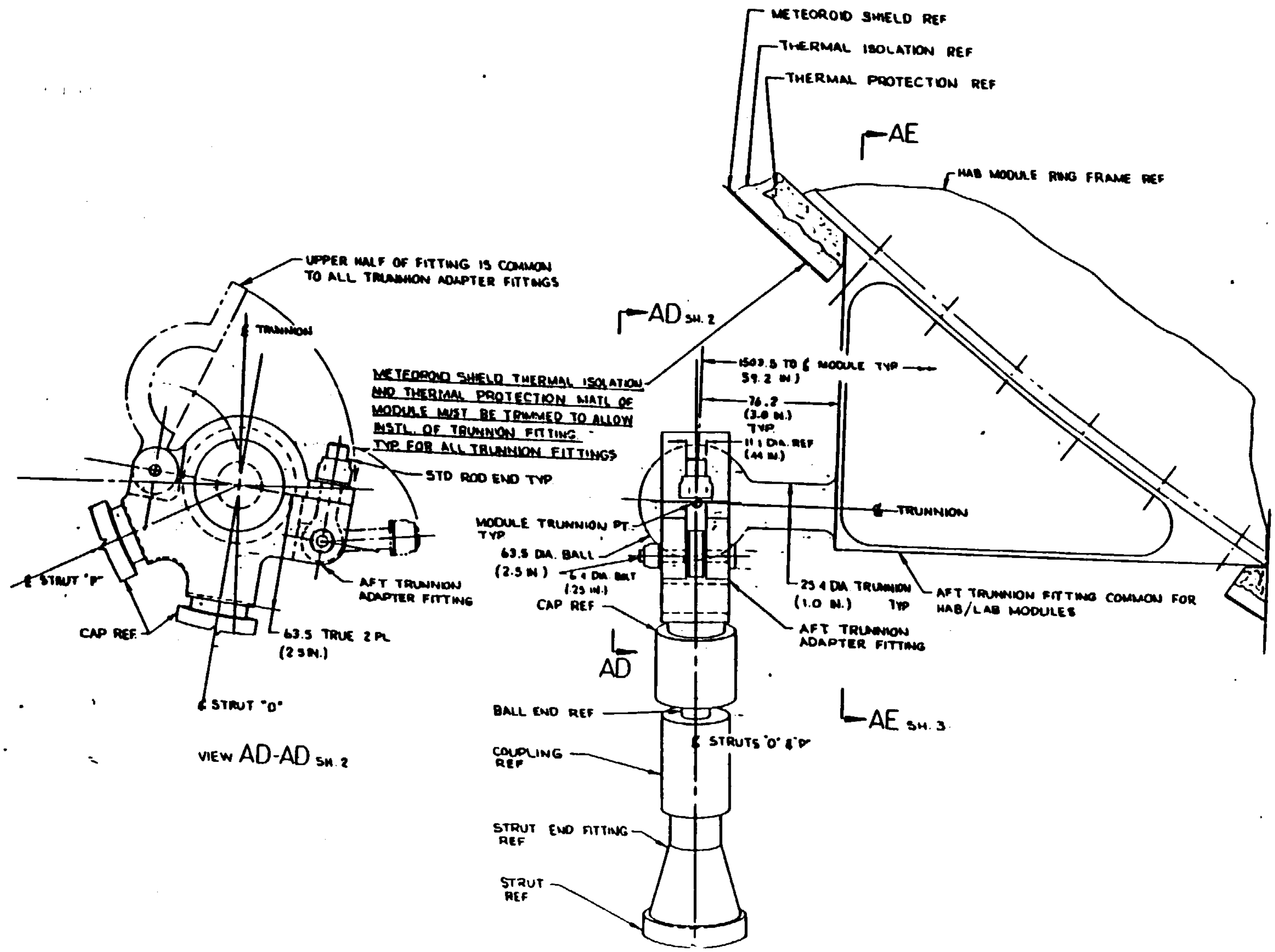



Figure 3.4-33. Module Attachment Fitting Preliminary Design

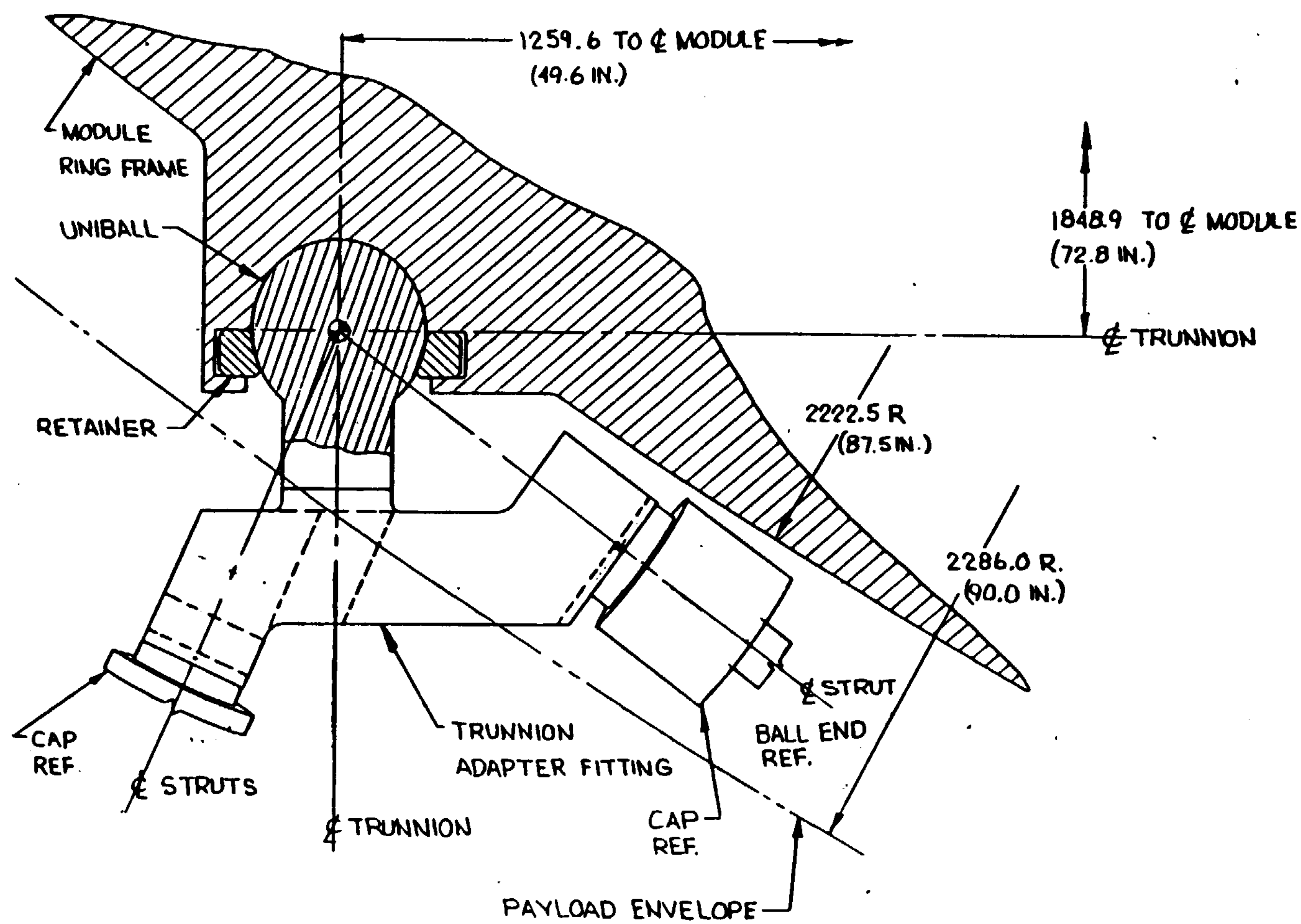



Figure 3.4-35. Alternate Module Attachment Fitting Eliminates EVA Installation of Trunnion Fitting

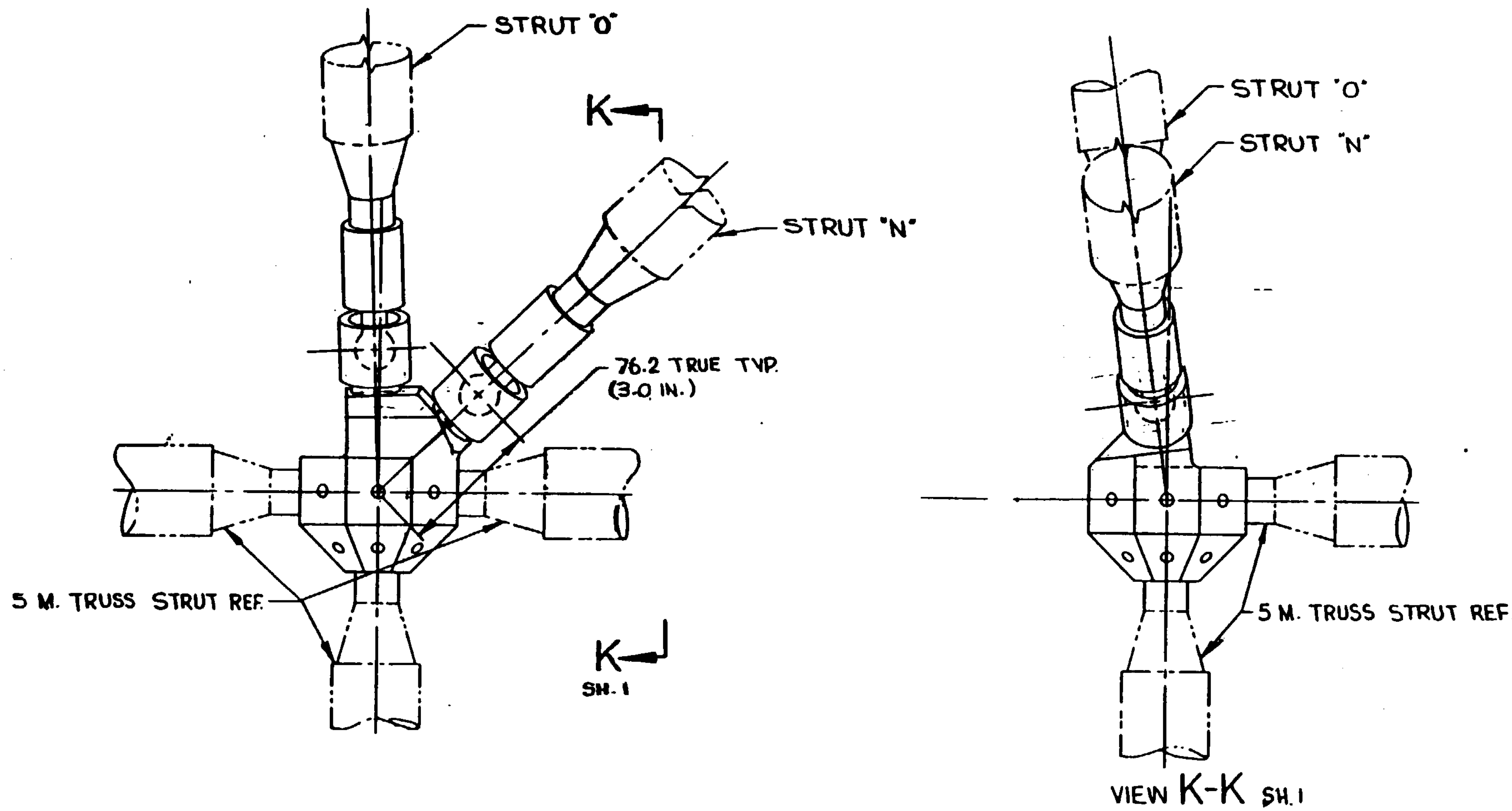



Figure 3.4-36. Truss Attachment Fitting Incorporated Into Standard Corner Fitting

tandem with the spherical clam-shell/trunnion fitting interface and the axial adjustment capability in the support struts (see Figure 3.4-32), provide for complete adjustment during assembly of a common module to the truss.

Analysis of the module and truss attachment fitting designs indicate positive margins of safety in all components. In many cases the margins of safety considerably exceed the 1.5 required for structures; however, EVA interfaces govern sizing in those instances. Many of the components are handled during EVA assembly and the dexterity of the standard EVA glove was a major consideration for sizing.

All of the module and truss attachment components are made of machined 2219 aluminum with the exception of the ball-ends on either end of the support struts which are made of A286 steel. Materials for fasteners were not selected although standard aerospace materials such as titanium, nickel alloys or steel alloys are more than adequate for this low strength application.

3.4.6.4 Utility Support Structures Design. Secondary support structures are required to route utilities from the truss structure to the common module end cones. An overall view of the design developed is shown in Figure 3.4-38. Both the electrical and data utilities and the active thermal control utilities are housed in two redundant utility trays. The size and location of common module heat exchangers and penetration locations are not firmly established and are assumed as shown in the figure. The objective of this design effort is not heat exchanger or penetration panel design; it is to define a concept for routing utilities from the modules to the truss. The design developed is easily modified to accomodate the final utility interface requirements.

Commonality is the key feature of this design. The standard utility tray used throughout the Space Station truss structure (see Figure 3.4-39) is also used to provide support for this routing. The utility tray can be scaled to satisfy requirements for quantity and sizing of utility lines as they evolve into a final design. The sizing used in this design effort is based on the utility interface definition described in section 3.4.5. Slip joints used in the standard tray are used in this design as well. The slip joints accomodate thermal growth and limit the loads transferred to the tray.

Hinged elbow joints are incorporated into the standard tray to accomodate bends in the routing (see Figure 3.4-40). The elbow joints are assembled on the ground and the tray assembly is stowed in a flat position for launch. On orbit, the trays are folded into their operating position. Electrical and data utilities are installed on orbit via hinged access doors (see Figure 3.4-39). Active thermal control fluid lines are pre-installed on the ground.

An umbilical pan adaptor is used to interface at the module electrical and data utilities penetration panel (see Figure 3.4-41). The two utility trays are attached to the adaptor on the ground. A power umbilical attachment device is envisioned for EVA attachment of

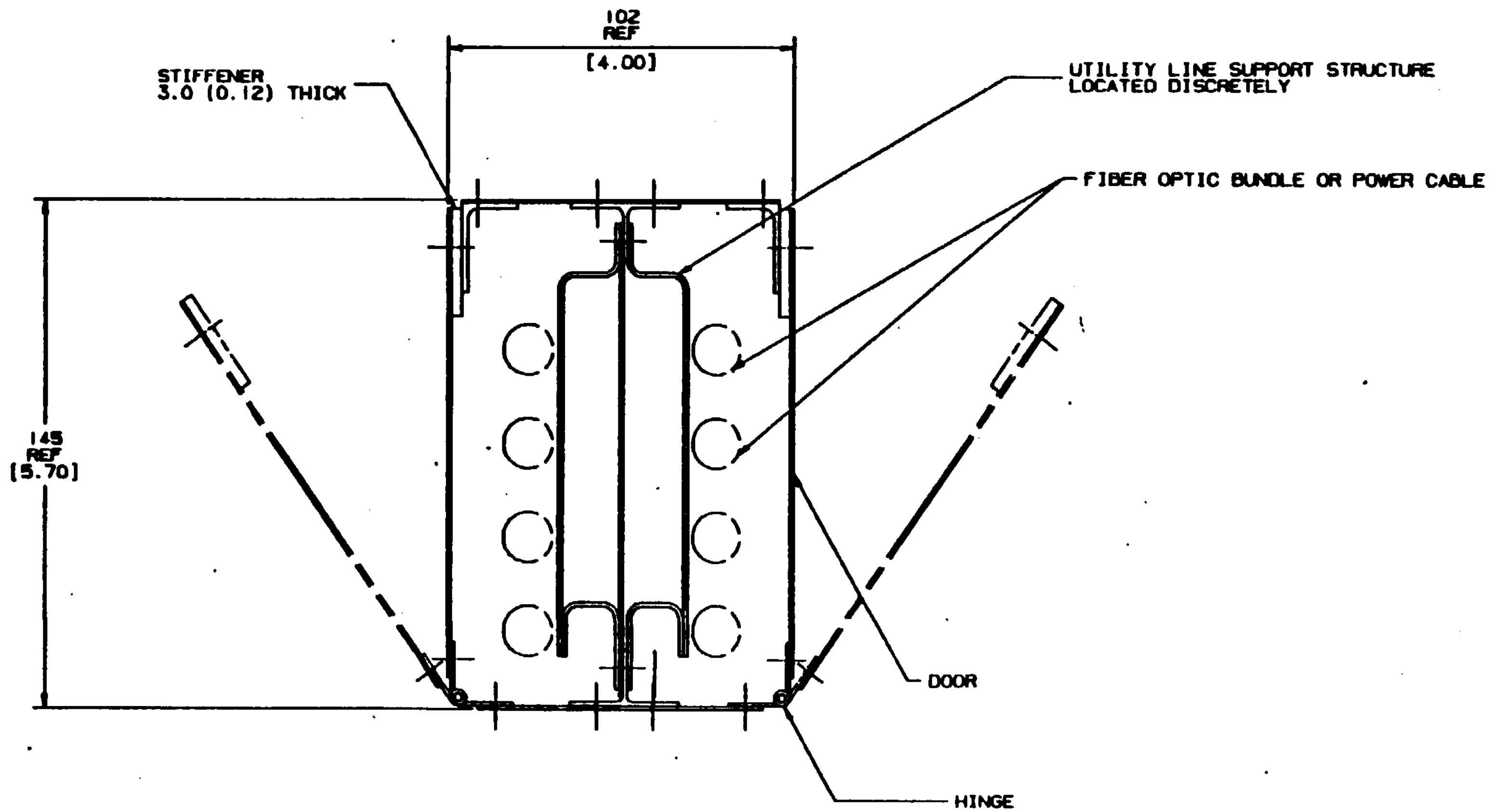



Figure 3.4-39. Standard Utility Tray Featured in Design

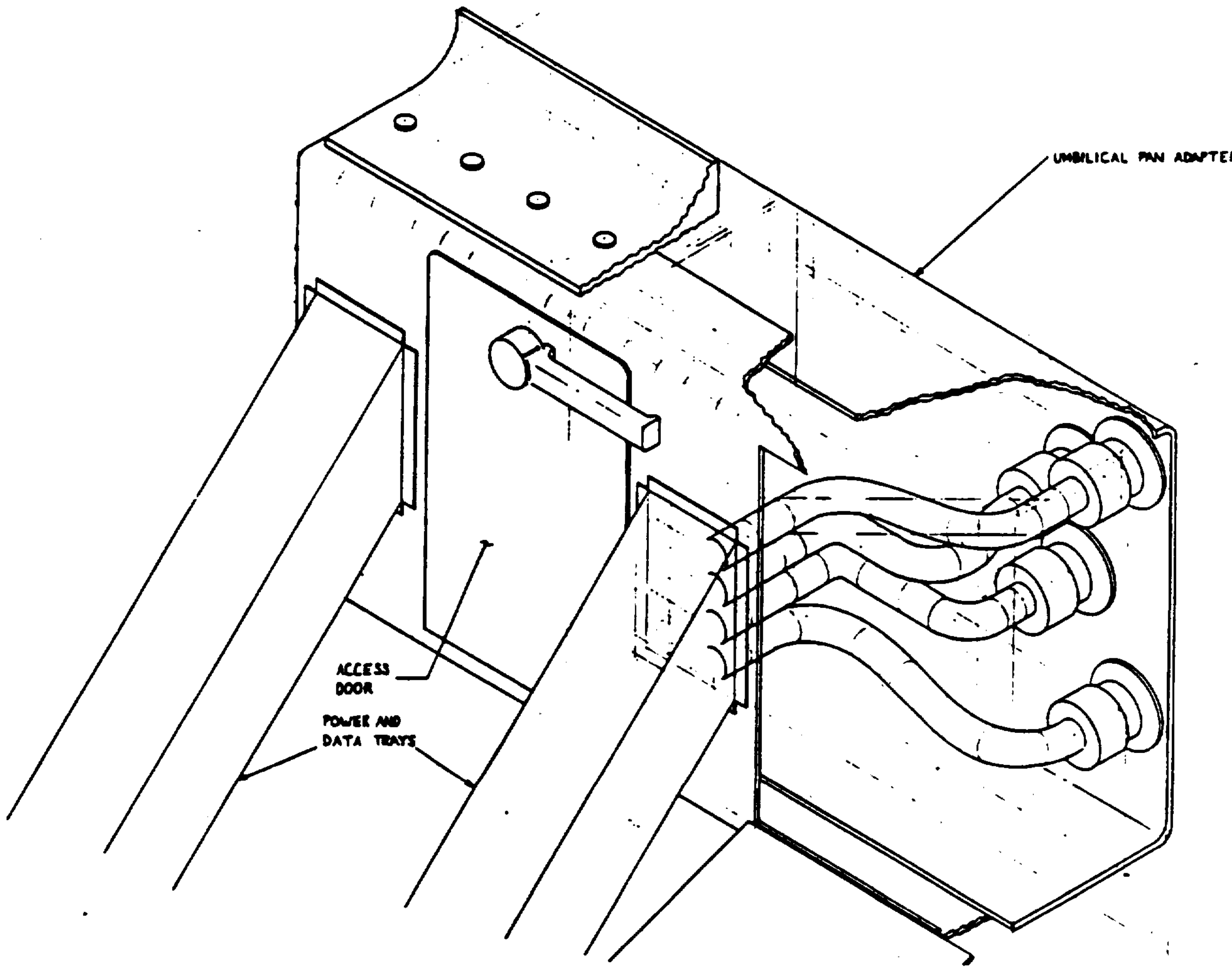



Figure 3.4-41. Umbilical Pan Adaptor Interfaces With Module Penetration Panel

## 4.0 REFERENCES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2. Ground Test Article for Deployable Space Structure Systems, Final Report, Contract NAS8-34657, Rockwell International report SSS 85-0164, October 1985.

3. Schwartz, M. M., Composite Materials Handbook, McGraw Hill Book Company, 1984.

4. Space Station Program Definition and Requirements, NASA/JSC document JSC 30000.

5. Space Station Projects Definition and Requirements Section 3: Space Station Requirements and Specifications - Work Package 2, NASA/JSC document JSC 31000.

6. Space Station Program Design Criteria and Practices, NASA/JSC document JSC 30213.

# APPENDICES

# APPENDIX A

## P75S/934 GRAPHITE EPOXY COMPOSITE LABORATORY TEST REPORT

LABORATORY TEST REPORT LTR 4492-4206

# EVALUATION OF P-75S/934 GRAPHITE/EPOXY COMPOSITE FOR DEPLOYABLE TRUSS STRUTS - SPACE STATION

May 1986

TR SC85-008

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SUMMARY

A limited material characterization test program has been conducted for P-75S/934 graphite/epoxy composite material. Tensile and compressive properties (strength, modulus, Poisson's ratio), thermal expansion properties, atomic oxygen exposure effects, and thermal cycling effects data were generated for 0.040 inch thick unidirectional laminates using 2.5 mil/ply P-75S/934 material. The unidirectional composite, as anticipated, is essentially resistant to microcracking during thermal cycling. Mechanical and thermophysical properties were generally consistent with predicted values while atomic oxygen exposure tests confirm the need for protective coatings for long-term space applications.

- Determine the thermal expansion characteristics between +200F and -150F.
- Evaluate the effects of thermal cycling on microcracking, mechanical properties, and thermal expansion characteristics of the material.

## 3.0 PROCEDURES AND RESULTS

The following paragraphs detail the materials, test methods, specimen configurations, and test results associated with the subject test program.

### 3.1 Composite Material

All tests were performed on laminates fabricated from a single batch of P-75S/934 graphite/epoxy from Fiberite Corporation, Winona, Minnesota (Mfg. ID HyE2034D; Batch C6-255). Material was provided as 6-inch wide tape at nominal 2.5 mils per ply.

### 3.2 Material Acceptance Tests

The pre-preg material was tested for conformance to the applicable requirements of Rockwell Material Specification MB0130-160. As shown in Table 1, the material conformed to these specification requirements.

Table 1. Acceptance Test Results

| Property | Requirement (MB0130-160) | Results |
|---|---|---|
| Fiber Areal Weight | - | 137.9 $g/m^2$ |
| Fiber Wetting | Filaments Completely Wetted | Acceptable |
| Alignment | Parallel within one degree | Acceptable |
| Gaps | 0.030 inch, max | <0.005 inch |
| Volatile Content | 2.0%, max | 0.71% |
| Resin Content | 38-44% (weight) | 38.02% |
| Tack | No Movement for 30-minutes | Acceptable |

One laminate (6.0 x 6.0 inch) was used to test the physical characteristics and short beam shear strength to the requirements of MB0130-160, and provide the longitudinal and transverse thermal expansion test specimens. The second laminate (22 x 32 inch) was used to fabricate the remaining specimens required by the Test Request. Process control data measured for both laminates were within specification requirements and are summarized in Table 2.

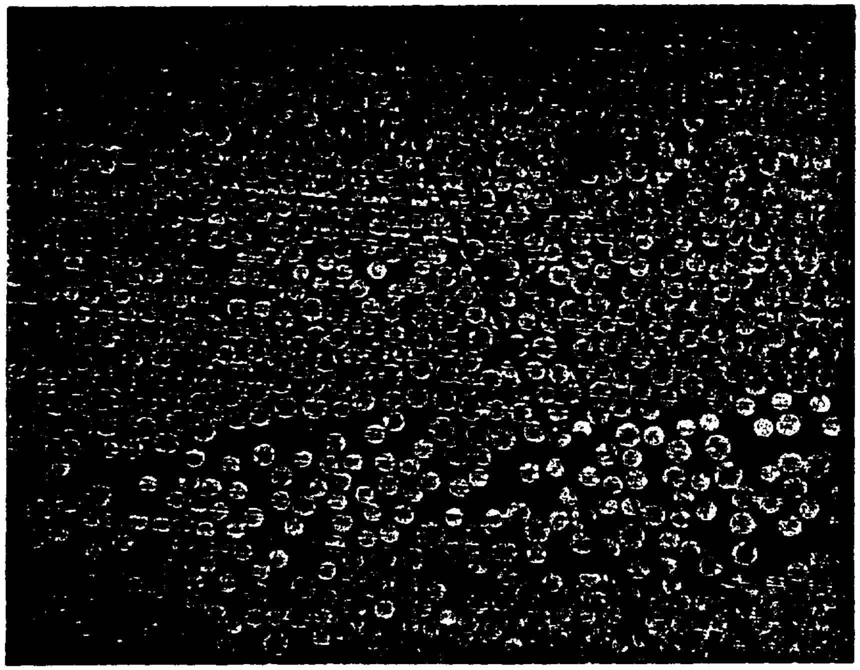
Table 2. Process Control Data for Cured Laminates

| Laminate ID | Cured Ply Thickness (mils) | Specific Gravity (g/cc) | Resin Content (W%) | Fiber Volume (V%) | Short Beam Shear Strength (KSI) |
|---|---|---|---|---|---|
| IU1 | 2.67 | 1.766 | 28.24 | 63.24 | 8.00 |
| IU1 | 2.44 | 1.771 | 27.69 | 63.90 | 8.80 |
| IU2 | 2.72 | 1.756 | 26.39 | 64.50 | 9.60 |
| IU2 | 2.53 | 1.751 | 29.01 | 62.03 | 8.90 |

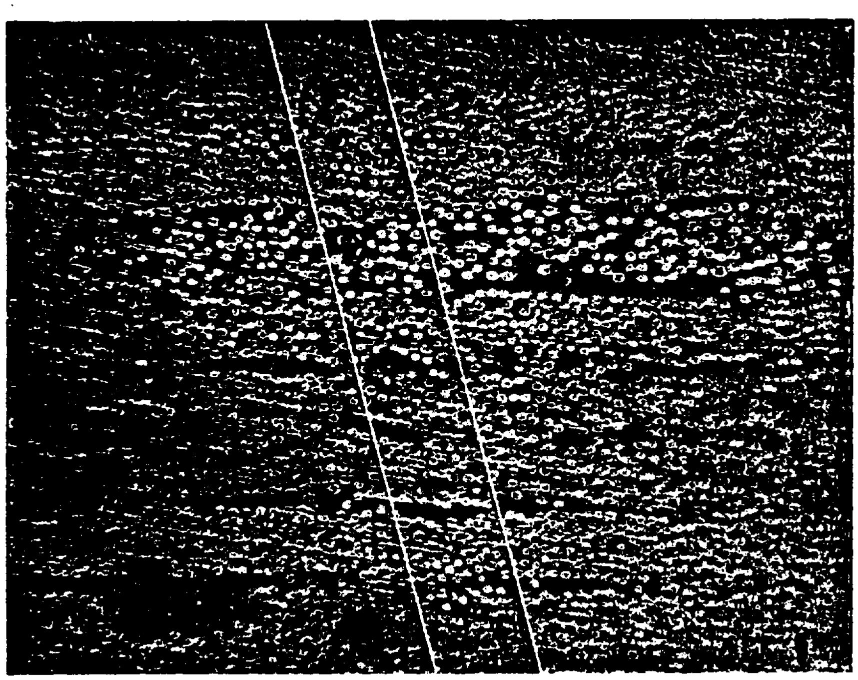
Nondestructive evaluation of both laminates was performed per MT0501-510 using "A-sensitivity" C-scan. No internal defects were evidenced.

3.4 Environmental Control/Moisture Absorption

Laboratory environment conditions were maintained at 70 to 80F and 52 to 62% relative humidity. When tested per ASTM D618 Procedure A for 88-hours, moisture absorption was verified to be less than 0.25 percent which has minor effect on material properties. To further minimize effect of absorbed moisture, all specimens were dried at 120F for 24 hours prior to testing.



Before Thermal Exposure



After Thermal Exposure

Figure 4 - P75s/934 Graphite/Epoxy Cross Section Before and After 400 Cycles Ranging from -150F to 200F

### 3.7 Atomic Oxygen Exposure

The effects of atomic oxygen exposure on the physical characteristics of the P-75S/934 composite were evaluated using methodology developed in the M&P Laboratory under separate IR&D activities (Reference 3). Low earth orbit atomic oxygen effects were simulated using a low temperature asher. Two by two-inch square test specimens were tested as follows:

- o Measure and record weight and dimensions.
- o Protect all surfaces with aluminum foil tape except an exposed "picture frame" of 1.5 x 1.75 inch on one surface of the specimen.
- o Suspend the specimen by a glass hanger in the center of the chamber oriented perpendicular to the longitudinal axis of the test chamber.
- o Expose at 100-watts of rf-power, 0.4mm Hg, and 55cc/minute oxygen flow for various times.

Weight loss and recession rates as a function of exposure time (up to nine hours) was measured and recorded. Significant loss of both resin and fiber were observed. Scanning electron microscope (SEM) examination was performed revealing the progressive erosion of resin and then fiber. The measured recession rate data, approaching two mils per hour, are plotted in Figure 5. SEM photographs illustrating the effects of the asher environment on the composite material are shown in Figure 6.

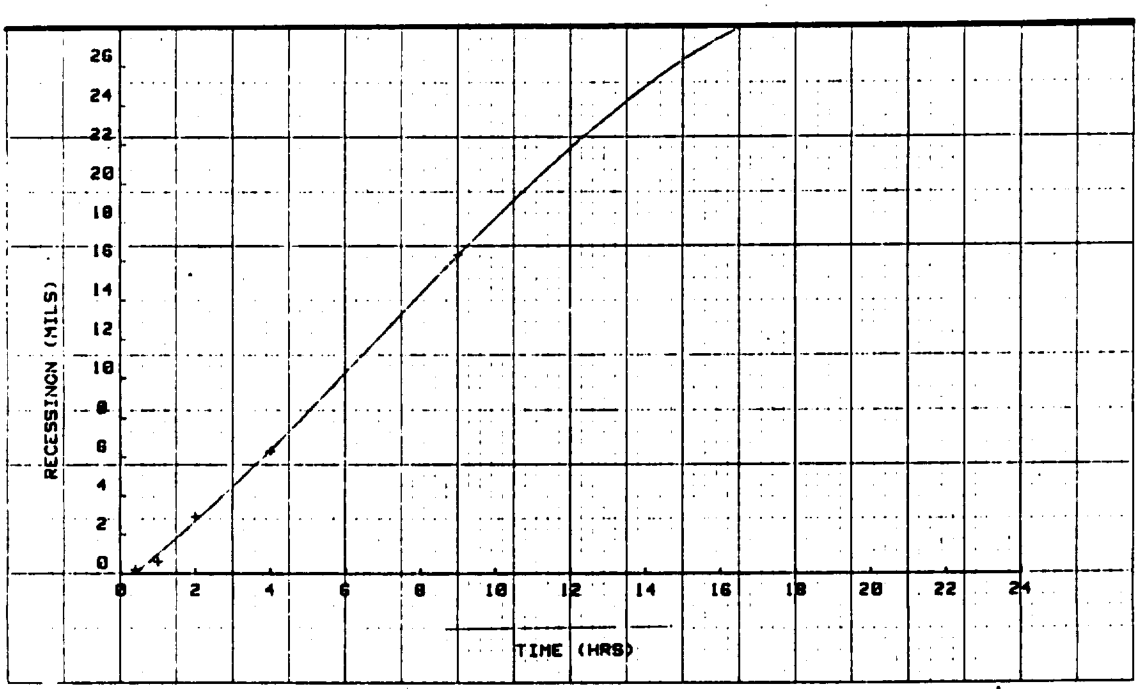



Figure 5 - Atomic Oxygen Exposure of P-75S/934 Graphite/Epoxy Composite

## 3.8 Tensile Properties

Tensile coupon blanks (0.75 x 8.0 inch) were cut from test laminate IU2. Three blanks were subjected to 500 thermal cycles between -150F and +200F. Pull tabs (0.06 inch thick) were bonded to specimen ends with HT-424 phenolic/epoxy adhesive film cured under vacuum for 45 minutes at 340F.

These coupons were initially machined to the reduced test section configuration of FED STD-406 shown in Figure 7. However, the failure mode for the first two specimens tested involved longitudinal splitting of the composite originating in the radius of the reduced test section. Therefore, subsequent test specimens were machined to the straight-sided configuration shown in Figure 8. All specimens were instrumented with one bi-axial strain gages mounted along the specimen centerline.

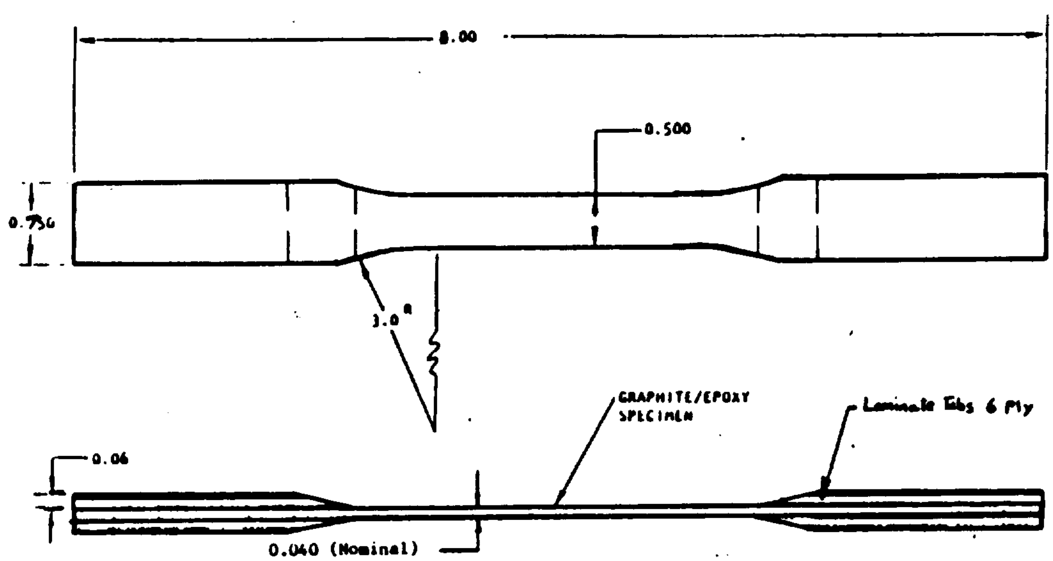



Figure 7 - Tensile Specimen Configuration (Original)

These relatively thick, high modulus fiber reinforced composites present unique problems when measuring elastic modulus properties. When tested in tension, the stress-strain relationship does not exhibit the single initial linear slope from which elastic modulus is conventionally determined. Rather, as stress is increased, the apparent stiffness of the system increases as evidenced by a second somewhat-linear segment of the load record. The point at which this inflection occurs is not consistent and is felt to reflect the shear lag associated with transfer of load from the exterior to the interior fibers. Therefore, three separate modulus values for each test are reported in Table 3:

E1: initial modulus calculated from the initial linear portion of the curve.

E2: mid-range, secant modulus calculated using strain recorded at 20 and 50 percent of the ultimate stress.

E3: upper-range modulus from the slope of the upper most-linear portion of the stress-strain curve.

Poisson's ratios were based upon initial linear slopes of the axial and transverse stress-strain curves.

Although several specimens failed under or near the pull tabs, differences in ultimate strength were not significant and, therefore, average ultimate strengths reported include all data.

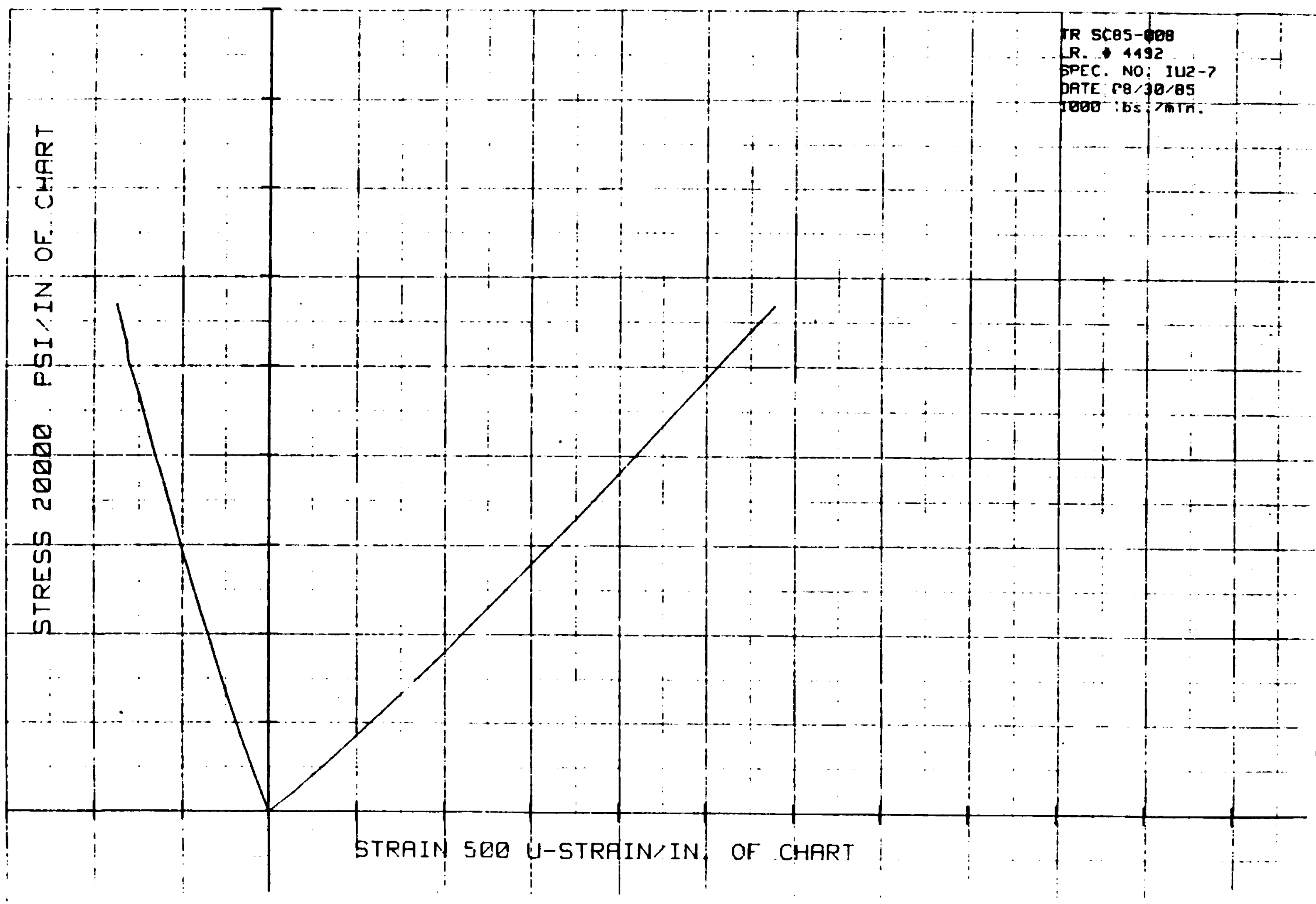
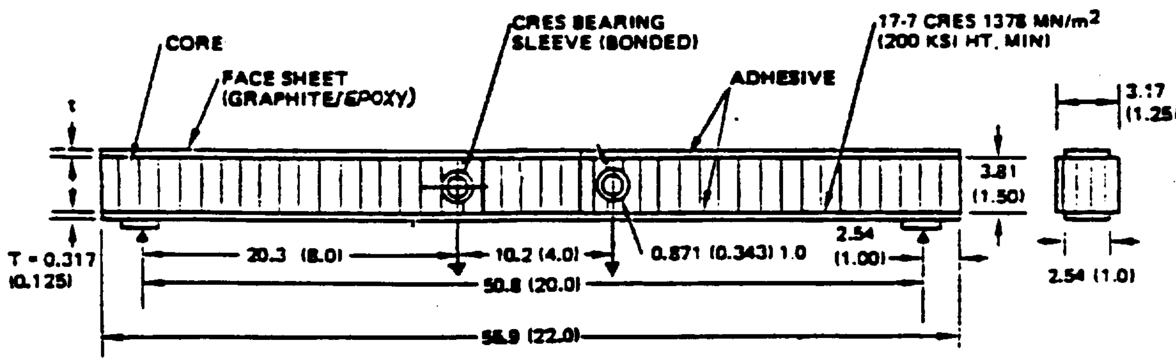



Figure 10 - Typical Longitudinal ($0^{o}$) Tensile Specimen Stress-Strain Curve of Bi-Axial Strain Gage Mounted on One Side

3.9 Compression Properties

Compression tests were performed using sandwich-beam specimens (one-inch wide by 22-inches long) constructed of 1.5-inch thick aluminum honeycomb core and bonded graphite/epoxy facing sheets (Figure 11). A 17-7PH Cres steel face sheet is used on the tension side of the specimen to assure failure in the compressive surface laminate. Face sheets were cut from laminate IU2, and all faying surfaces sanded with 320 grit paper. Details were bonded to 1/8-5052- 22PCF aluminum core using HT-424 phenolic/epoxy film adhesive per MA0106-301 and cured under vacuum for 3-hours at 290F. Specimens were then fitted with internal steel load-bearing bushings, and instrumented with axial strain gages placed in the center of the four-inch test span.

FLEX SANDWICH BEAM TEST –
ULTIMATE COMPRESSION STRESS ON FACE SHEET




Specimen dimensions in centimeters & (inches)

Stress = 4P/( tW [ K+0.5(T+t) ] )

where:

P = Applied Load
W = Beam Width
K = Core Thickness
t = Compression Face Sheet Thickness
T = Tension Face Sheet Thickness

Figure 11 - Longitudinal Compression Beam Configuration

Testing was performed on MTS closed loop electrohydraulic test machines. A typical room temperature test set-up is shown in Figure 12. High and low test temperatures were achieved and maintained through use of environmental chambers.

Fifteen composite beams were tested in four point flex in general accordance with Rockwell specification LF0001-008 using a loading rate of 500-pounds per minute. A Hewlett-Packard 9845 data acquisition system monitored, calculated, recorded and plotted the stress-strain data in real time. Five specimens were tested at room temperature and five each at -150F and +200F following a ten-minute soak at the test temperature. Test results are summarized in Table 4 and a typical compression stress-strain curve is shown in Figure 13.

TABLE 4 - COMPRESSION TEST RESULTS

| SPECIMEN NO. | ULTIMATE STRESS (KSI) | STRAIN TO FAILURE ($\mu$IN/IN) | MODULUS KSI | TEST TEMP (F) | LENGTH OF DEBOND (INCH) |
|---|---|---|---|---|---|
| IU2-1 | 62.4 | 2194 | 35.2 | 75 | 6.5 |
| IU2-2 | 62.5 | 2304 | 36.2 | 75 | 10.5 |
| IU2-3 | 57.0 | 2022 | 35.3 | 75 | 9.5 |
| IU2-4 | 60.4 | 2208 | 32.9 | 75 | 10.0 |
| IU2-5 | 55.5 | 1955 | 32.9 | 75 | 8.5 |
| AVG. | 59.4 | 2137 | 34.2 | 75 | 9.0 |
| IU2-6 | 75.3 | 5837 | 32.0 | -150 | 10.6 |
| IU2-7 | 66.8 | 3069 | 29.0 | -150 | 10.0 |
| IU2-8 | 73.6 | 7280 | 32.0 | -150 | 16.0 |
| IU2-9 | 75.0 | 7934 | 32.0 | -150 | 12.7 |
| IU2-10 | 72.9 | 4344 | 34.0 | -150 | 11.5 |
| AVG. | 72.7 | 4633 | 32.0 | -150 | 12.1 |
| IU2-11 | 60.1 | 2084 | 35.0 | 200 | 4.0 |
| IU2-12 | 32.7 | 1036 | 33.0 | 200 | 8.0 |
| IU2-13 | 50.7 | 1648 | 34.0 | 200 | 4.0 |
| IU2-14 | 56.0 | 2062 | 33.0 | 200 | 2.0 |
| IU2-15 | 48.3 | 1562 | 34.0 | 200 | 5.0 |
| AVG. | 49.6 | 1679 | 33.8 | 200 | 5.4 |

Compressive stress was calculated directly from the applied load (see Figure 11). Elastic modulus was determined from the slope of the initial linear portion of the stress-strain curve. Failures were by a delamination of the compressive face sheet between the first and second ply (core-side), and the length of the debond was measured and recorded.

### 3.10 Thermal Expansion Propeties

Thermal expansion test specimens (0.050 x 3.0 inch) were machined from test laminate IU1. Three longitudinal and three transverse specimens, conforming to the requirements of Fed Std 406, Method 1021, were machined from the 18-ply unidirectional laminate. Thermal expansion data were obtained by push rod dilatometry methods per ASTM E 228.

Upon completion of the baseline thermal expansion testing, the six test specimens were subjected to 500 thermal cycles (-150 to +200F) examined for microcracking and re-tested for thermal expansion characteristics.

Thermal expansion test results are summarized in Table 5. There was no significant CTE change as the result of thermal cycling or atomic oxygen exposure.

## 4.0 DISCUSSION OF RESULTS

Thermophysical and mechanical property test results were as expected except that tensile strength and modulus were slightly lower, possibly due to failures near the end-tabs. Normally, unidirectional ultra-high modulus graphite fiber laminates are tested in thinner sections to avoid these gripping problems. Grip problems also obscured the -150F tensile results which were expected to be slightly stronger than room temperature values. Test methods were generally adequate except that use of a less brittle adhesive system is indicated for specimen fabrication.

Thermal cycling test results were correct for unidirectional specimens which develop a relatively minor stress between resin matrix and graphite fiber. A worst case for thermal-cycling induced microcracking would be a cross-plied laminate which develops high interply stress.

Atomic oxygen exposure caused rapid erosion of the epoxy matrix material with subsequent erosion of the graphite fiber. While correlation of the exposure time to actual service life is far from precise, the data indicate the potential for significant composite erosion over a 10-year life of a Space Station sturcture if left unprotected in LEO environment.

REFERENCES

(1) LTR 2780-4264. Pitch-75S/934 Mechanical and Physical Properties for Determination of "B" Design Allowables.

(2) TR SC85-008, Evaluation of Advanced Composite for Deployable Truss Struts.

(3) STS 85-0348, Low Earth Orbit (LEO) Atomic Oxygen Effects Simulation with Low Temperature Asher

TEST SPECIFICATIONS USED IN THE EVALUATION

MB0130-160, STSD Material Specification, Graphite/Epoxy Resin Prepreg - Thin Gauge Unidirectional Tape

MT0501-510, STSD Quality Assurance Specification, Inspection, Ultrasonic

ASTM D 618, Conditioning Plastic and Electrical Insulating Materials for Testing

Fed. Test Method Std. No. 406, Plastics, Method of Testing

MT0302-001, STSD Quality Assurance Specification, Test Method Standards for Advanced Composite Materials

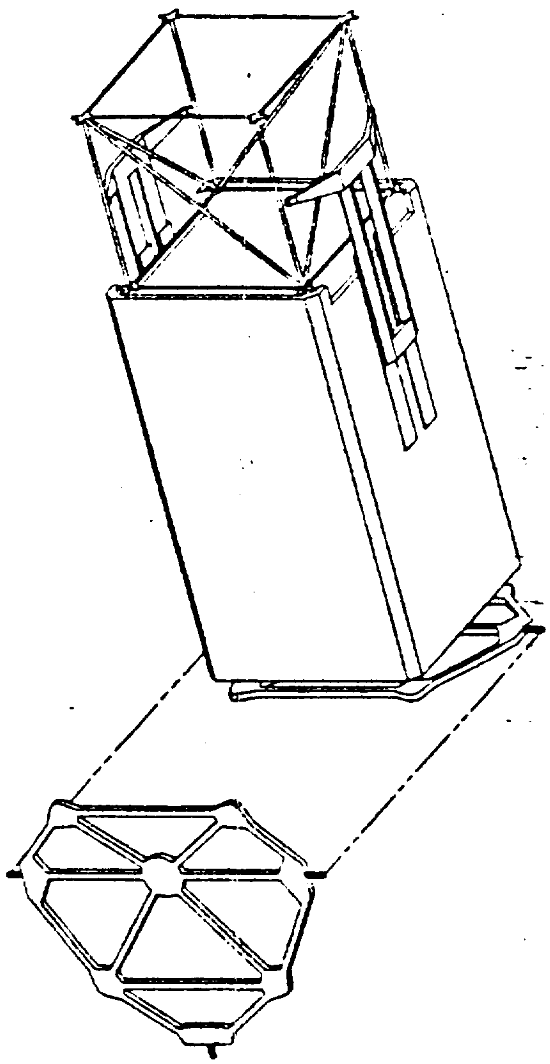
MA0106-301, STSD Process Specification, Bonding with Epoxy Adhesives

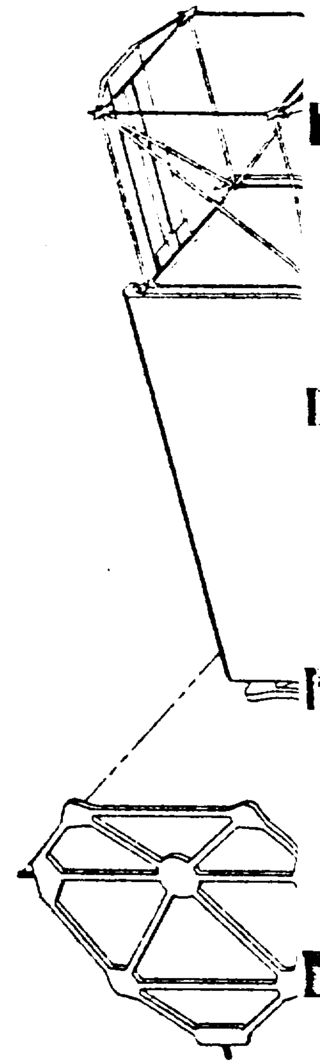
LF 0001-008, NAAO Test Procedure, Service Graphite/Epoxy Composite, 350F, Chemical, Physical and Mechanical Test Methods

ASTM D 228, Linear Thermal Expansion of Rigid Solids with A Vitreous Silica Dilatometer

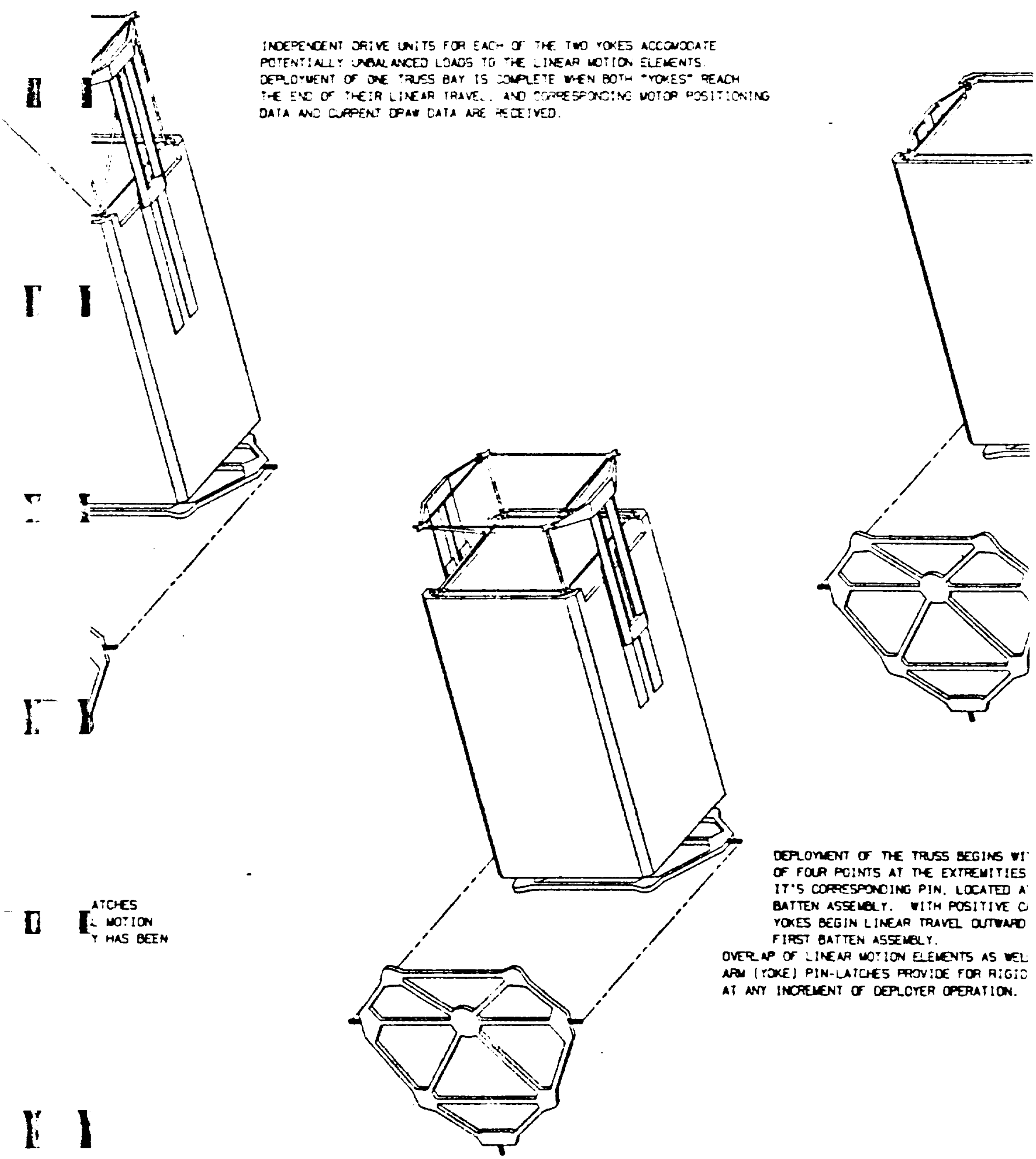
APPENDIX B

DESIGN DRAWINGS





AS ONE BAY IS FULLY DEPLOYED, THE YOKE'S PIN-L
RELEASE, AND THE LINEAR ARMS BEGIN A RECIPROCA
TO THE DEPLOYER, WHERE THE NEXT BATTEN ASSEMBL
DRAWN INTO THE "READY" POSITION.


INDEPENDENT DRIVE UNITS FOR EACH OF THE TWO YOKES ACCOMODATE
POTENTIALLY UNBALANCED LOADS TO THE LINEAR MOTION ELEMENTS.
DEPLOYMENT OF ONE TRUSS BAY IS COMPLETE WHEN BOTH "YOKES" REACH
THE END OF THEIR LINEAR TRAVEL, AND CORRESPONDING MOTOR POSITIONING
DATA AND CURRENT DRAW DATA ARE RECEIVED.
ATCHES
L MOTION
Y HAS BEEN
DEPLOYMENT OF THE TRUSS BEGINS WI
OF FOUR POINTS AT THE EXTREMITIES
IT'S CORRESPONDING PIN, LOCATED A
BATTEN ASSEMBLY. WITH POSITIVE C
YOKES BEGIN LINEAR TRAVEL OUTWARD
FIRST BATTEN ASSEMBLY.
OVERLAP OF LINEAR MOTION ELEMENTS AS WEL
ARM (YOKE) PIN-LATCHES PROVIDE FOR RIGID
AT ANY INCREMENT OF DEPLOYER OPERATION.

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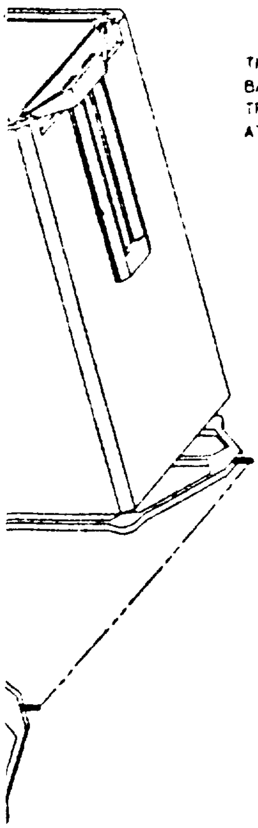
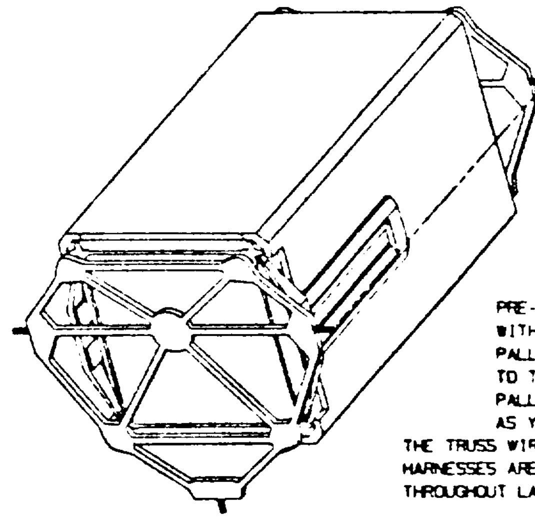


THE FORWARD PALLET NEED NOT BE REMOVED FROM THE ORBITER PAYLOAD
BAY THROUGHOUT THE DEPLOYMENT PHASE. THEREFORE NO ACTIVE LATCHES ARE REQUIRED.
TRUSS HOUSING/PALLET INTERFACE IS ANGLED TO PROVIDE ROTATIONAL CLEARANCE.
AT THIS PHASE, THE DEPLOYER IS FULLY UPRIGHT AND NORMAL TO THE X AXIS OF THE ORBITER.



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OF THE DEPLOYER "YOKE" PICKING UP
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APTURE CONFIRMED, THE TWO DEPLOYER
FROM THE HOUSING, CARRYING THE

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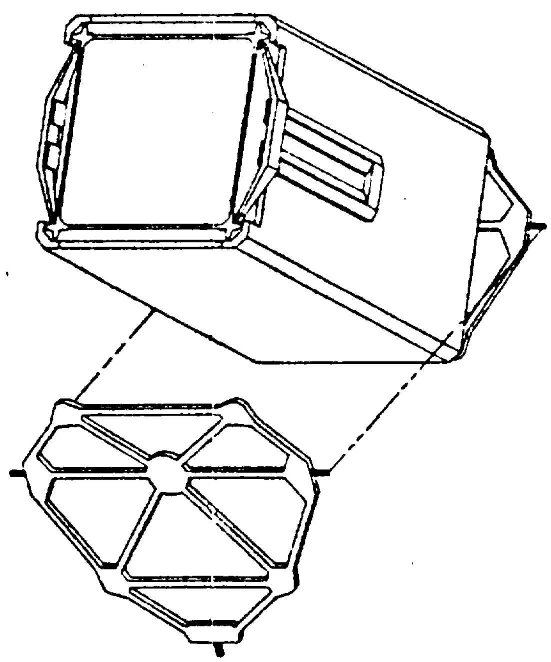
ITY AND ROOT-STRENGTH



THE FIRST PHASE OF THE DEPLOYME
OF THE DEPLOYER HOUSING FROM TH
PROVIDES FOR EVA UNPINNING OF A
OF FOUR CORNERS OF THE HOUSING

4 3

KAGED DEPLOYABLE TRUSS IS CARRIED
THE ORBITER PAYLOAD BAY BY TWO STRUCTURAL
S. THE AFT PALLET REACTS X₀ AND Z₀ LOADS
ORBITER SILL LONGERON WHILE THE FORWARD
ACCOMOCATES X₀, Z₀ LOADS TO THE SILL, AS WELL
LOADS TO THE KEEL.
TRAY AND ASSOCIATED ELECTRICAL SYSTEM
LD IN COMPRESSION BETWEEN THESE TWO PALLETS
H PHASE.

NT SEQUENCE REQUIRES THE SEPARATION
E FORWARD PALLET. THIS CONCEPT
SIMPLE CLEVIS FITTING AT EACH
TO PALLET INTERFACE.

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Rockwell International — Space Station Systems Division

LINEAR DEPLOYER

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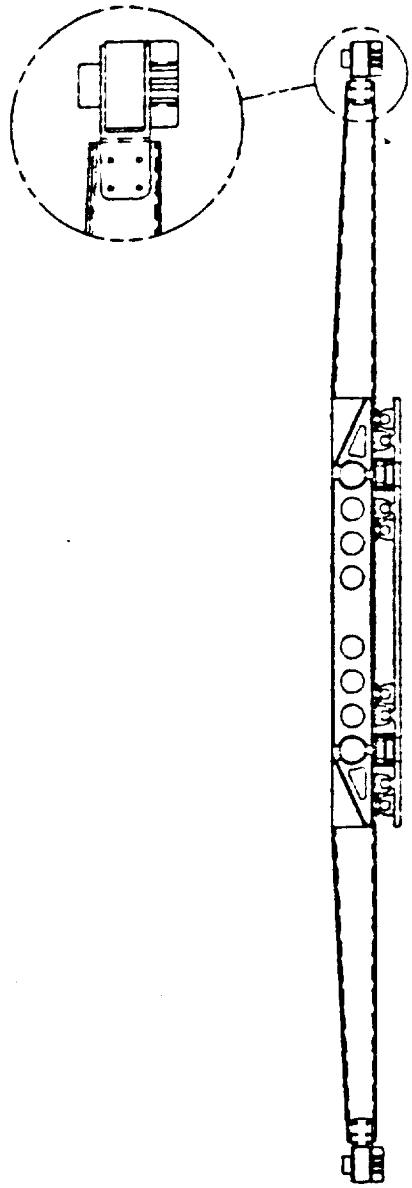

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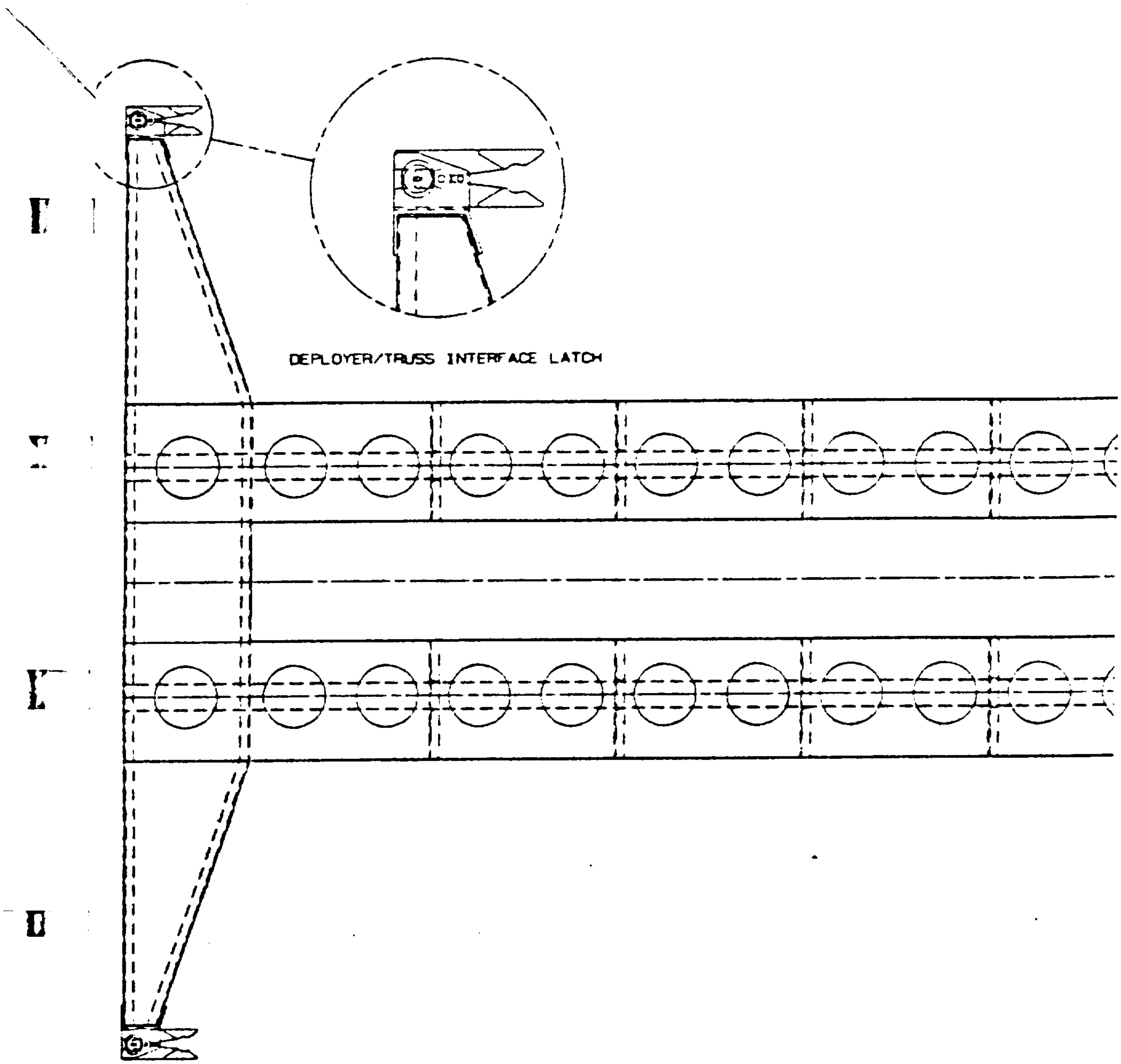
DEPLOYER/TRUSS INTERFACE LATCH

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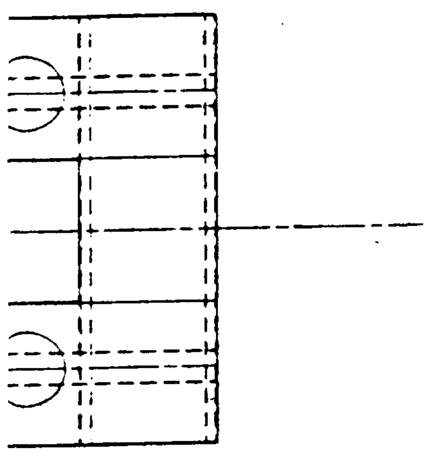

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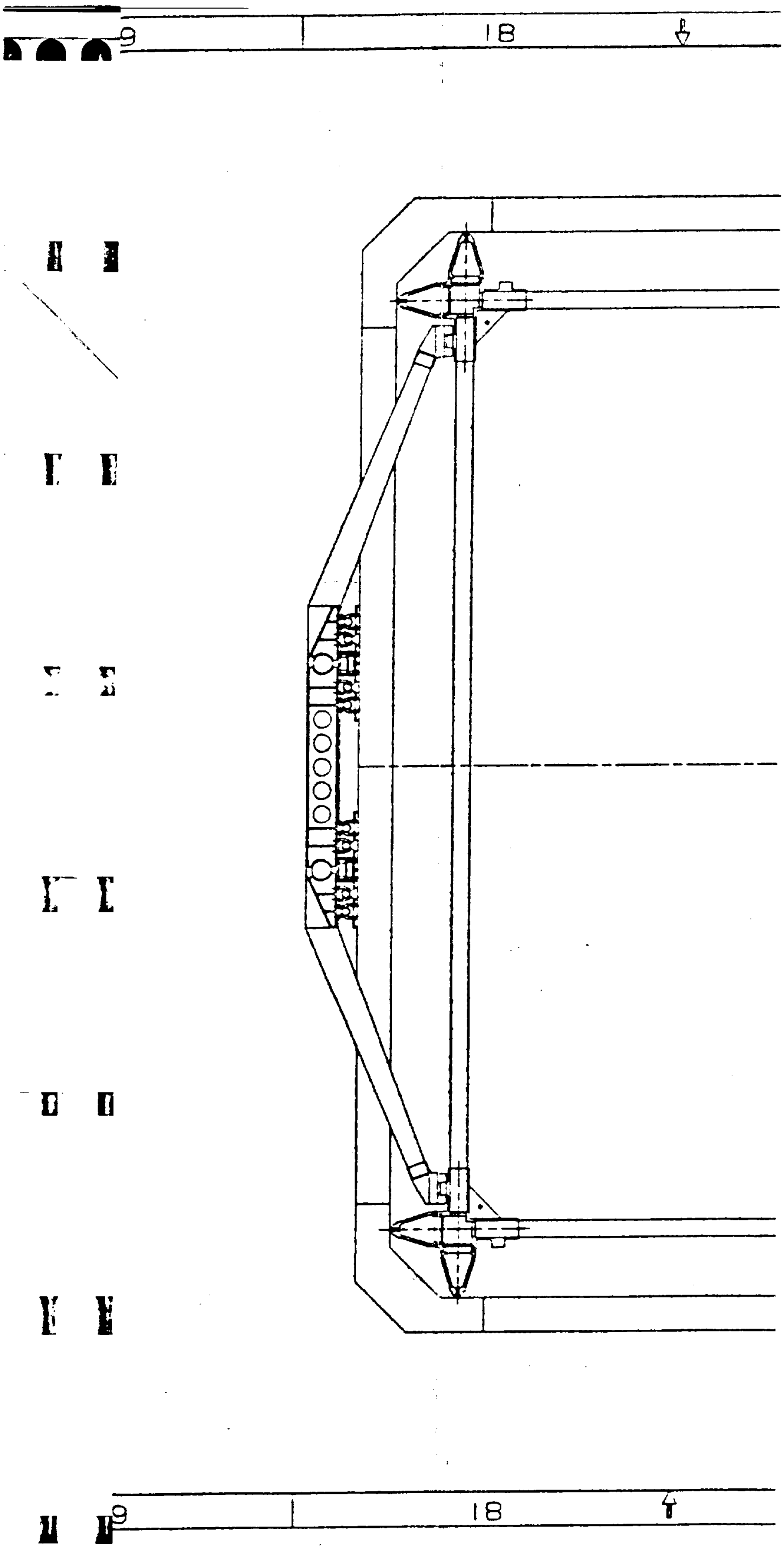

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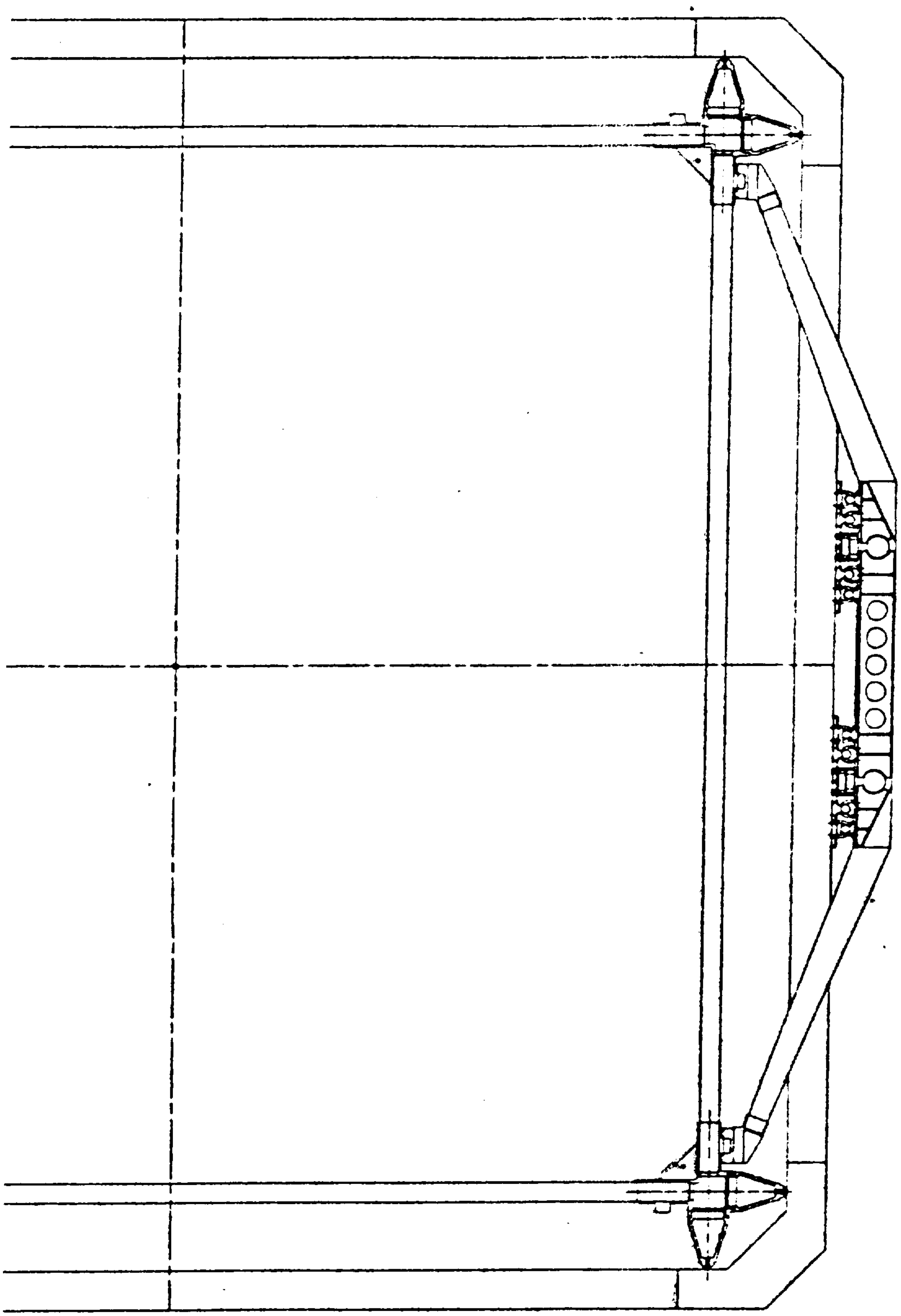

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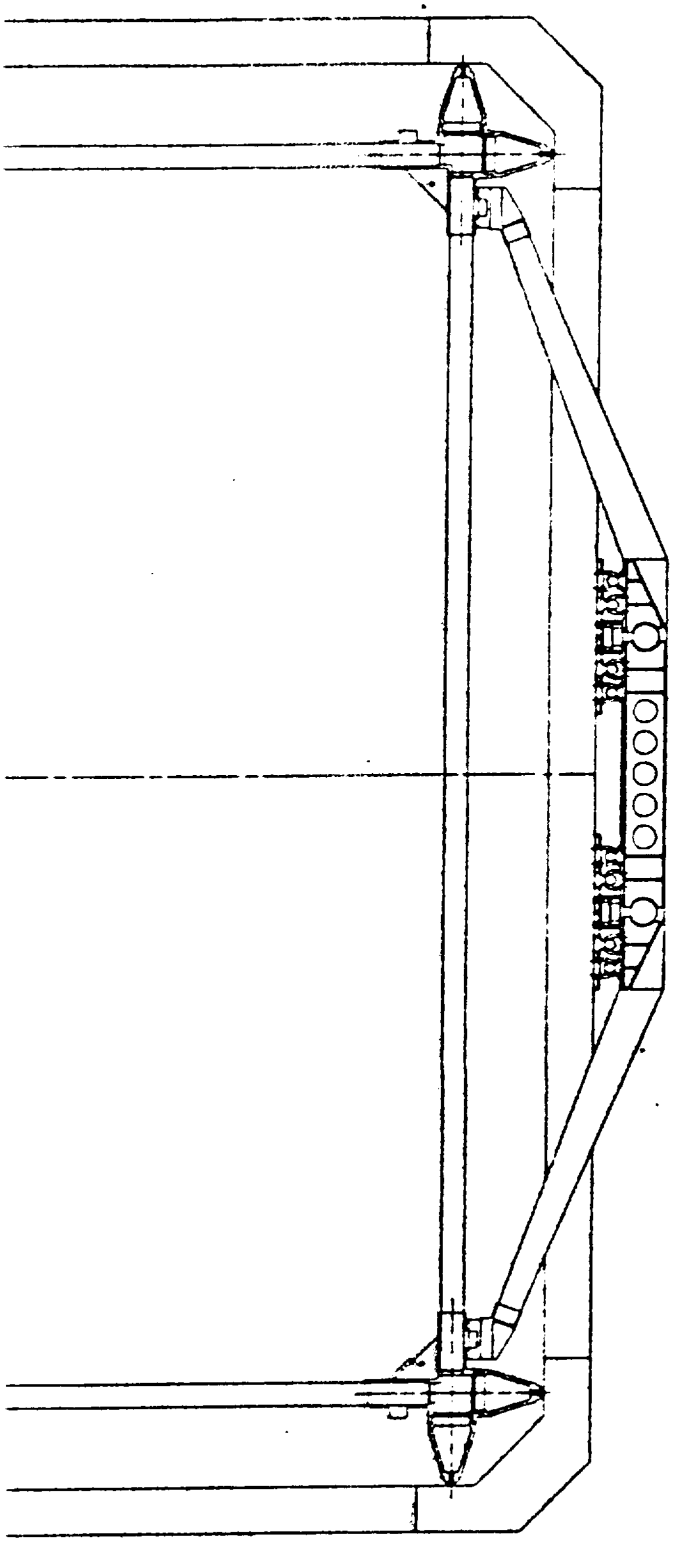

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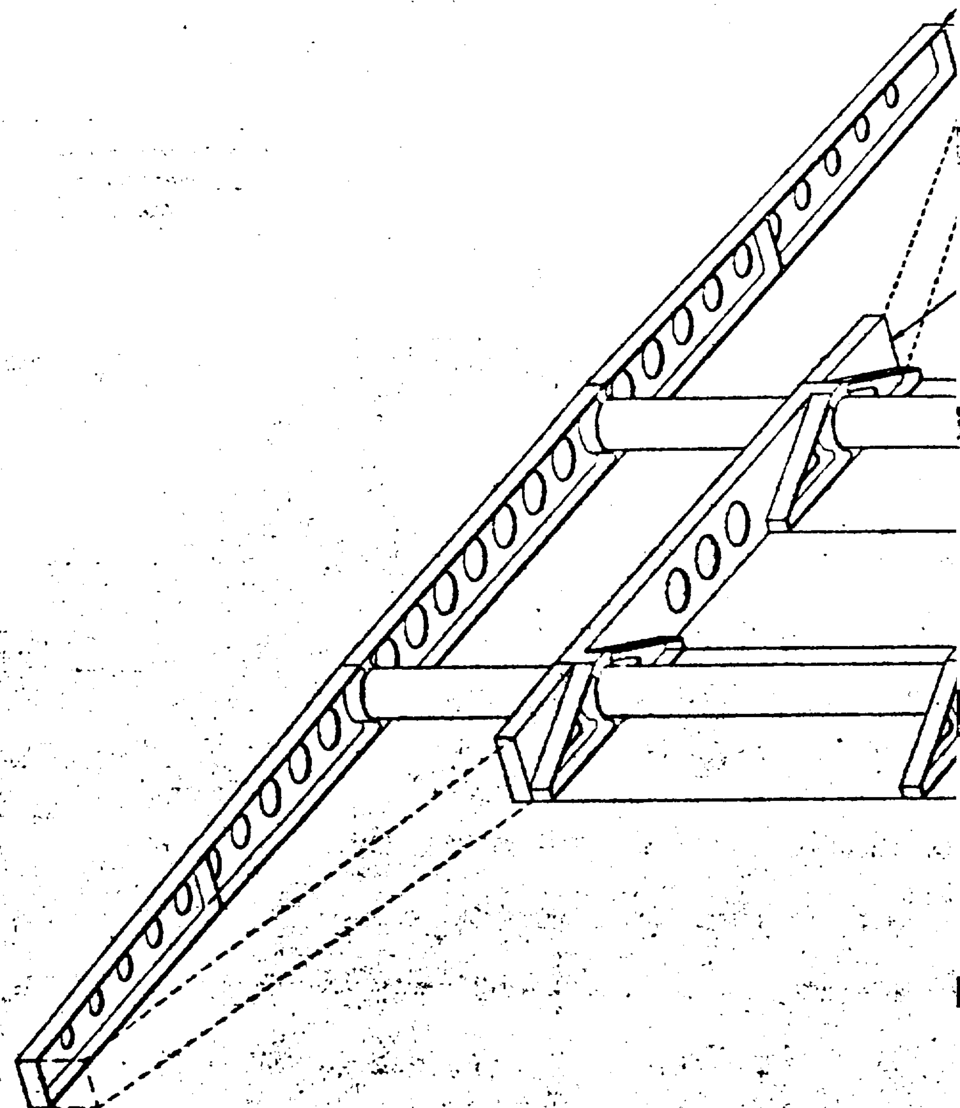

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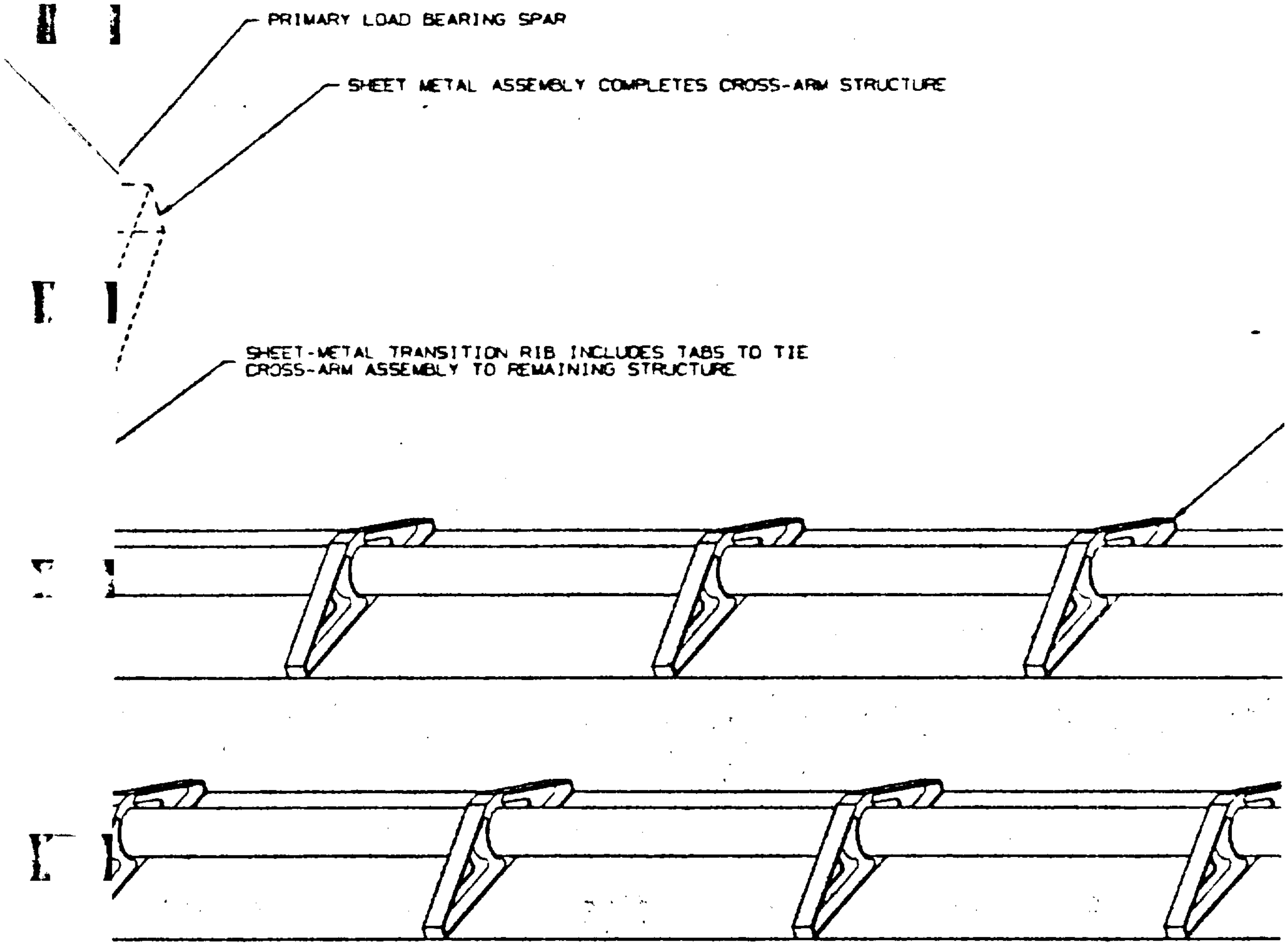


LINEAR MOTOR DEPLOYER
CARRIAGE ASSEMBLY

SHEET METAL SKINS NOT SHOWN FOR CLARITY

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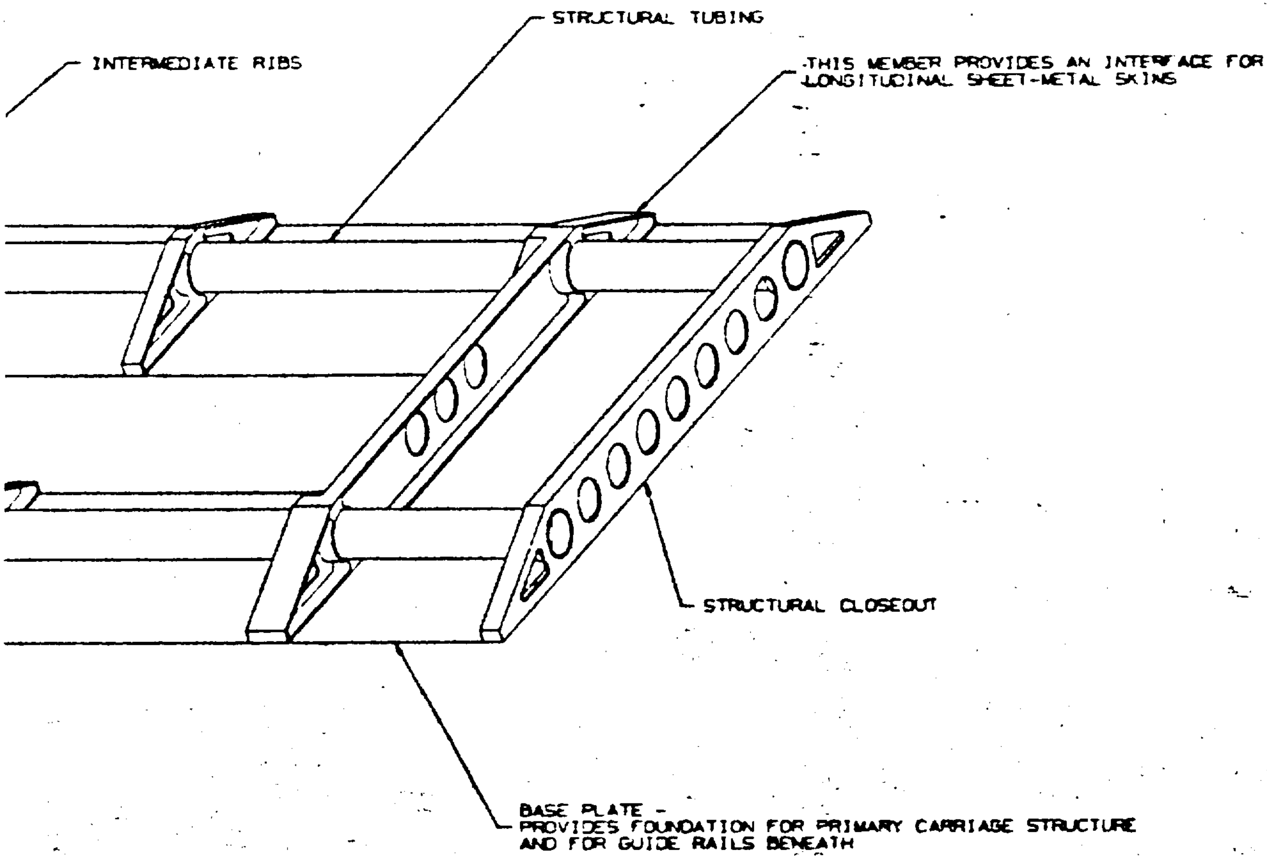
STRUCTURAL TUBING
INTERMEDIATE RIBS
THIS MEMBER PROVIDES AN INTERFACE FOR LONGITUDINAL SHEET-METAL SKINS
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BASE PLATE - PROVIDES FOUNDATION FOR PRIMARY CARRIAGE STRUCTURE AND FOR GUIDE RAILS BENEATH

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THIS MEMBER PROVIDES AN INTERFACE FOR
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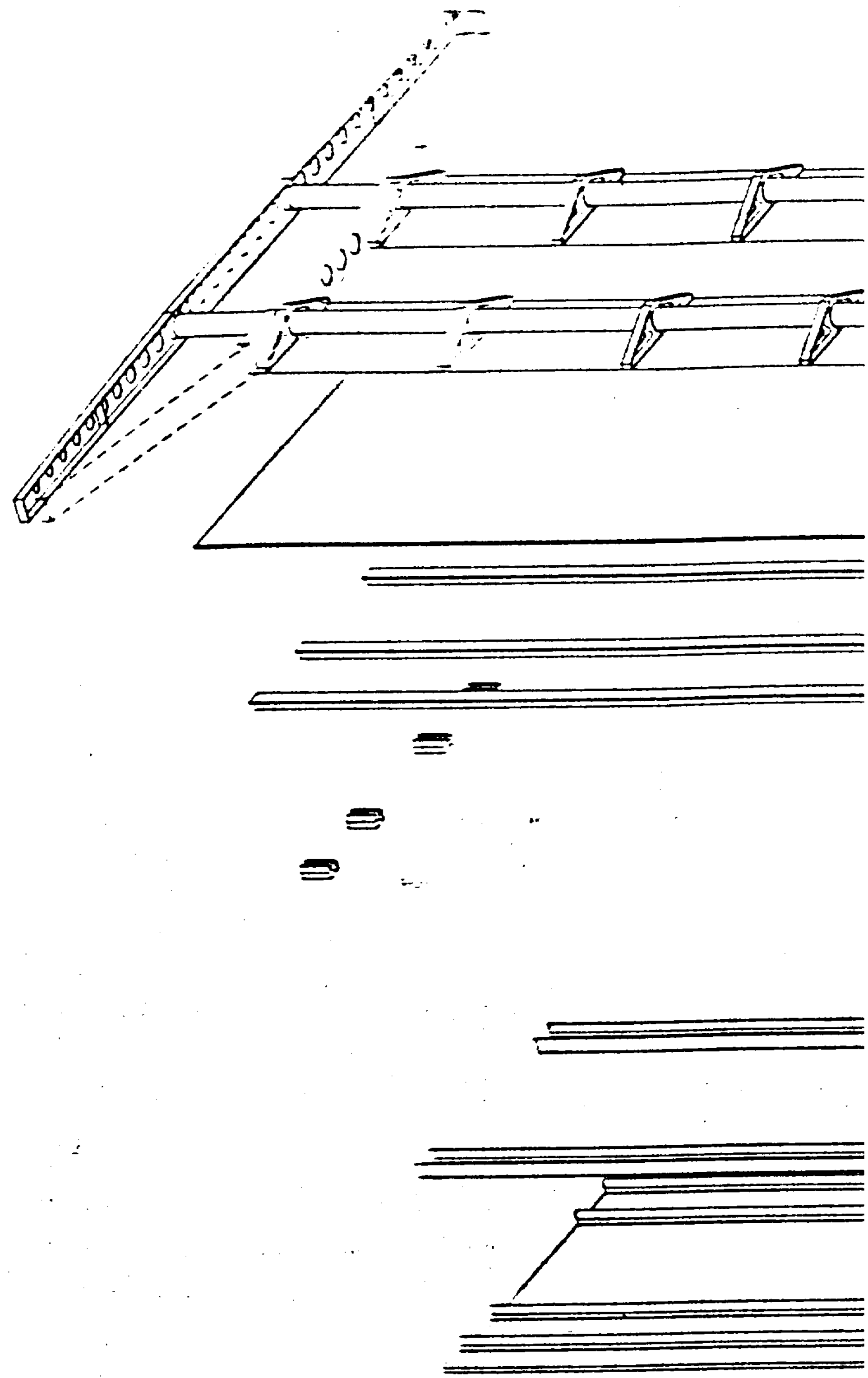

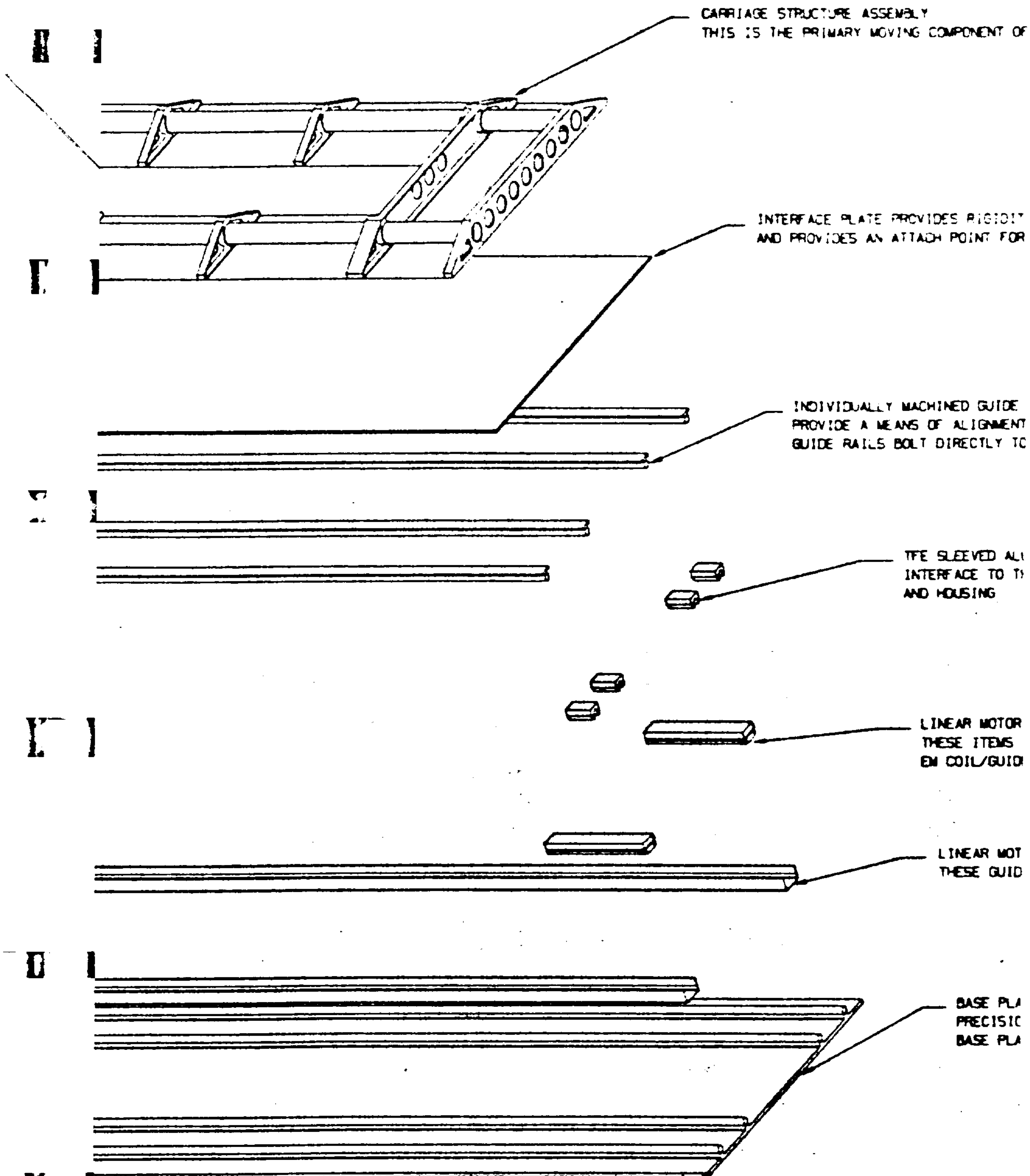
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TO OVERALL STRUCTURE
LINEAR GUIDE RAILS AND LM MAGNET ASSEMBLY

RAIL SUPPORTS
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THESE SUPPORTS

MINUM LINEAR BUSHINGS PROVIDE A LOW COST, ACCEPTABLE TOLERANCE
E GUIDE RAILS FOR COMPLETE LOAD PATH BETWEEN TRUSS, DEPLOYER.

MAGNET ASSEMBLY
ARE ACTIVATED VIA MODULATED IR-LED OPTICAL COUPLING TO THE
E ASSEMBLY FOR CONTROL AND FEEDBACK DATA TRANSFER

OR ELECTROMAGNETIC COIL/GUIDE ASSEMBLY
ES RIGIDLY MOUNT TO THE BASE PLATFORM

TFORM INCLUDES INTEGRALLY MACHINED RAIL SUPPORTS
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TE ASSEMBLY ATTACHES TO BOTH LEFT & RIGHT SIDE OF TRUSS HOUSING

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RAIL SUPPORTS
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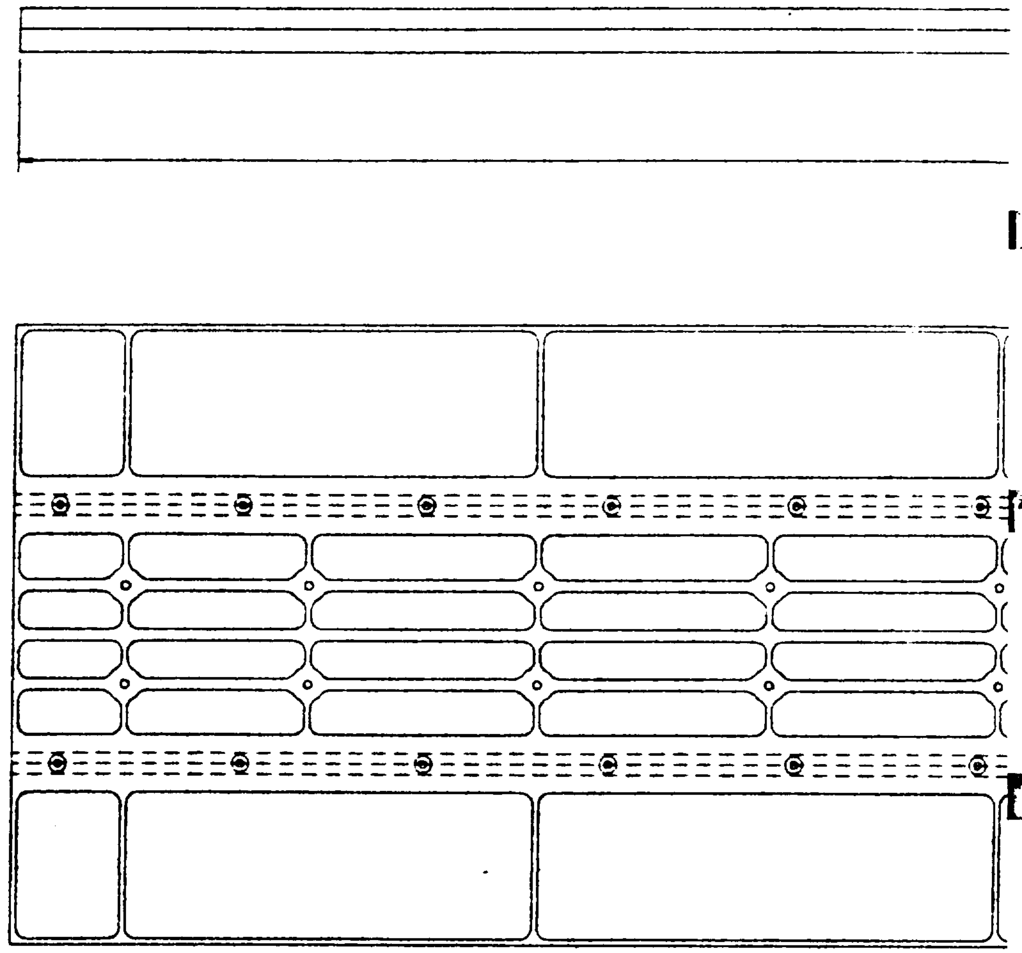

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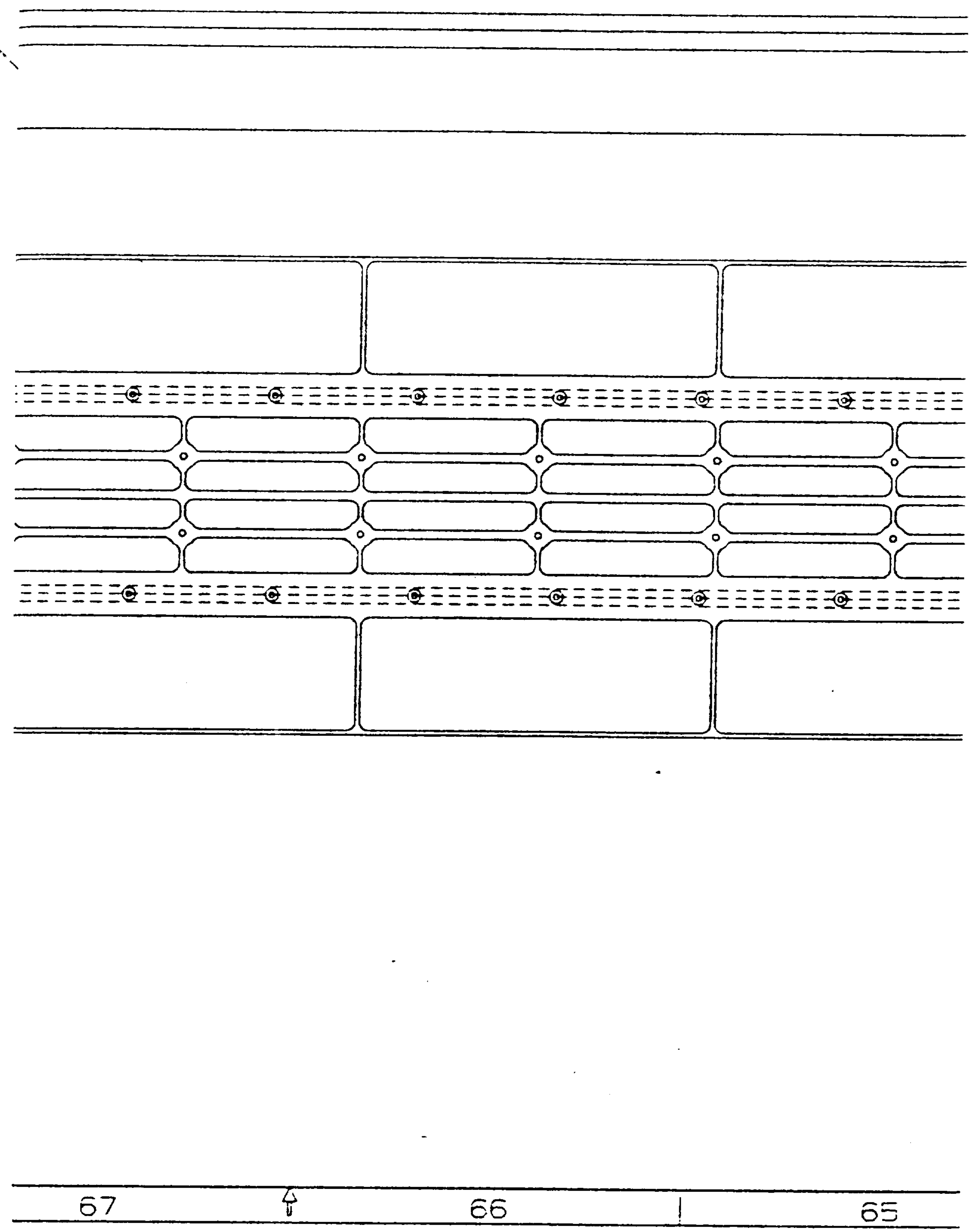
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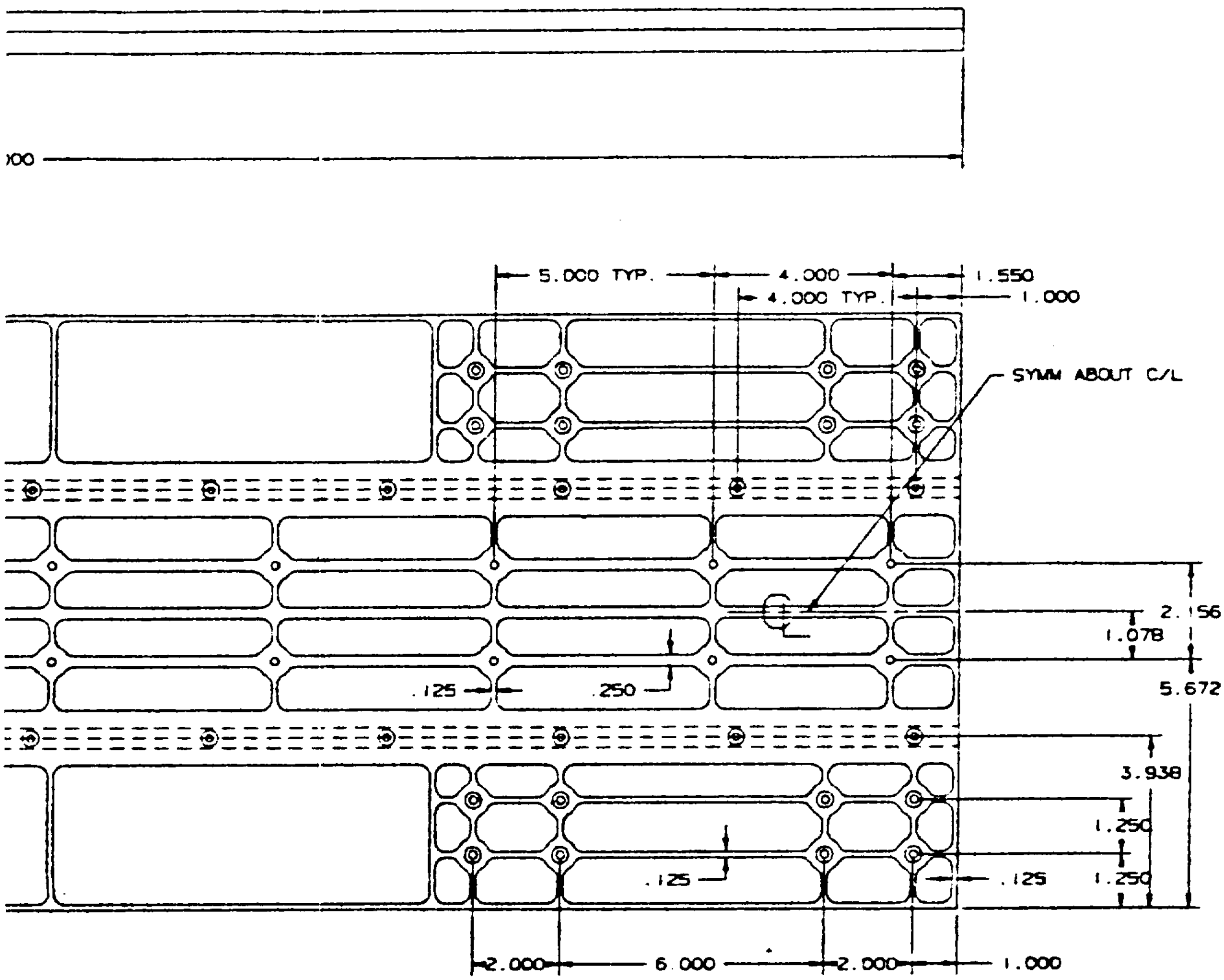
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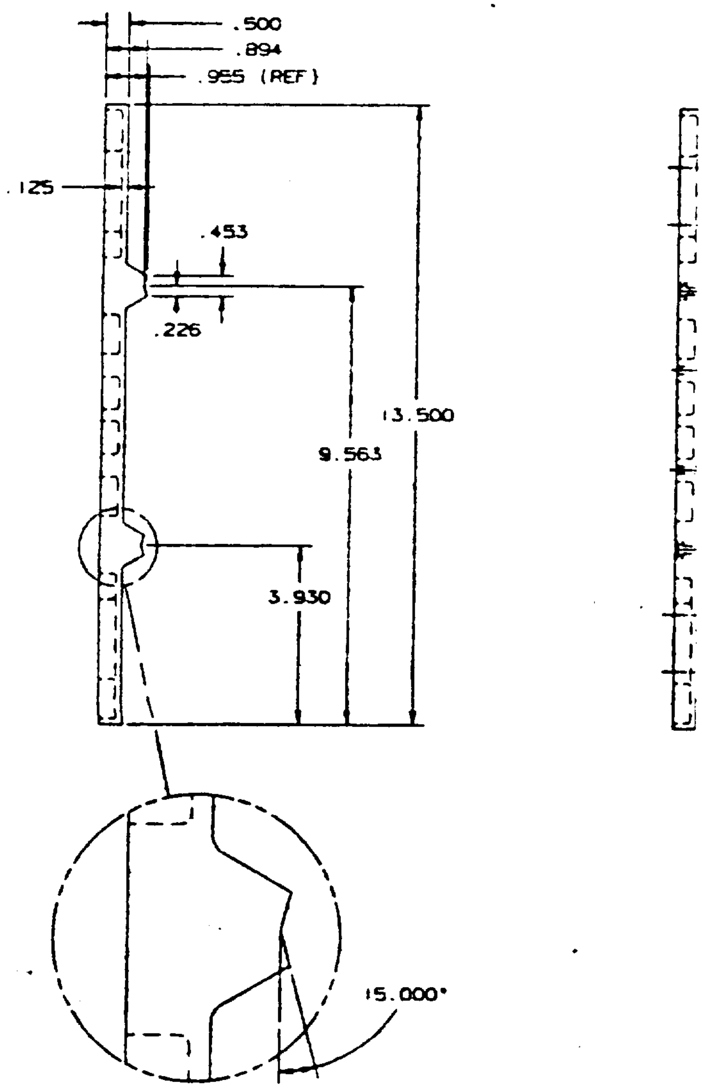
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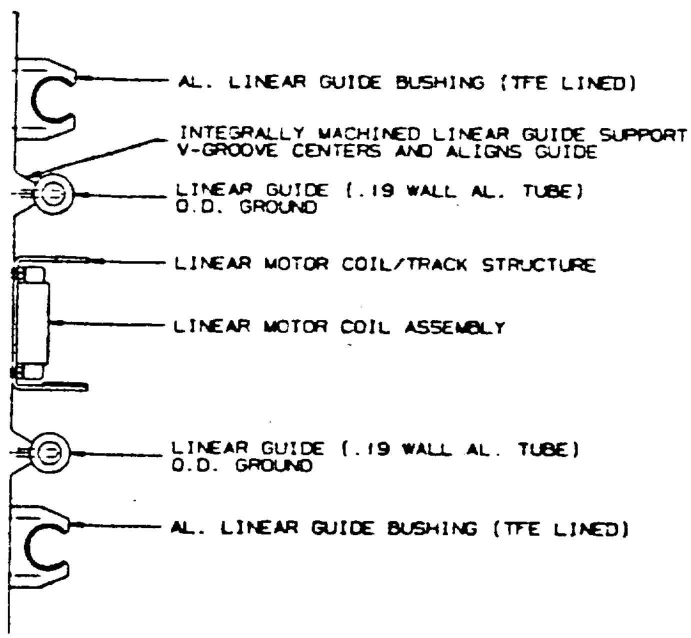


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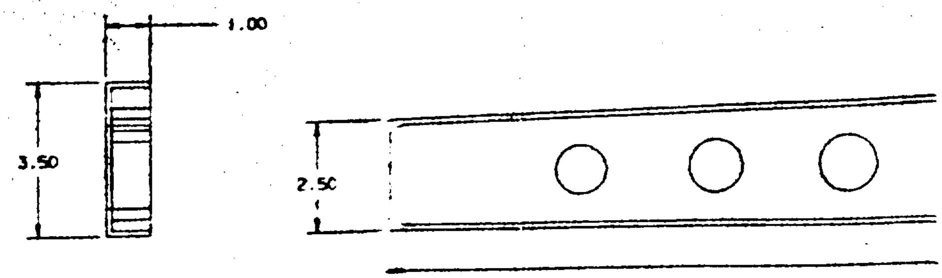


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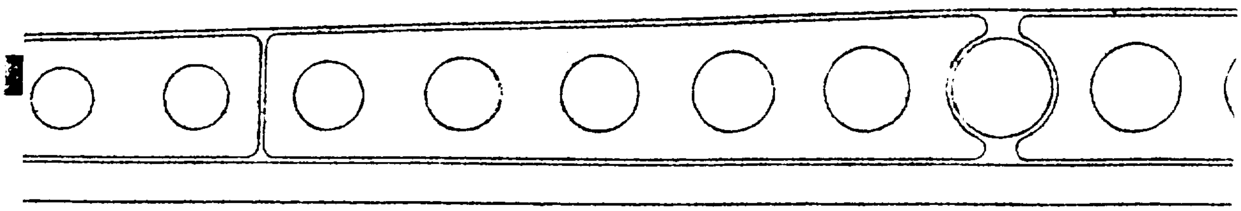

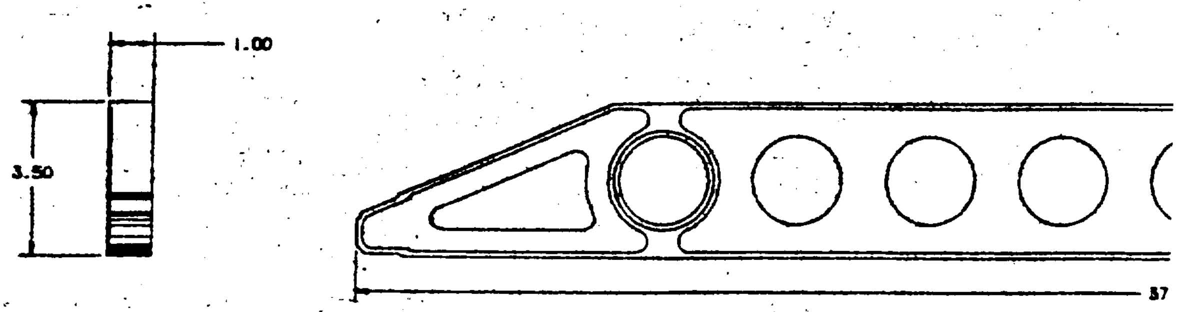


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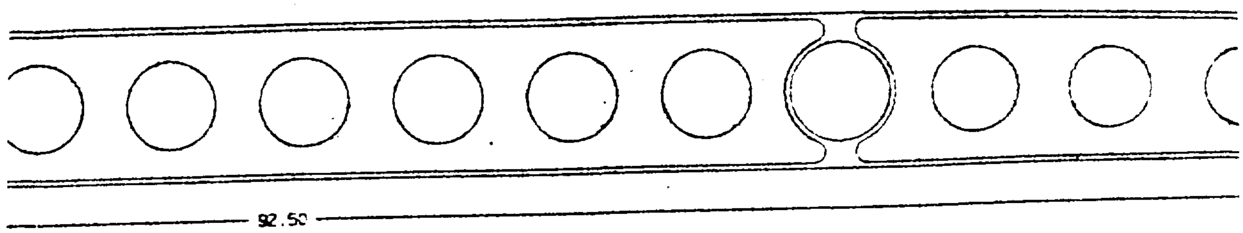


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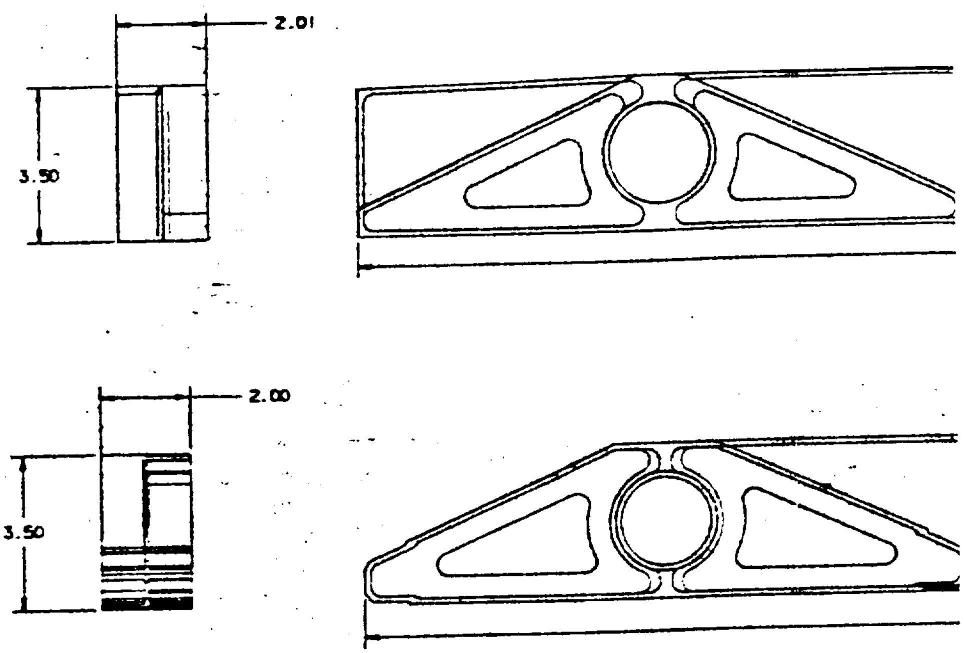


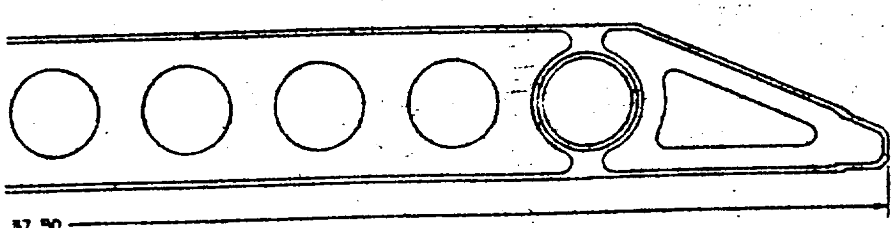


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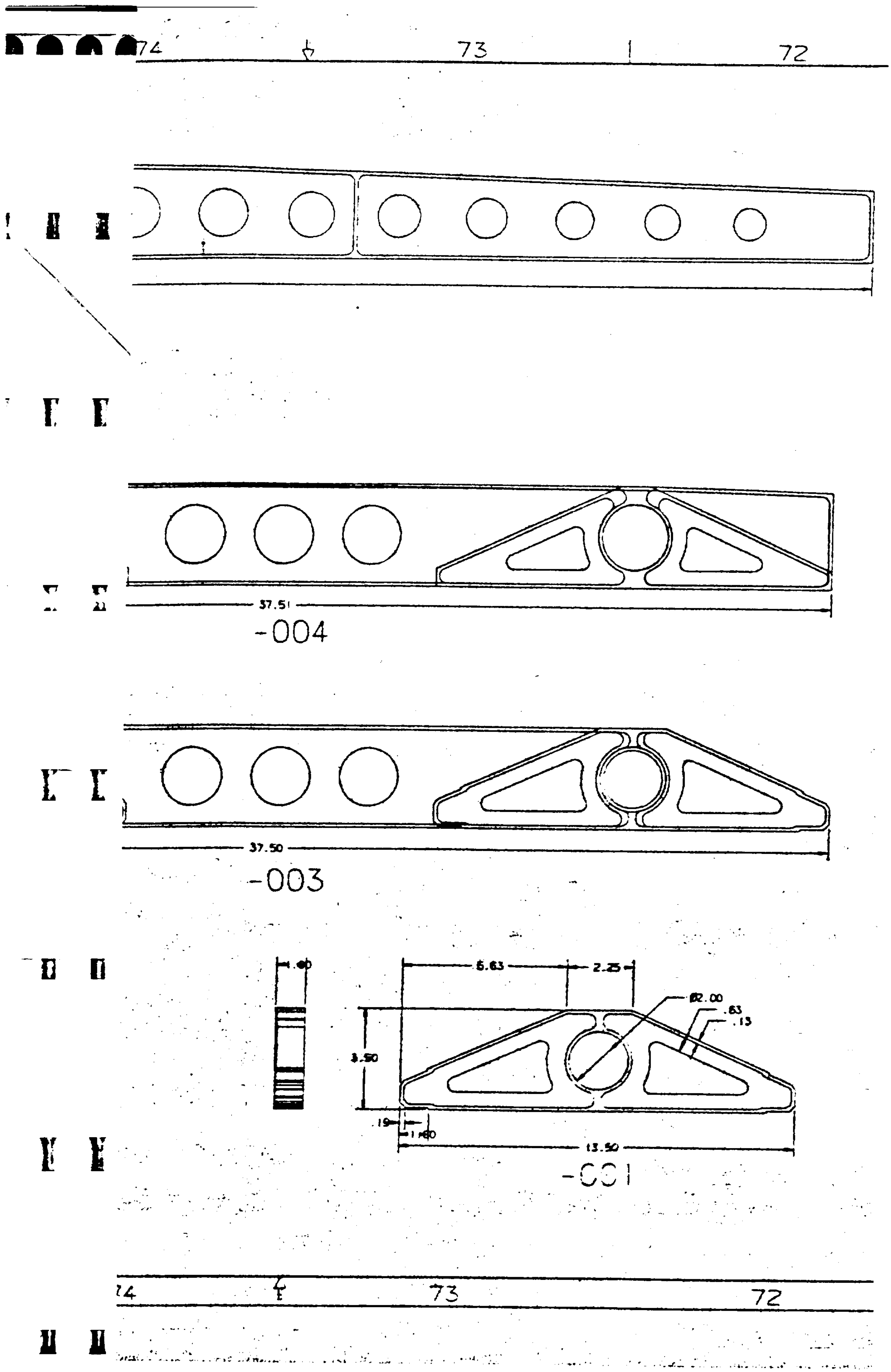


74
73
72
37.51
-004
37.50
-003
5.63
2.25
.63
.13
3.50
.19
13.50
-001
74
73
72

71 | 70

## REVISIONS

| ZONE | LTR | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|
| | | | | |

D

C

B

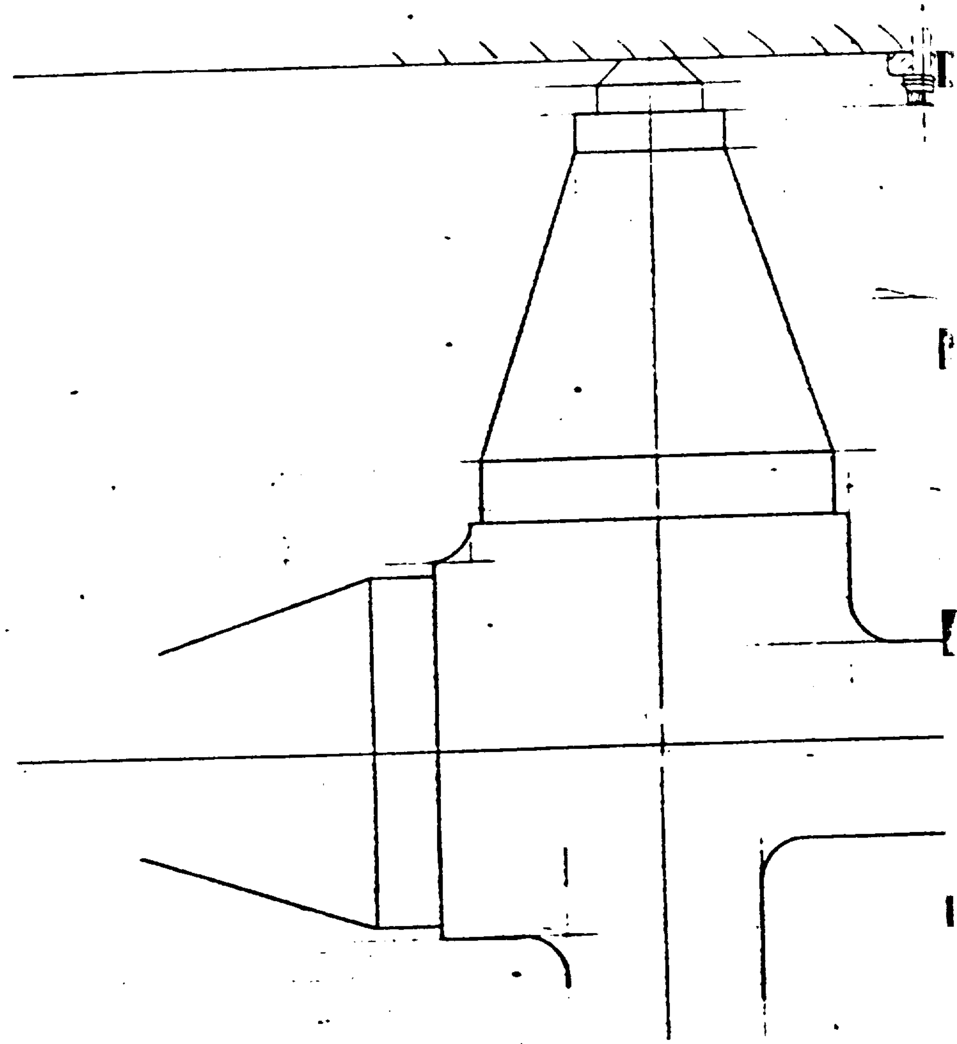
85828-026

A

-B8-

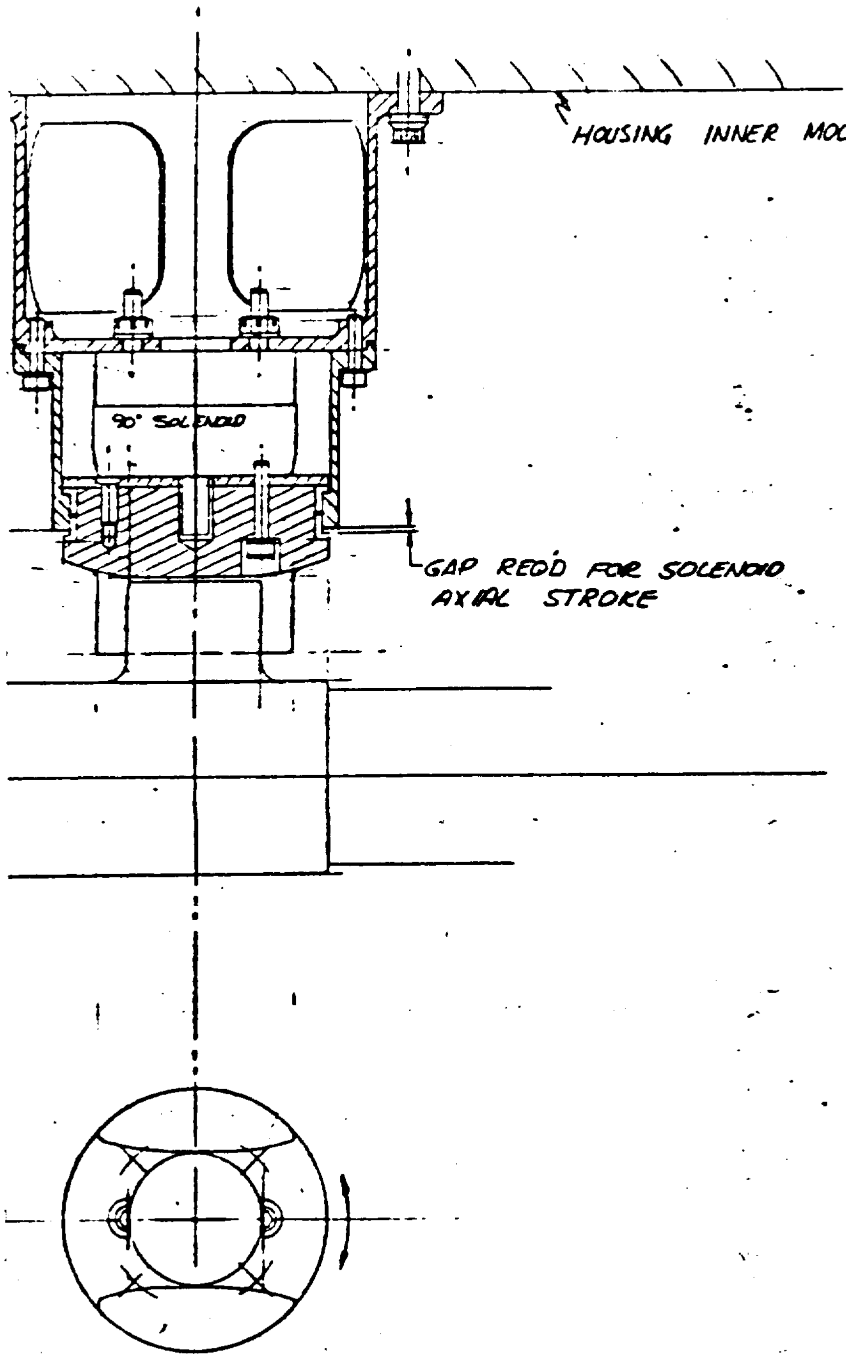
| SIZE | CODE IDENT NO. | DRAWING NO. |
|---|---|---|
| | 03953 | 85828-026 |
| SCALE 1/2 | | SHEET 6 of 7 |

71 CAD/CAM 70 DCN-



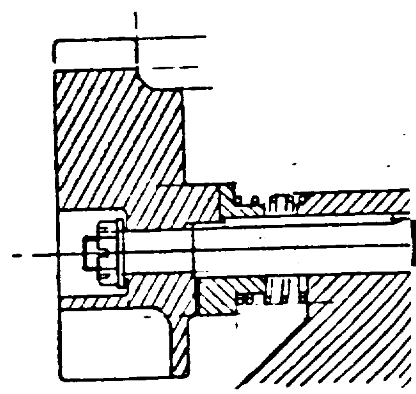
ALTERNATE RETENTION LATCH

SOLENOID OPERATED

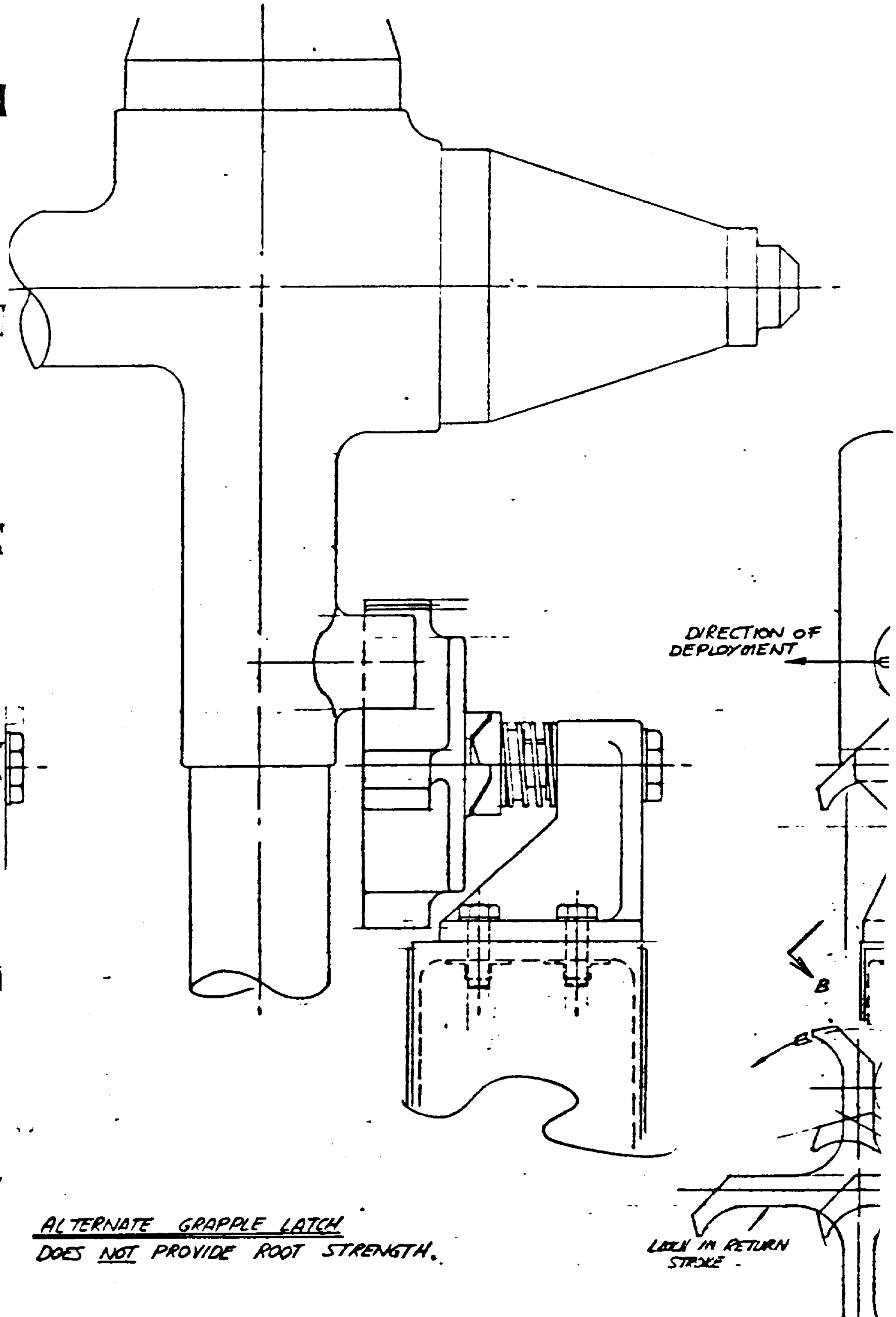



LINEAR DEPLOYER - BATTEN RETENTION LATCH

BDM 11-1-85

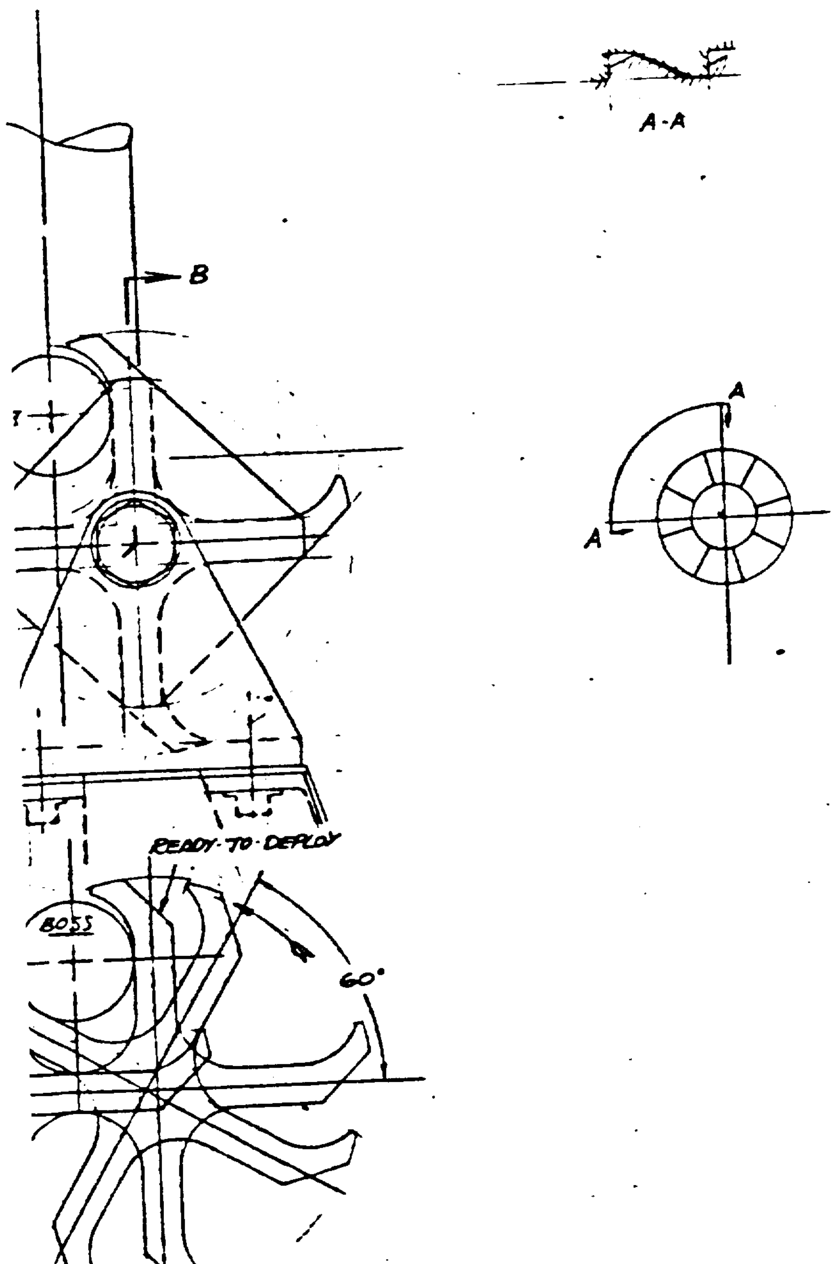


B-B

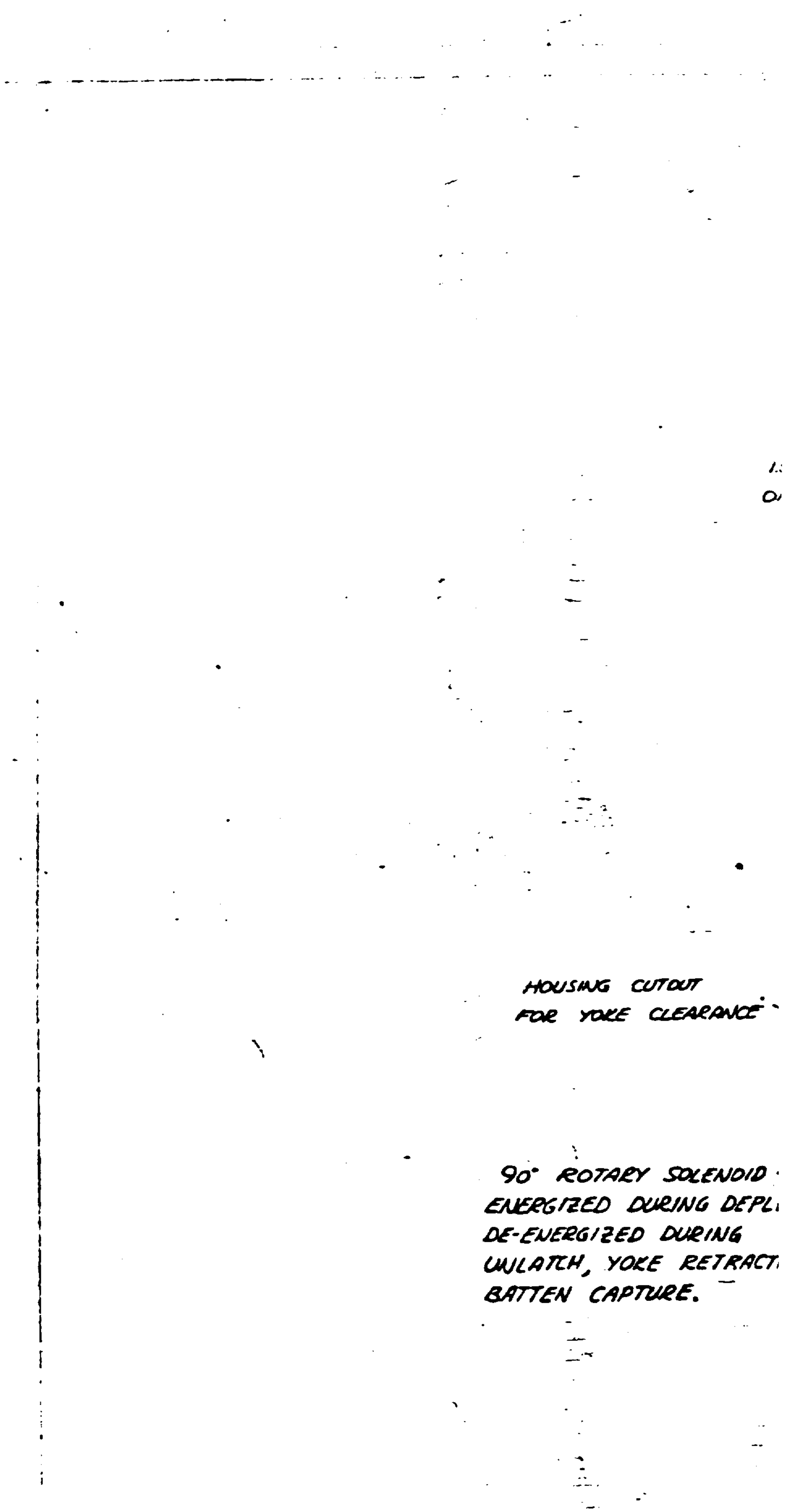



ALTERNATE GRAPPLE LATCH
DOES NOT PROVIDE ROOT STRENGTH.

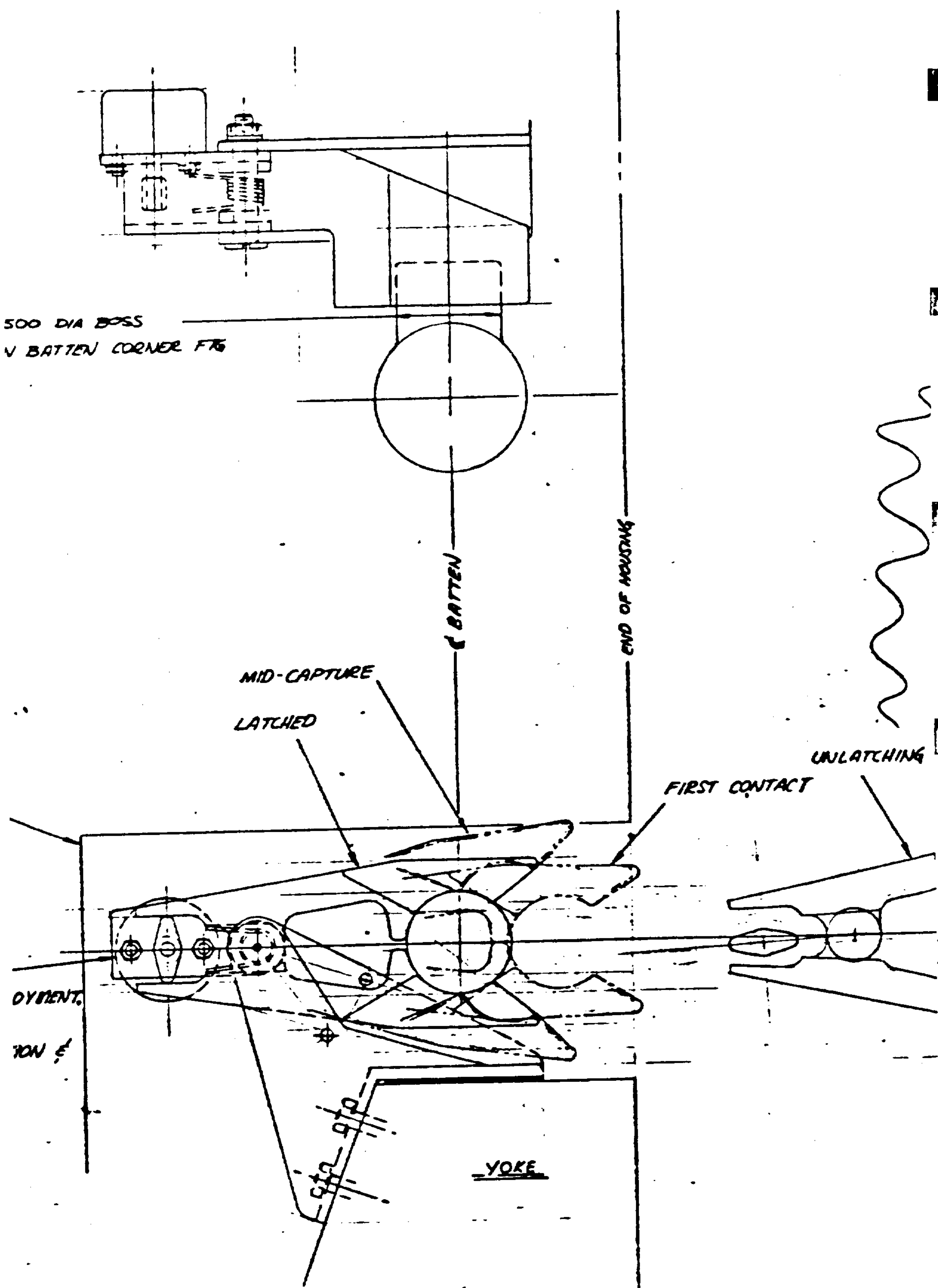
ON CARRIAGE RETURN STROKE ROTA
ROTATES AGAINST FORCE GENERATI
60° ROTATION, CAM FORCE CHANGE
TO NEXT READY-TO-DEPLOY P



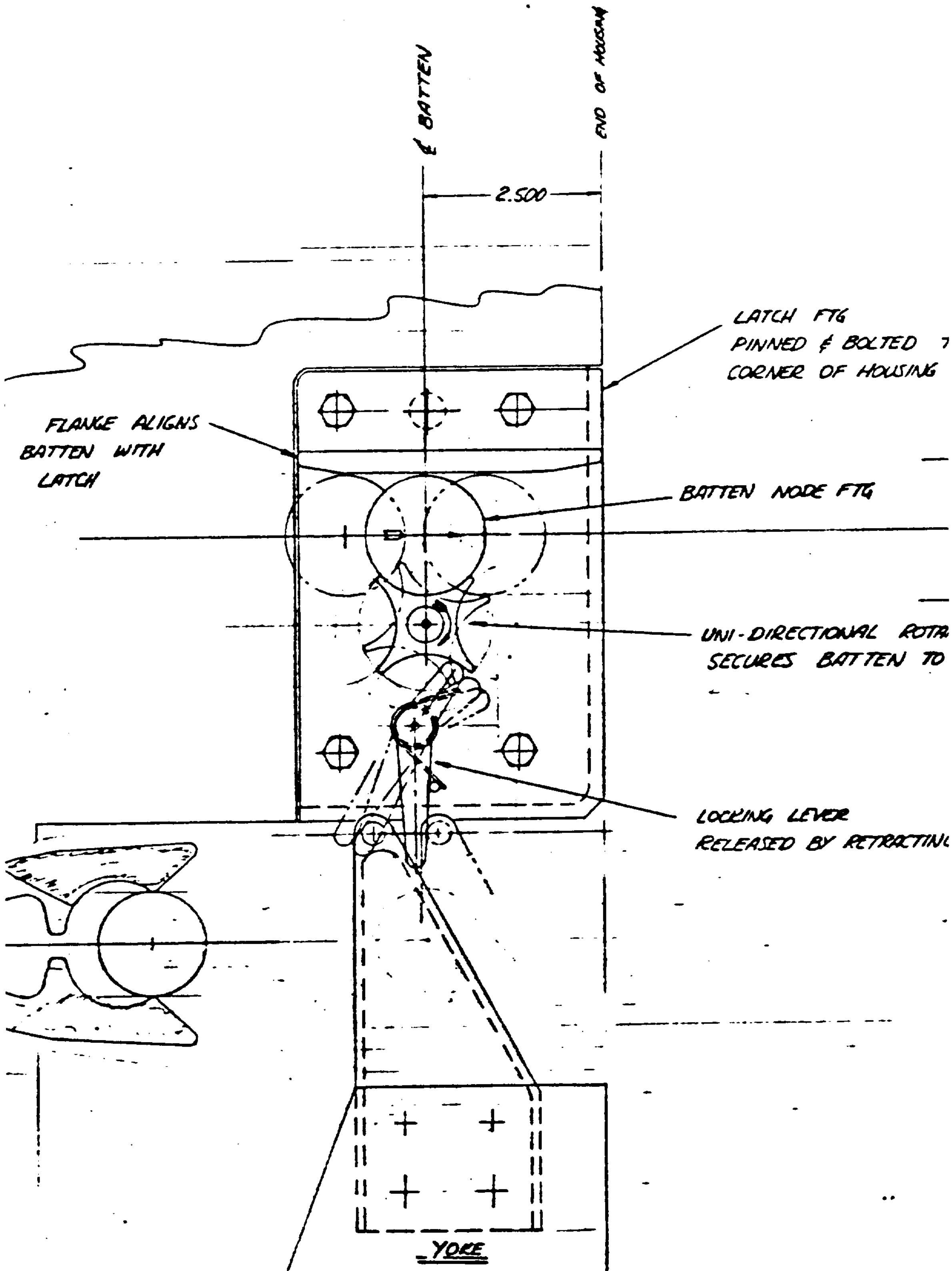

y LATCH-CONTACTS BOSS ON BATTEN AND
D BY CAM SURFACE ON PAWL. AFTER
DIRECTION AND COMPLETES 90° ROTATION
SITION


HOUSING CUTOUT
FOR YOKE CLEARANCE
90° ROTARY SOLENOID
ENERGIZED DURING DEPL
DE-ENERGIZED DURING
UNLATCH, YOKE RETRACT
BATTEN CAPTURE.

OCT 85

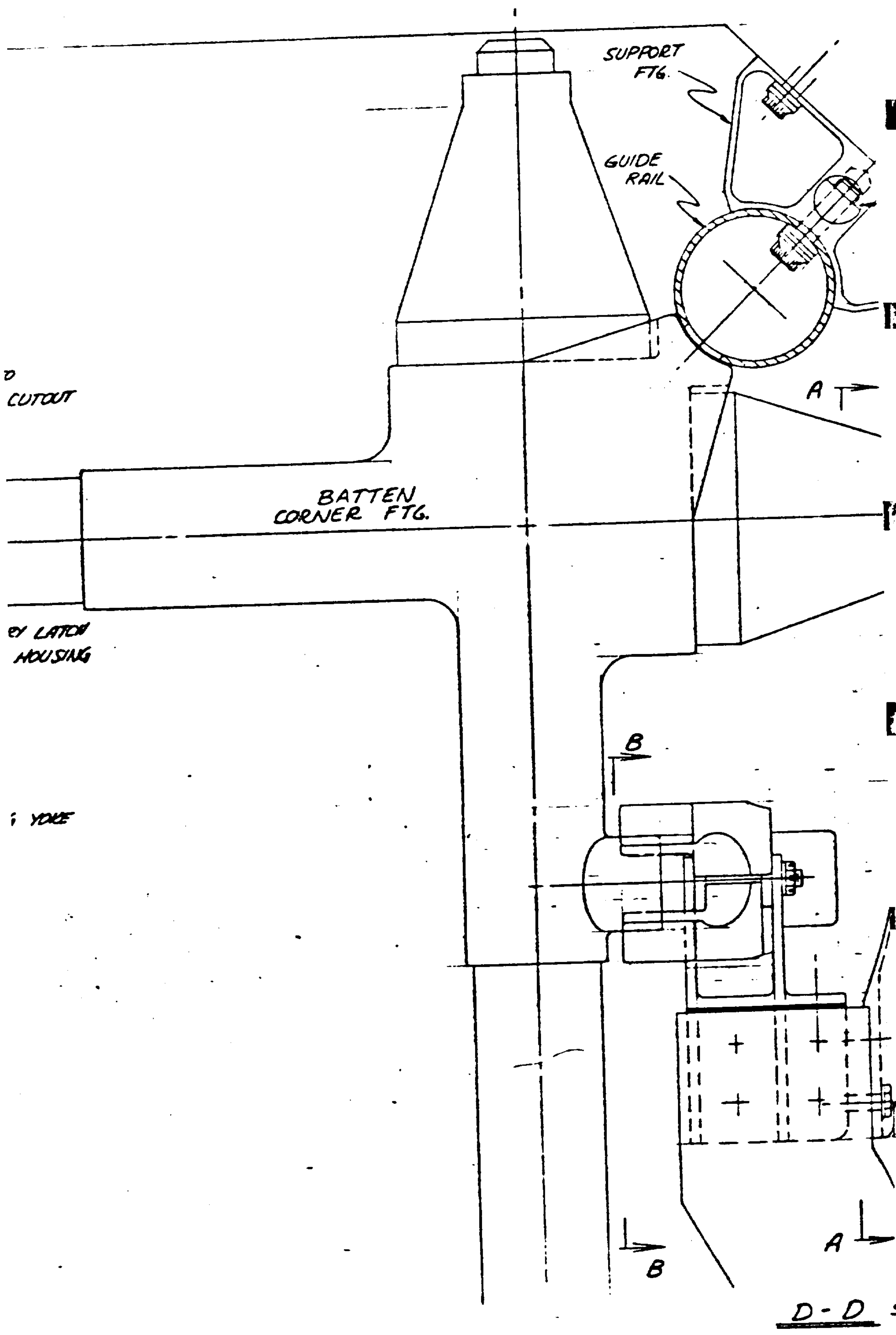


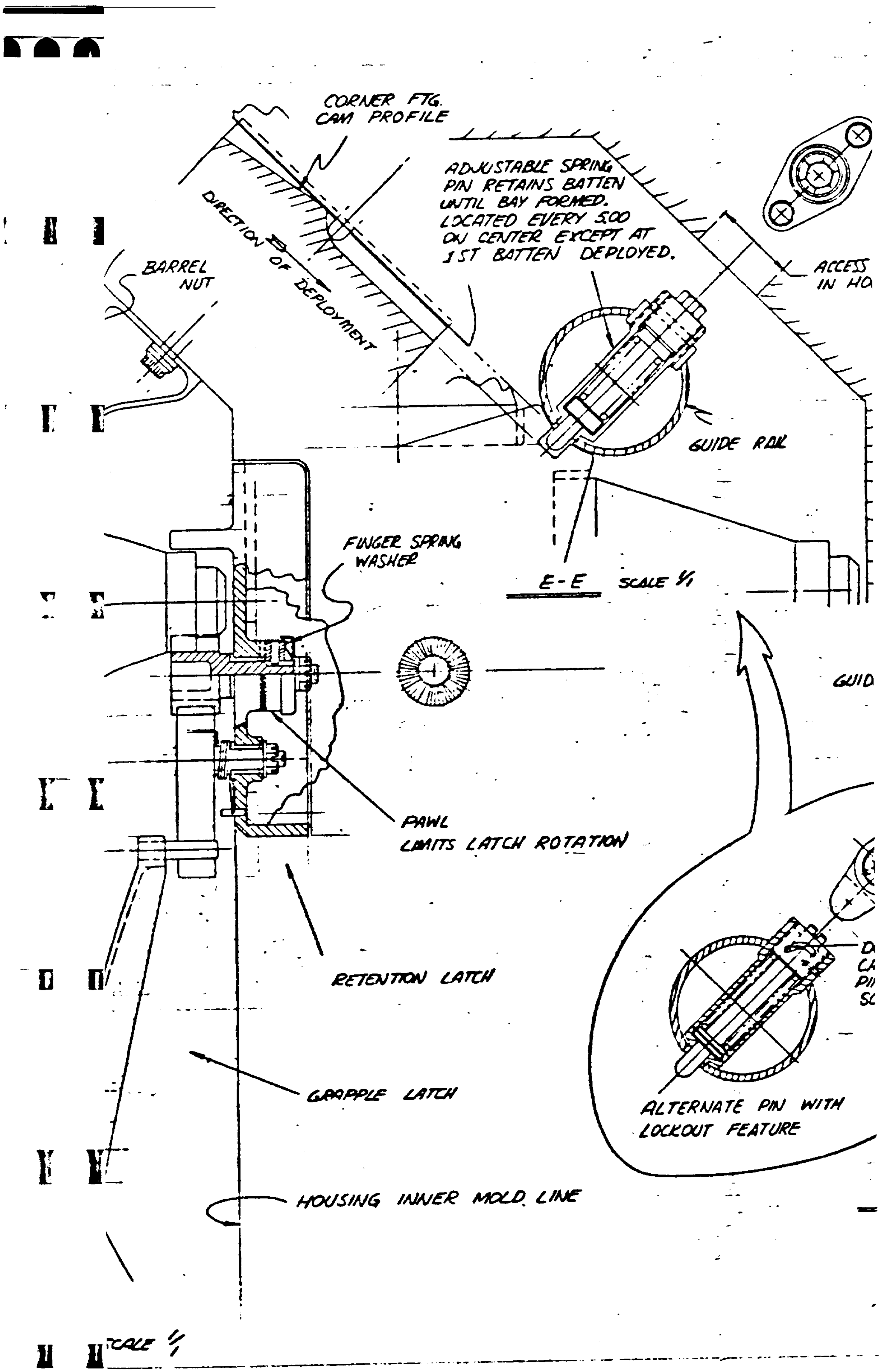

B-B GRAPPLE LATCH
SECURES BATTEN TO YOKE
AND PROVIDES ROOT STRENGTH
TO TRUSS DURING DEPLOYMENT.

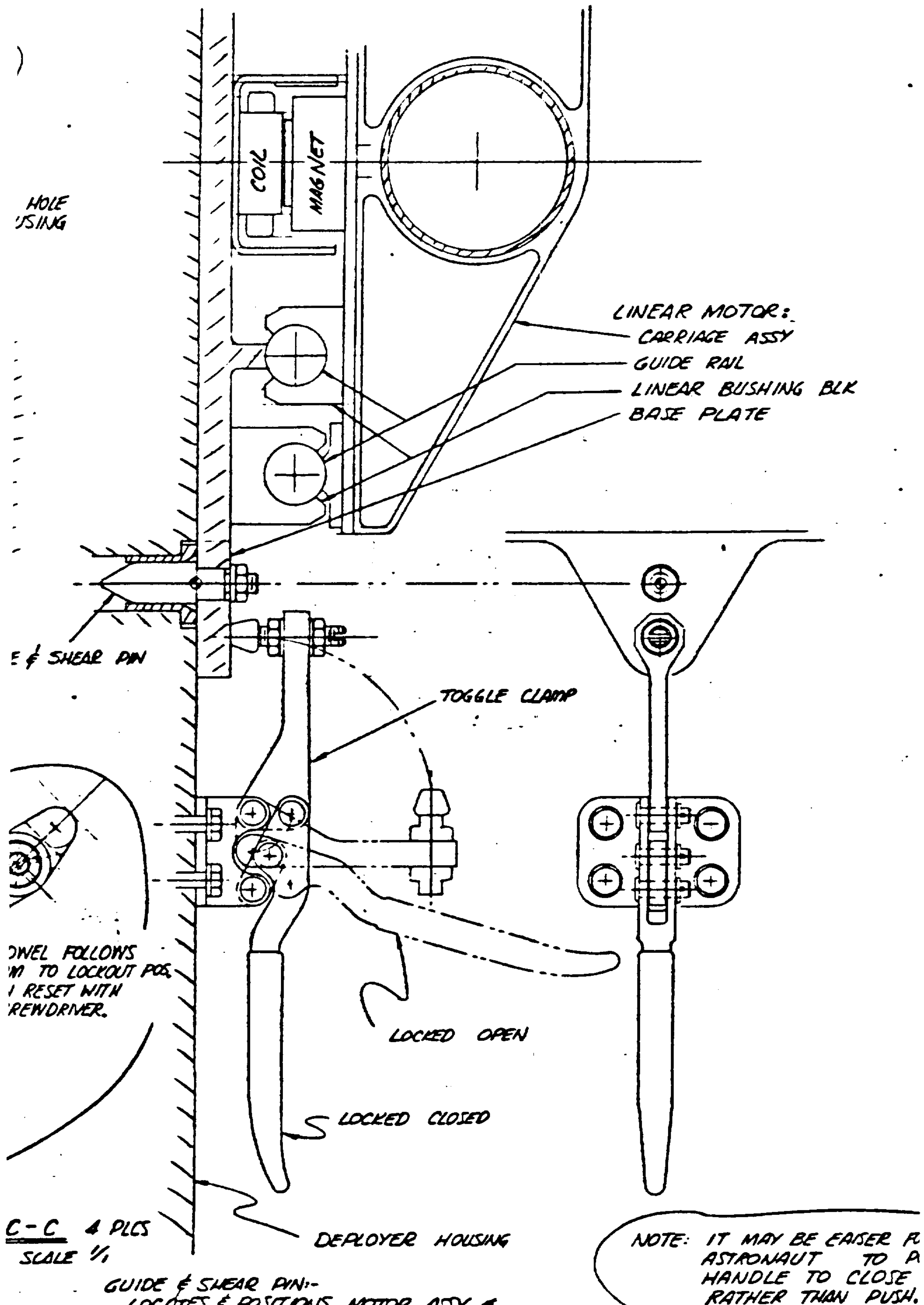



A-A RETENTION LATCH

SECURES BATTEN TO HOUSING
AND PROVIDES ROOT STRENGTH
TO TRUSS DURING CARRIAGE
RETRACTION.

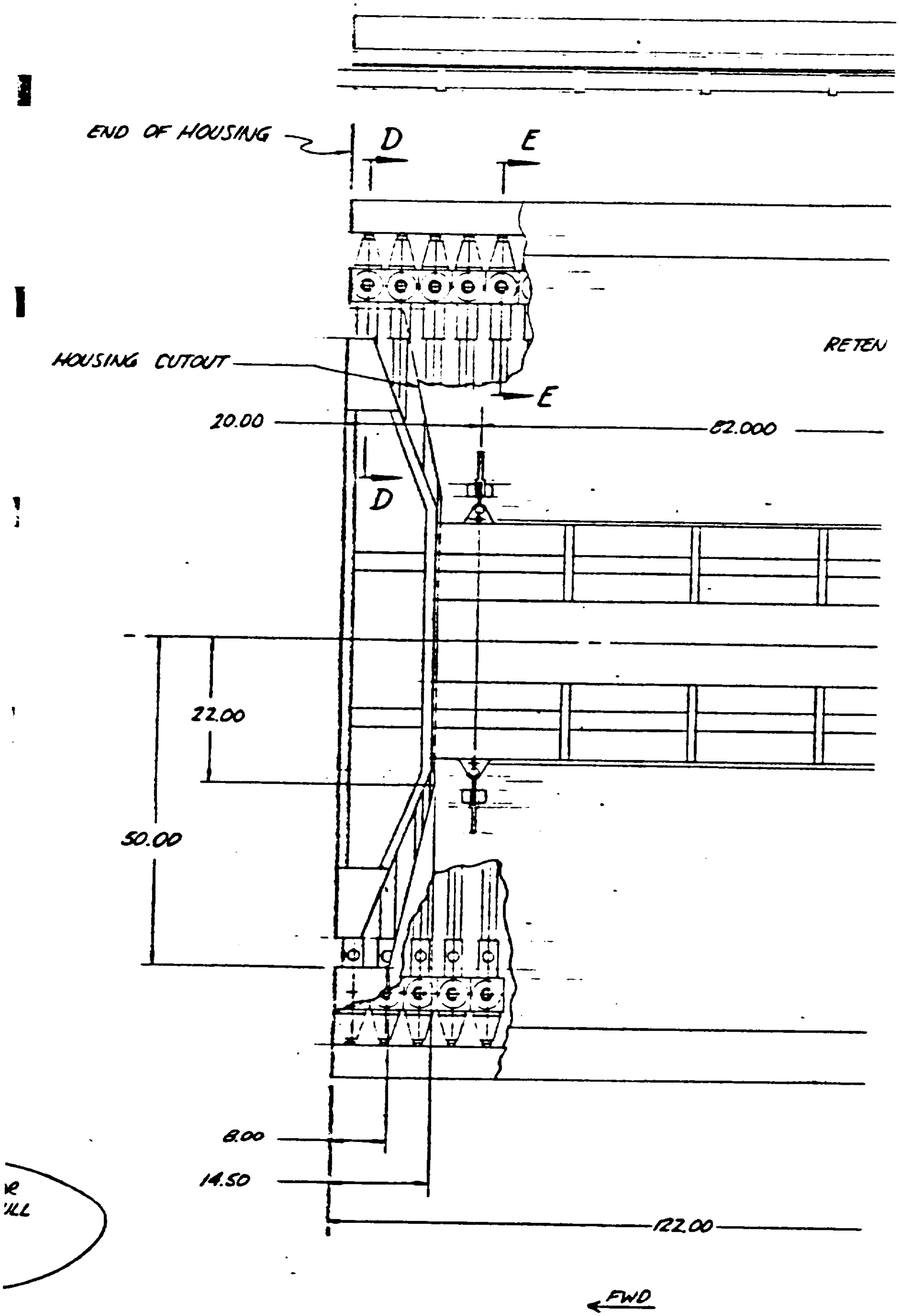

SUPPORT FTG.
GUIDE RAIL
CUTOUT
BATTEN CORNER FTG.
LATCH HOUSING
YOKE
A
B
D-D


CORNER FTG.
CAM PROFILE
ADJUSTABLE SPRING PIN RETAINS BATTEN UNTIL BAY FORMED. LOCATED EVERY 5.00 ON CENTER EXCEPT AT 1ST BATTEN DEPLOYED.
DIRECTION OF DEPLOYMENT
BARREL NUT
GUIDE RAIL
FINGER SPRING WASHER
E-E SCALE 1/1
PAWL
LIMITS LATCH ROTATION
RETENTION LATCH
GRAPPLE LATCH
ALTERNATE PIN WITH LOCKOUT FEATURE
HOUSING INNER MOLD LINE

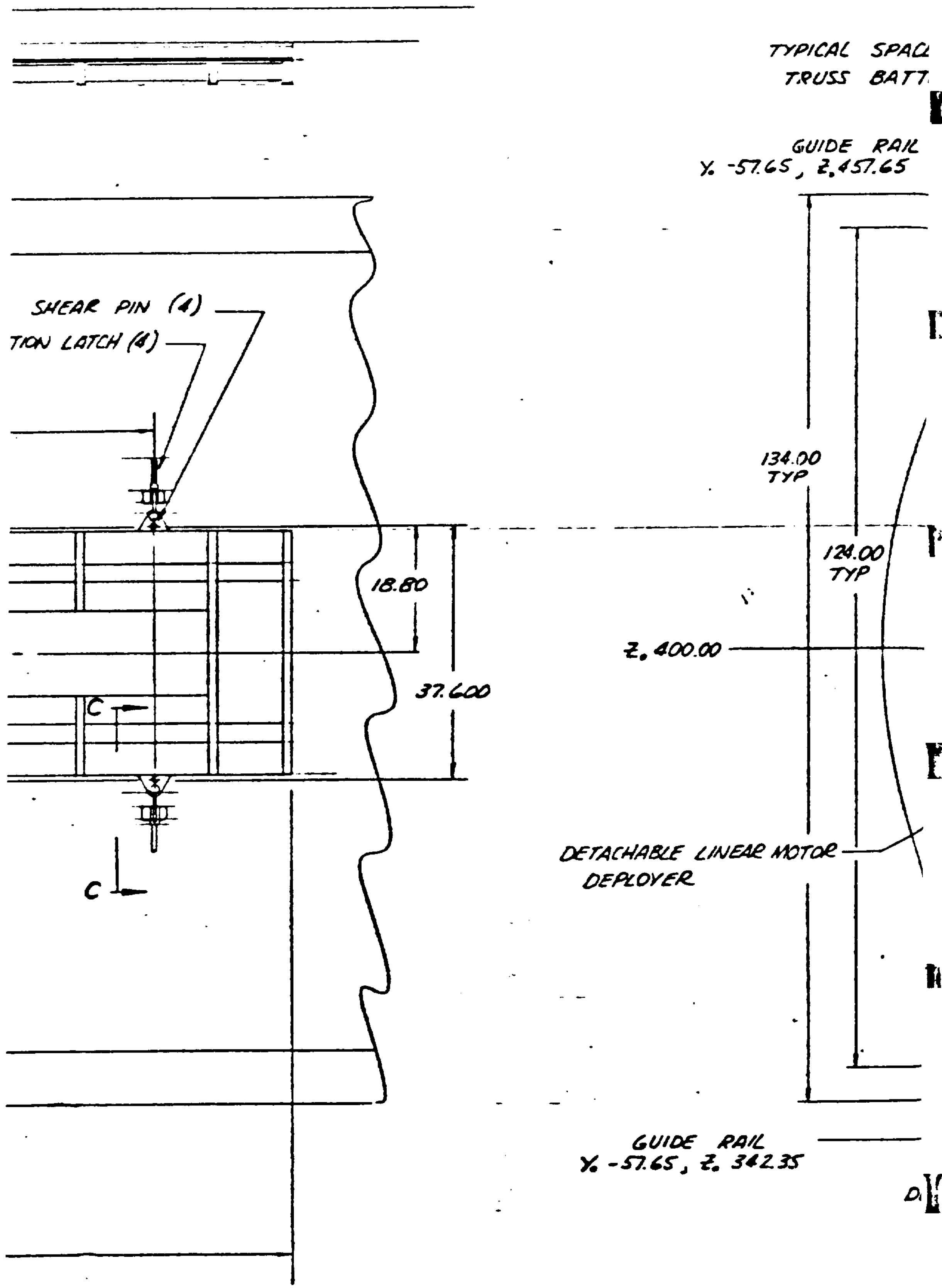



GUIDE & SHEAR PIN:-
LOCATES & POSITIONS MOTOR ASSY & TRANSFERS SHEAR LOADS TO HOUSING.

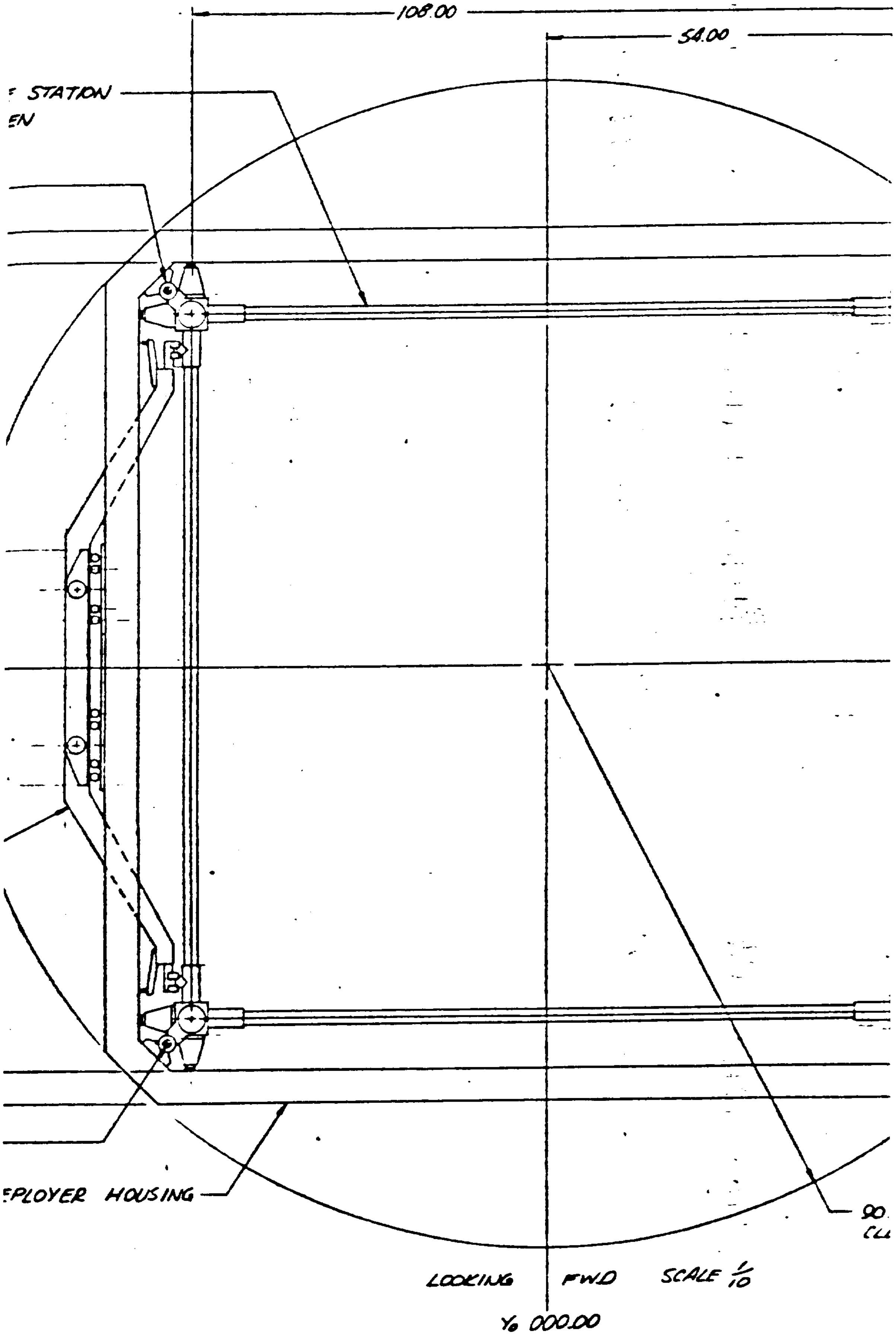
TOGGLE CLAMP:-
LATCHES MOTOR ASSY TO HOUSING & TRANSFERS OUTBD LOADS TO HOUSING



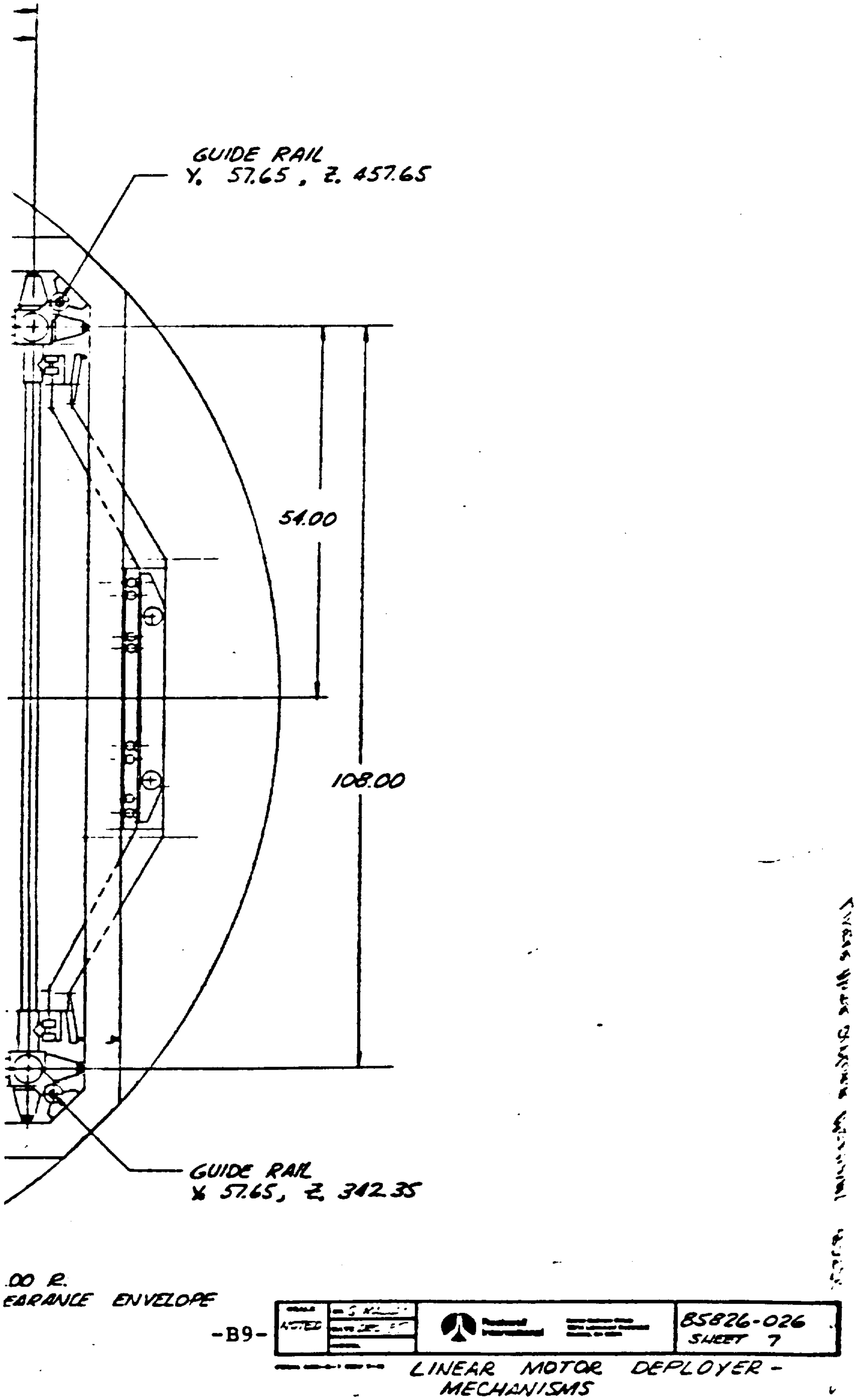
END OF HOUSING
D
E
HOUSING CUTOUT
E
RETEN
20.00
82.000
D
22.00
50.00
8.00
14.50
122.00
FWD



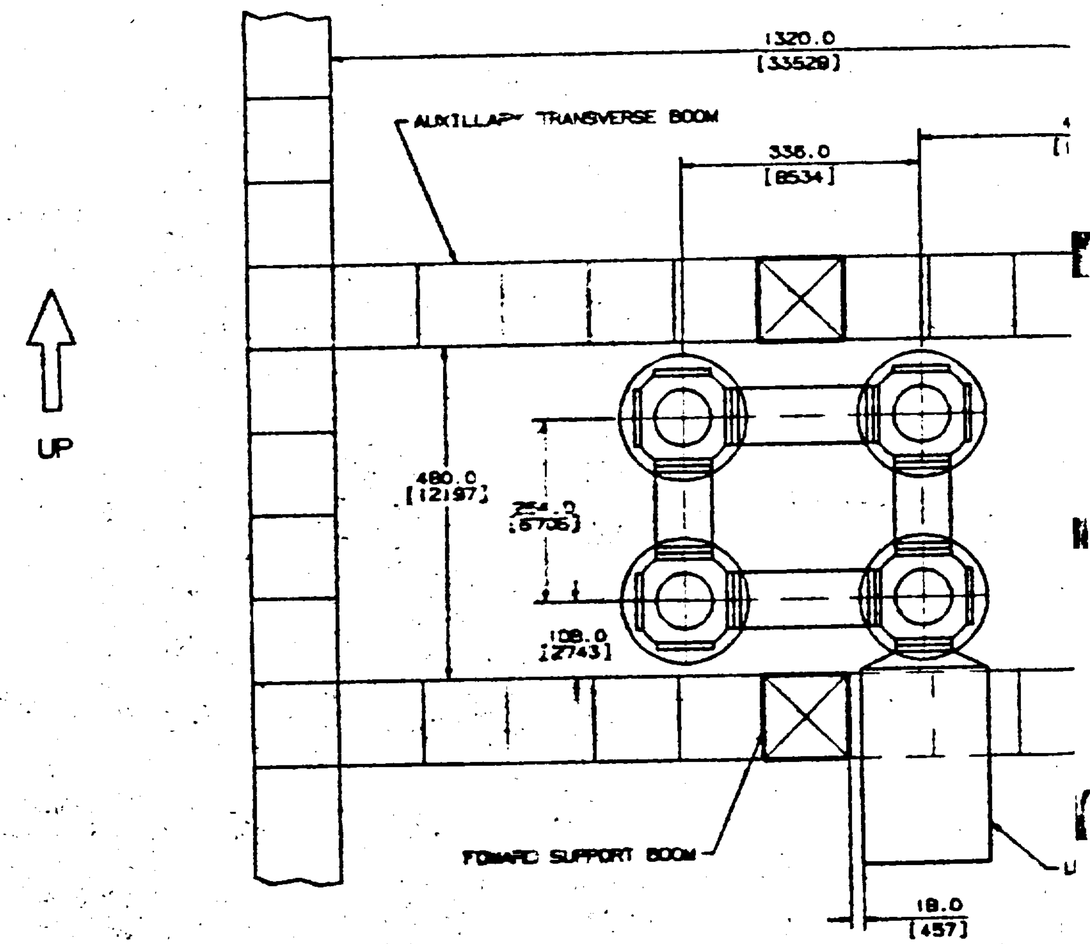
TYPICAL SPAC
TRUSS BATT
GUIDE RAIL
Y. -57.65, Z. 457.65
SHEAR PIN (4)
TION LATCH (4)
134.00
TYP
124.00
TYP
18.80
37.600
Z. 400.00
C
C
DETACHABLE LINEAR MOTOR
DEPLOYER
GUIDE RAIL
Y. -57.65, Z. 342.35



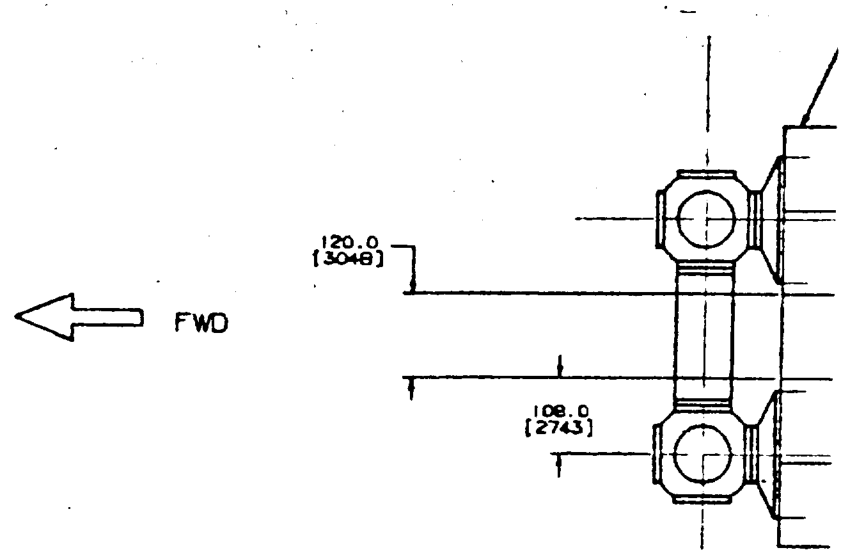
108.00
54.00
STATION
EN
EPLOYER HOUSING
90.
CL
LOOKING FWD SCALE 1/10
Y0 000.00


GUIDE RAIL
Y. 57.65 , Z. 457.65
54.00
108.00
GUIDE RAIL
Y 57.65, Z. 342.35
.00 R.
EARANCE ENVELOPE
85826-026
SHEET 7
LINEAR MOTOR DEPLOYER - MECHANISMS

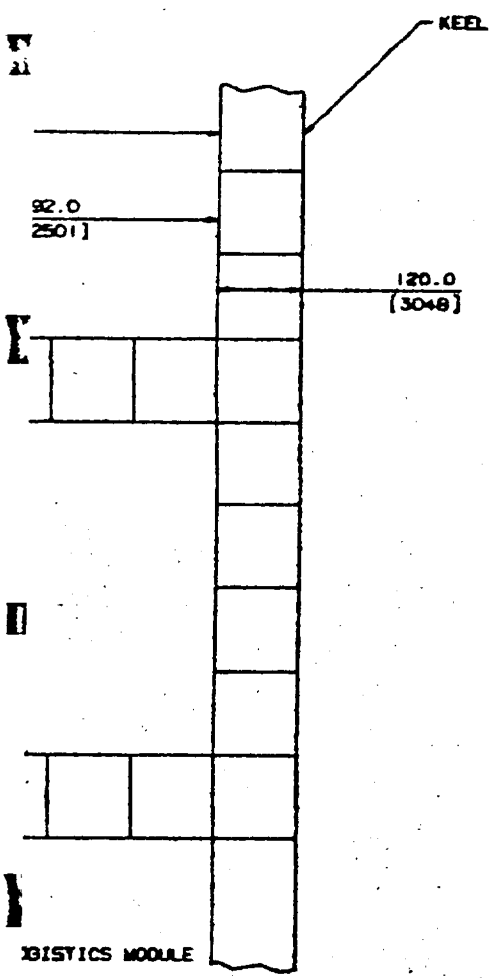
Module Support Concept, 3.05-Meter (10-Foot) Truss



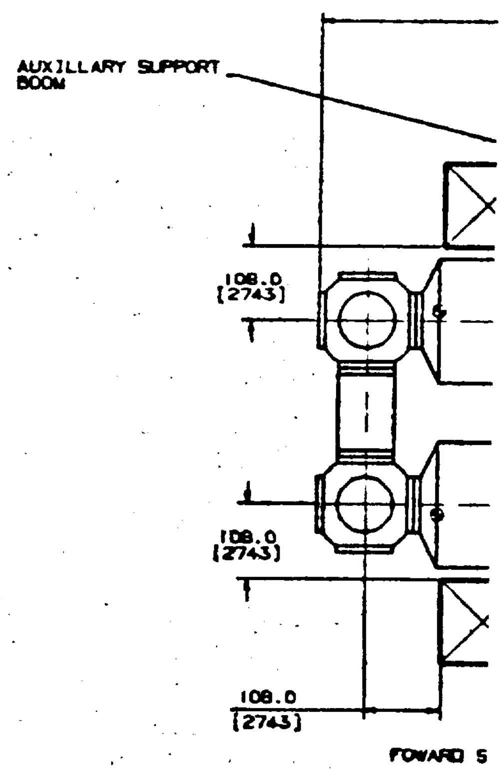

VIEW LOOKING AFT



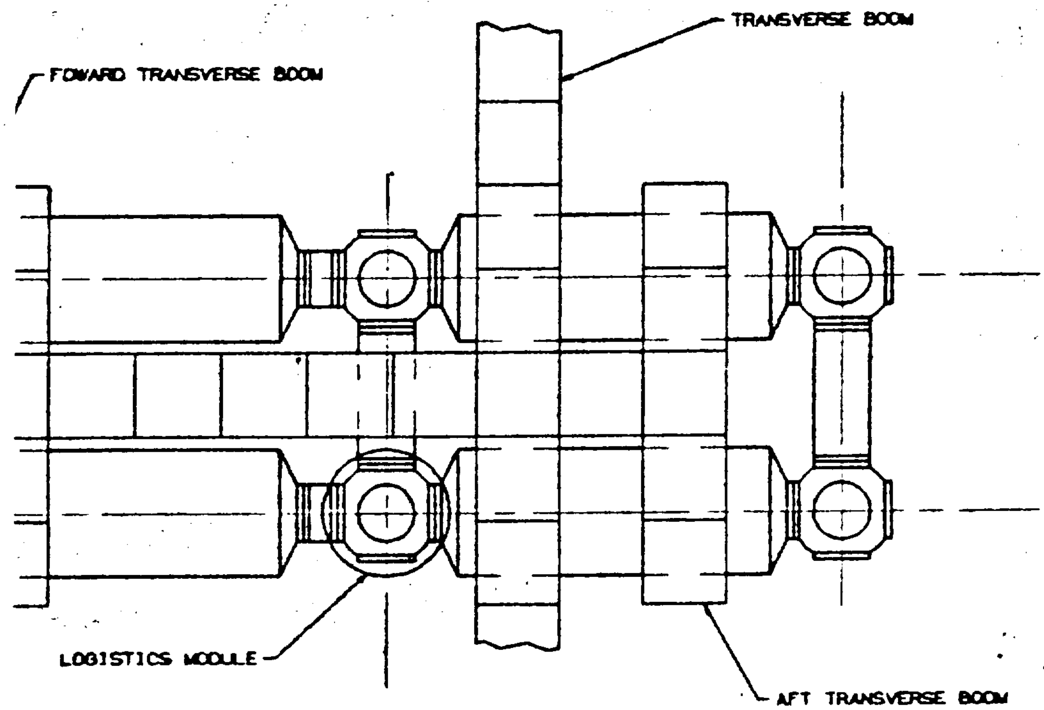
FWD
120.0
[3048]
108.0
[2743]

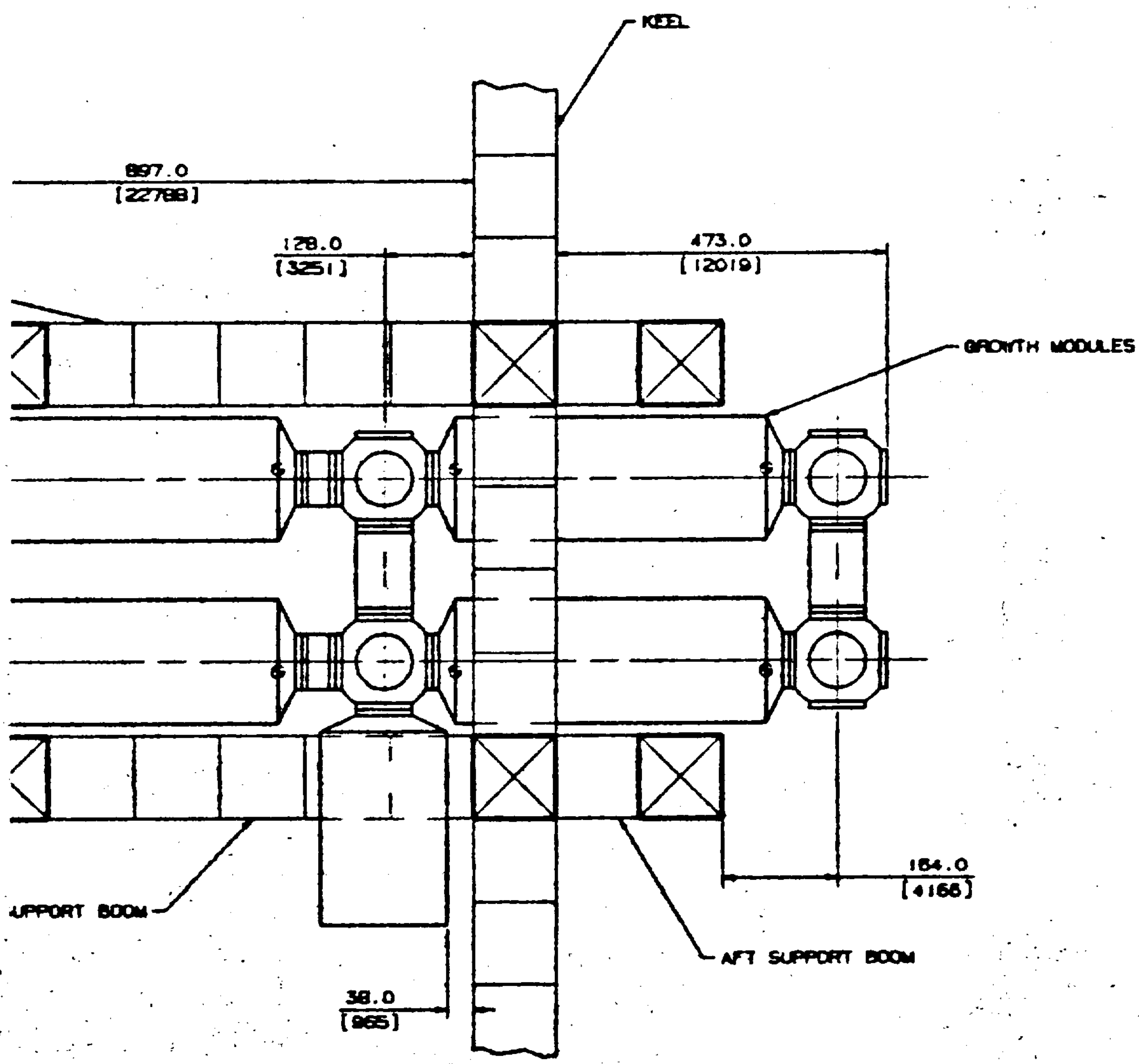
KEEL
92.0
2501]
120.0
[3048]
GISTICS MODULE

AUXILLARY SUPPORT BOOM
108.0
[2743]
108.0
[2743]
108.0
[2743]
FOWARD S




VIEW LOOKING DOWN




SIDE VIEW

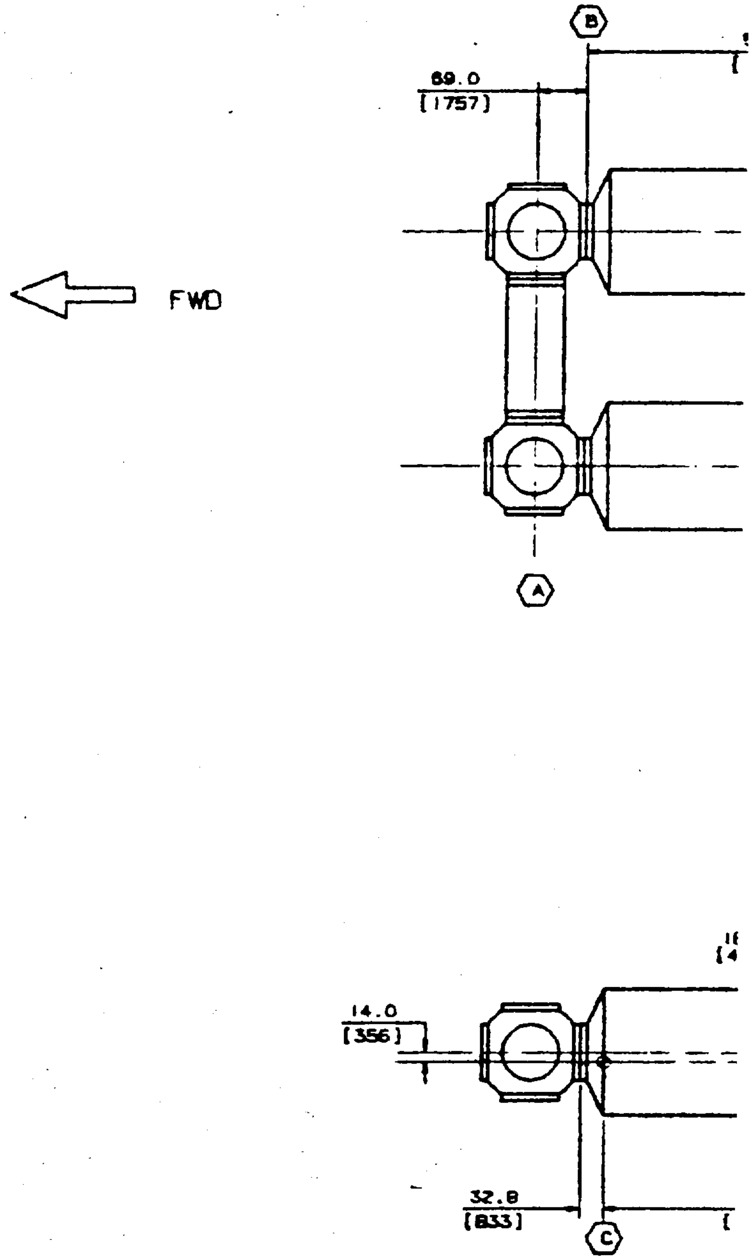
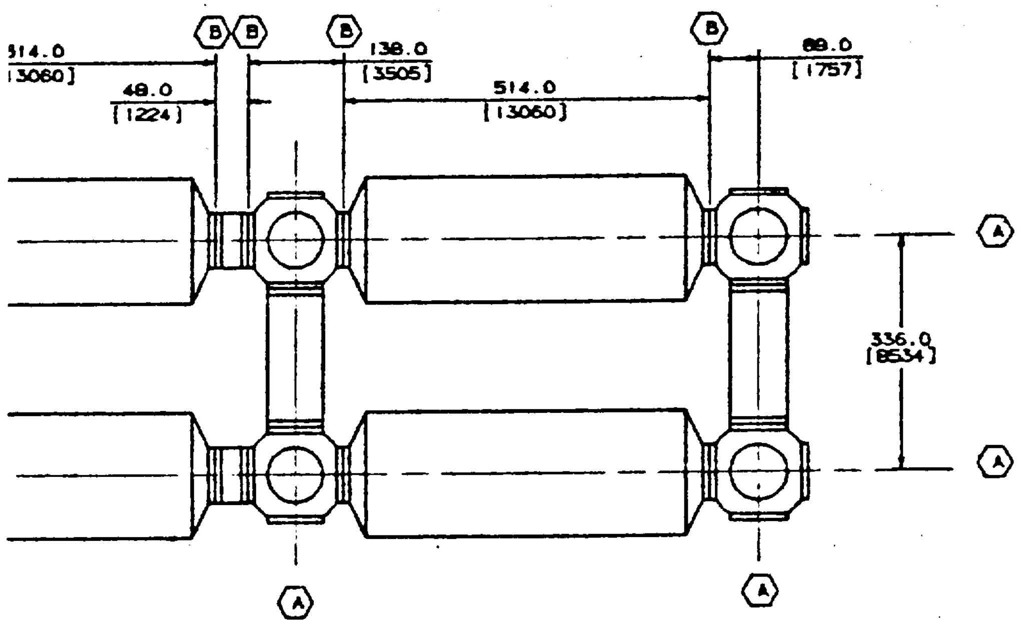



FIGURE 8 MODULE PATTE

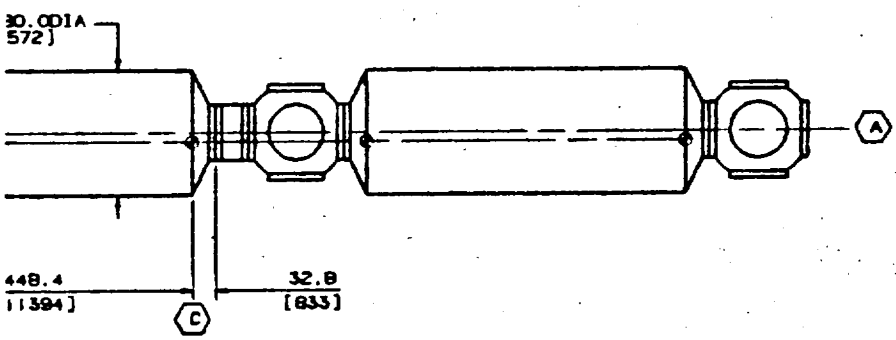
(A) = MODULE/NODE/TUNN

(B) = BERTHING PORT IN

(C) = MODULE TRUNNION




PLAN VIEW




SIDE VIEW

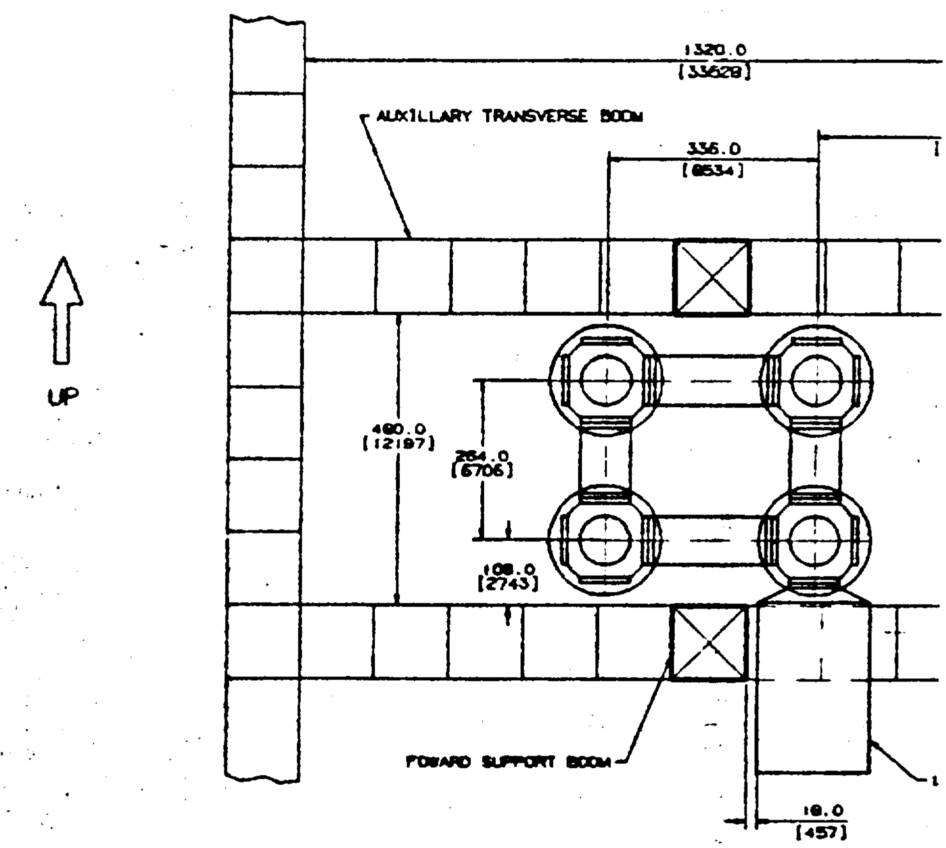
:RN

EL CENTERLINE

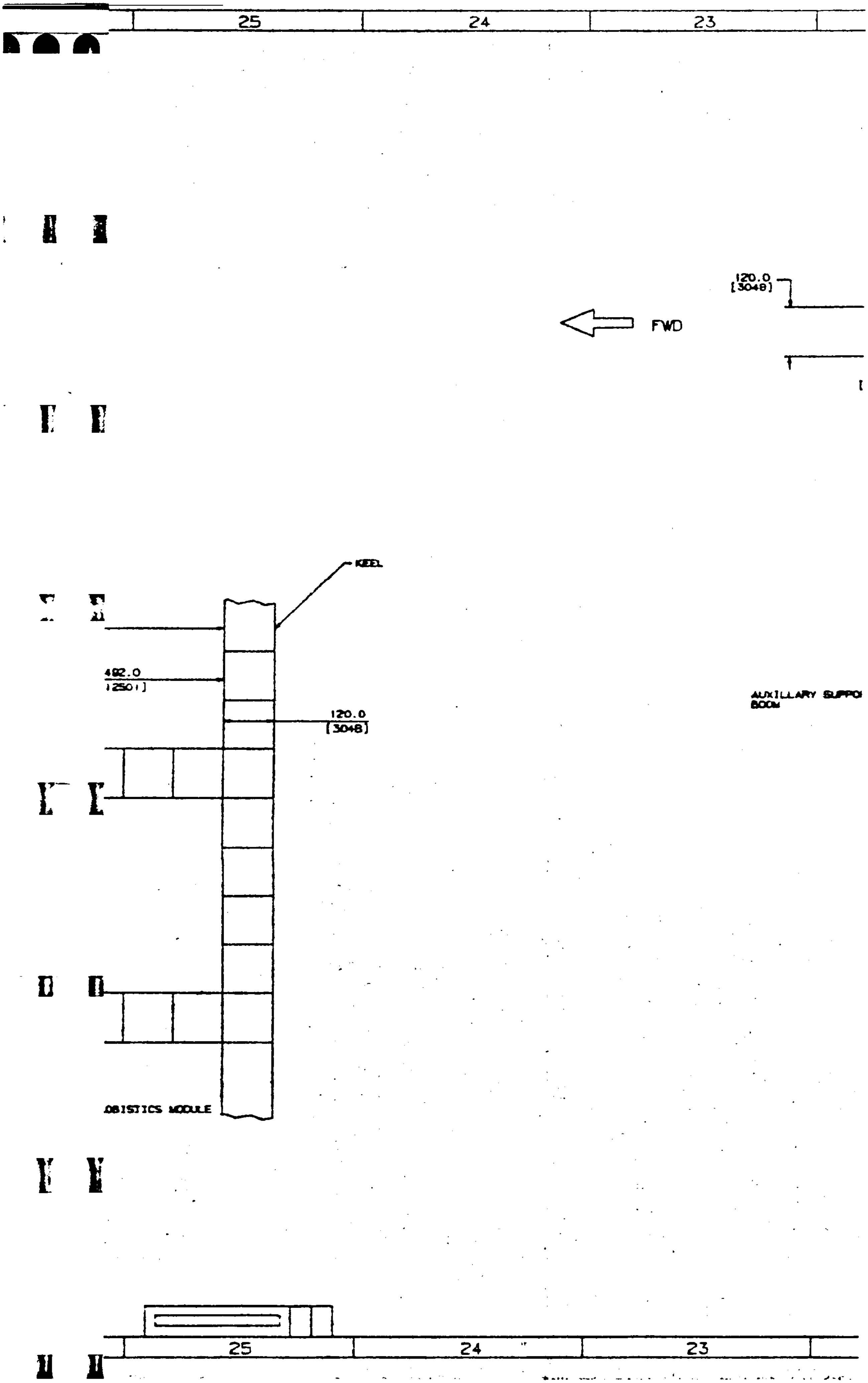
TERFACE

.OCATION

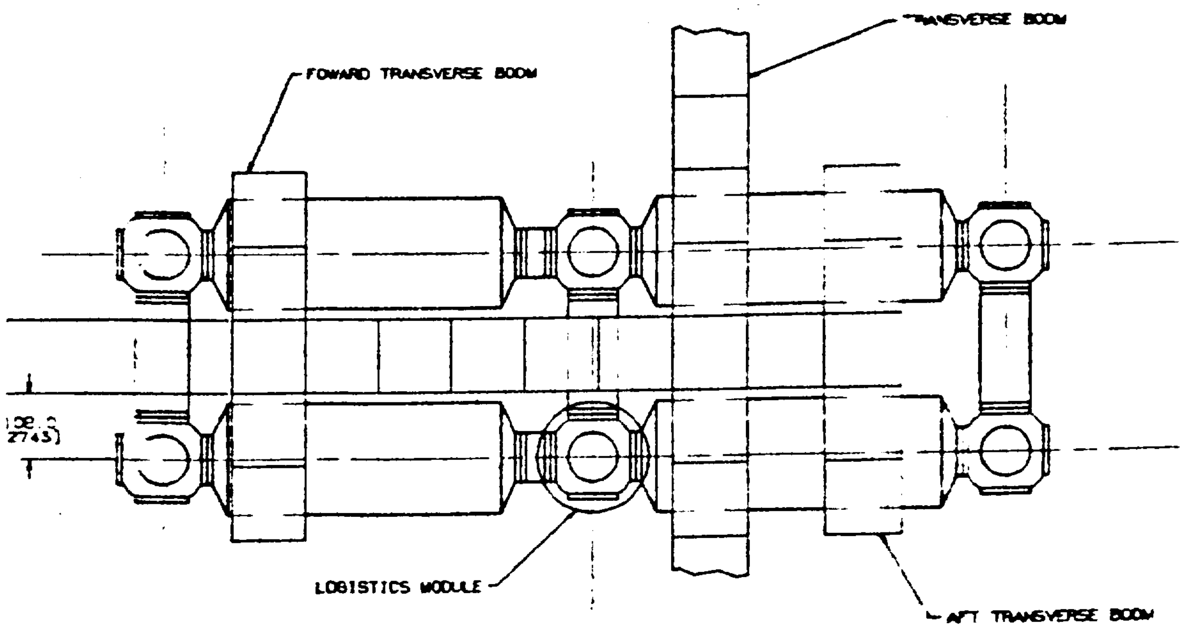
TITLE : 10FT MODULE PATTERN LOCATION - GROWTH
PART NAME : 10FTGR12N
WORKFILE : ATTACH10G
USER : MARINO
DATE : 1.3.86
SCALE 1/200



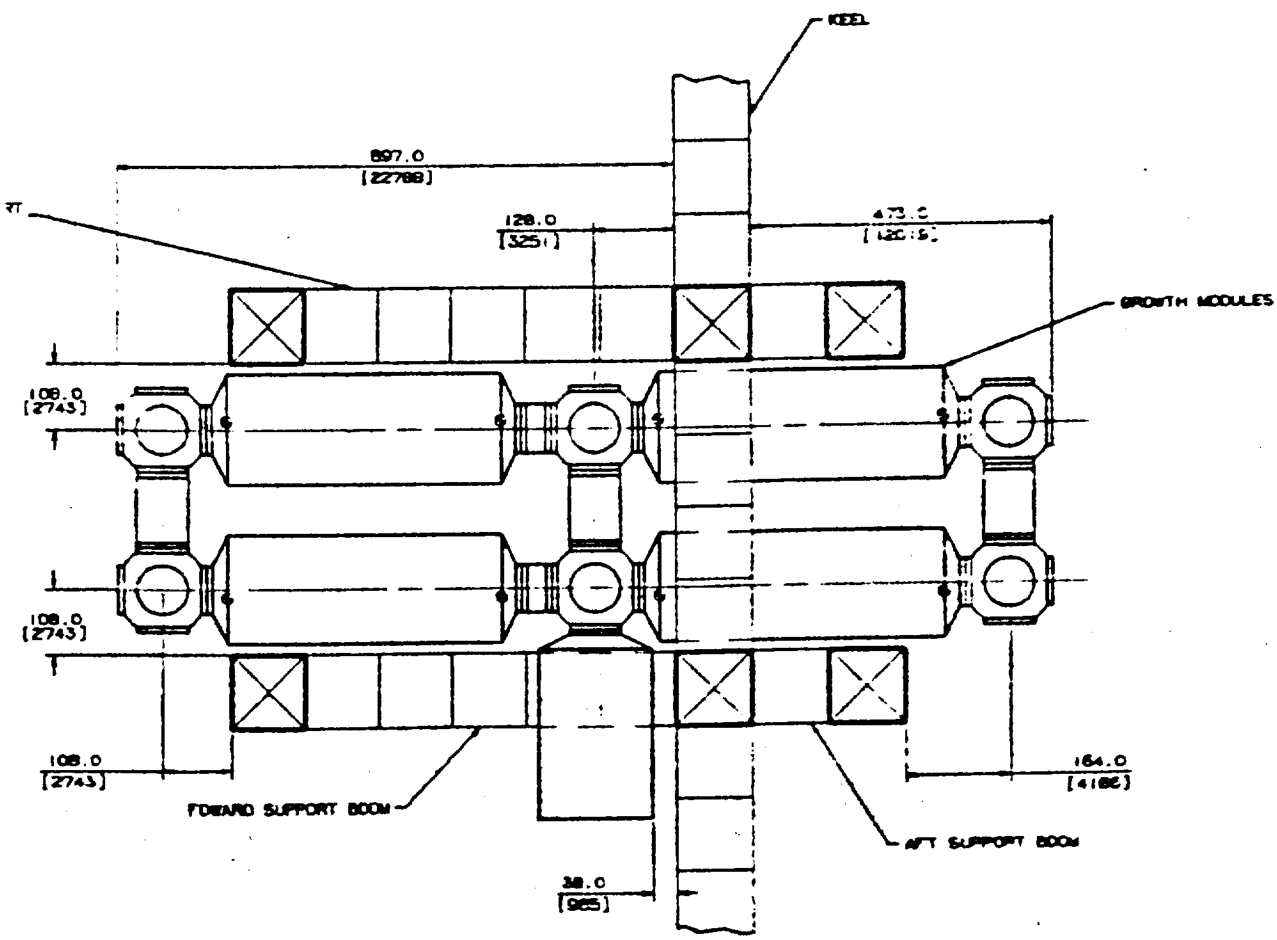

VIEW LOOKING AFT



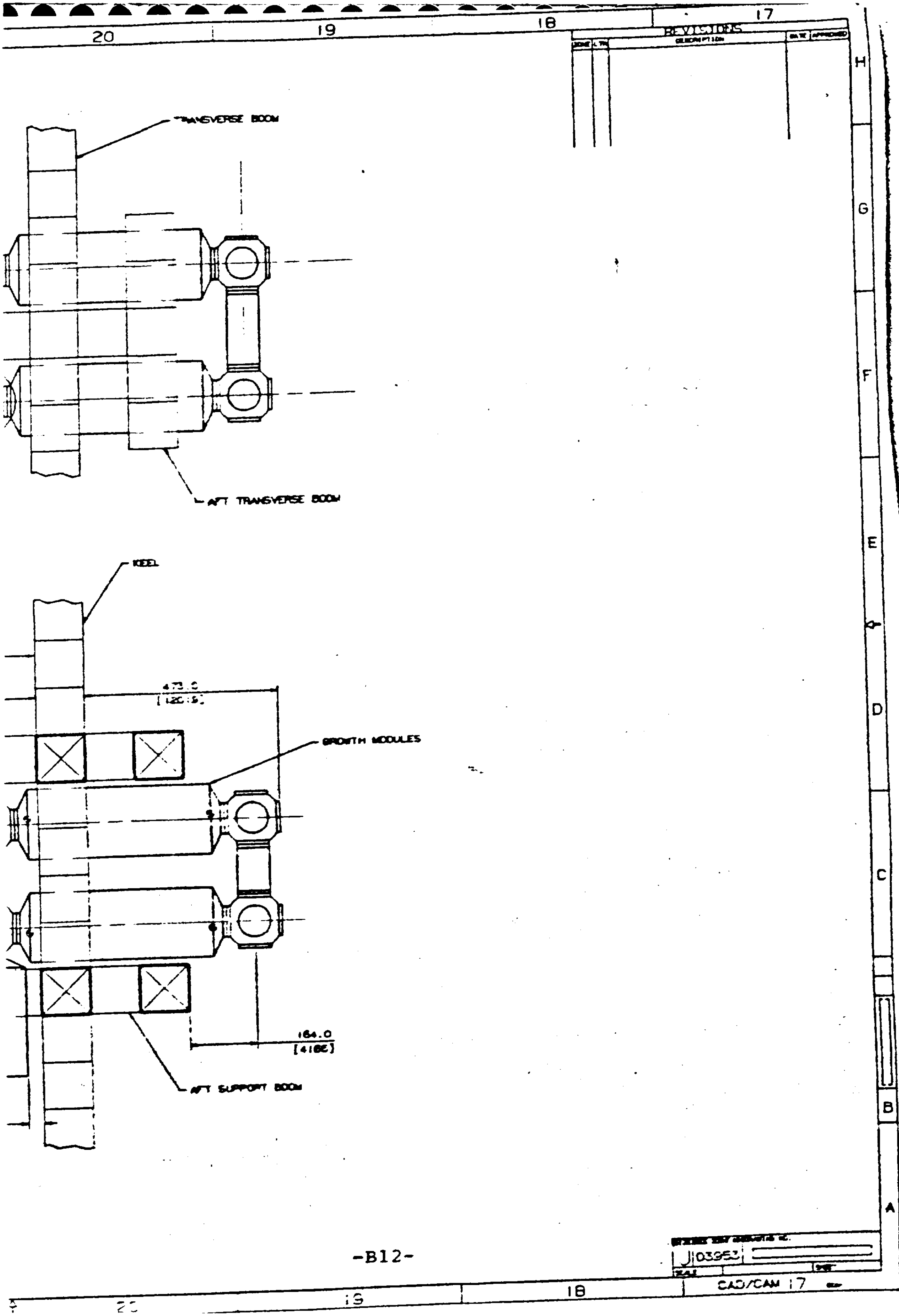
25
24
23
120.0
[3048]
FWD
KEEL
492.0
[2501]
120.0
[3048]
AUXILLARY SUPPO
BOOM
OBISTICS MODULE
25
24
23

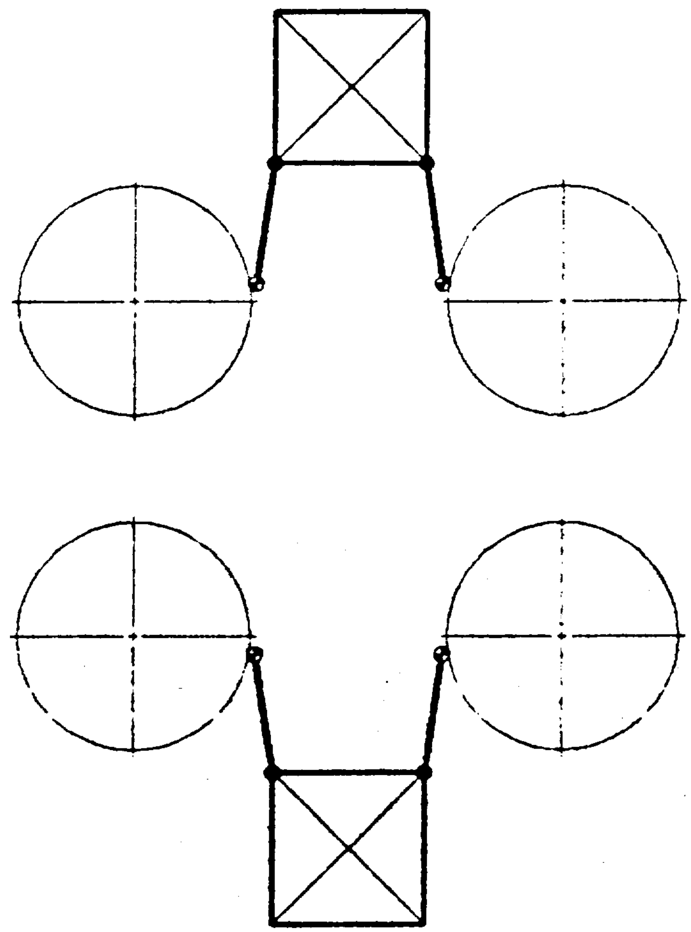



VIEW LOOKING DOWN



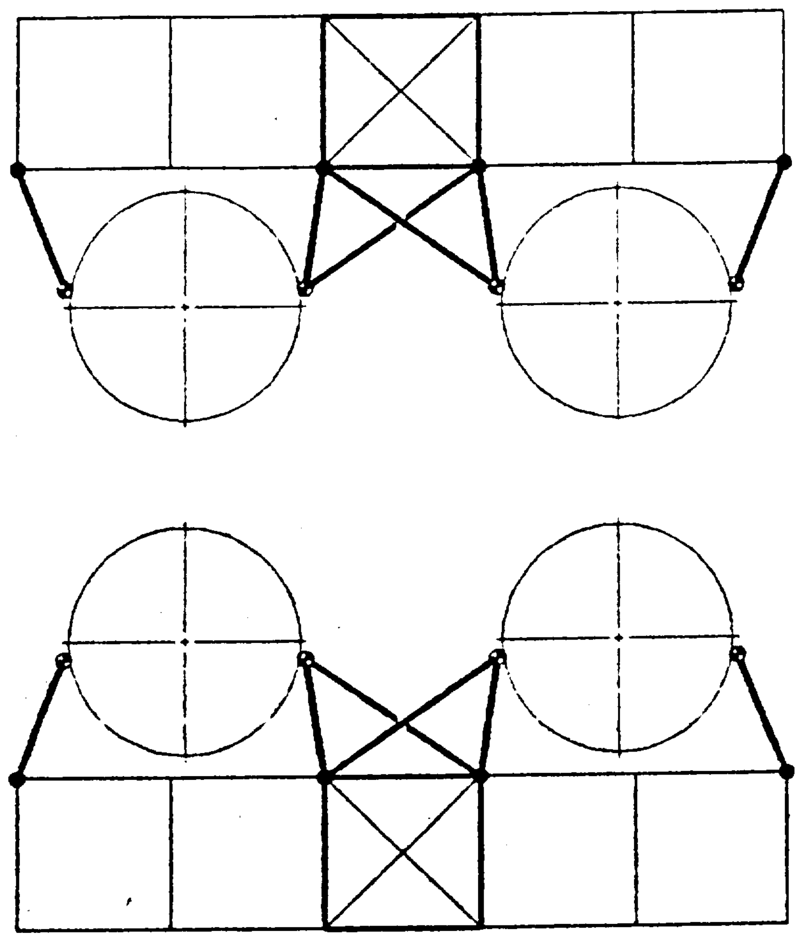

SIDE VIEW


20
19
18
17
REVISIONS
DESCRIPTION
H
G
F
E
D
C
B
A
TRANSVERSE BOOM
AFT TRANSVERSE BOOM
KEEL
GROWTH MODULES
164.0
AFT SUPPORT BOOM
CAD/CAM 17



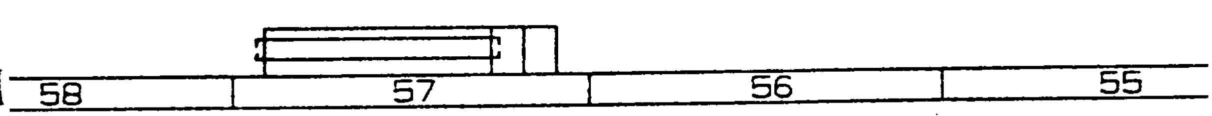
SECTION D-D

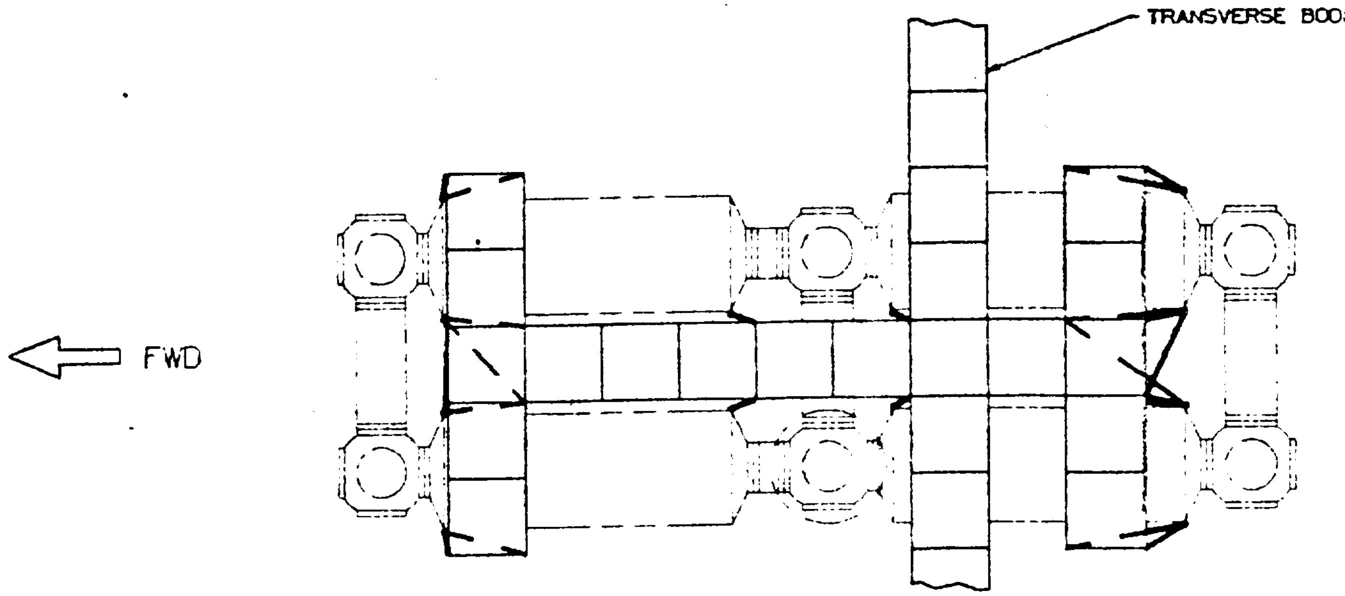
SCALE 1/100



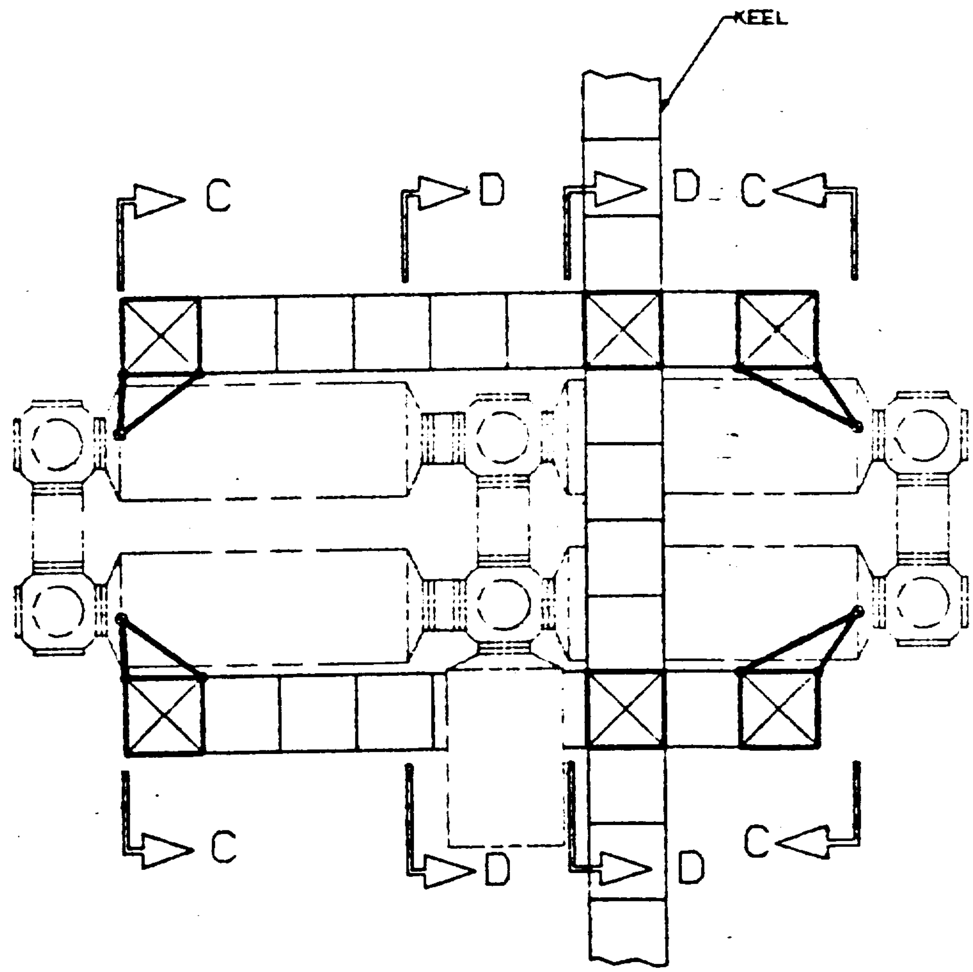
SECTION C-C

SCALE 1/100

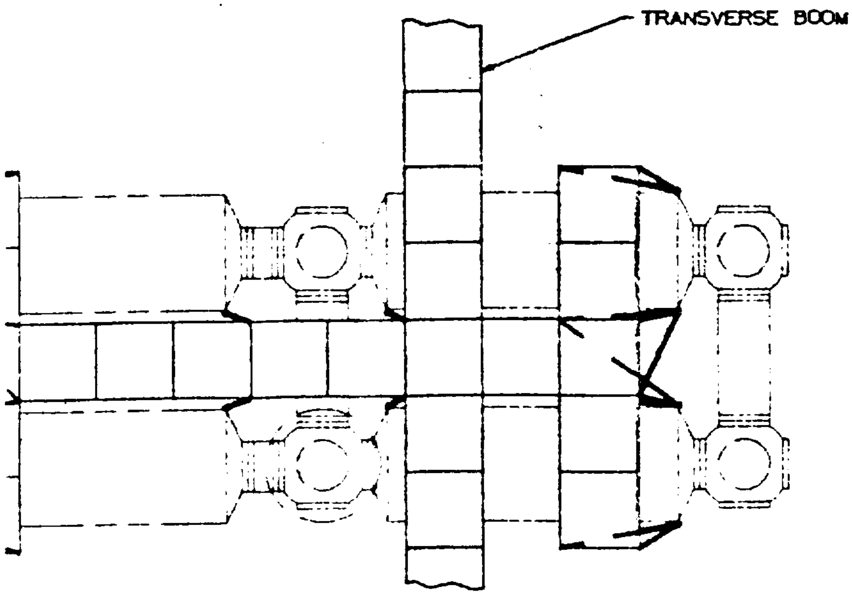




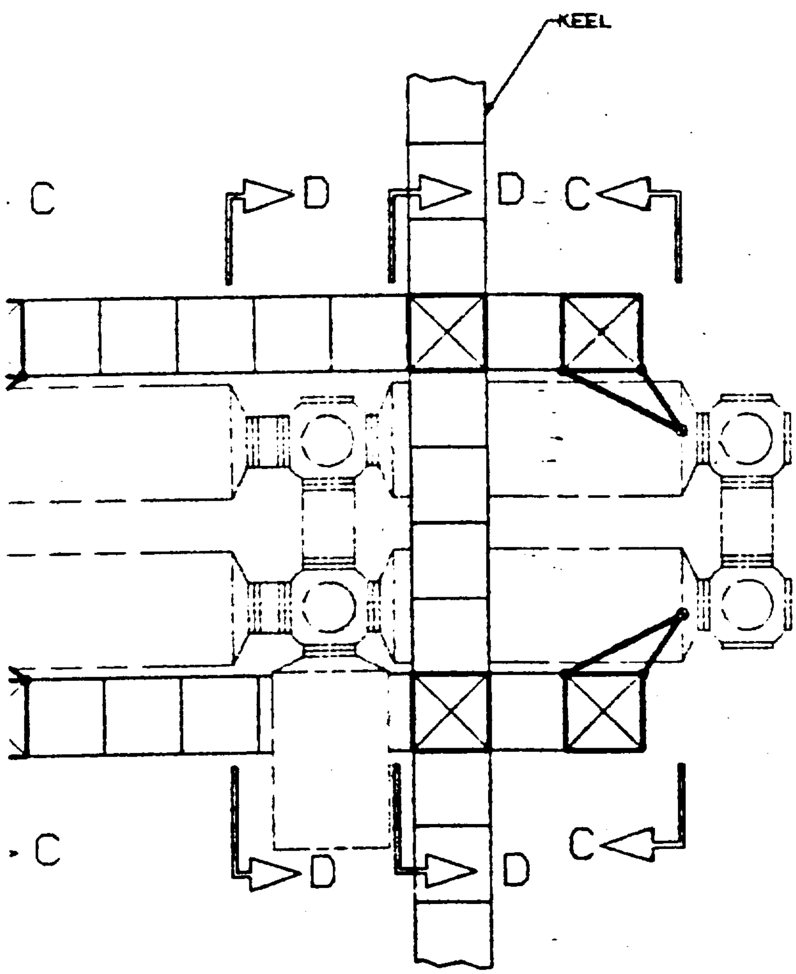

VIEW LOOKING DOWN




SIDE VIEW




VIEW LOOKING DOWN




SIDE VIEW

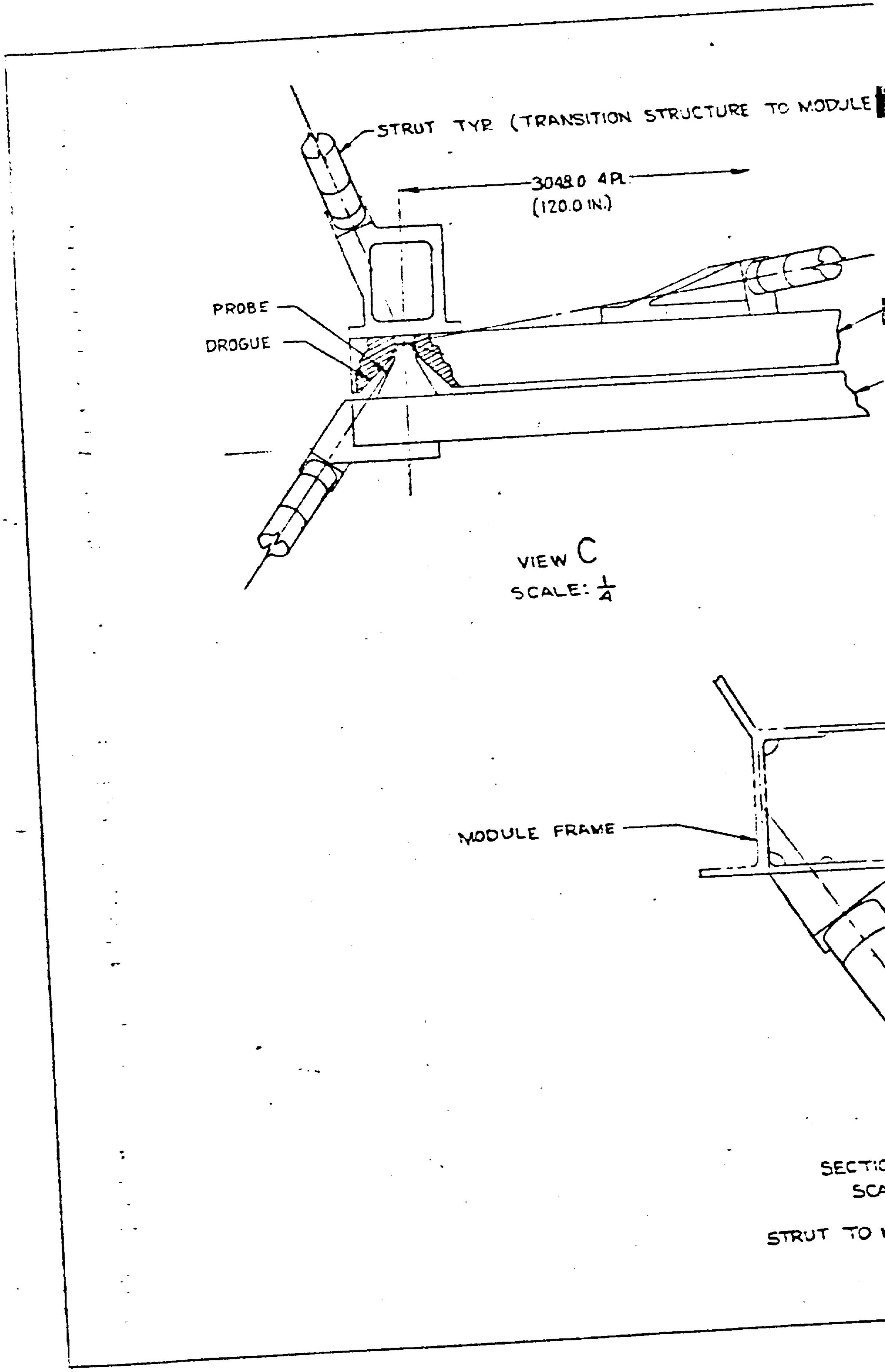


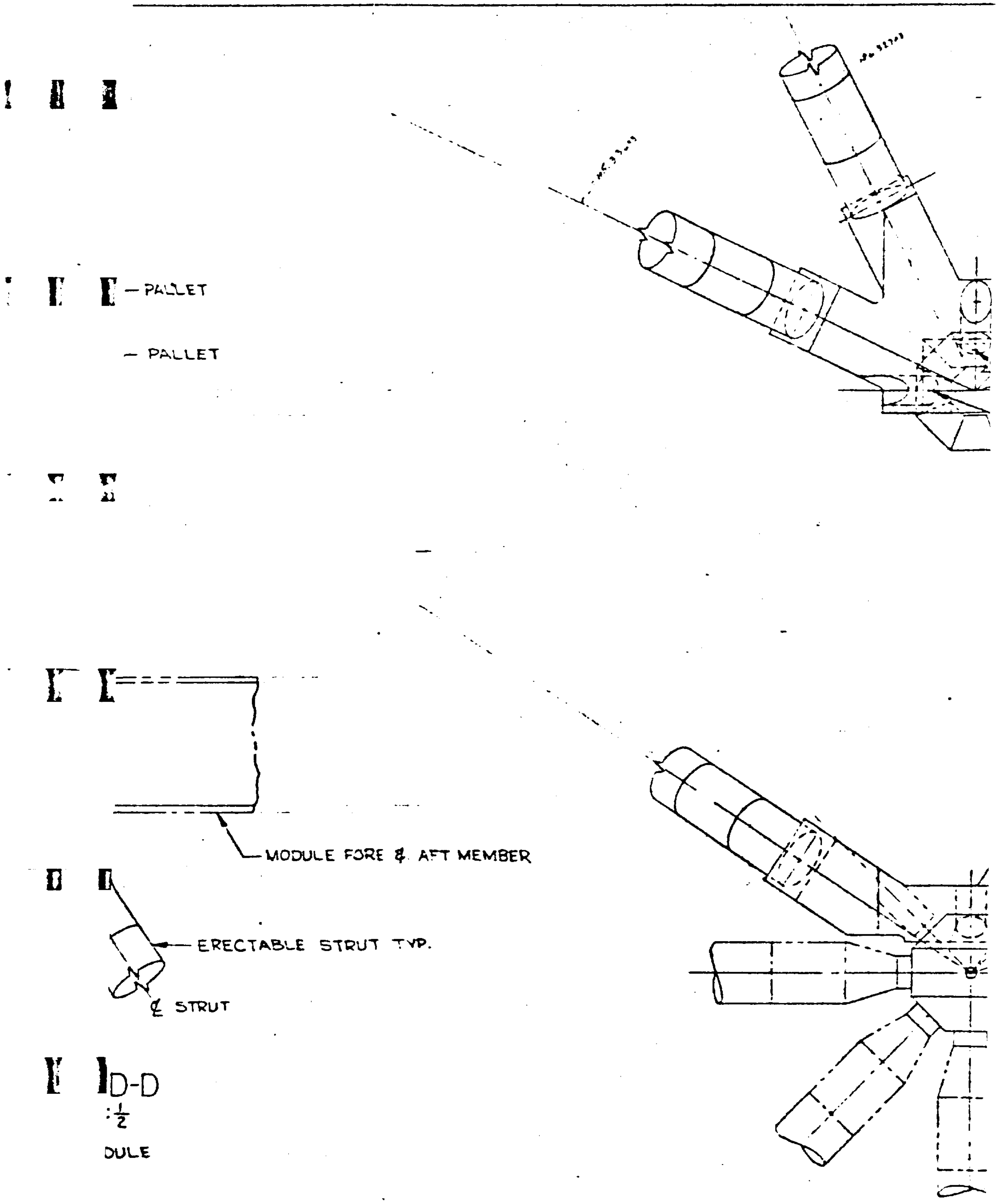
J03953

52 51 50 CAD/CAM 49

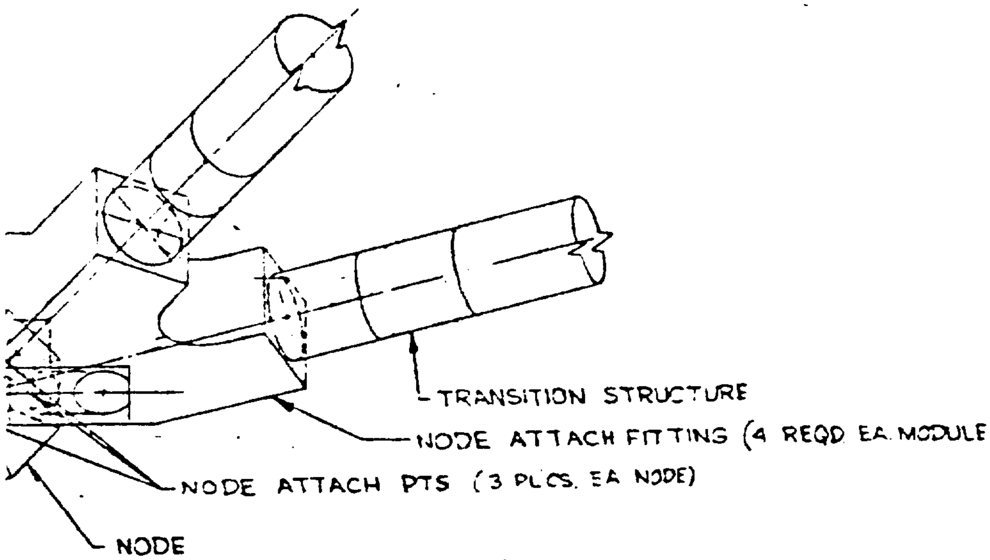
Module Installation--Palletized

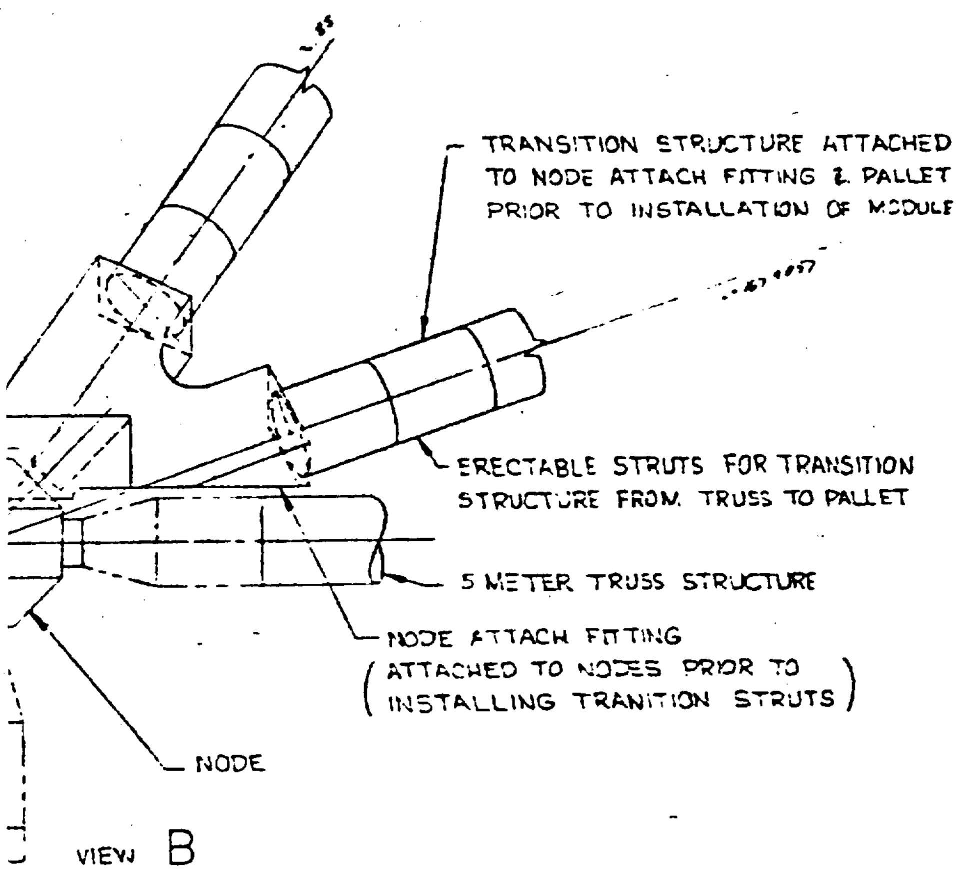
Drawing 84325-414


STRUT TYP (TRANSITION STRUCTURE TO MODULE
3048.0 4PL
(120.0 IN.)
PROBE
DROGUE
VIEW C
SCALE: 1/4
MODULE FRAME
SECTIC
SCA
STRUT TO

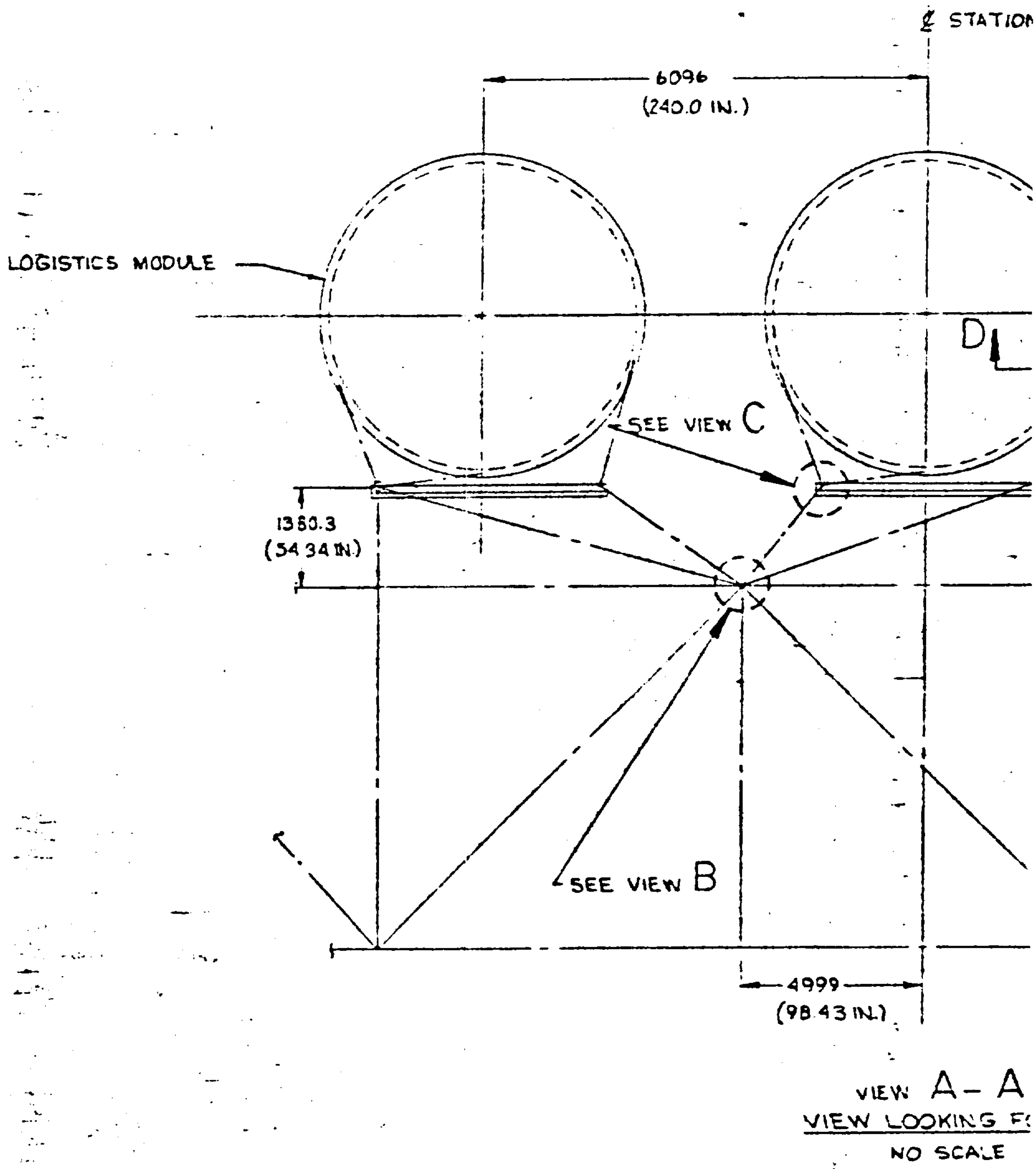


— PALLET
— PALLET
MODULE FORE & AFT MEMBER
ERECTABLE STRUT TYP.
℄ STRUT
D-D
:$\frac{1}{2}$
DULE

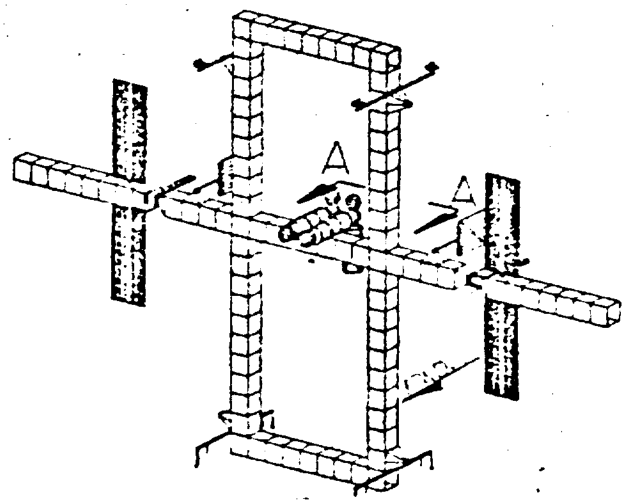



VIEW B
SCALE: ½



℄ STATION
6096
(240.0 IN.)
LOGISTICS MODULE
D
SEE VIEW C
1380.3
(54.34 IN.)
SEE VIEW B
4999
(98.43 IN.)
VIEW A– A
VIEW LOOKING F
NO SCALE




ORIENTATION VIEW
NO SCALE

— MODULE

— ℄ TRUNNION

℄ FORE & AFT MEMBER ON MODULE

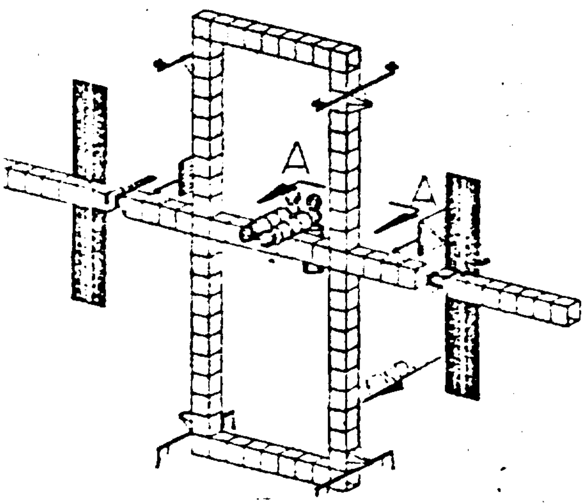
— TRANSITION STRUCTURE FROM MODULE
TO PALLET. (ATTACHED TO MODULE
PRIOR TO STATION INSTALLATION)

— INSULATION

TION STRUCTURE FROM
T TO TRUSS STRUCTURE

RSE BOOM TRUSS

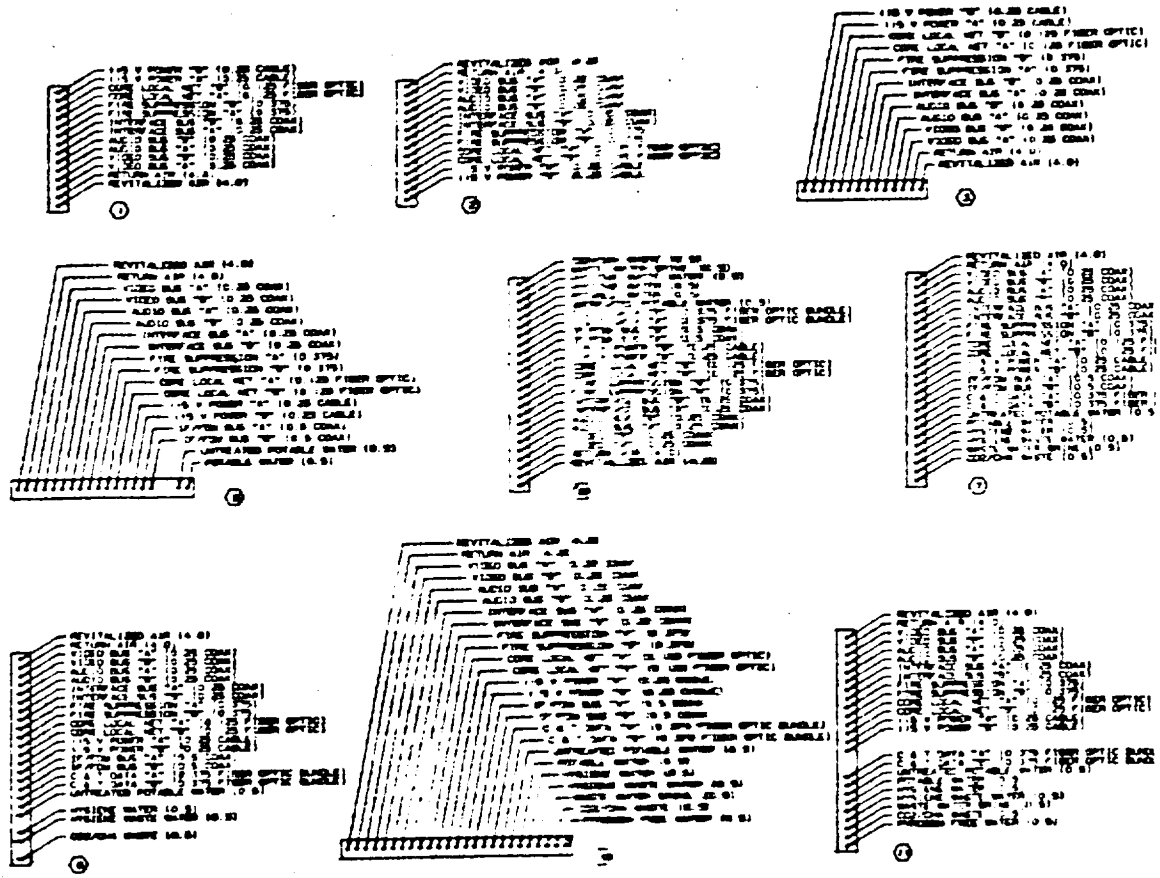
MODULE INSTAL



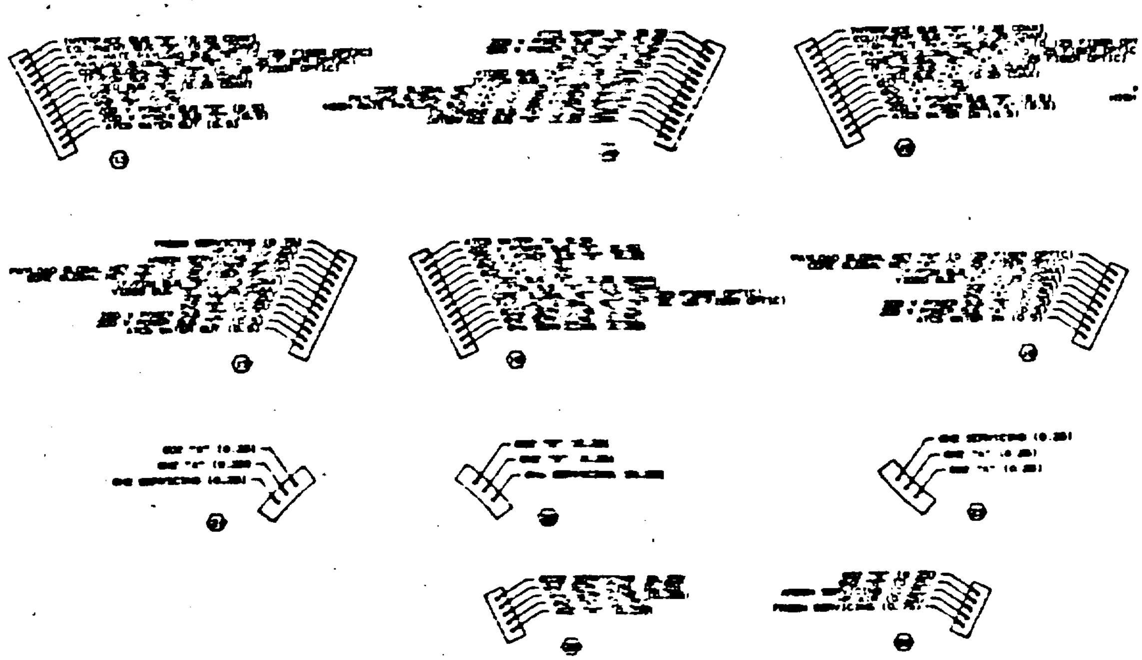

ORIENTATION VIEW
NO SCALE

.E
E
)

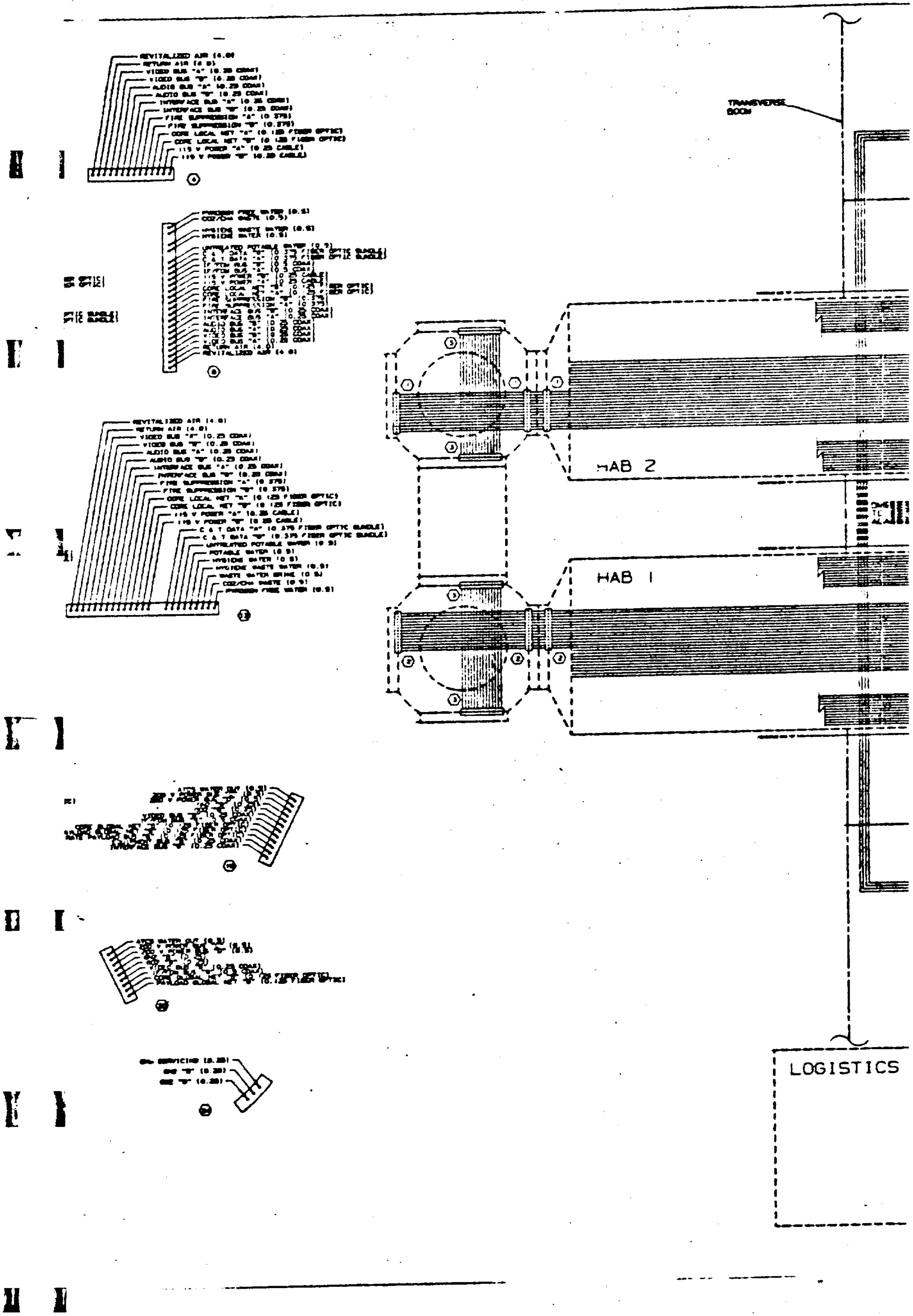
| | | |
|---|---|---|
| MODULE INSTALLATION - PALLETIZED | | 84325-414 |



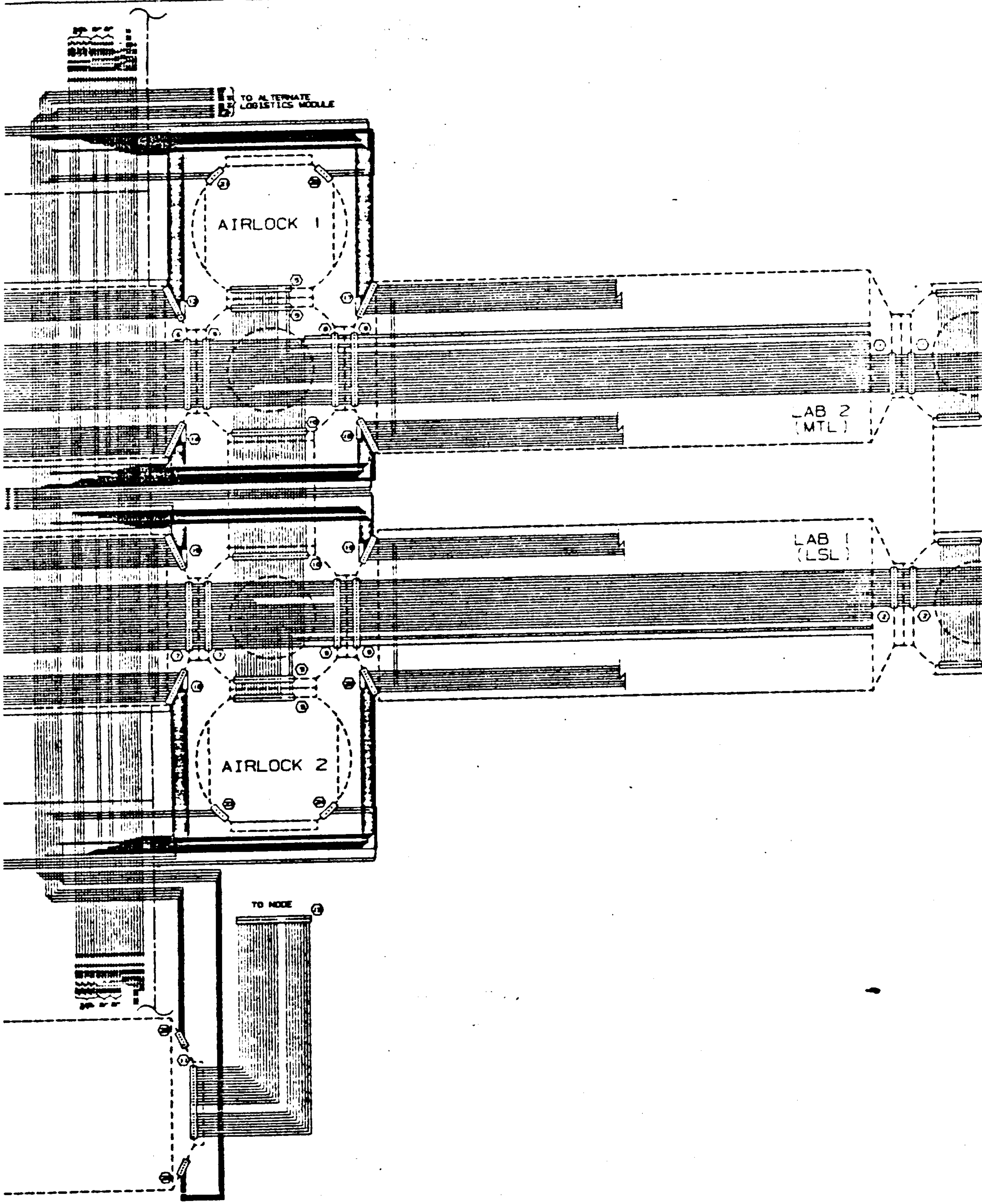
.A CONNECTIONS



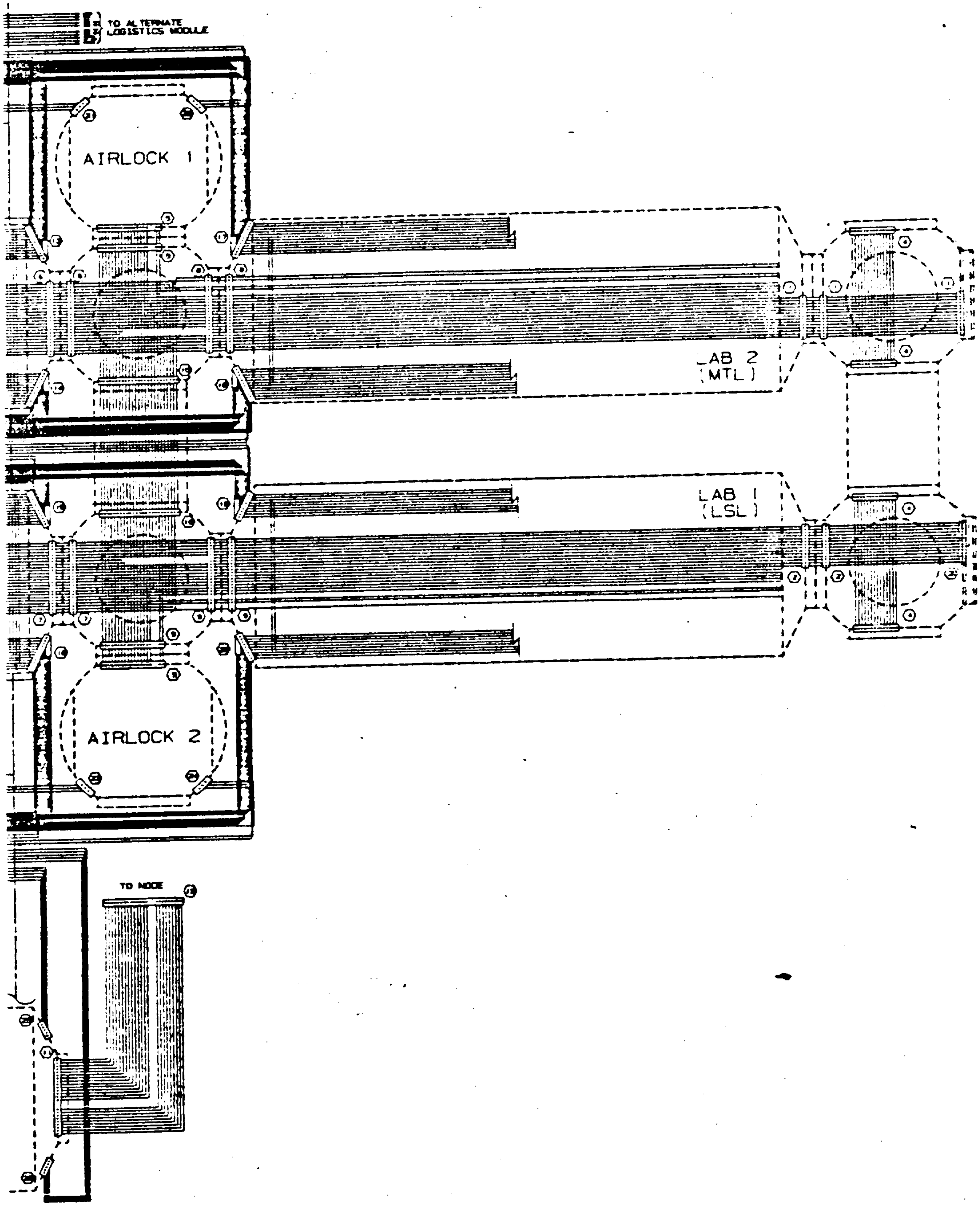
E.A CONNECTIONS



TRANSVERSE BOOM
HAB 2
HAB 1
LOGISTICS



TO ALTERNATE LOGISTICS MODULE
AIRLOCK 1
LAB 2 (MTL)
LAB 1 (LSL)
AIRLOCK 2
TO NODE



TO ALTERNATE LOGISTICS MODULE
AIRLOCK 1
LAB 2 (MTL)
LAB 1 (LSL)
AIRLOCK 2
TO NODE

**Internal Letter** Rockwell International

Date: March 19, 1986 — 592-DWO-86-009

TO: [illegible] File

FROM: [illegible] E.A. Rylander, SSSD - Downey, D/592-180 AA15, 2-3035

Subject: Design Study for Drawing # 84325-405

DESIGN OBJECTIVES:

To define the [illegible] utility routing of the ATCS, PMAD, C & T, DMS, fluid service, and ECLSS subsystems for the Reference Configuration [illegible] modules, [illegible] of utility line paths requiring structural support.

ASSUMPTIONS:

The [illegible] line routings for most subsystems were obtained from the subsystem groups. A singly redundant fire suppression system with 0.375 inch line diameters was assumed. Also, the servicing fluids were assumed to be supplied from the Logistics Module. The [illegible] of utility lines and connections are shown schematically, and thus do not represent the exact location of line runs and connections. Most utilities are routed internally to provide shortest routing paths, easier serviceability, less EVA, and less [illegible] protection of lines. Utility lines which extend to the [illegible], or which are [illegible] are routed externally. Each module and airlock has two external penetrations to [illegible] redundant systems. These penetrations are through the conical end sections of the modules which are closest to the [illegible]. There are two ATCS heat exchangers (35° F and 70° F) located external to each module near the external utility penetrations. The primary and redundant ATCS [illegible] lines for both temperature loops are routed from throughout the space station to the module heat exchangers corresponding to the same temperature. A single water line from each module passes through both heat exchangers and back into the module.

TRADES EVALUATED:

Concepts of primarily externally routed utilities have been considered to preserve the tunnels & base structures and mechanisms with minimal [illegible] in the station. However, these concepts require additional utility support structure, thermal control for water lines, and EVA for [illegible] and connection of most utilities. Concepts using common internal utility lines routed throughout all modules were also considered.

OPEN ISSUES:

- Fire suppression system
- Growth
- Redundant paths for internal utilities through the other transfer tunnels
- Source of service fluids

K.O. Rylander

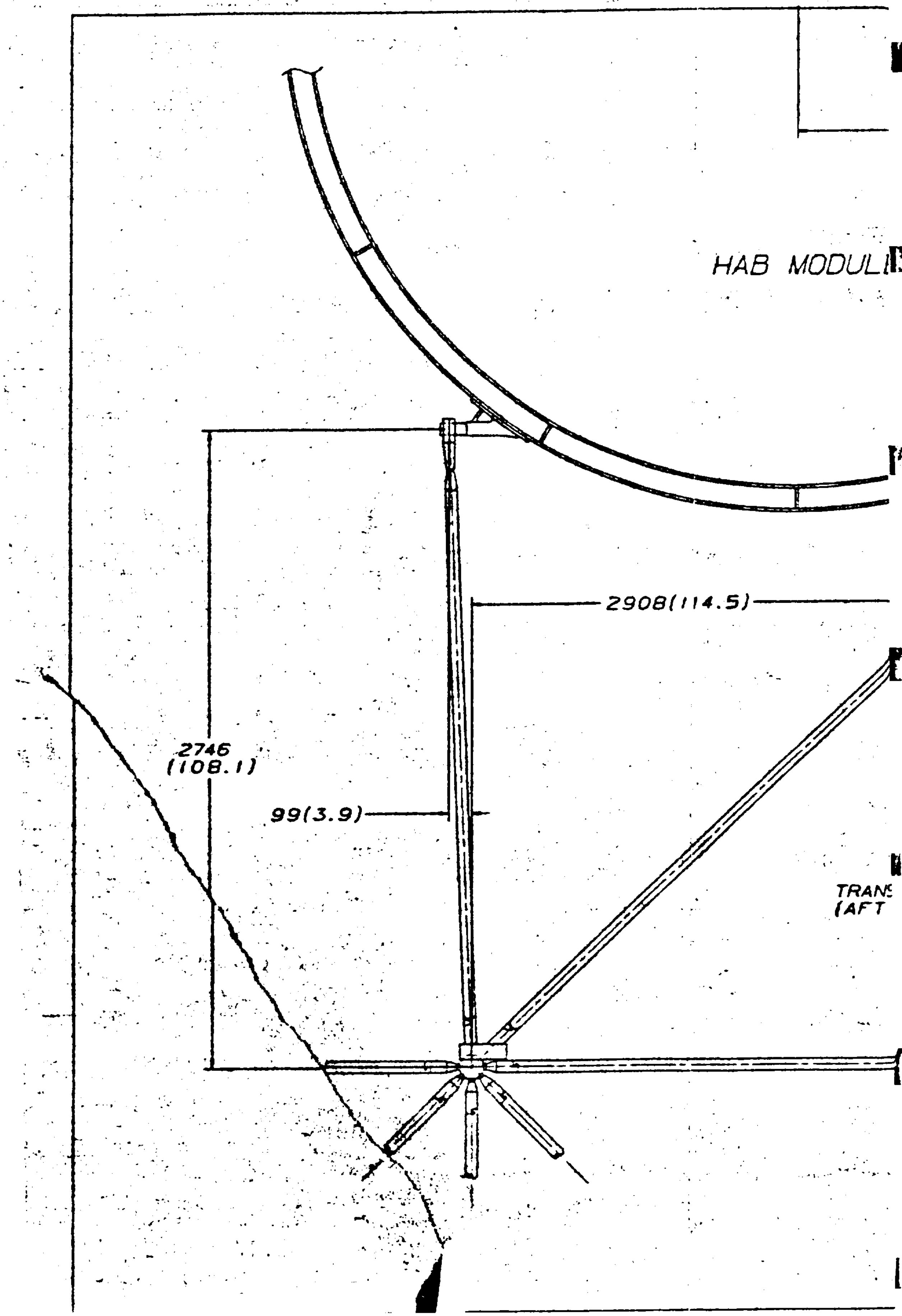
E.A. Rylander
Structural Design
Space Station Systems Division

[illegible]

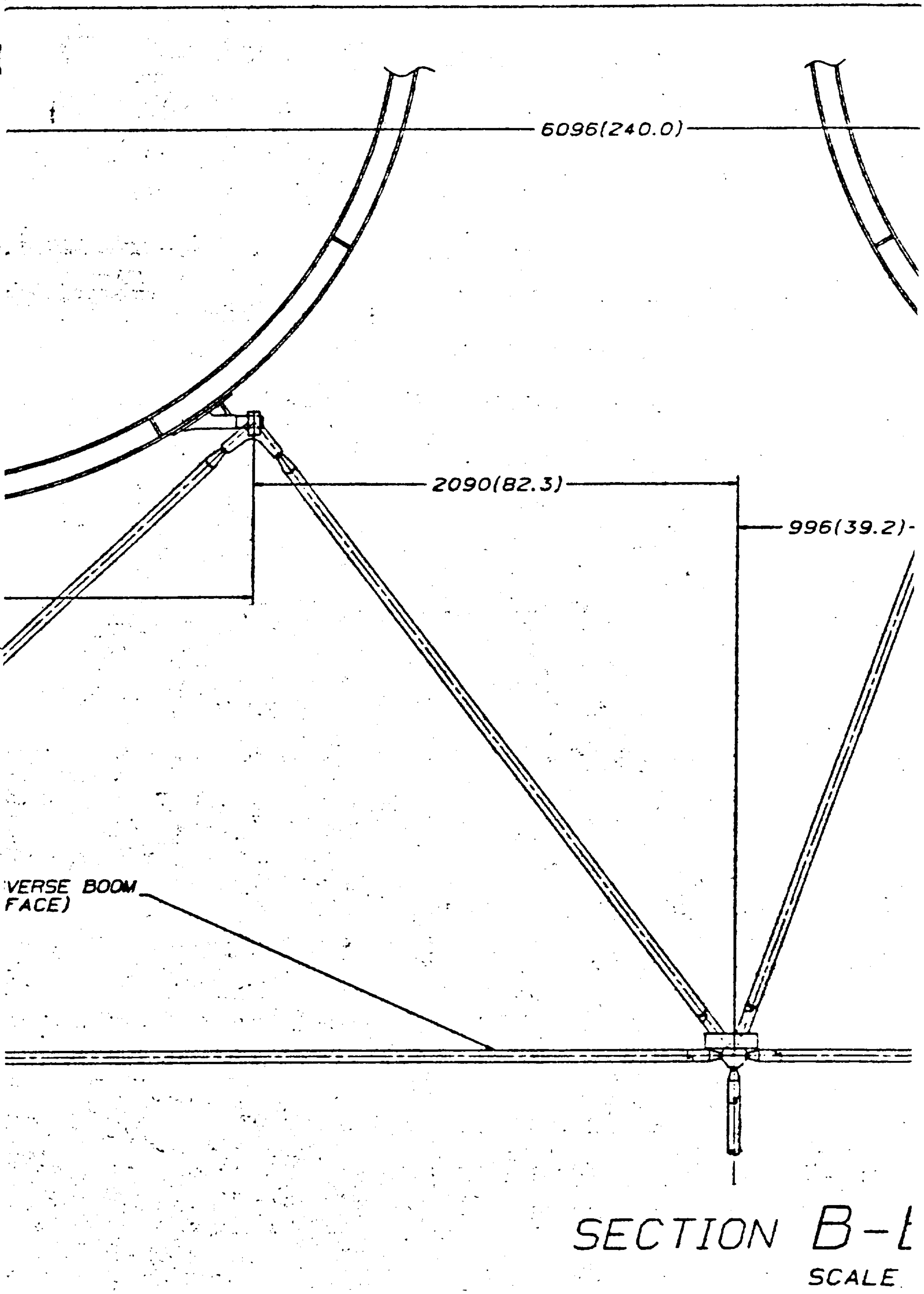
317-

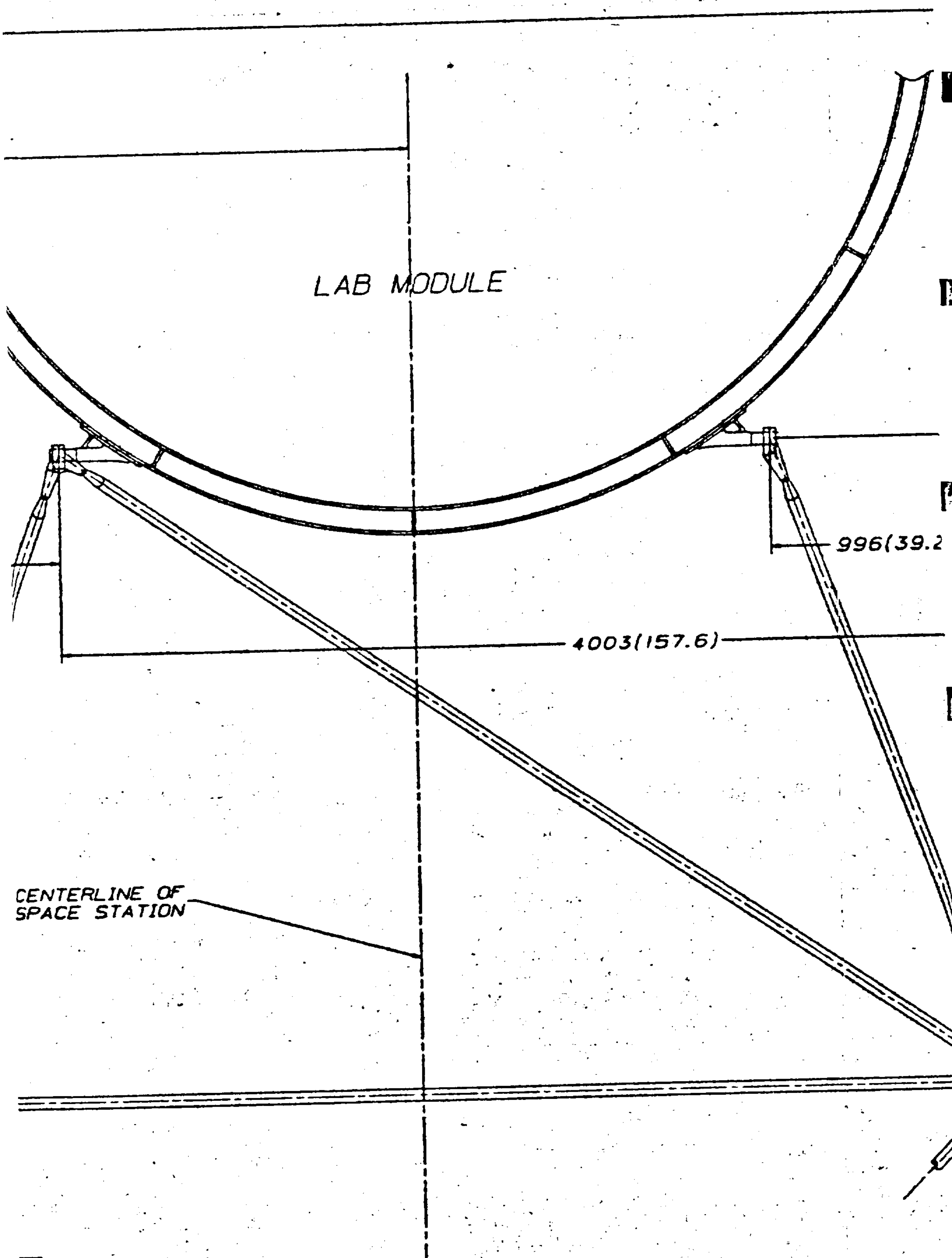
| | | | |
|---|---|---|---|
| DR BY | [illegible] | | Rockwell International |
| CHK BY | [illegible] | | |
| DESIGN | | | PRESSURIZED MODULE UTILITIES SCHEMATIC - REFERENCE CONFIGURATION |
| STRESS | | | |
| M & P | | | |
| WEIGHTS | | | |
| THERMAL | | | |
| ELECT | | | DRAWING NO. 84325-405 — SHEET 1 OF 1 — REVISION — SCALE: --- |
| ECLSS | | | |
| MFG | | | |

592-29070-41801-30000-100 CAD/CAM



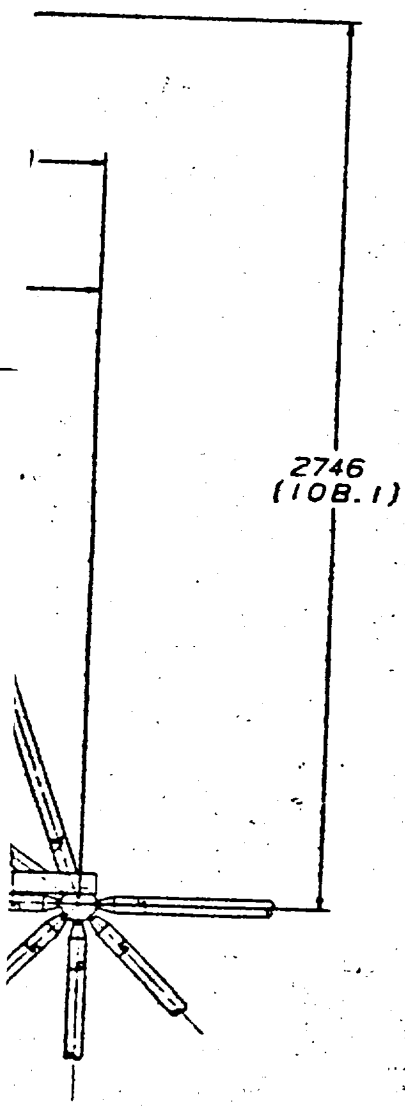
HAB MODULI
2908(114.5)
2746
(108.1)
99(3.9)
TRANS
(AFT

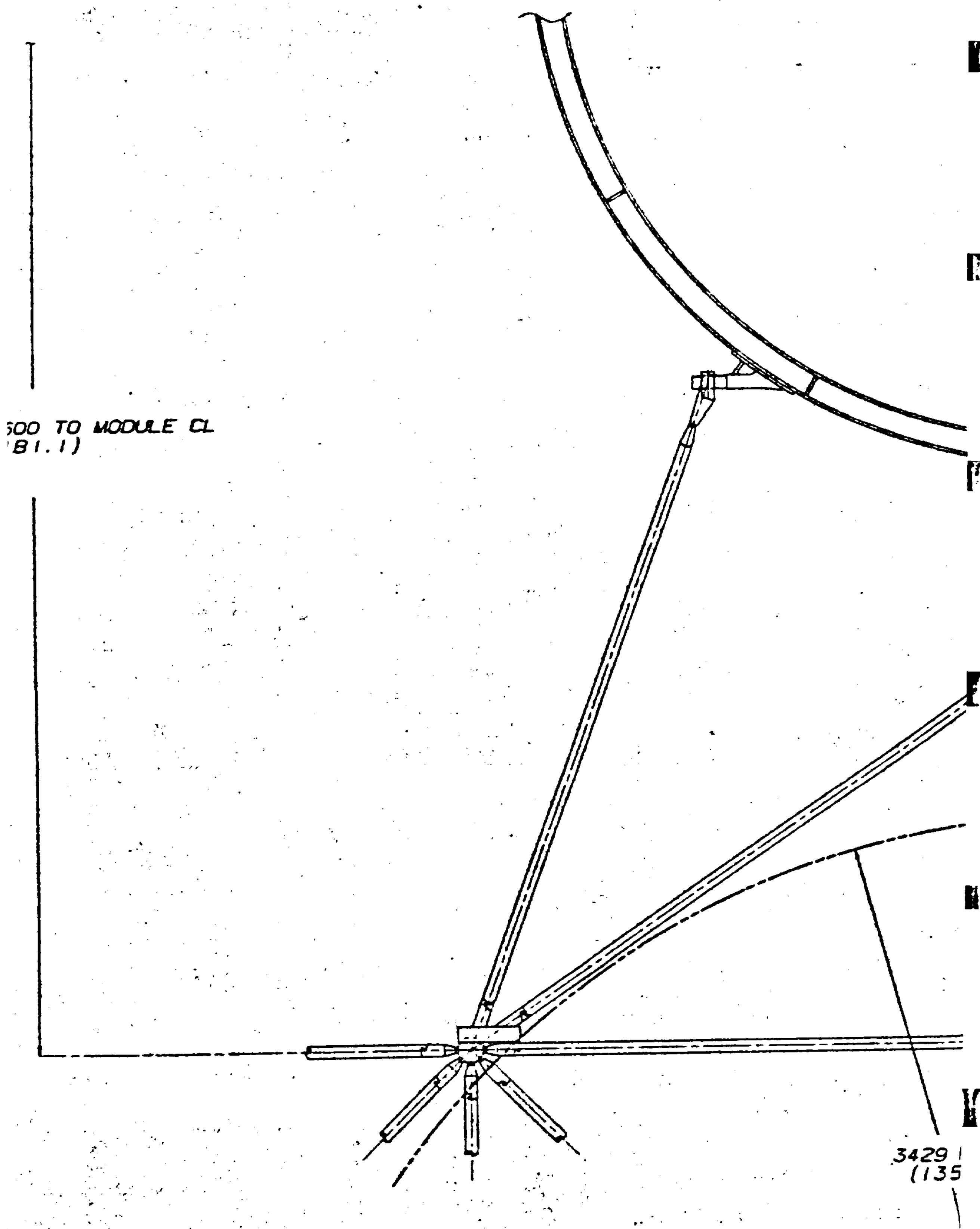

6096(240.0)
2090(82.3)
996(39.2)
VERSE BOOM
FACE)
SECTION B-
SCALE



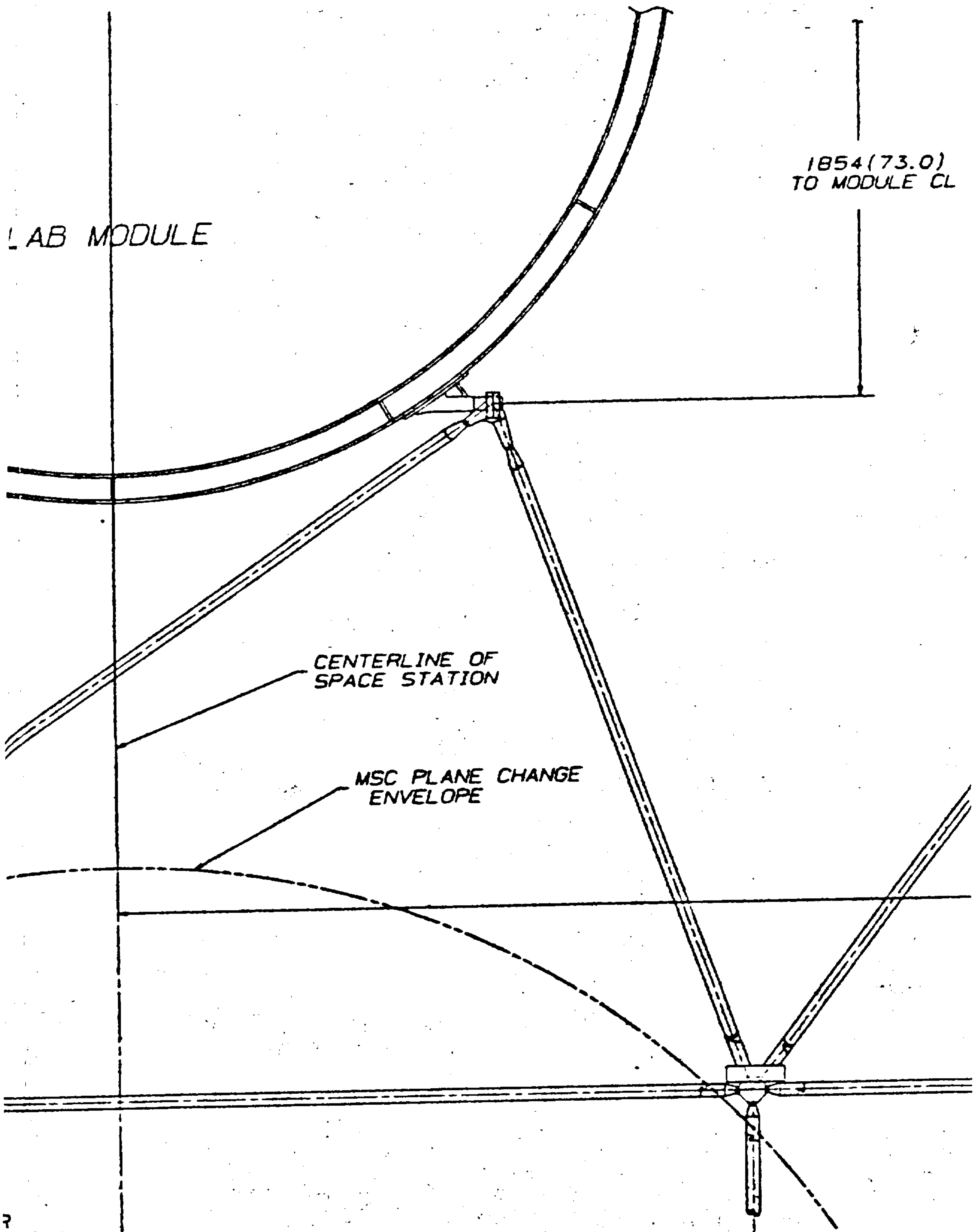

3 (VIEW LOOKING FOWARD)

: 1/10


2746
(108.1)

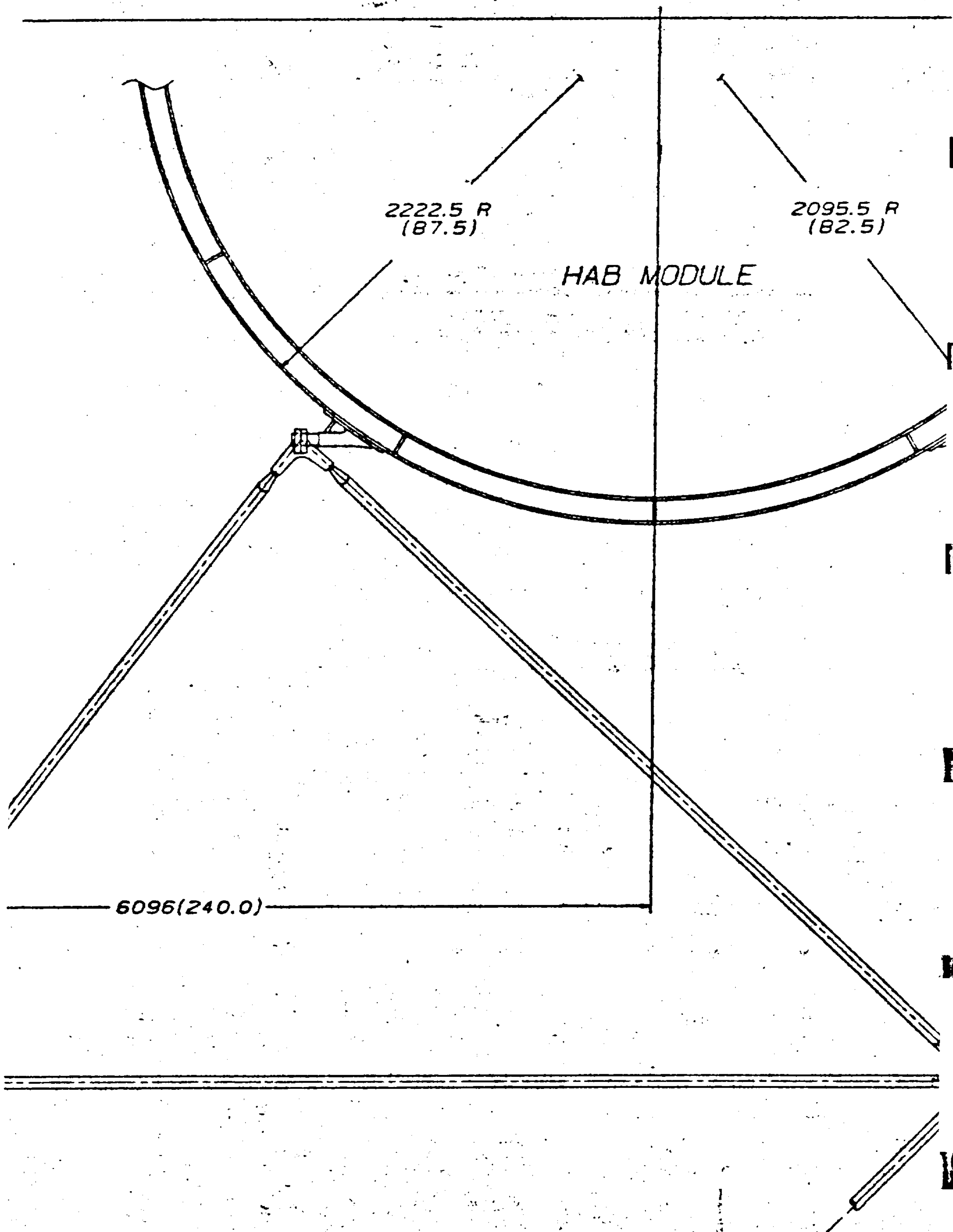


;00 TO MODULE CL
(B1.1)
3429
(135

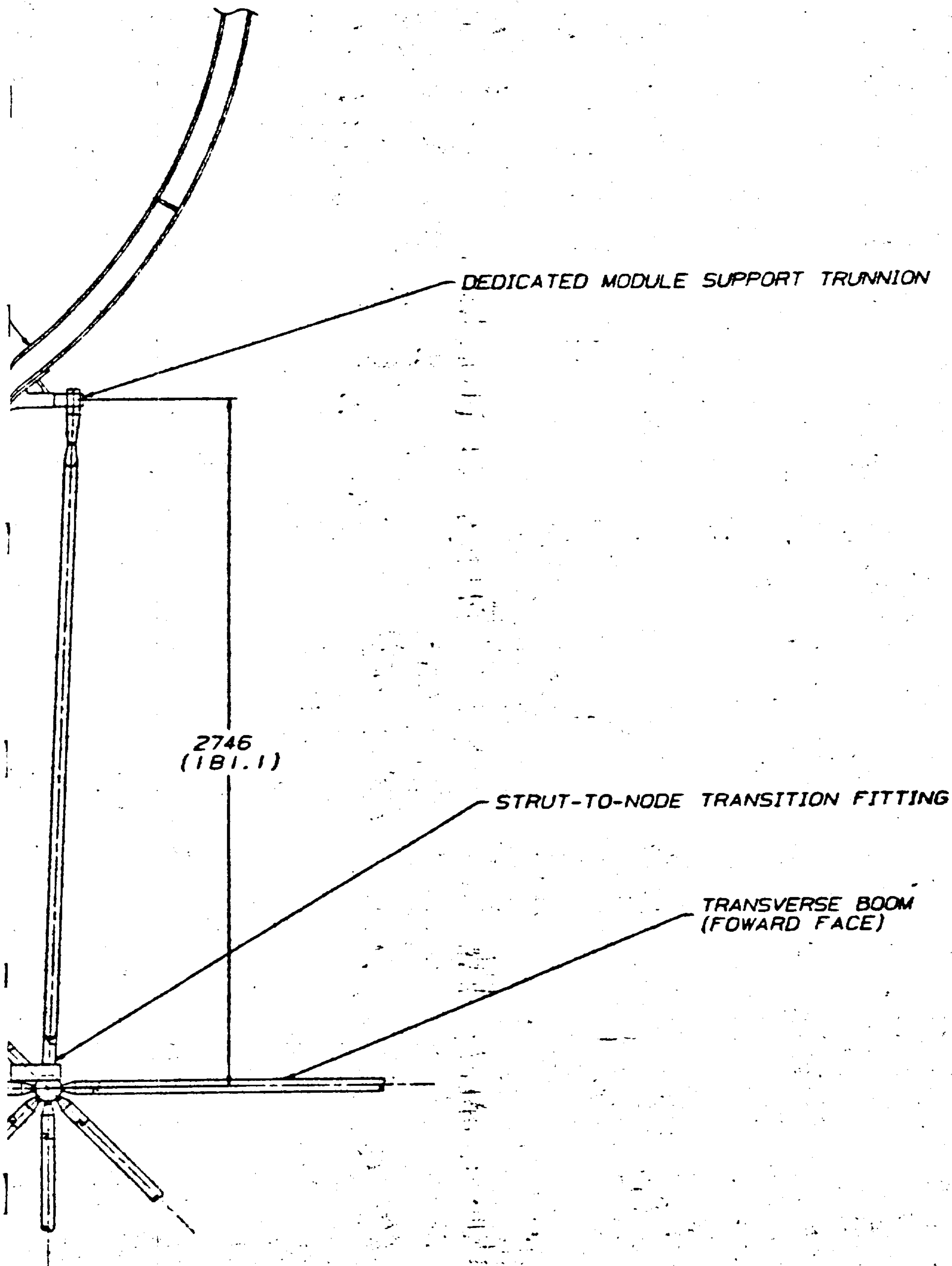


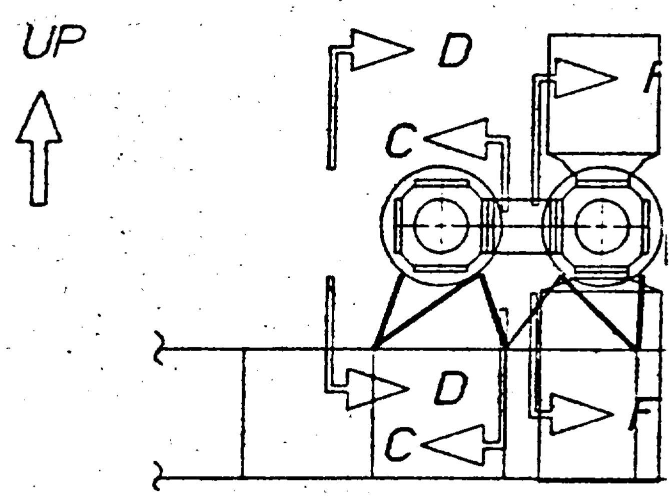

SECTION A-

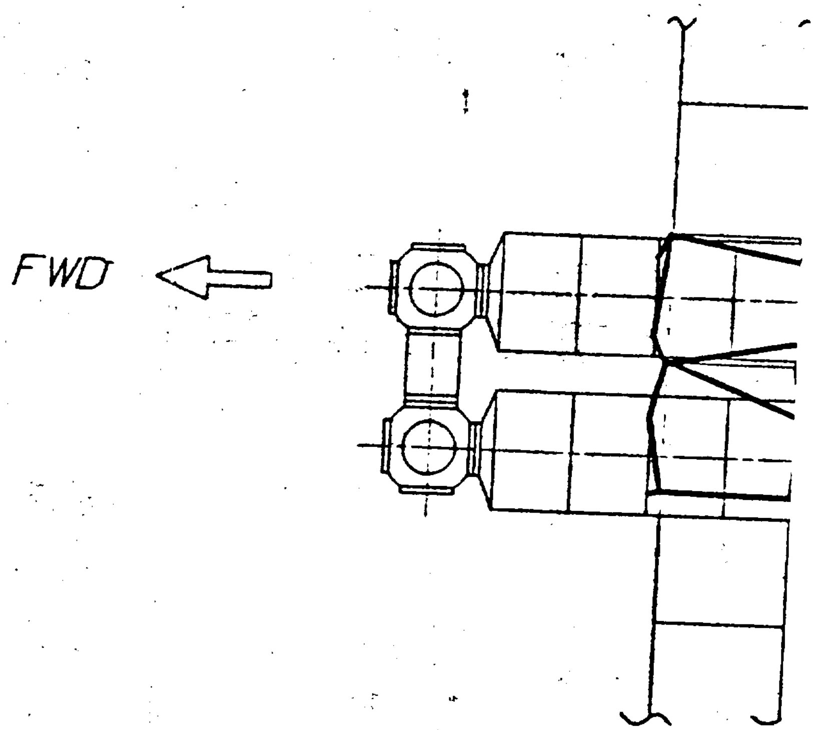
SCALE

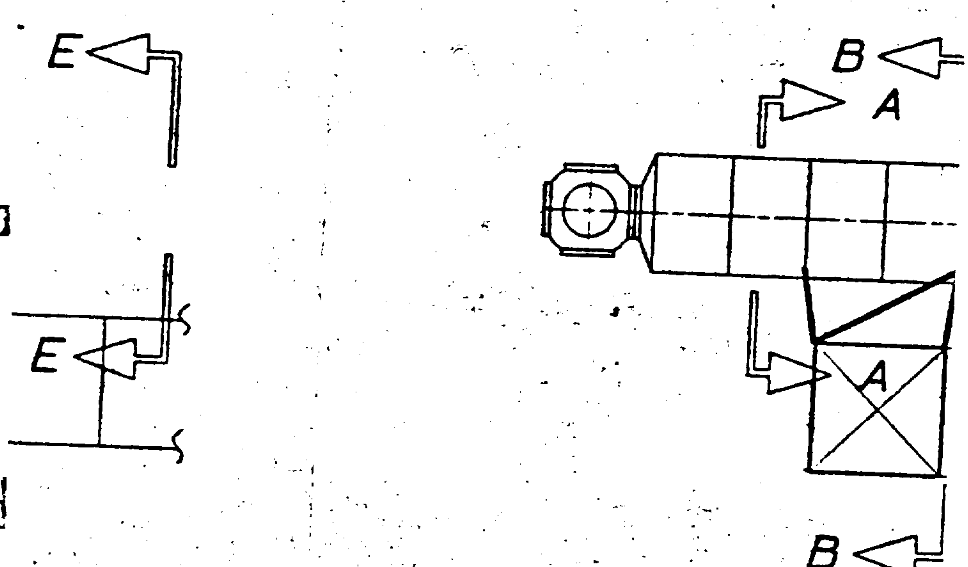


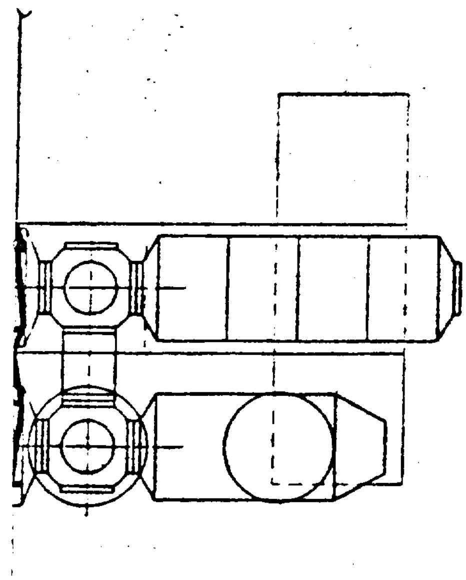

A (VIEW LOOKING AFT)
: 1/10

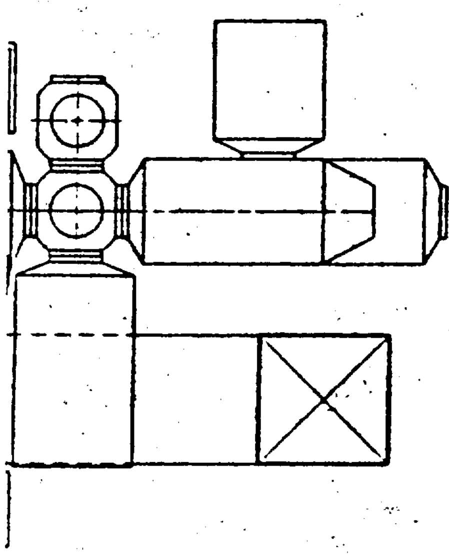

DEDICATED MODULE SUPPORT TRUNNION
2746
(181.1)
STRUT-TO-NODE TRANSITION FITTING
TRANSVERSE BOOM
(FOWARD FACE)


UP
D
C
D
C


FWD


E
B
A
A
E
B





*NOTES:*
*1. ALL DIMENSIONS ARE IN MILLI*
*IN PARENTHESES, BY THE VALUE*

| | |
|---|---|
| DR BY | TOM MARINO 4/2/8 |
| CHK BY | |
| DESIGN | |
| STRESS | |
| M & P | |
| WEIGHTS | |
| THERMAL | |
| ELECT | |
| [illegible] | |
| MFG | |

DRAW

843



592-2907C-4 ·80 -3000

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS, FOLLOWED, IN PARENTHESES, BY THE VALUE IN INCHES.

| | | |
|---|---|---|
| DR BY TOM MARINO 4/2/86 | Rockwell International | Space Station Division |
| CHK BY | MODULE SUPPORT CONCEPT, 5M ERECTABLE TRUSS | |
| DESIGN | | |
| STRESS | | |
| M & P | | |
| WEIGHTS | | |
| THERMAL | | |
| ELECT. | DRAWING NO. | SHEET / REVISION |
| EDL&S | 84325-429 | OF 3 / SCALE: NOTED |
| MFG | | |

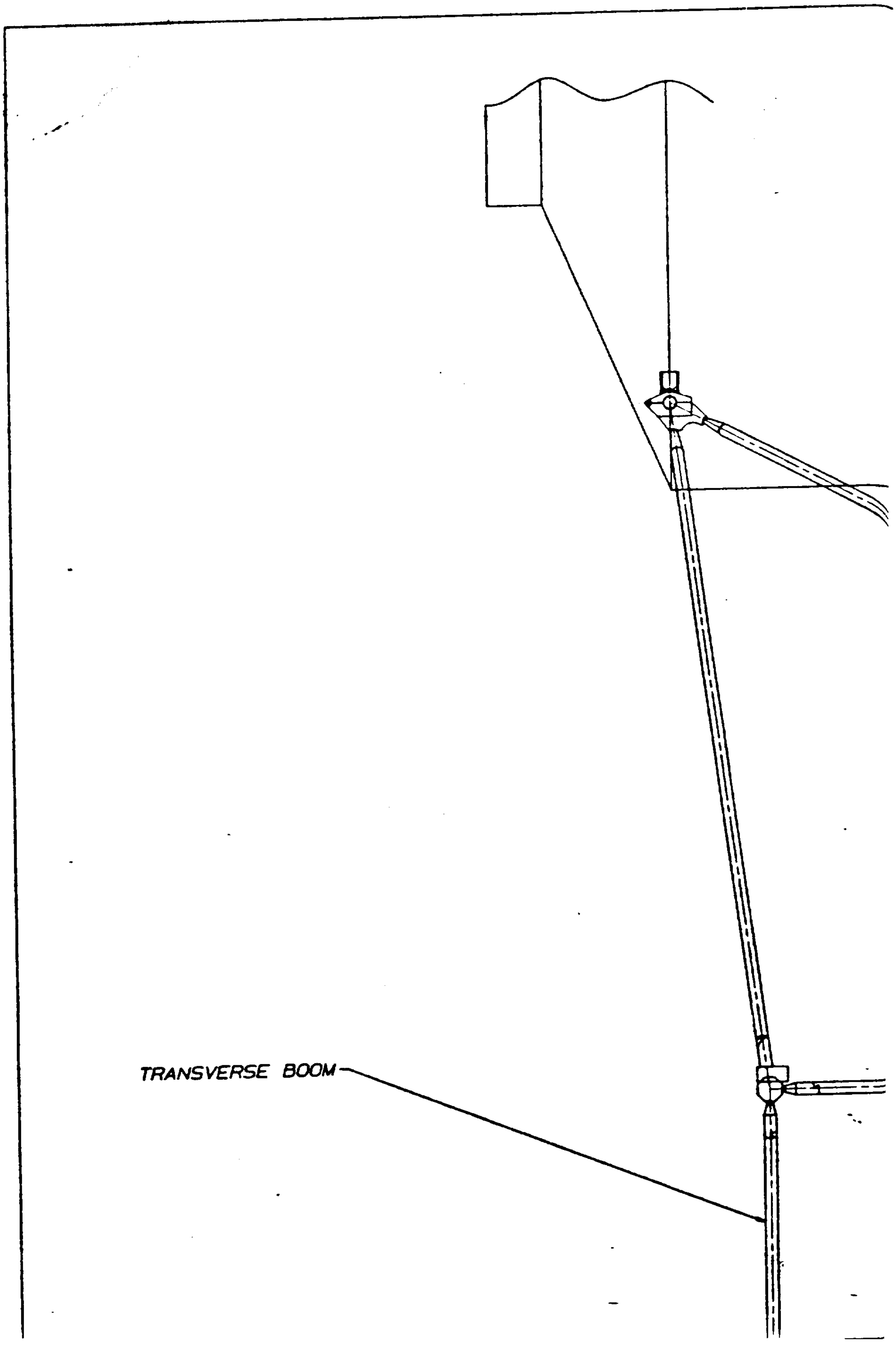
592-29070-4 801-30000-100 CAD/CAM

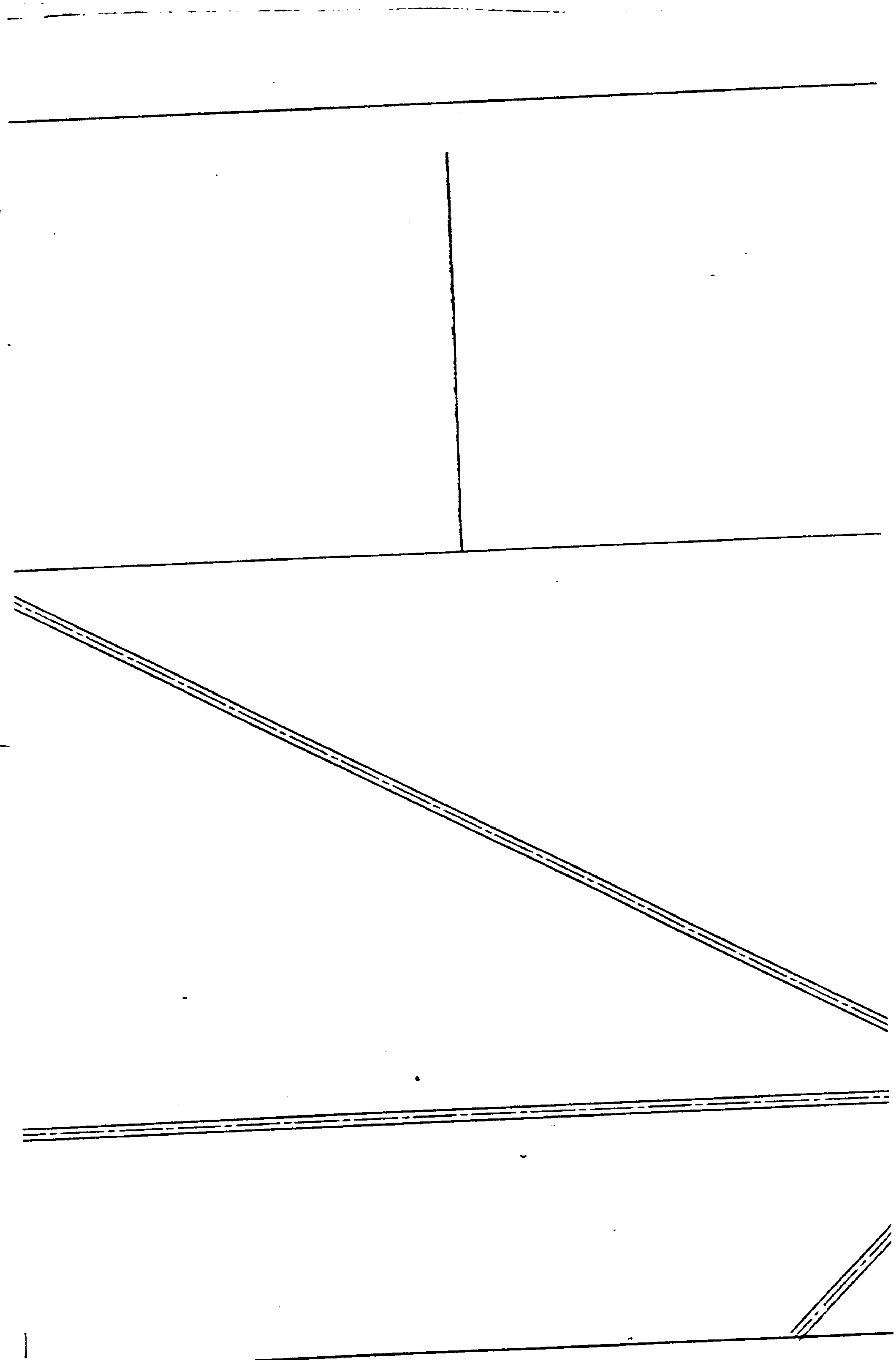
Pressurized Module Utilities Schematic--Reference Configuration

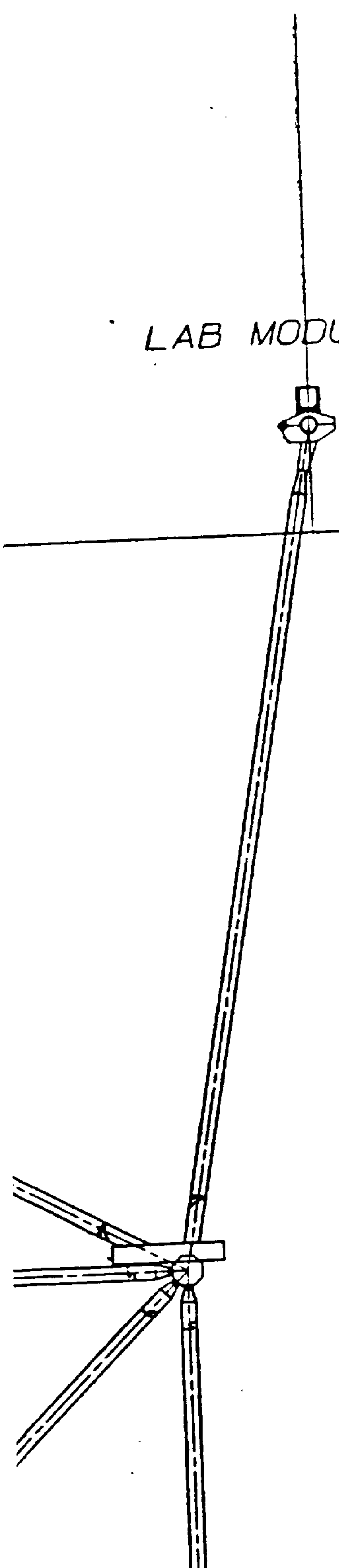
Drawing 84325-405

Module Support Concept--5-Meter Truss

Drawing 84325-429

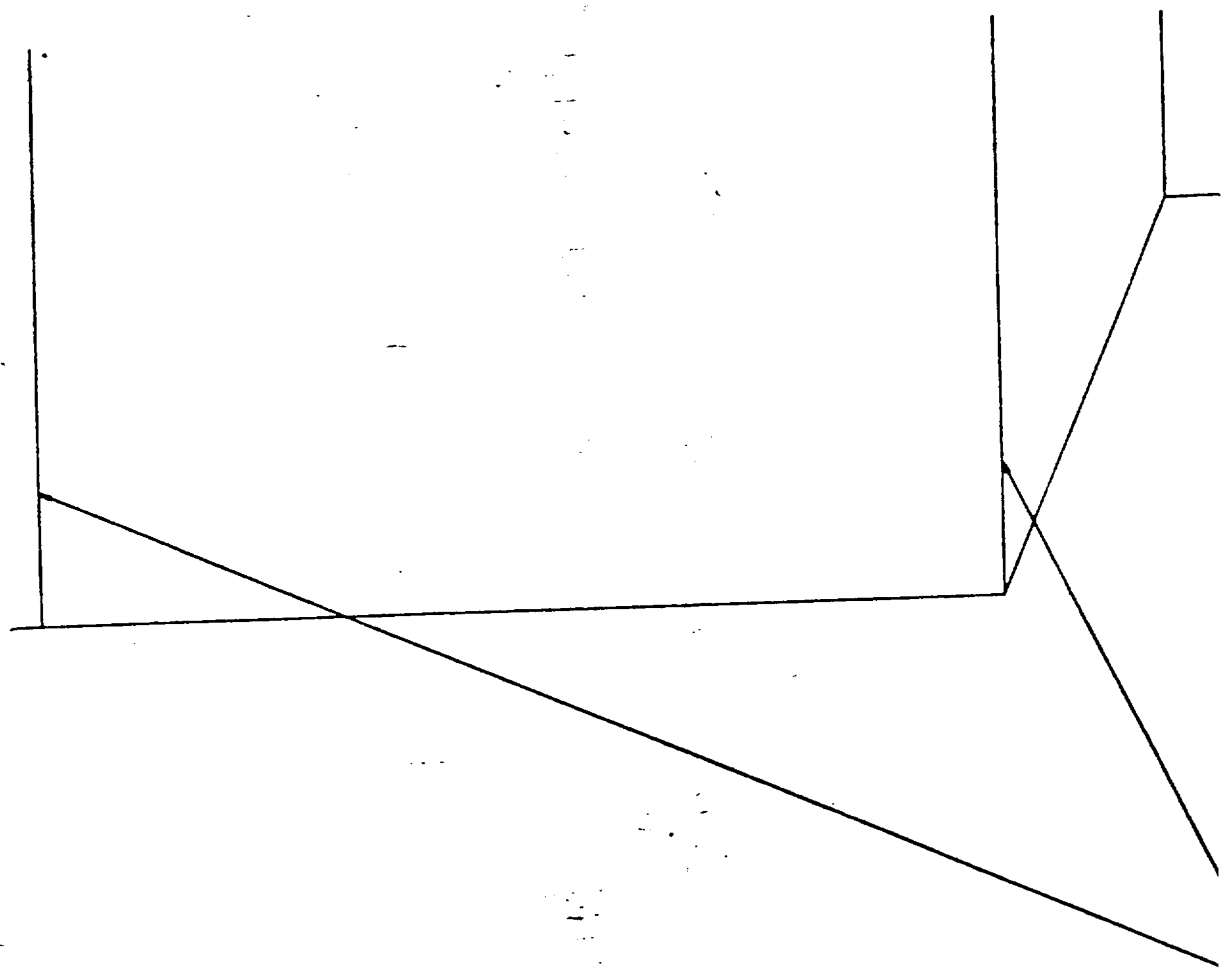

TRANSVERSE BOOM

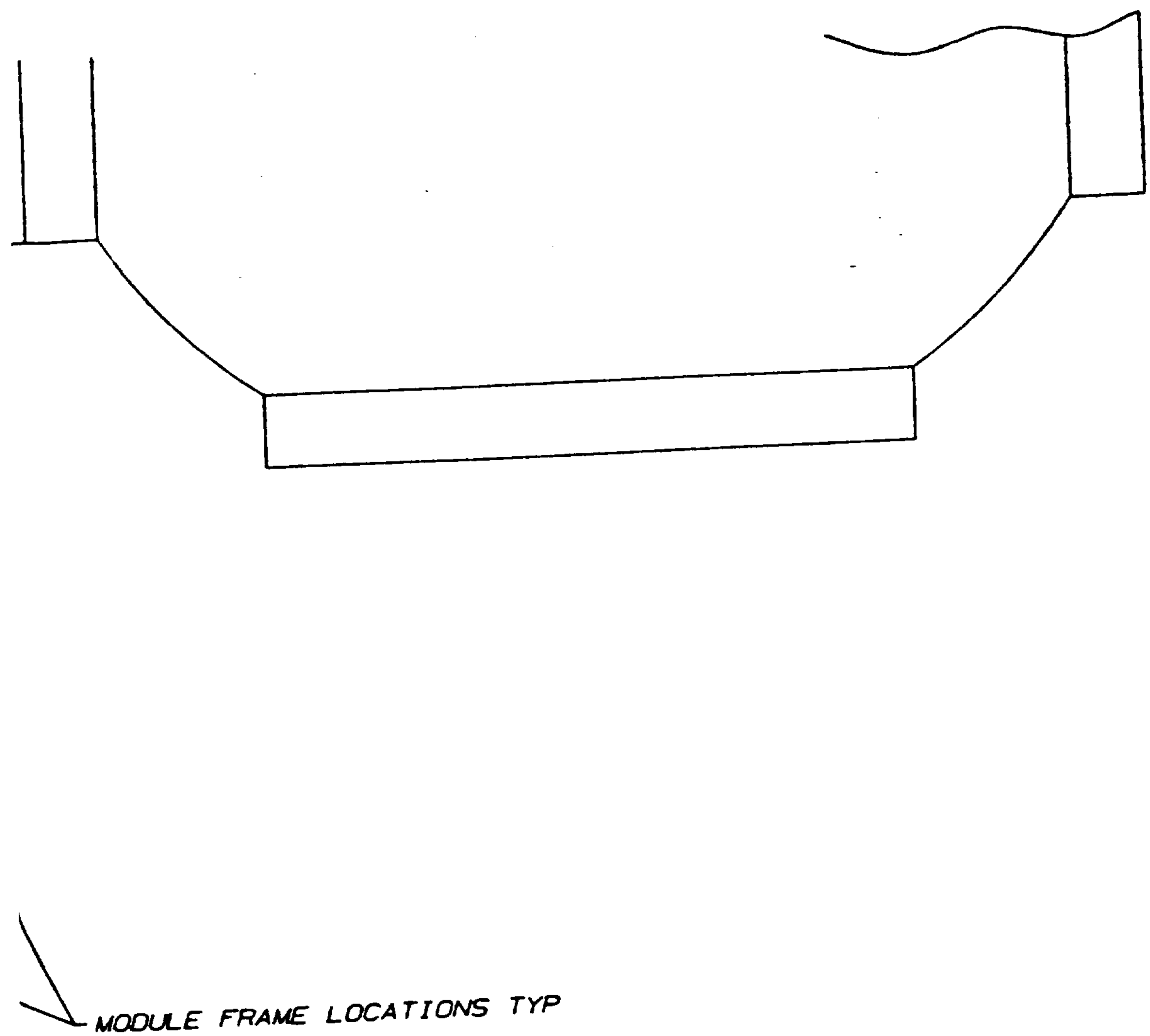





VIEW D-D

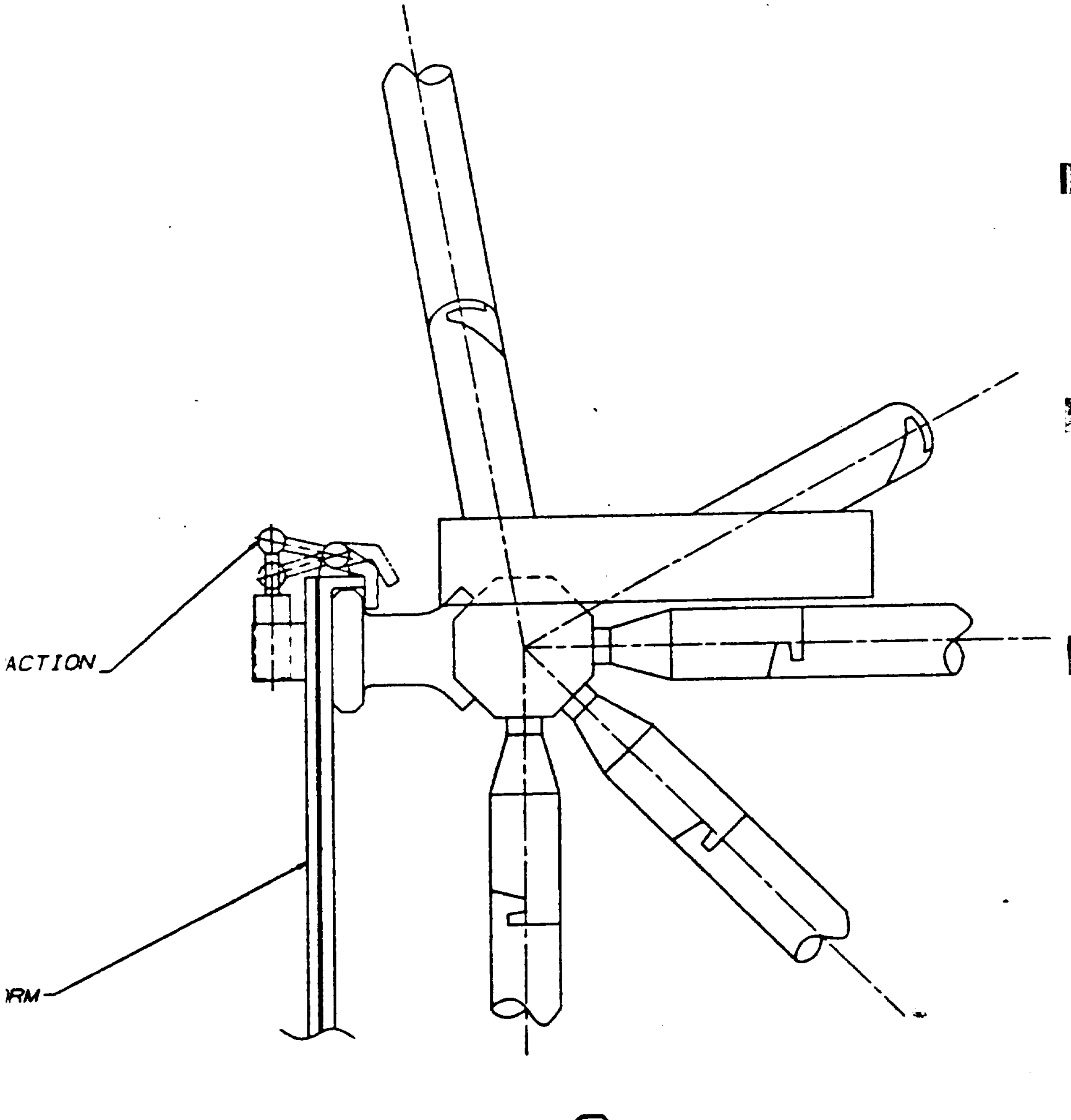
SCALE : 1/10




MODULE FRAME LOCATIONS TYP

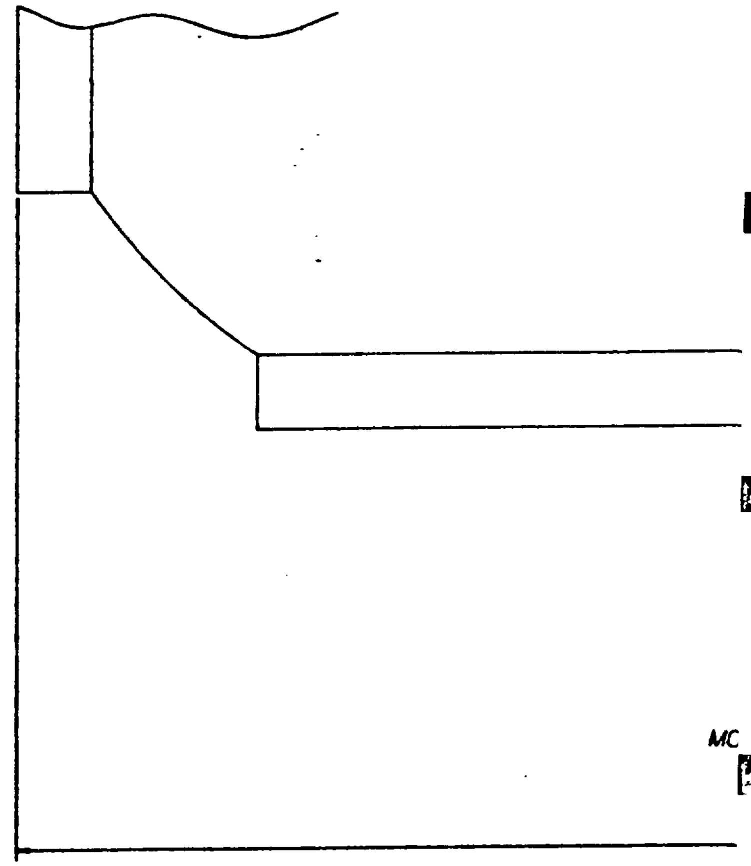
RAIL LIP RETR
MECHANISM

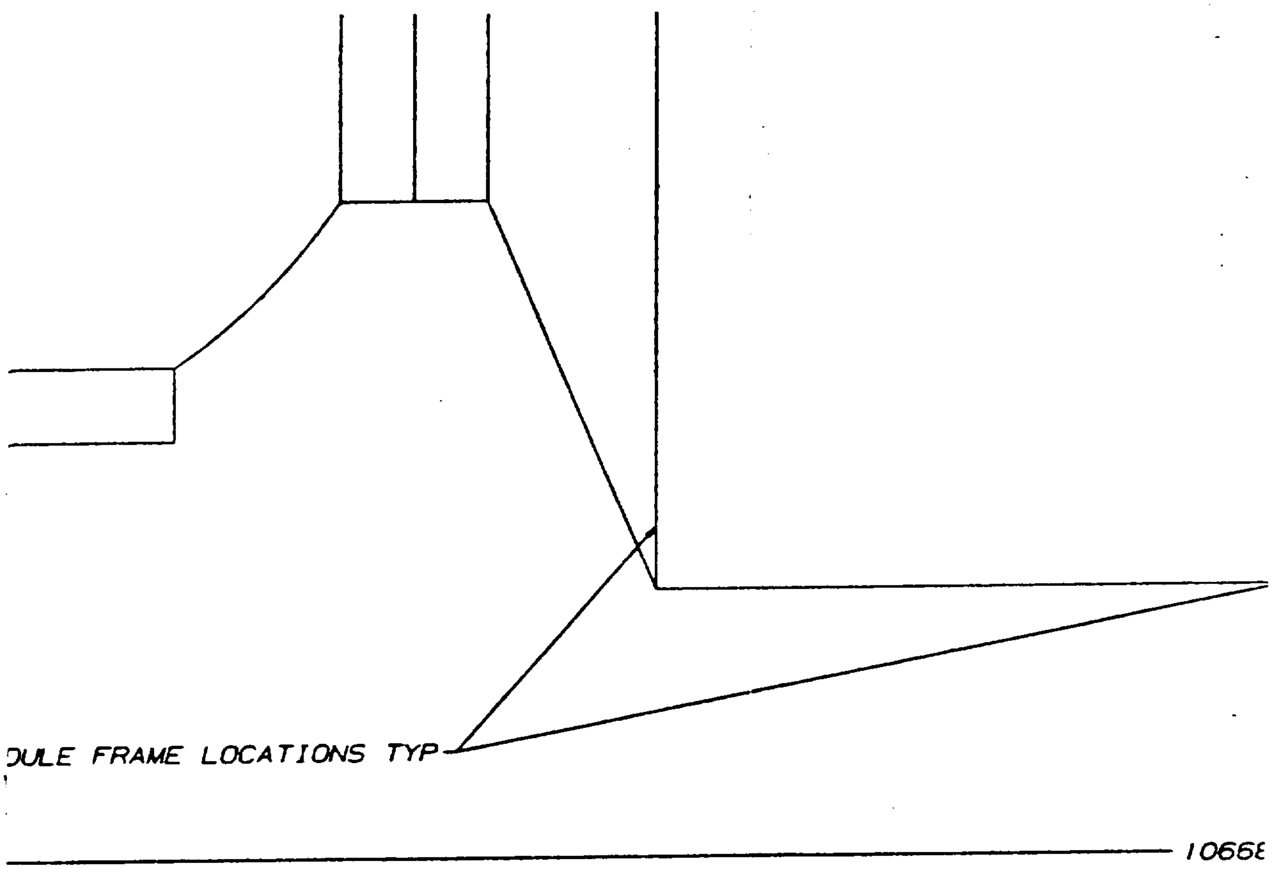
MSC PLATF(




VIEW G

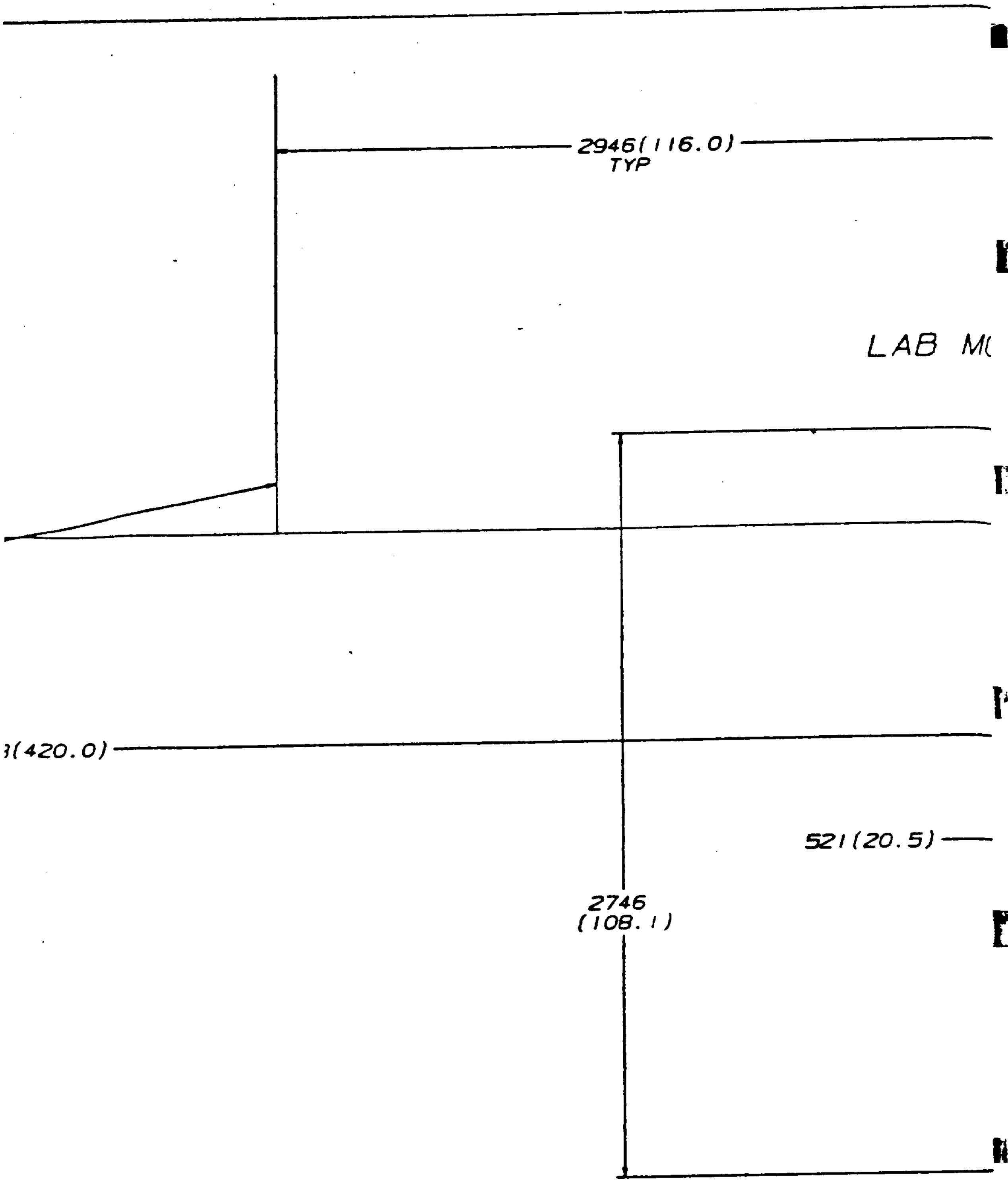
SCALE : 1/2


MC



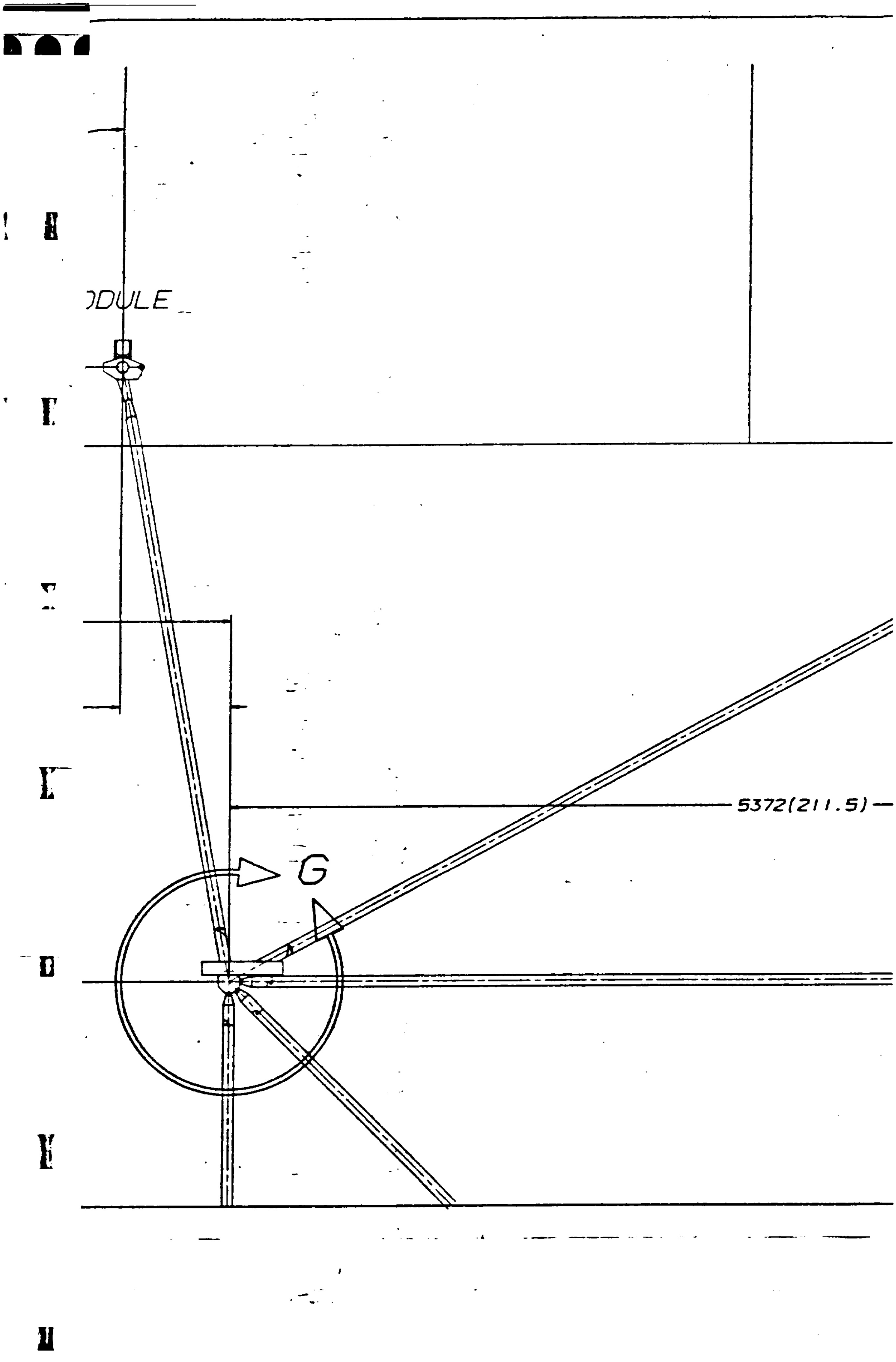

VIEW

SCALE

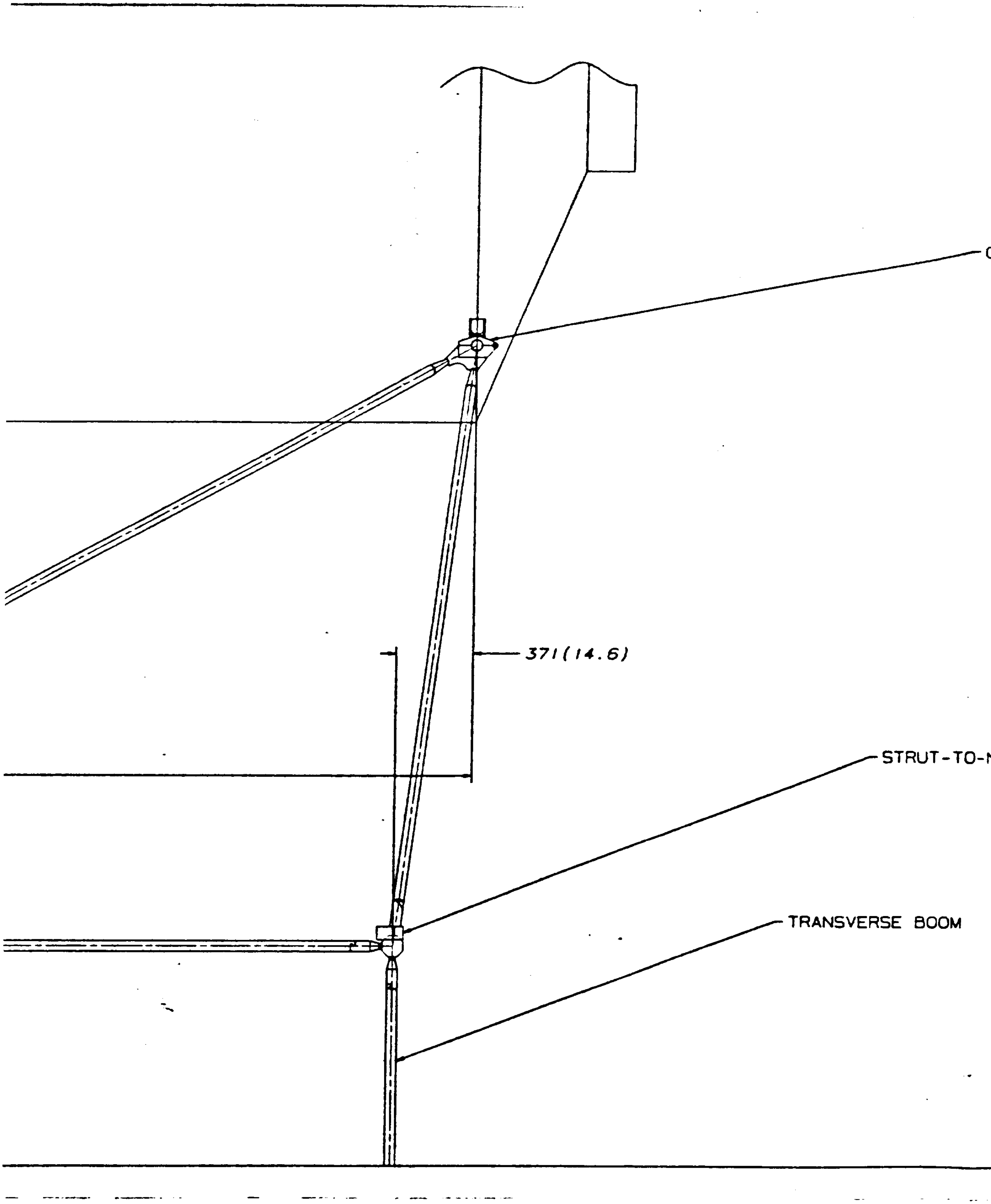


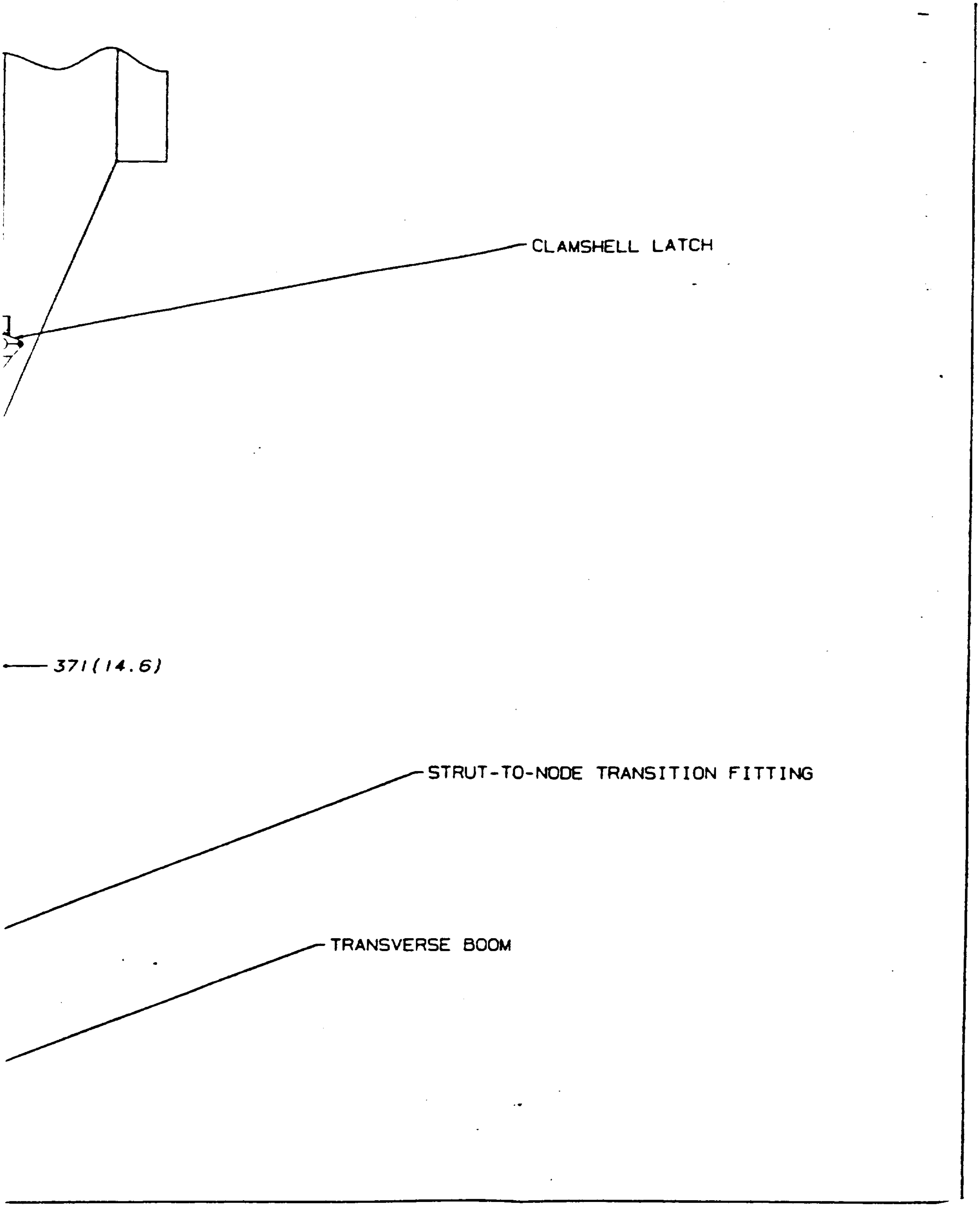

C-C

: 1/10

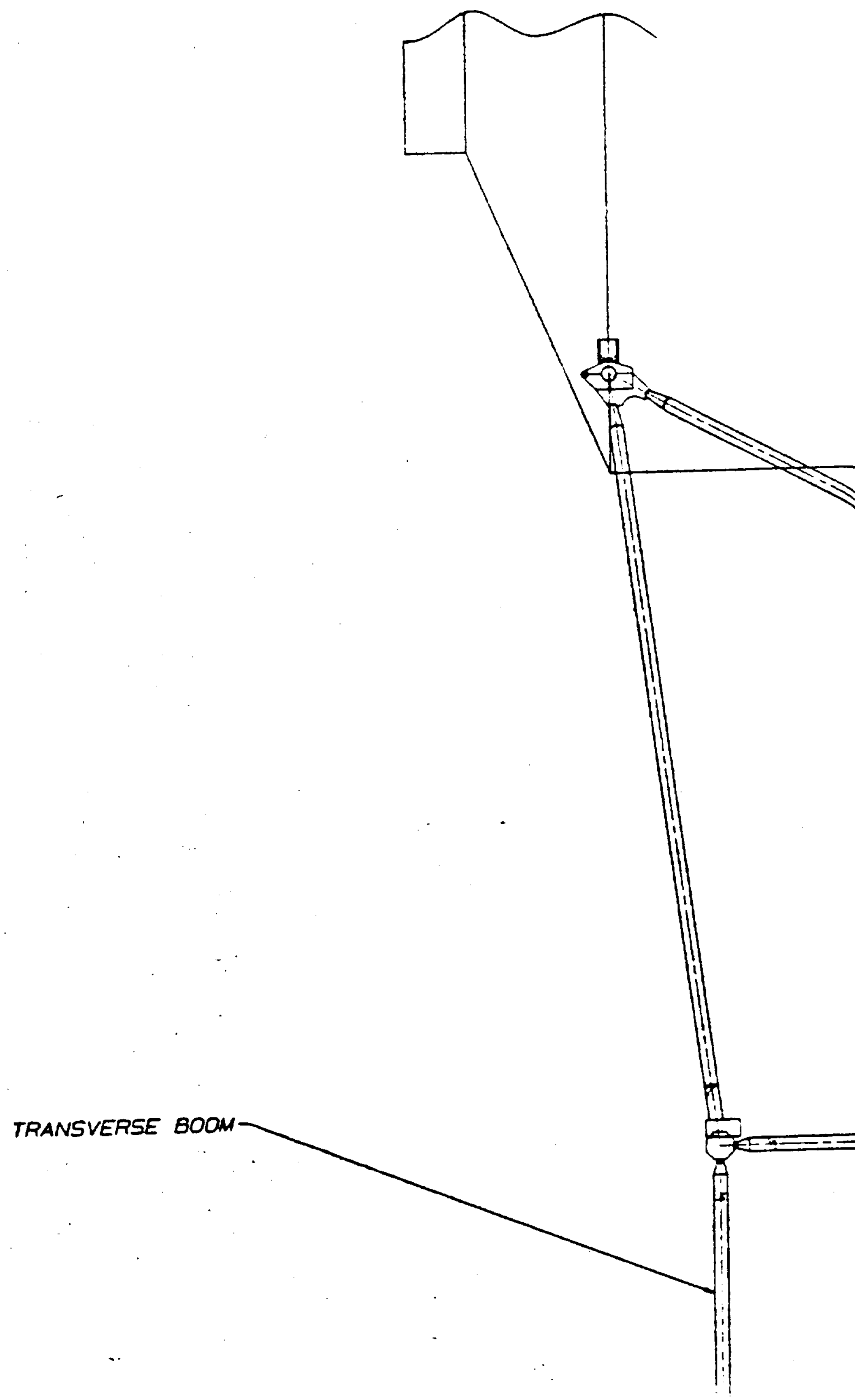


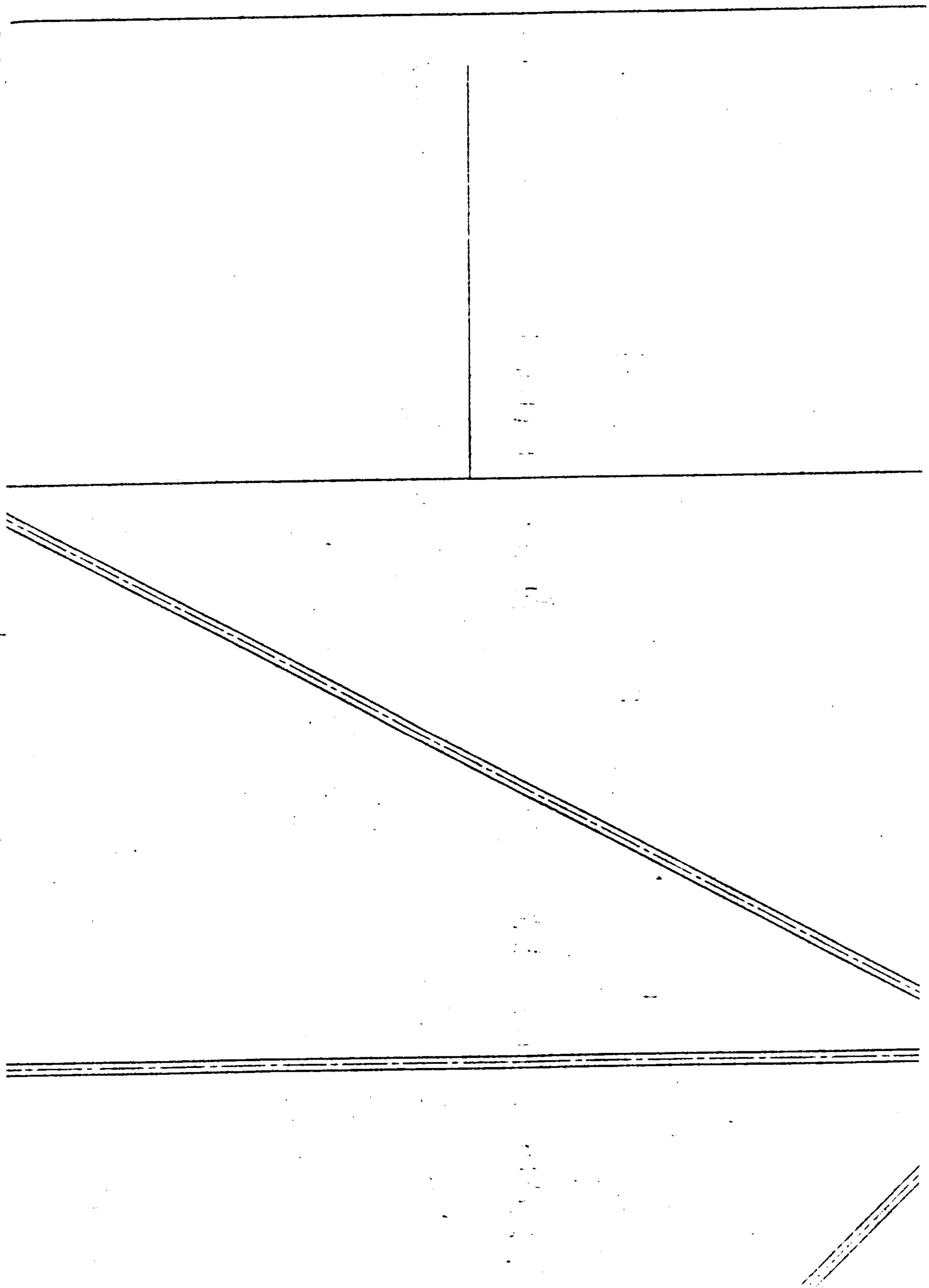
ODULE
5372(211.5)
G

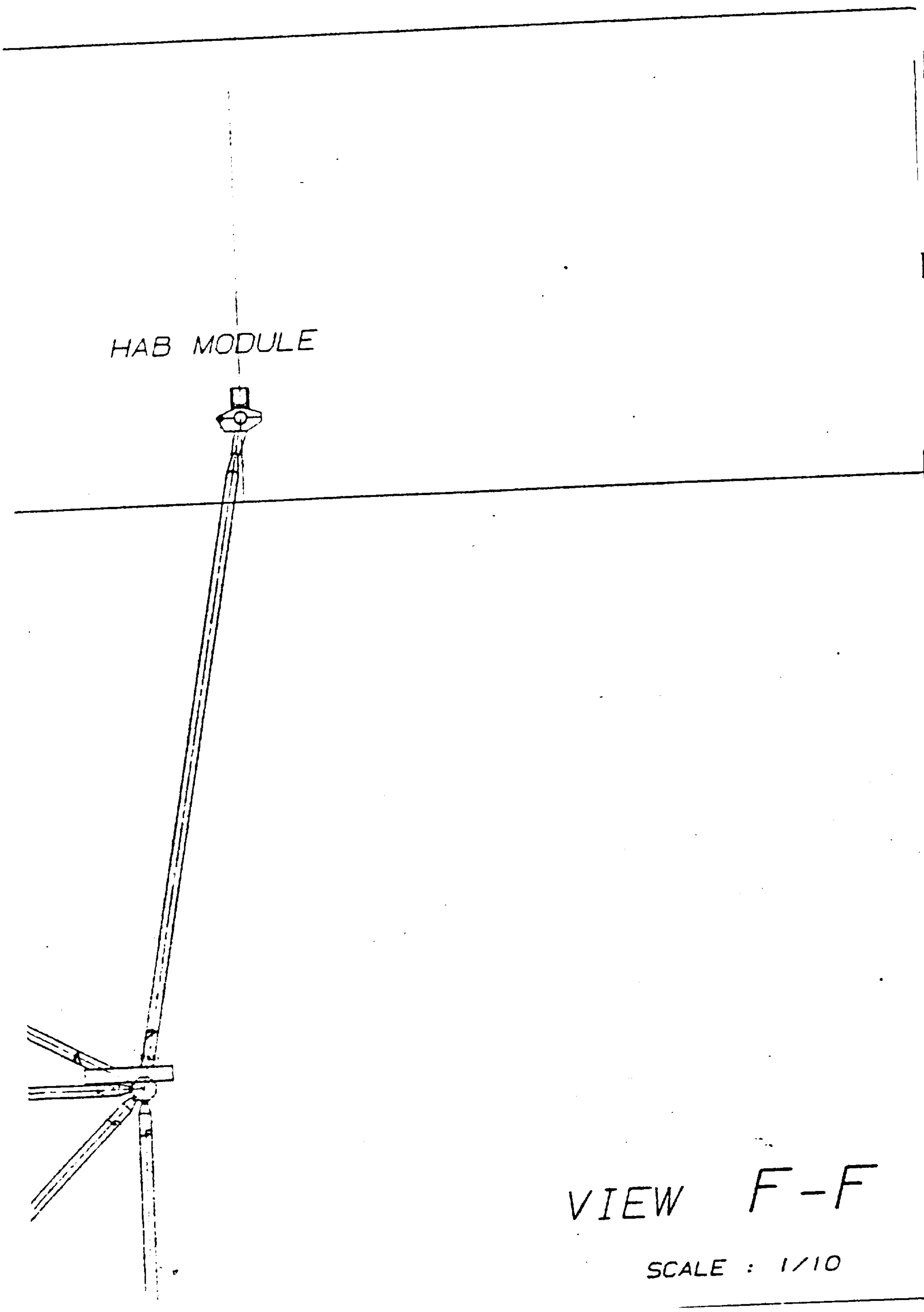

371(14.6)
STRUT-TO-
TRANSVERSE BOOM



CLAMSHELL LATCH
371(14.6)
STRUT-TO-NODE TRANSITION FITTING
TRANSVERSE BOOM

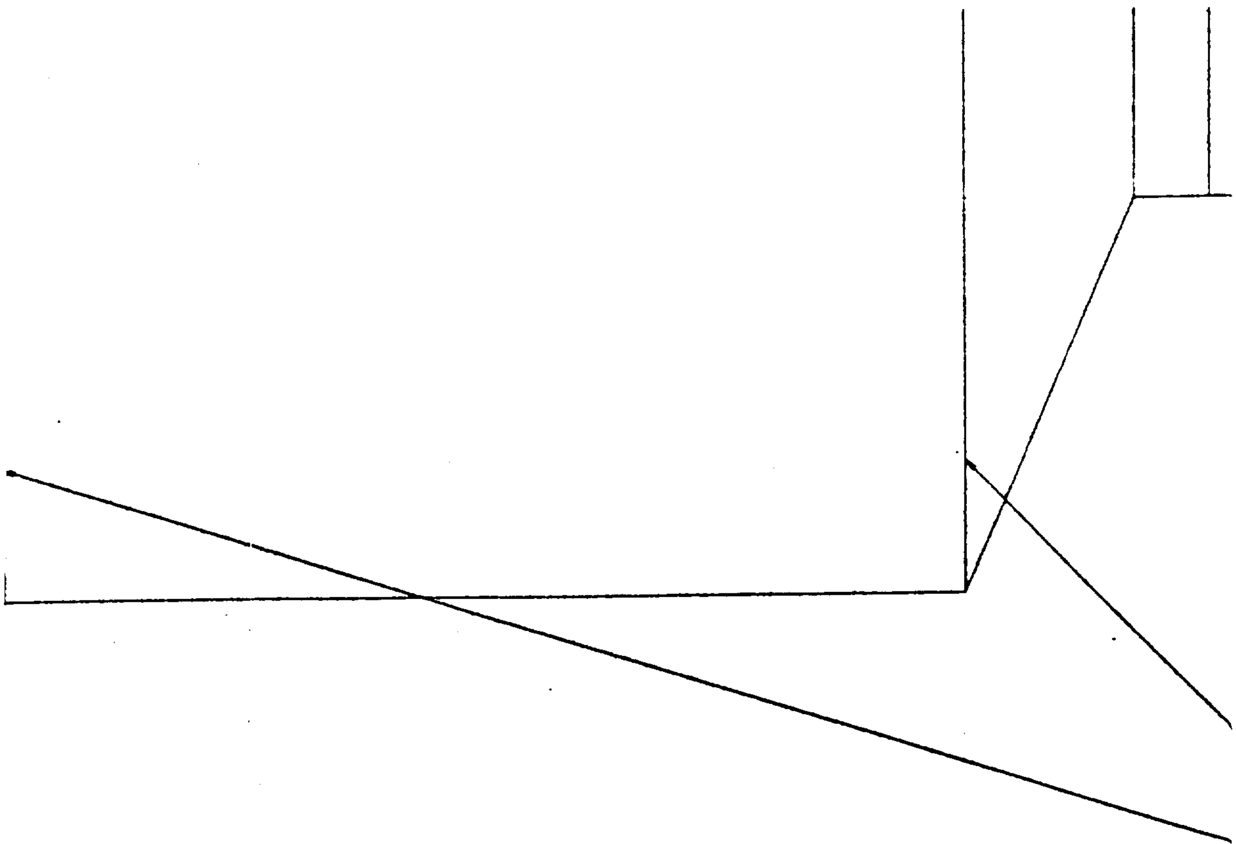

TRANSVERSE BOOM

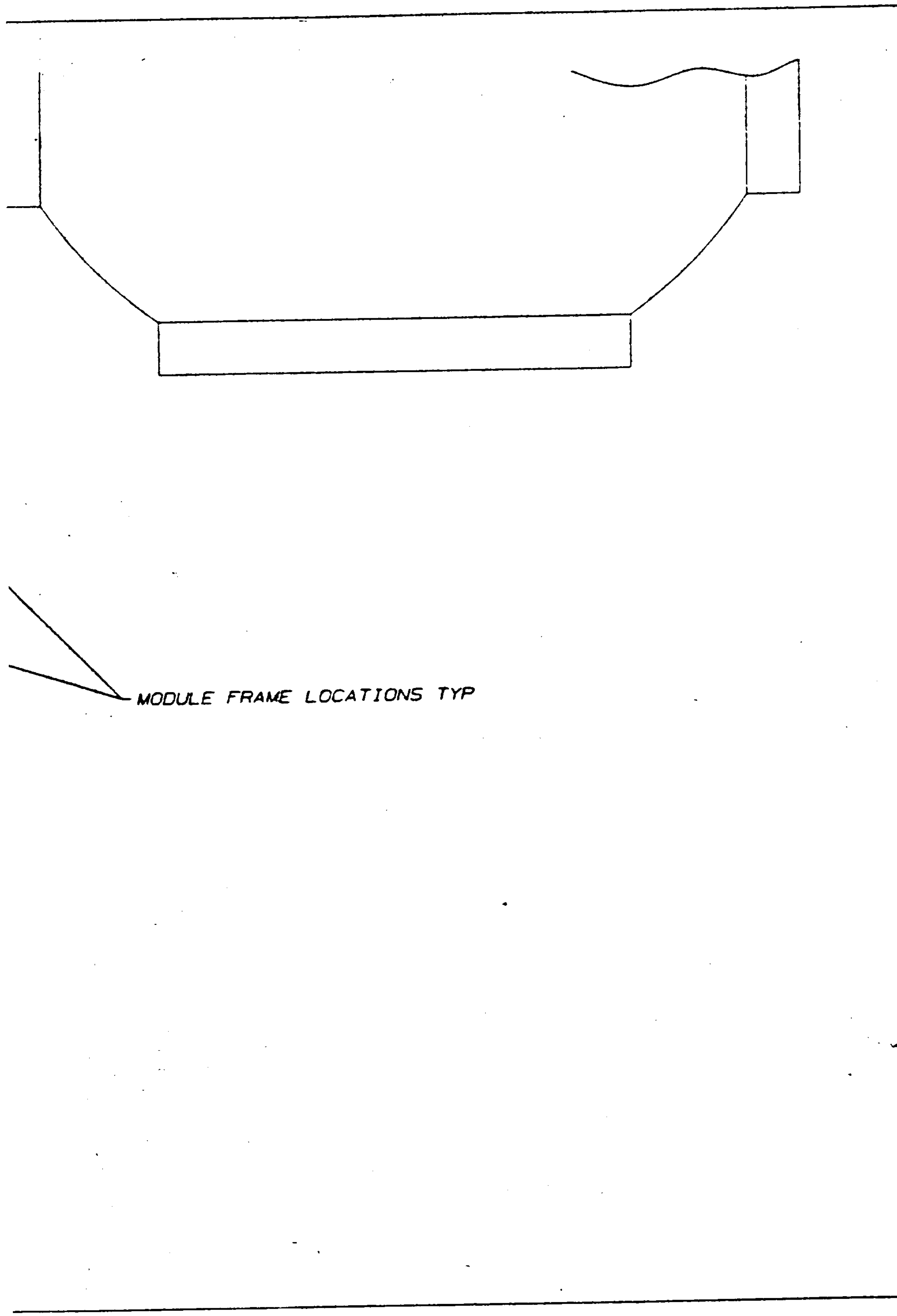


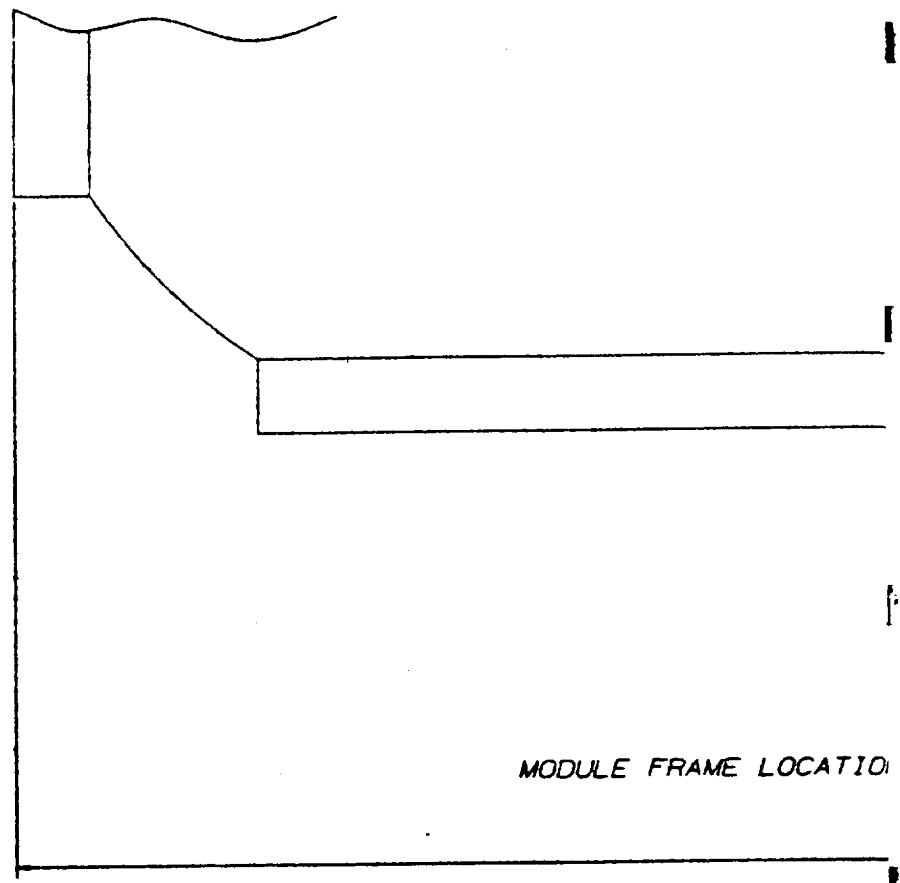


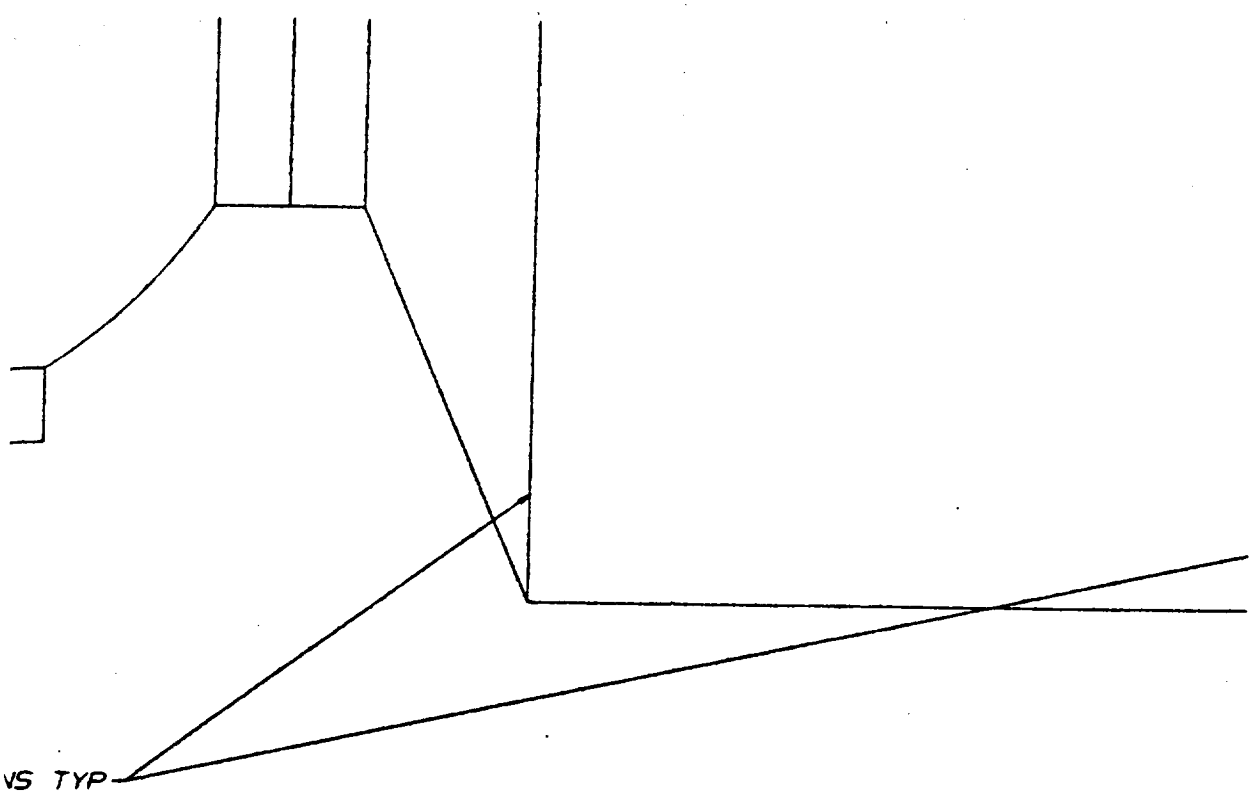

VIEW F-F

SCALE : 1/10



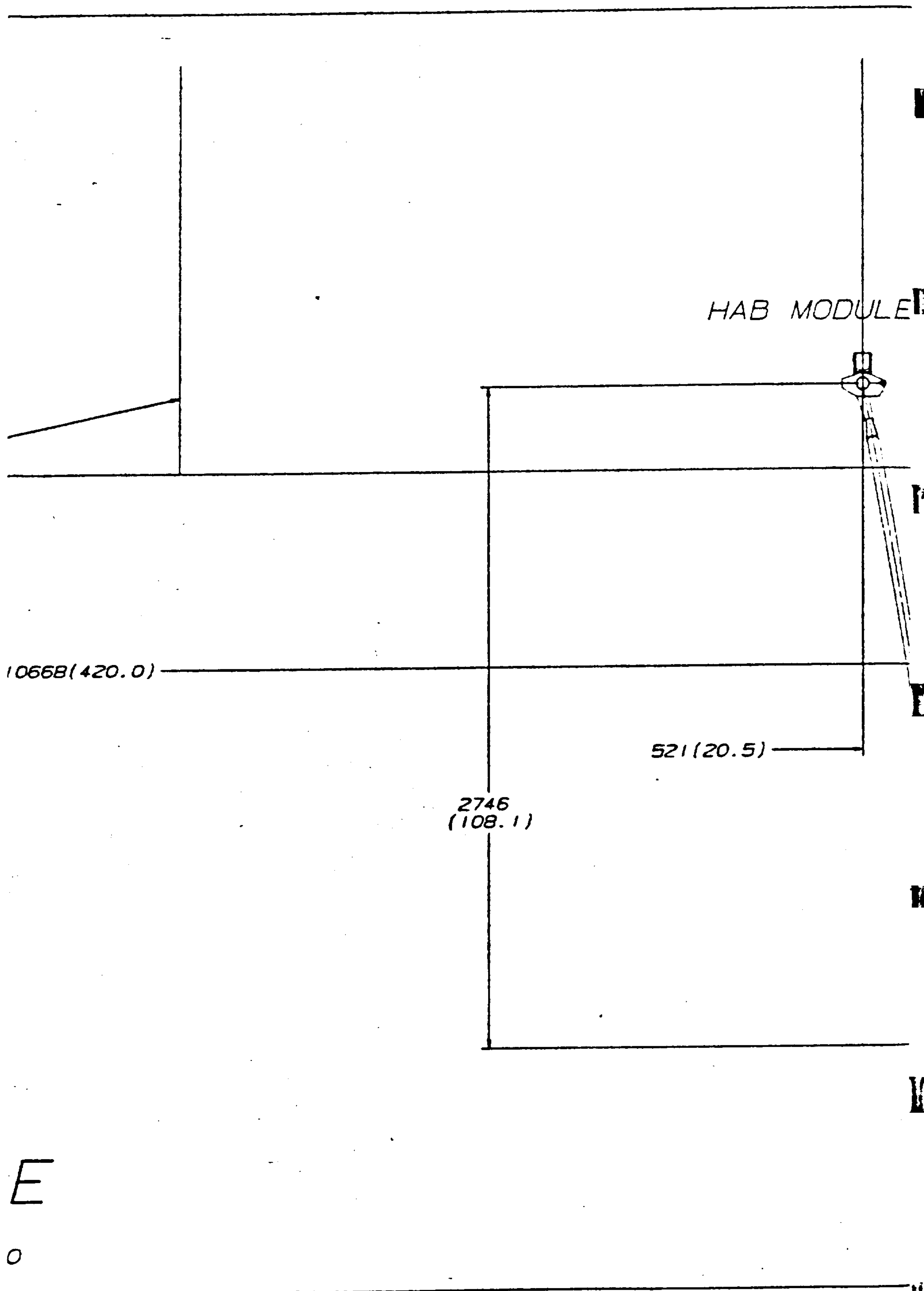

MODULE FRAME LOCATIONS TYP

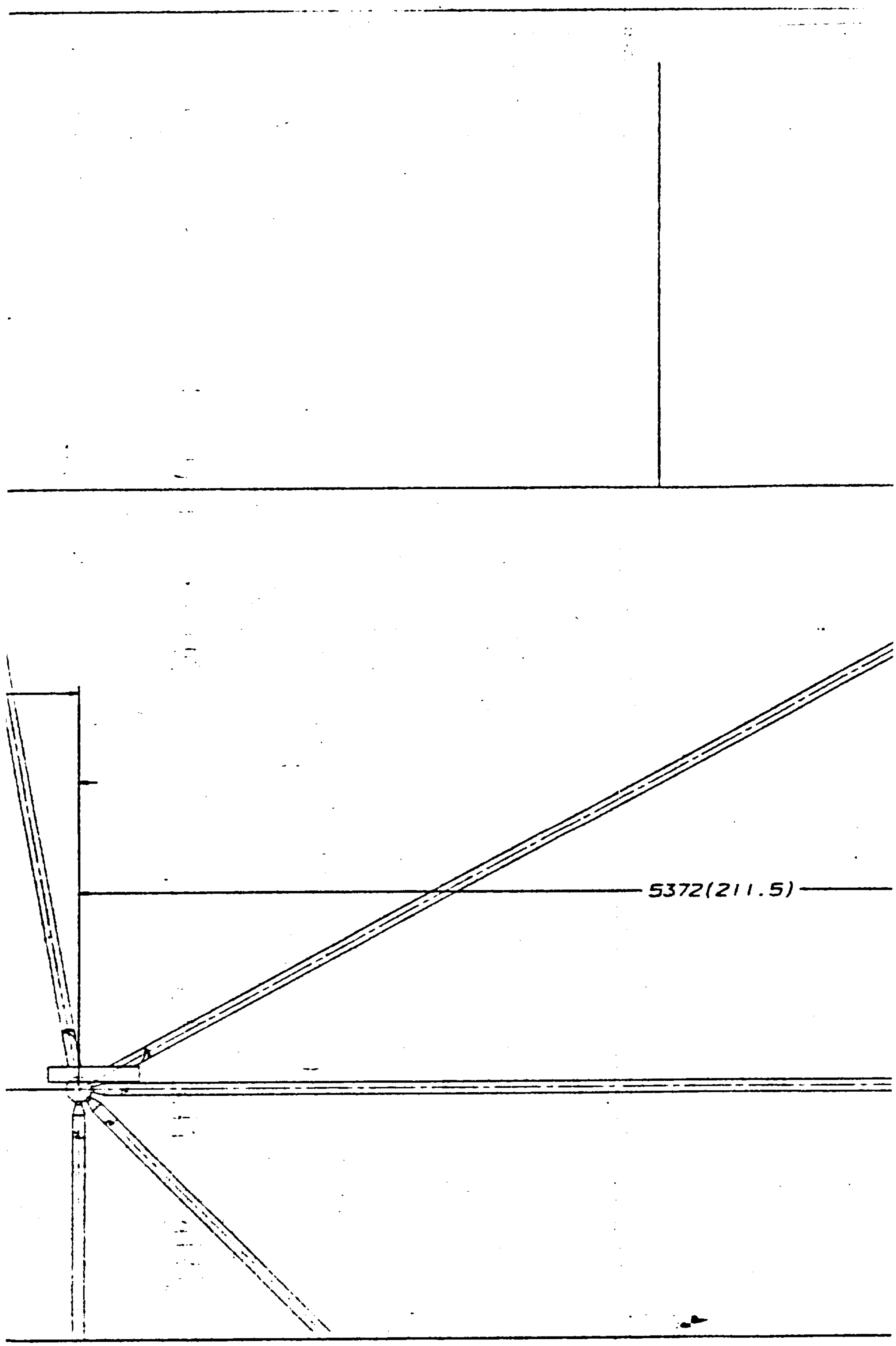

MODULE FRAME LOCATIO

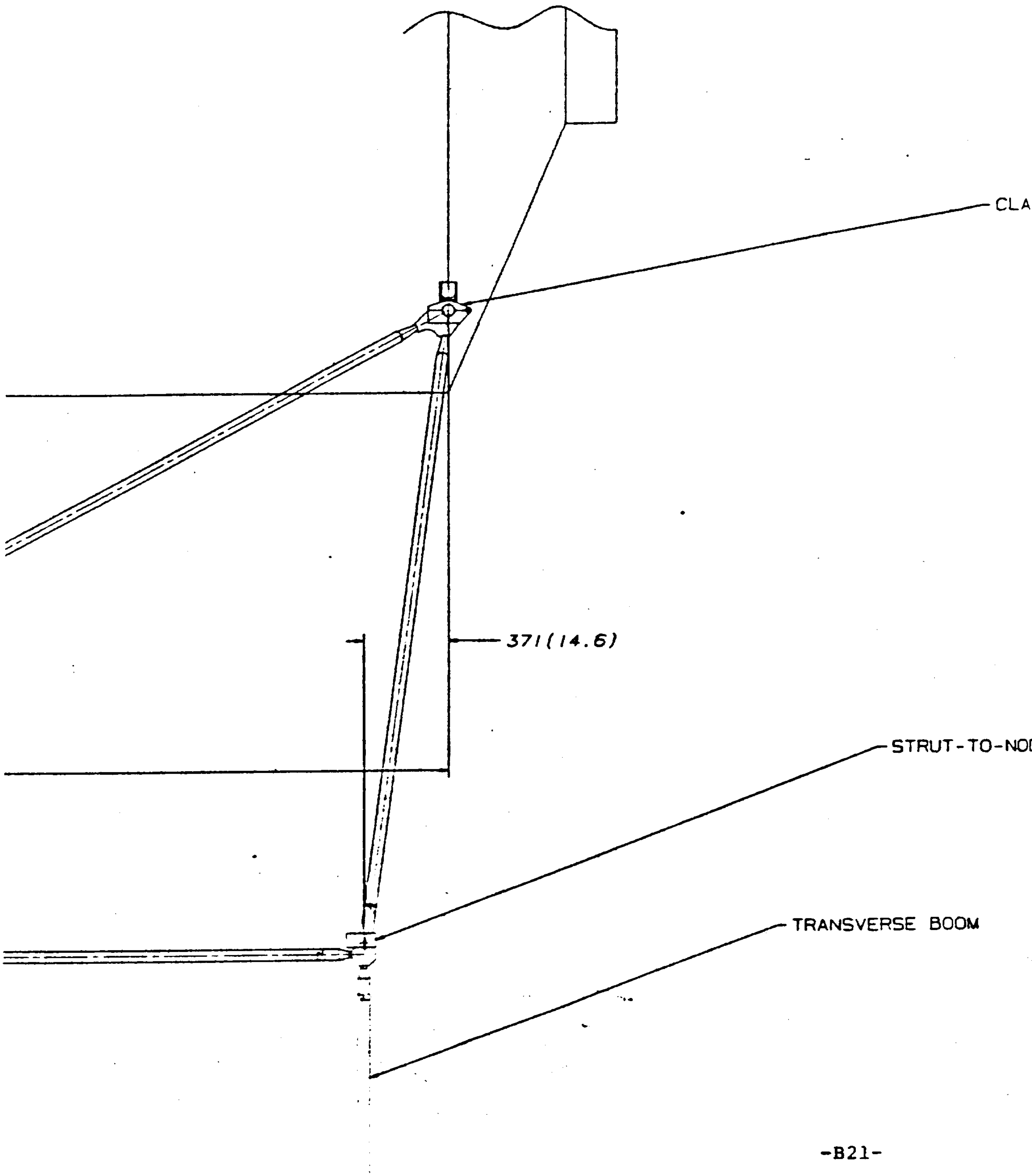


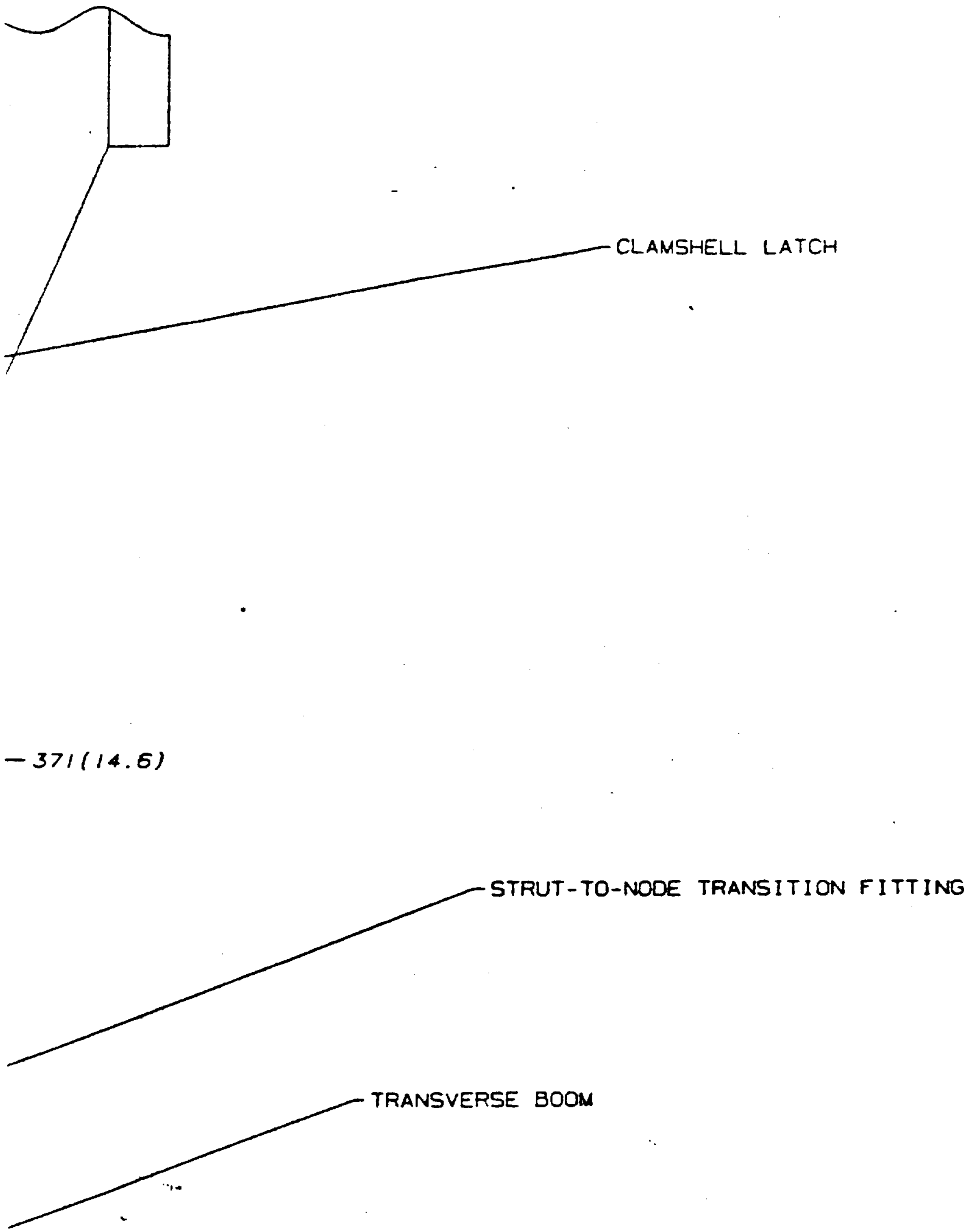

VIEW E-

SCALE : 1/1


HAB MODULE
10668(420.0)
521(20.5)
2746
(108.1)
E
O


5372(211.5)


CLA
371(14.6)
STRUT-TO-NOD
TRANSVERSE BOOM

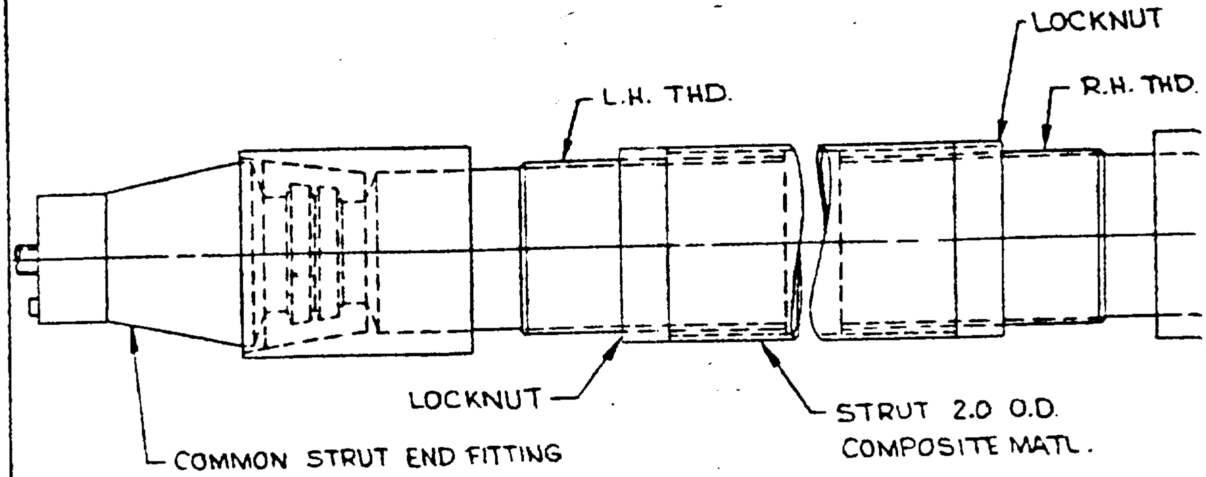

CLAMSHELL LATCH
371(14.6)
STRUT-TO-NODE TRANSITION FITTING
TRANSVERSE BOOM

Module Attach Concepts--5-Meter Erectable Truss

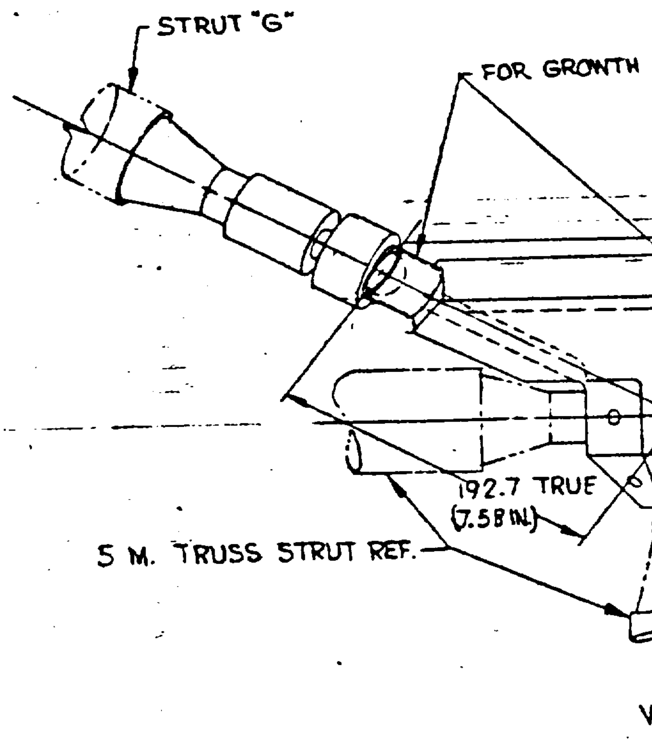
Drawing 84325-449

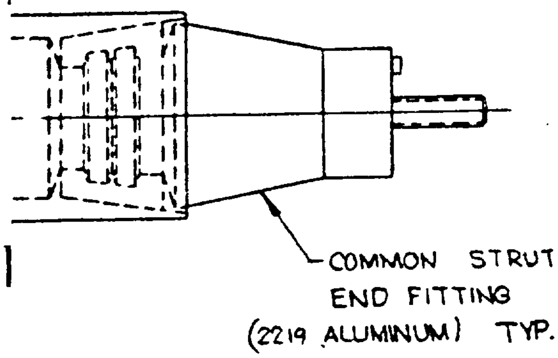
5 METER ERECTABLE TRUSS
MODULE ATTACH CONCEPTS -
STRUTS

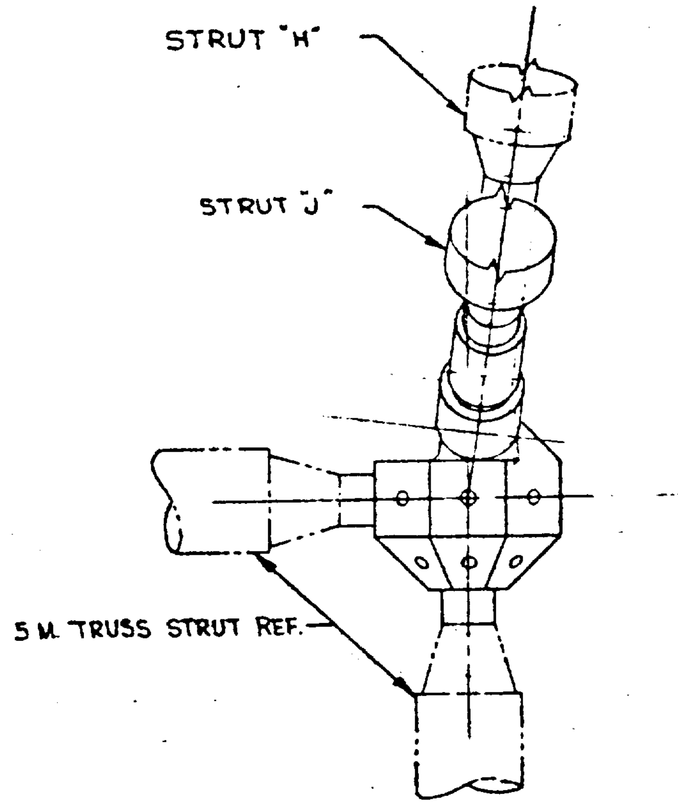
84325 - AAG SHEET 1 OF 3



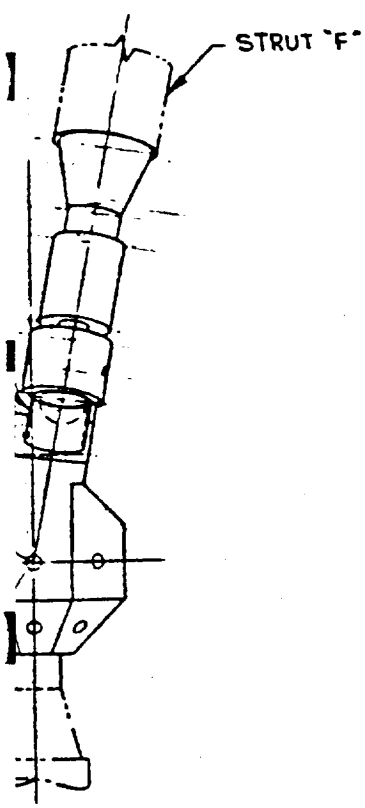

VIEW AG
SCALE: 1/1
TYPICAL STRUT



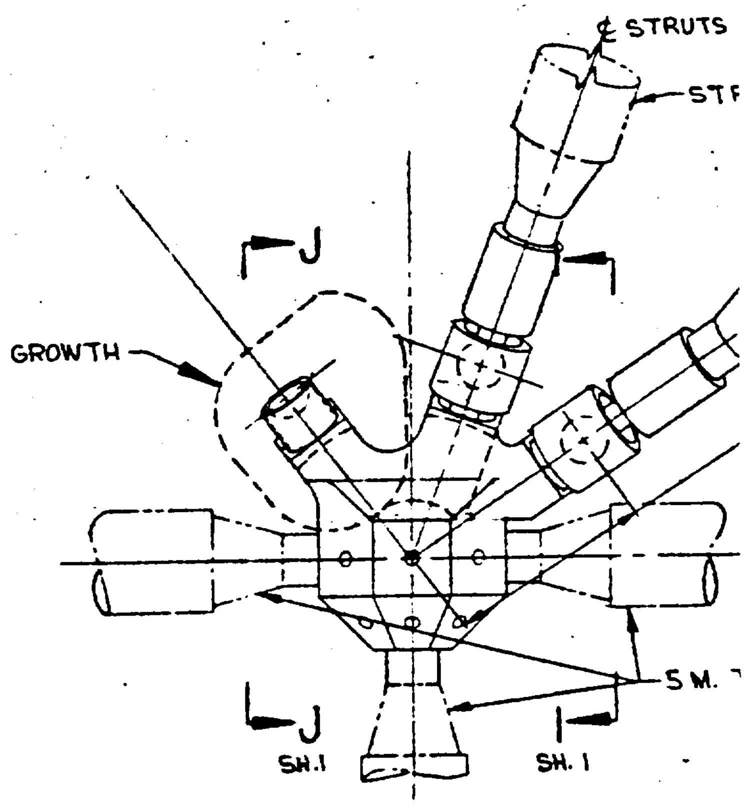


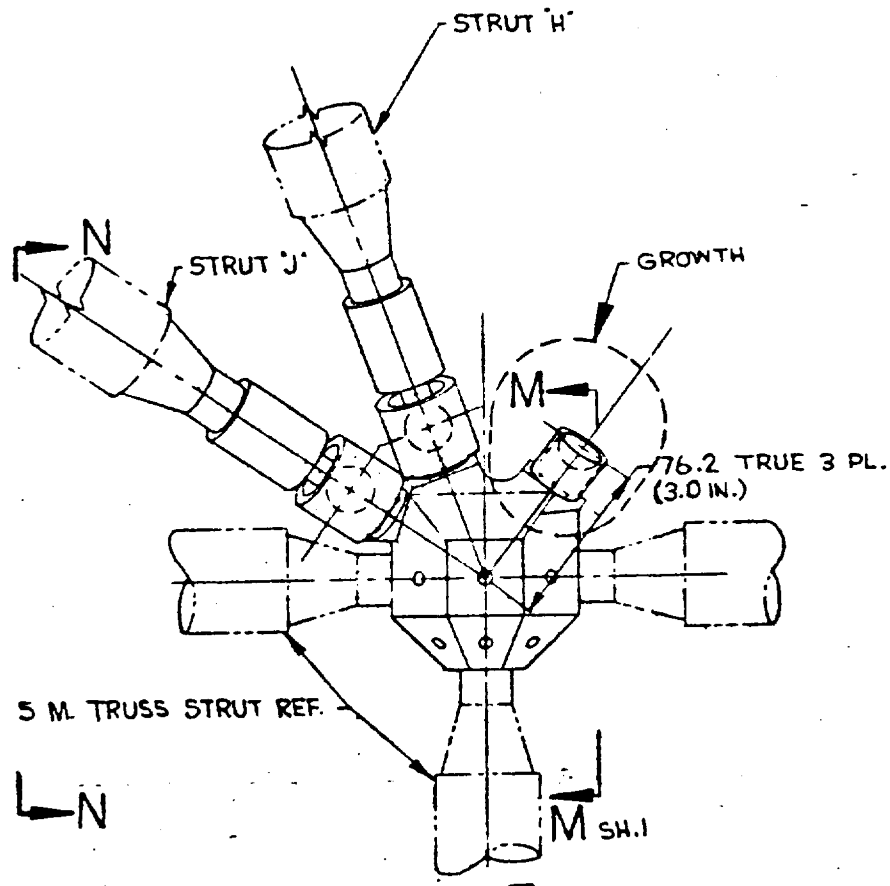

VIEW N-N SH. 1



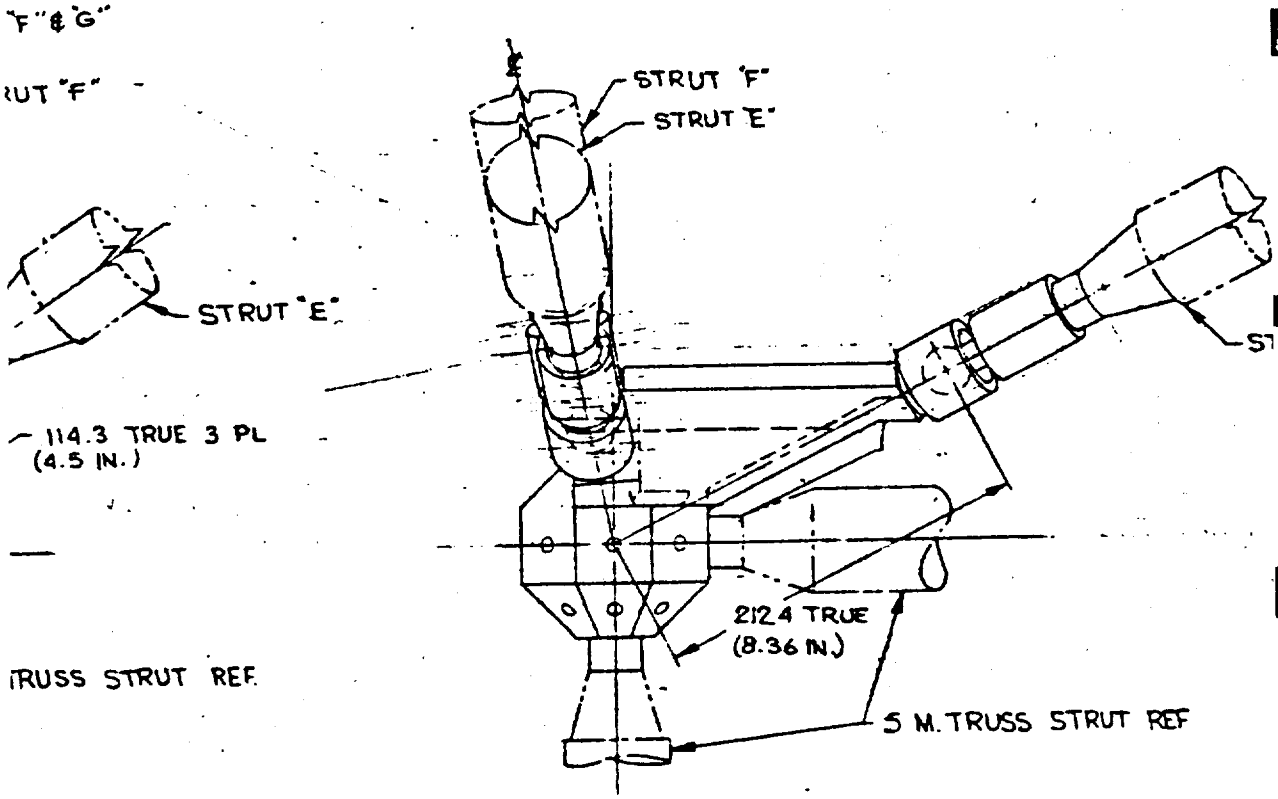

IEW J-J SH. 1



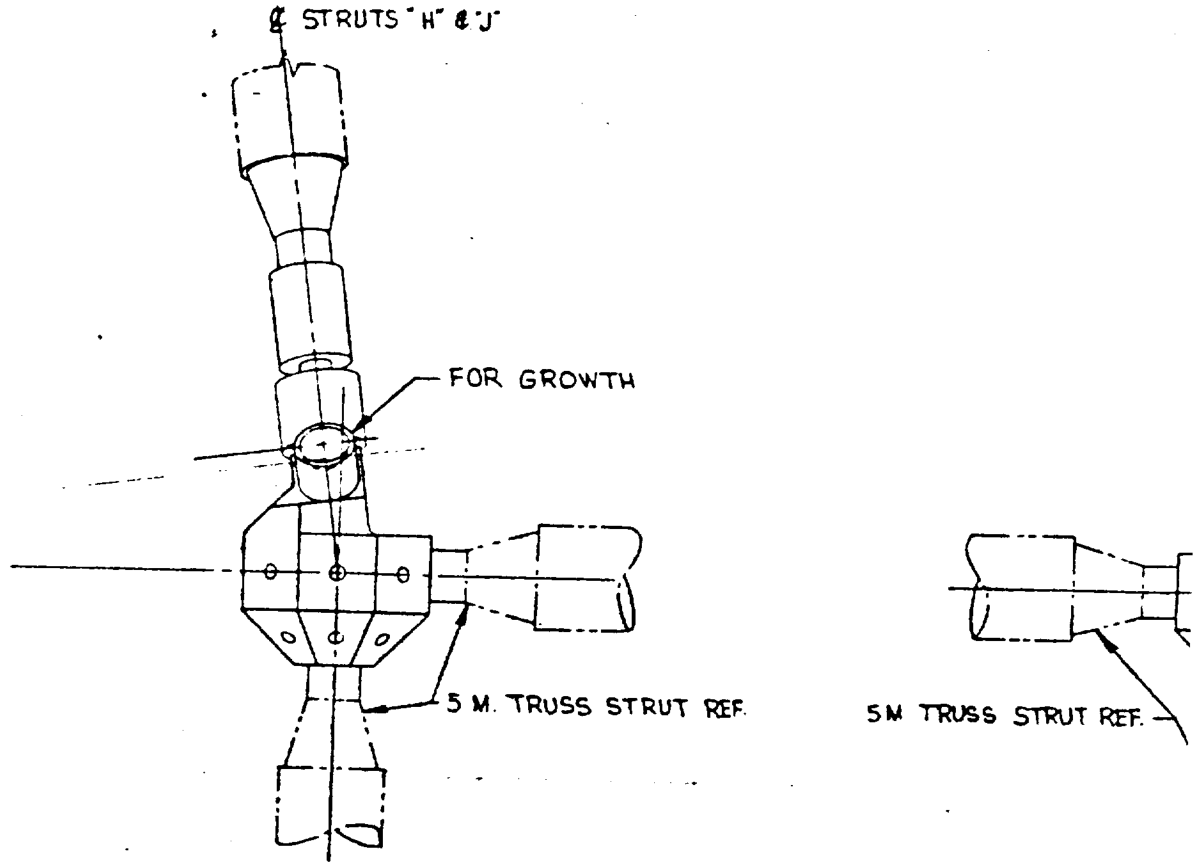

VIEW C SH. 1



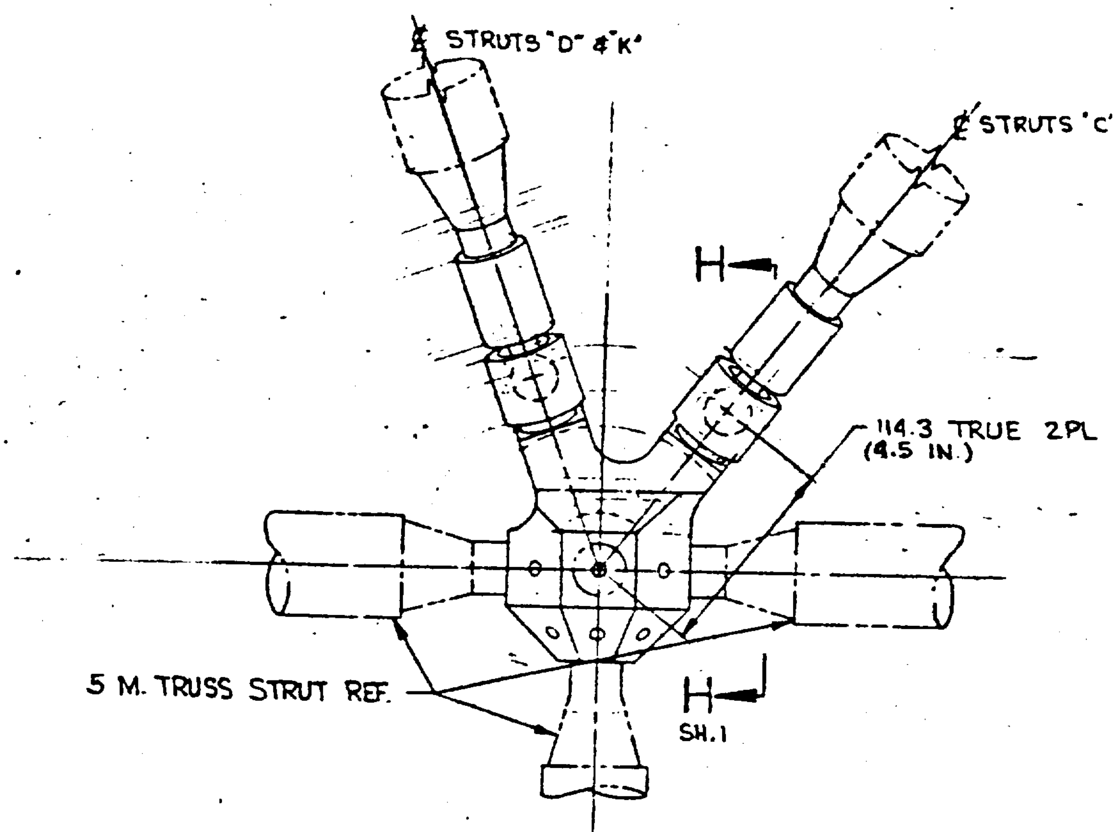

VIEW F SH. 1




VIEW I-I SH. 1

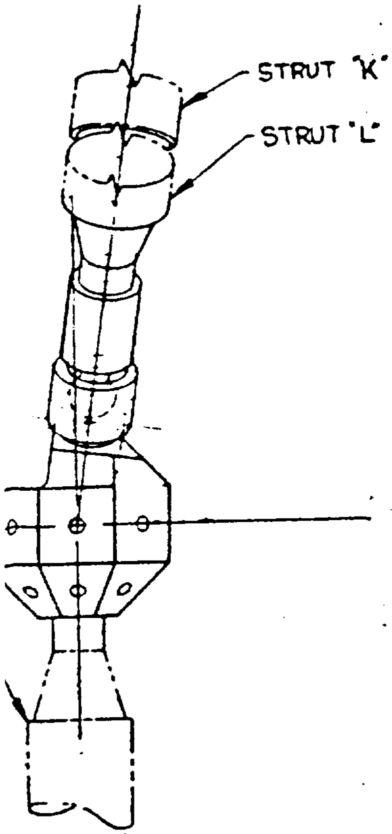



VIEW M-M SH. 1

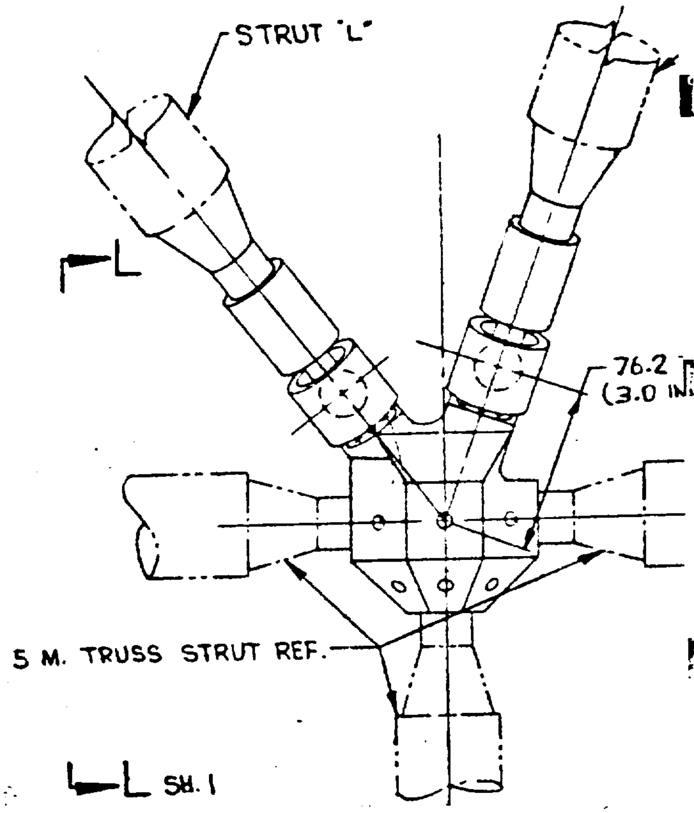



'RUT 'G"

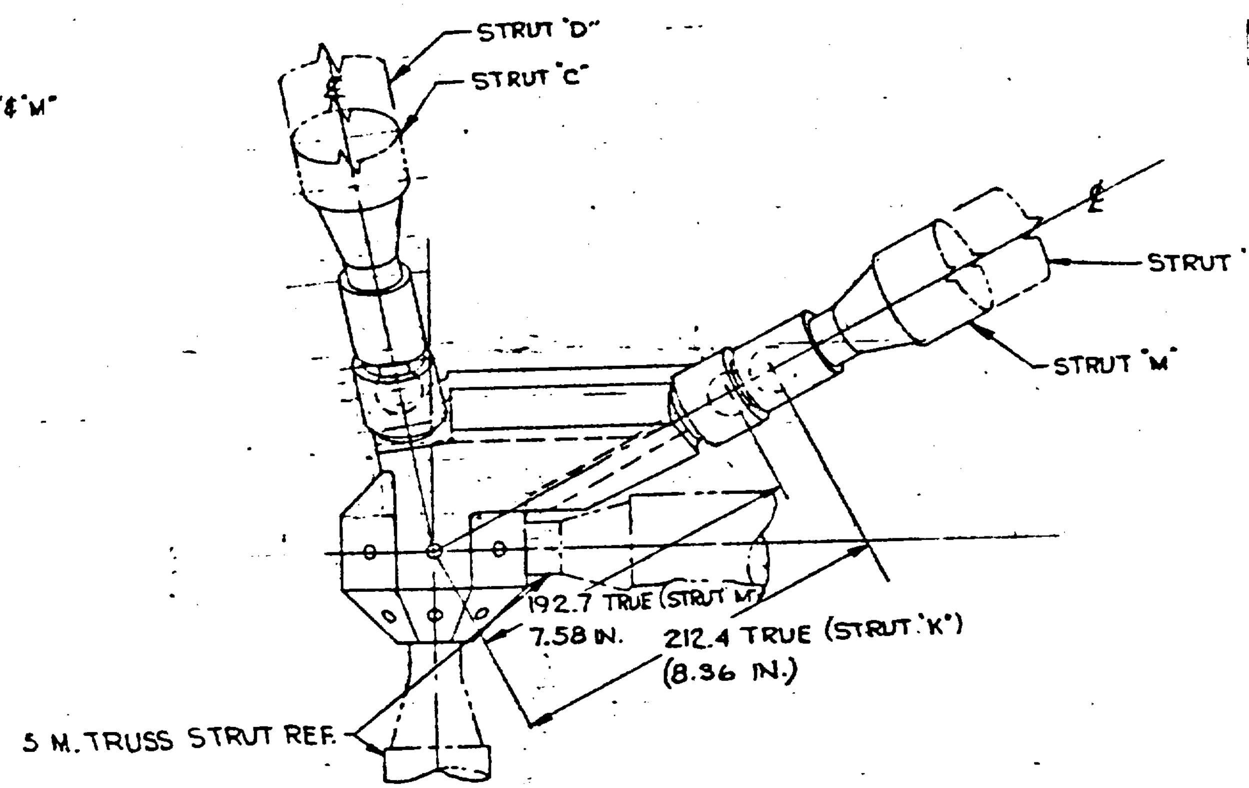
VIEW B SH. 1



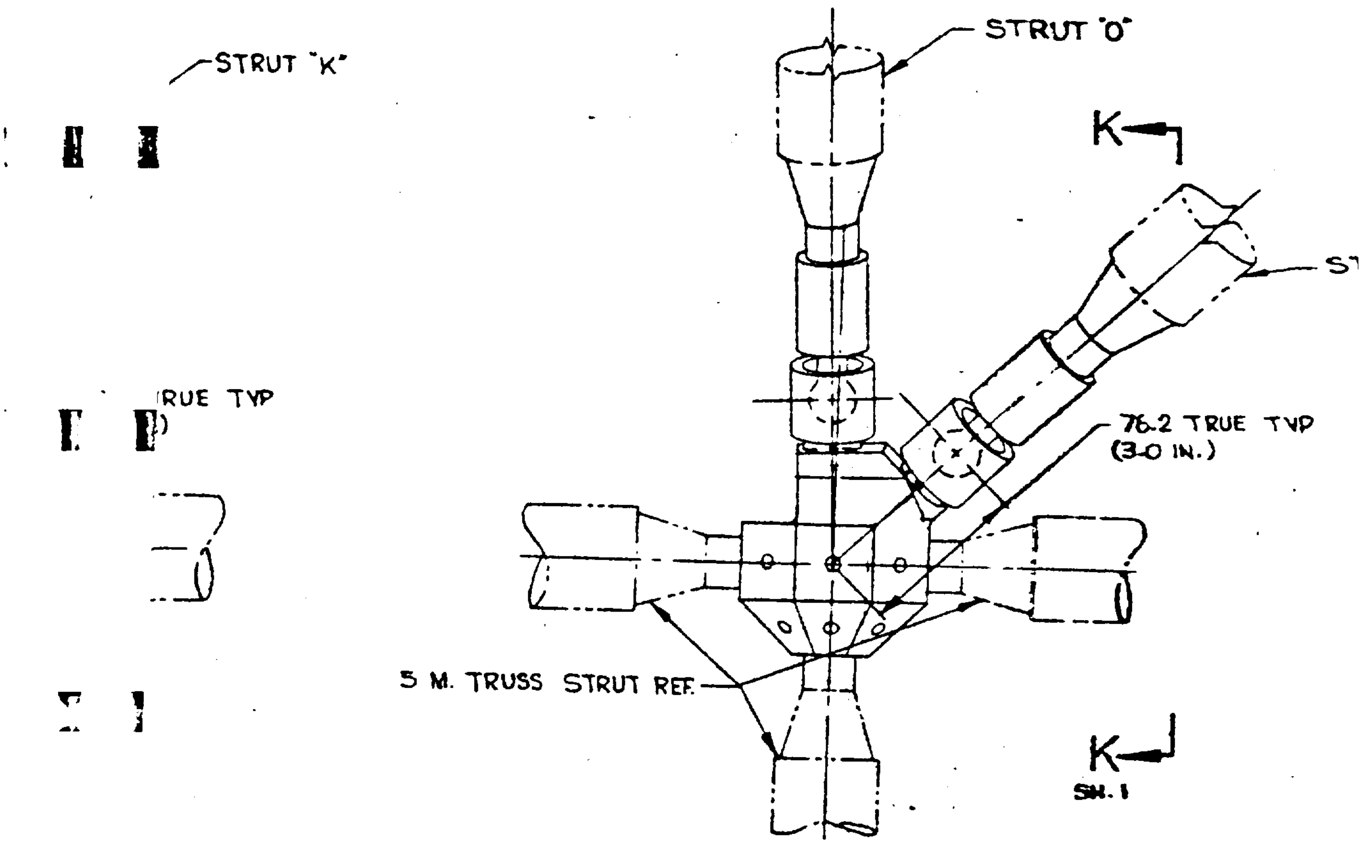

VIEW L-L SH. 1



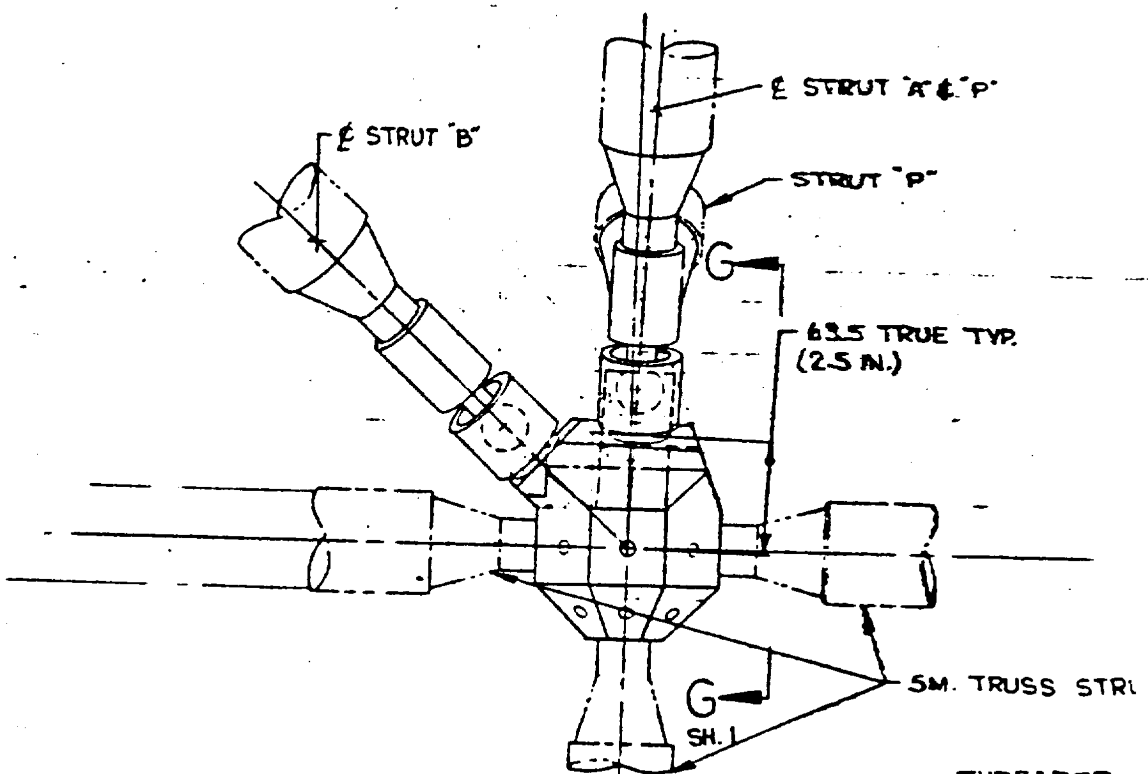

VIEW E SH. 1




VIEW H-H SH. 1

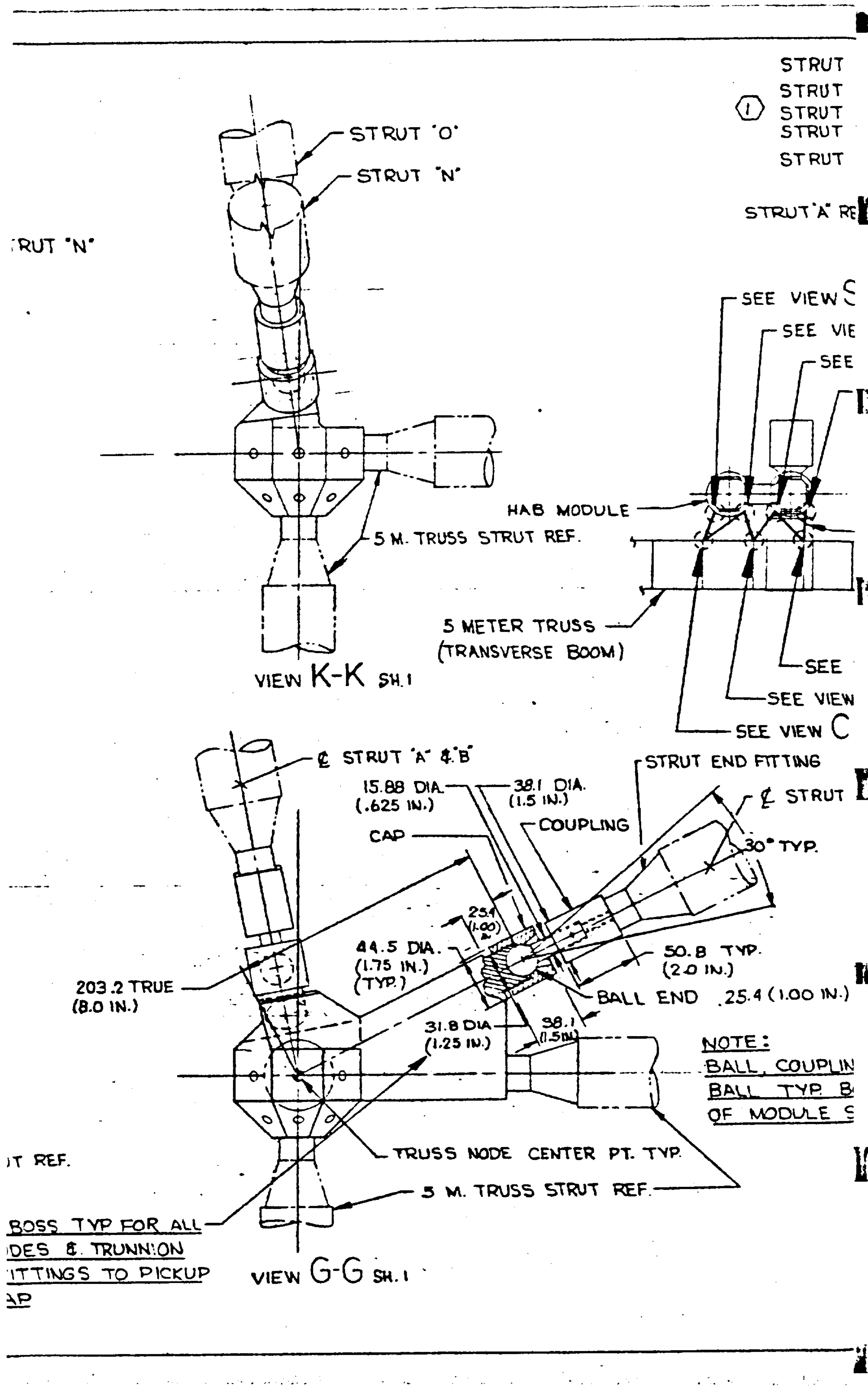


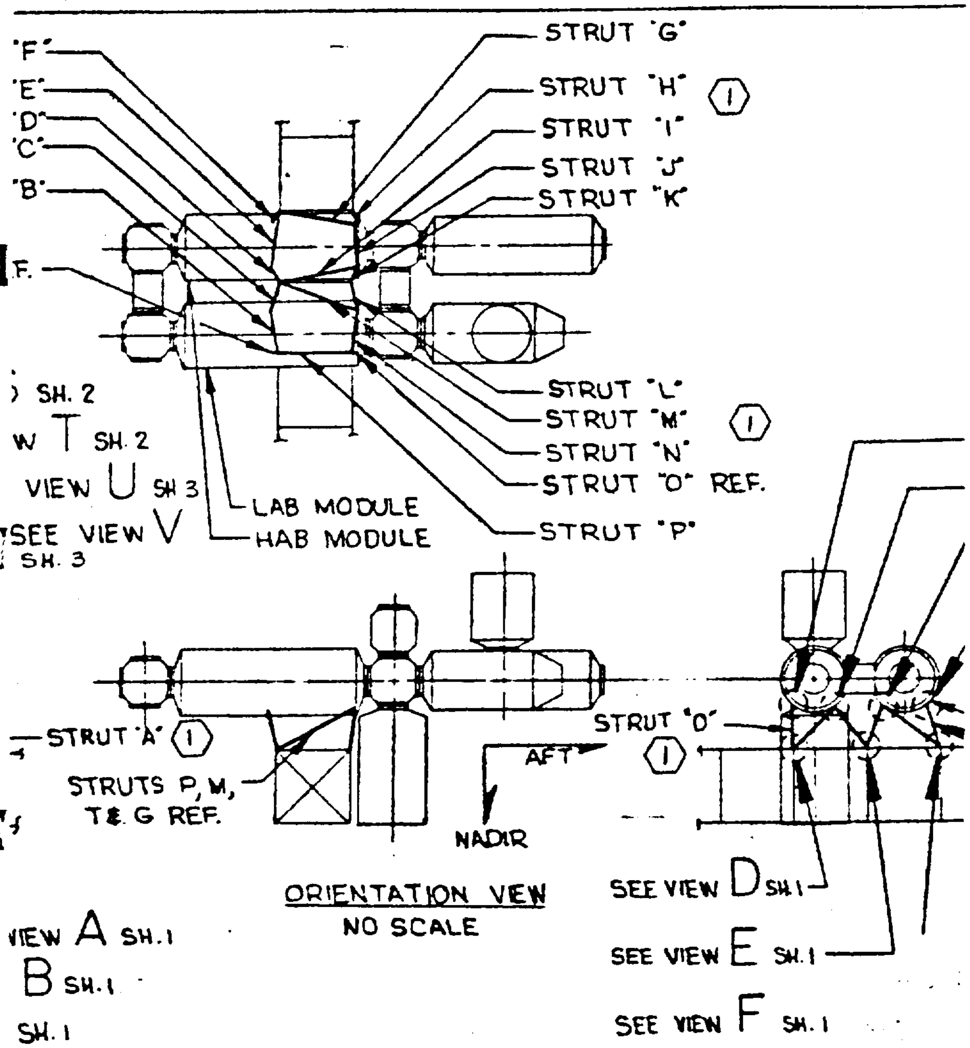

VIEW D SH. I




VIEW A SH I

THREADED
SPECIAL NC
ADAPTER F
BALL & C


STRUT
STRUT
STRUT
STRUT
STRUT
1
STRUT 'A' RE
STRUT 'O'
STRUT 'N'
RUT 'N'
SEE VIEW S
SEE VIE
SEE
HAB MODULE
5 M. TRUSS STRUT REF.
5 METER TRUSS
(TRANSVERSE BOOM)
SEE
SEE VIEW
SEE VIEW C
VIEW K-K SH.1
℄ STRUT 'A' & 'B'
STRUT END FITTING
15.88 DIA.
(.625 IN.)
38.1 DIA.
(1.5 IN.)
℄ STRUT
COUPLING
CAP
30° TYP.
25.4
(1.00)
44.5 DIA.
(1.75 IN.)
(TYP.)
50.8 TYP.
(2.0 IN.)
203.2 TRUE
(8.0 IN.)
BALL END .25.4 (1.00 IN.)
31.8 DIA.
(1.25 IN.)
38.1
(1.5 IN.)
NOTE:
BALL, COUPLIN
BALL TYP. B
OF MODULE S
TRUSS NODE CENTER PT. TYP.
IT REF.
5 M. TRUSS STRUT REF.
BOSS TYP FOR ALL
DES & TRUNNION
ITTINGS TO PICKUP
AP
VIEW G-G SH.1



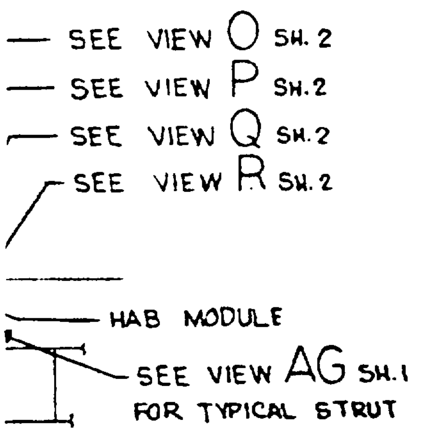

ORIENTATION VIEW
NO SCALE

"P"

| STRUT (1) | STRUT LENGTH (2) | |
|---|---|---|
| | MILLIMETERS | INCHES REF. |
| A | 2796.6 | 110.10 |
| B | 4034.8 | 158.85 |
| C | 3490.0 | 137.40 |
| D | 2967.2 | 116.82 |
| E | 4883.0 | 192.25 |
| F | 2967.2 | 116.82 |
| G | 6113.6 | 240.69 |
| H | 2944.2 | 115.91 |
| I | 6113.6 | 240.69 |
| J | 4869.4 | 191.71 |
| K | 2944.2 | 115.91 |
| L | 3471.6 | 136.68 |
| M | 6384.3 | 251.35 |
| N | 4016.8 | 158.14 |
| O | 2772.4 | 109.15 |
| P | 6030.3 | 237.51 |

DIA. TYP.

G, &
OTH ENDS
UPPORT STRUTS




7. BALL ENDS ARE TO BE MADE FROM A286 MATERIAL.
6. STRUT END FITTINGS, CAPS, COUPLINGS, NODES, AND TRUNNION ADAPTER FITTINGS ARE TO BE MADE FROM 2219 AL.
5. FOR MODULE INSTALLATION:
   a. ASSEMBLE STRUTS TO TRUNNION ADAPTER FITTING ASSY. THEN TO ASSYS.
   b. LOWER MODULE TILL TRUNNION BALL RESTS IN THE HEMISPHERICAL CAVITY OF THE LOWER PORTION OF THE TRUNNION ADAPTER FITTING. STRUT LENGTHS MAY HAVE TO BE ADJUSTED. ADJUSTMENTS MAY BE MADE BY LOOSENING THE STRUT CHEC NUTS AND ROTATING THE STRUT TO LENGTHEN OR SHORTEN THE STRUT. WHEN ADJUSTMENTS ARE COMPLETED, TIGHTEN CHEC NUTS USING AN INSTALLATION TOOL.
   c. WHEN ALL FOUR TRUNNION BALLS ARE FULLY NESTED IN THE TRUNNION ADAPTER FITTING CAVITIES, CLOSE THE UPPER HALF OF THE ADAPTER FITTING OVER THE TRUNNION BALL AND SECURE IN PLACE BY ROTATING THE ROD END INTO THE SLOT & TIGHTEN THE NUT USING THE INSTALLATION TOOL.
4. STRUT LENGTHS ARE TO BE PRESE ON THE GROUND.
3. BALL ENDS, CAPS, COUPLINGS, STRUT END FITTINGS ARE TO BE ASSEMBLED TO TRUNNION ADAPTER FITTINGS PRIOR TO PACKAGING.
2. ALL DIMENSIONS IN MILLIMETERS.
2) 1. TRUE LENGTH FROM TRUSS NODE CENTER PT. TO MODULE TRUNNION PT.

NOTES: UNLESS OTHERWISE SPECIFIED:



| | | | |
|---|---|---|---|
| SCALE 1/2 | DR B.K. 20851 DATE 9-26-86 | Rockwell International | |
| MODULE ATTACH CONCEPTS- 5 METER ERECTABLE TRUSS, GO 41801 | | | 8. SH |

SH. 2

SH. 2

SH. 2

SH. 2

E

AG SH. 1

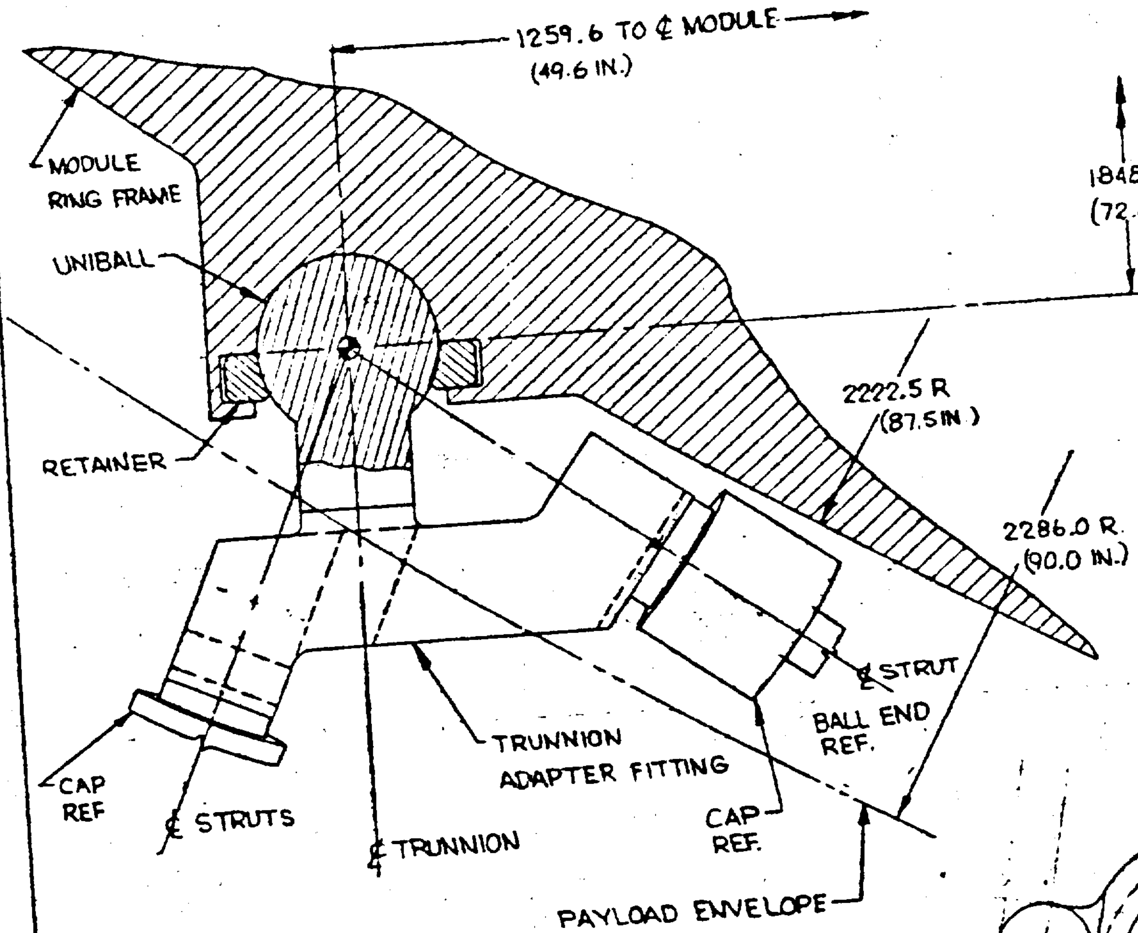
AL STRUT

E TO BE MADE FROM A286 MATERIAL.
TTINGS, CAPS, COUPLINGS, NODES, AND
APTER FITTINGS ARE TO BE MADE FROM 2219 AL.
INSTALLATION:
STRUTS TO TRUNNION ADAPTER FITTING
N TO ASSYS.
ODULE TILL TRUNNION BALL RESTS IN THE
RICAL CAVITY OF THE LOWER PORTION OF
NNION ADAPTER FITTING. STRUT LENGTHS
TO BE ADJUSTED. ADJUSTMENTS MAY BE
LOOSENING THE STRUT CHEC NUTS AND ROTAT-
TRUT TO LENGTHEN OR SHORTEN THE STRUT.
JUSTMENTS ARE COMPLETED, TIGHTEN
TS USING AN INSTALLATION TOOL.
FOUR TRUNNION BALLS ARE FULLY NESTED
RUNNION ADAPTER FITTING CAVITIES, CLOSE
R HALF OF THE ADAPTER FITTING OVER THE
BALL AND SECURE IN PLACE BY ROTATING
ND INTO THE SLOT & TIGHTEN THE NUT USING
LLATION TOOL.
THS ARE TO BE PRESE ON THE GROUND.
CAPS, COUPLINGS, STRUT END FITTINGS
SEMBLED TO TRUNNION ADAPTER
RIOR TO PACKAGING.
ONS IN MILLIMETERS.
TH FROM TRUSS NODE CENTER PT. TO
UNNION PT.
SS OTHERWISE SPECIFIED:

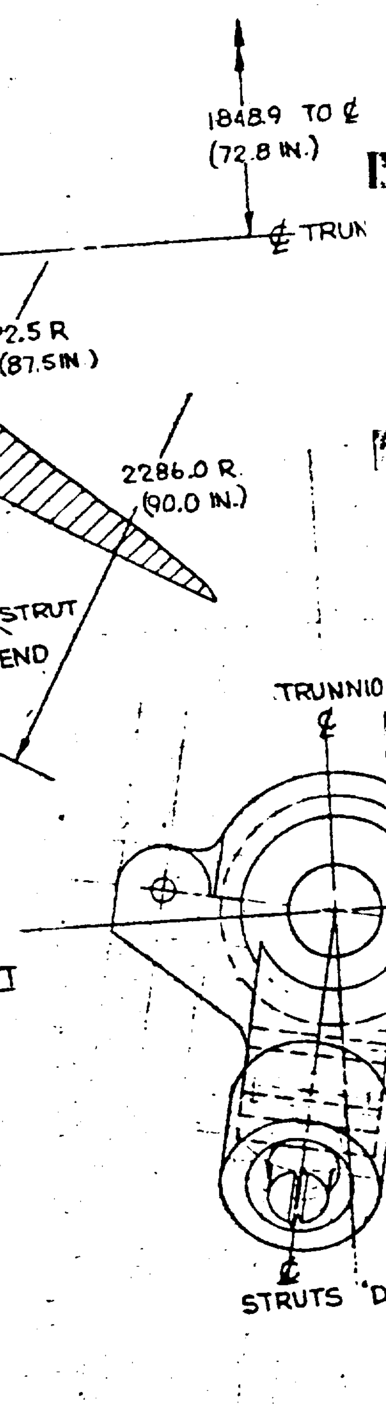


| SCALE $\frac{1}{2}$ | B.N. 20851 / DATE 9-24-84 | Rockwell International | |
|---|---|---|---|
| MODULE ATTACH CONCEPTS- 5 METER ERECTABLE TRUSS, G O 41801 | | | 84325-449 SHEET 1 OF 3 |

84325-449 SHEET 1 OF 3
MODULE ATTACH CONCEPTS -
5 METER ERECTABLE TRUSS



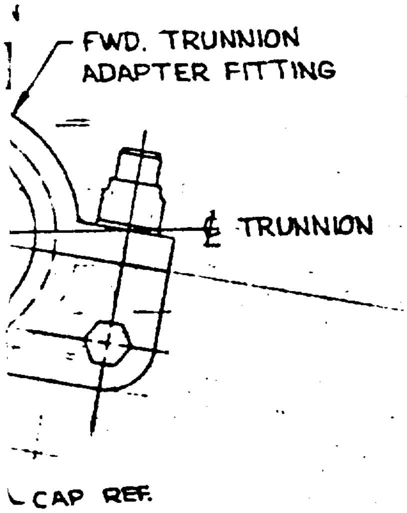

VIEW AF SH. 2
ALTERNATE TRUNNION ATTACH CONCEPT

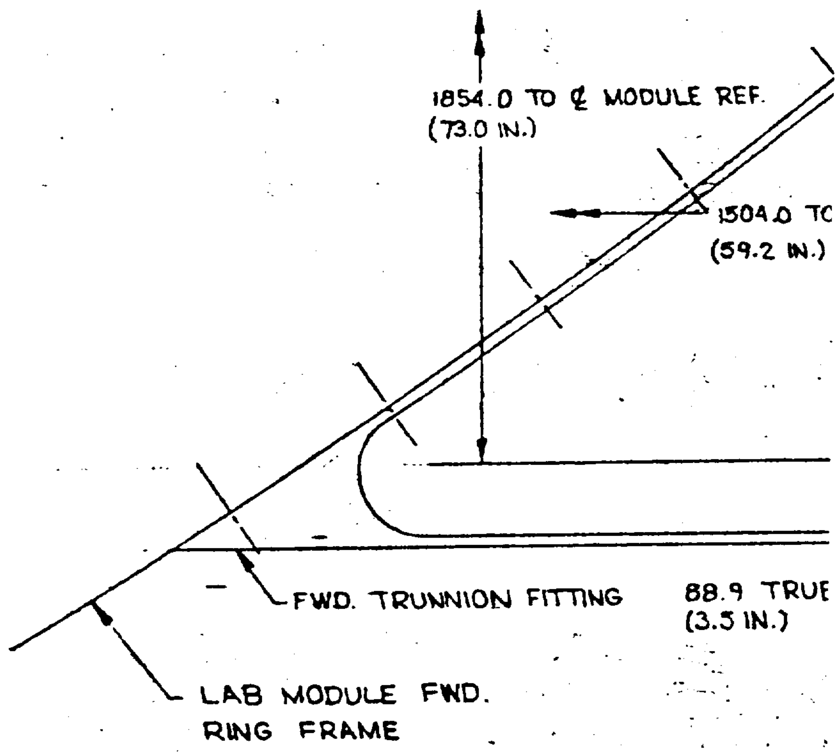



VIEW Y-

ODULE

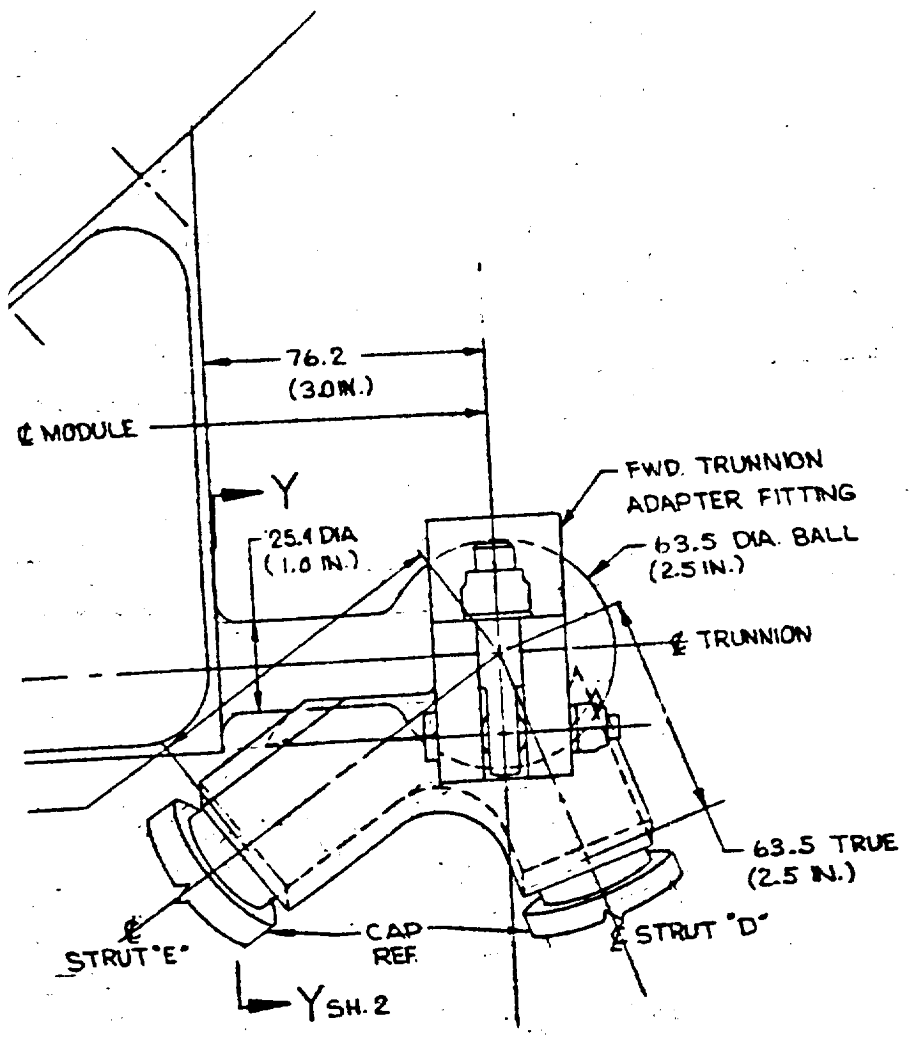
NION



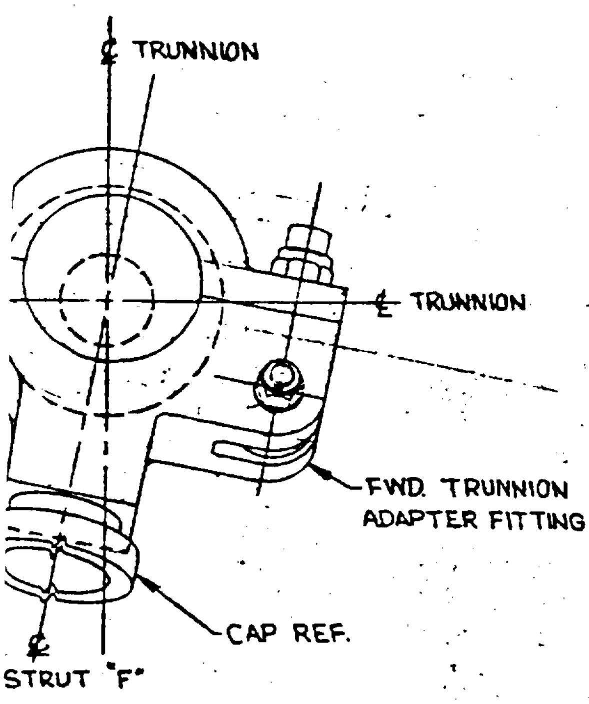




"E"

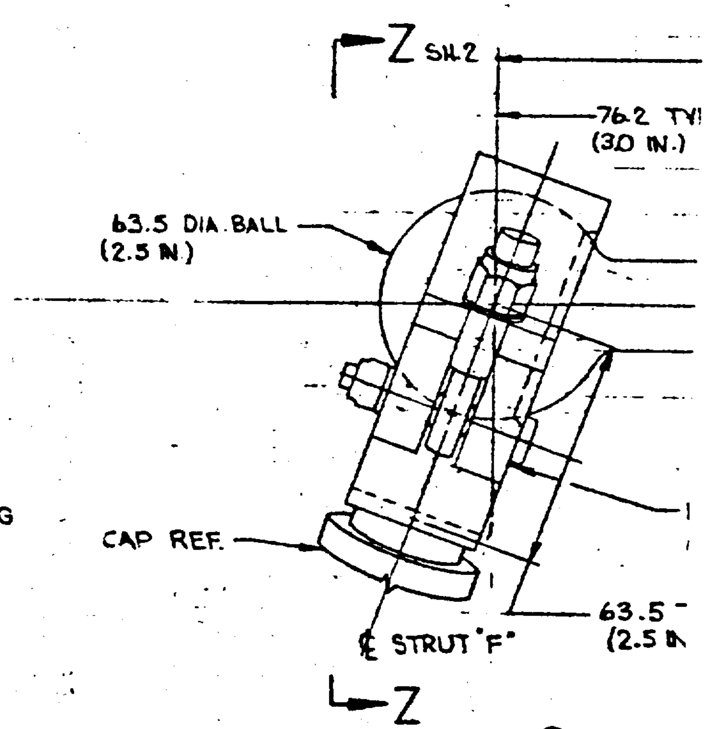
SH. 2



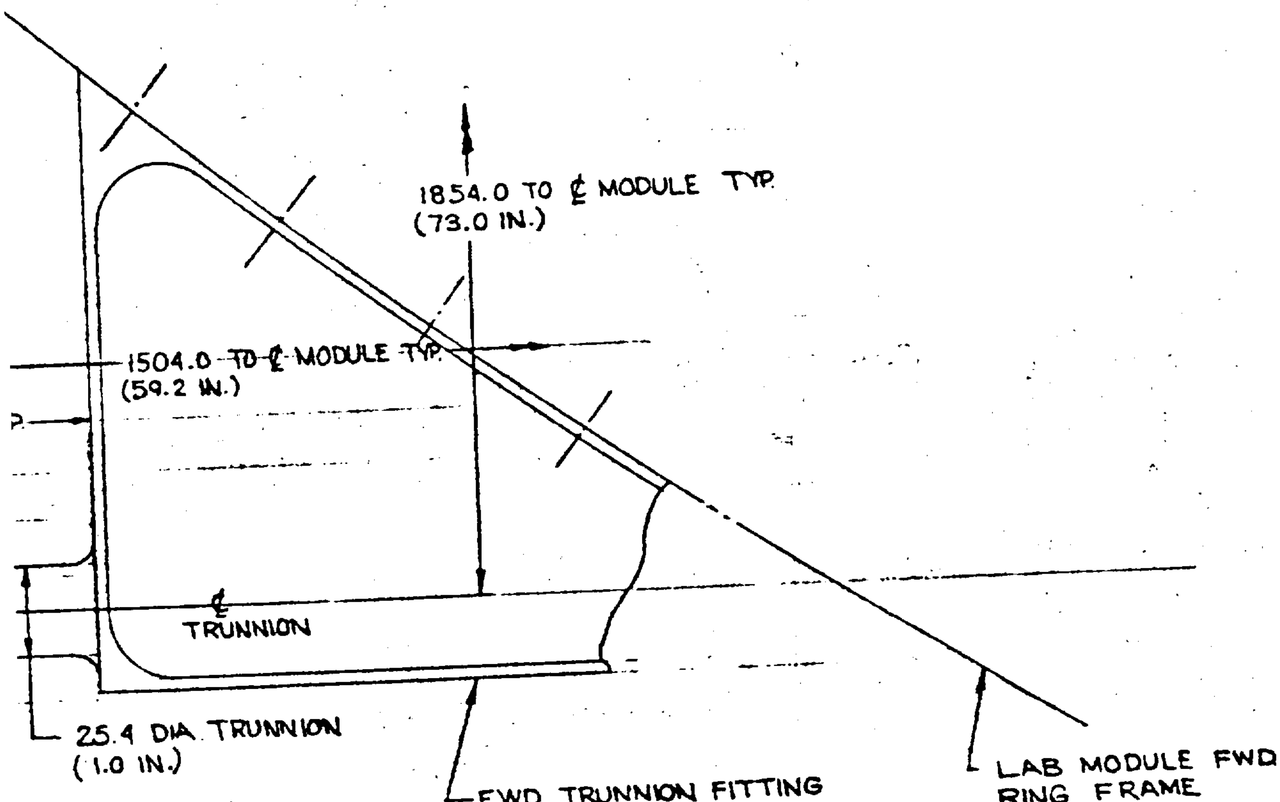

VIEW T SH. 1
VIEW LOOKING AFT




VIEW Z-Z SH.2

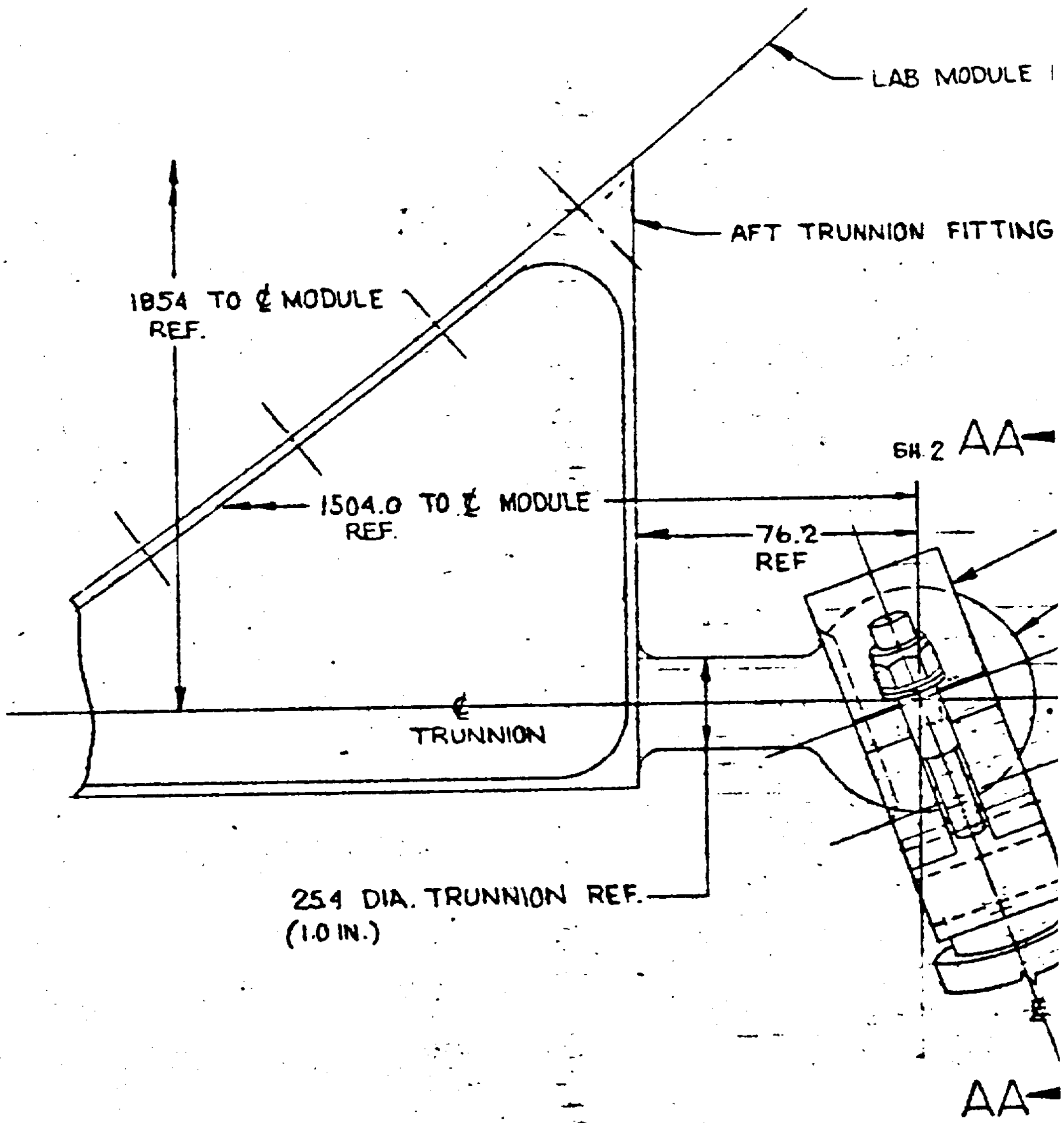



VIEW S SH. 1
VIEW LOOKIN AFT



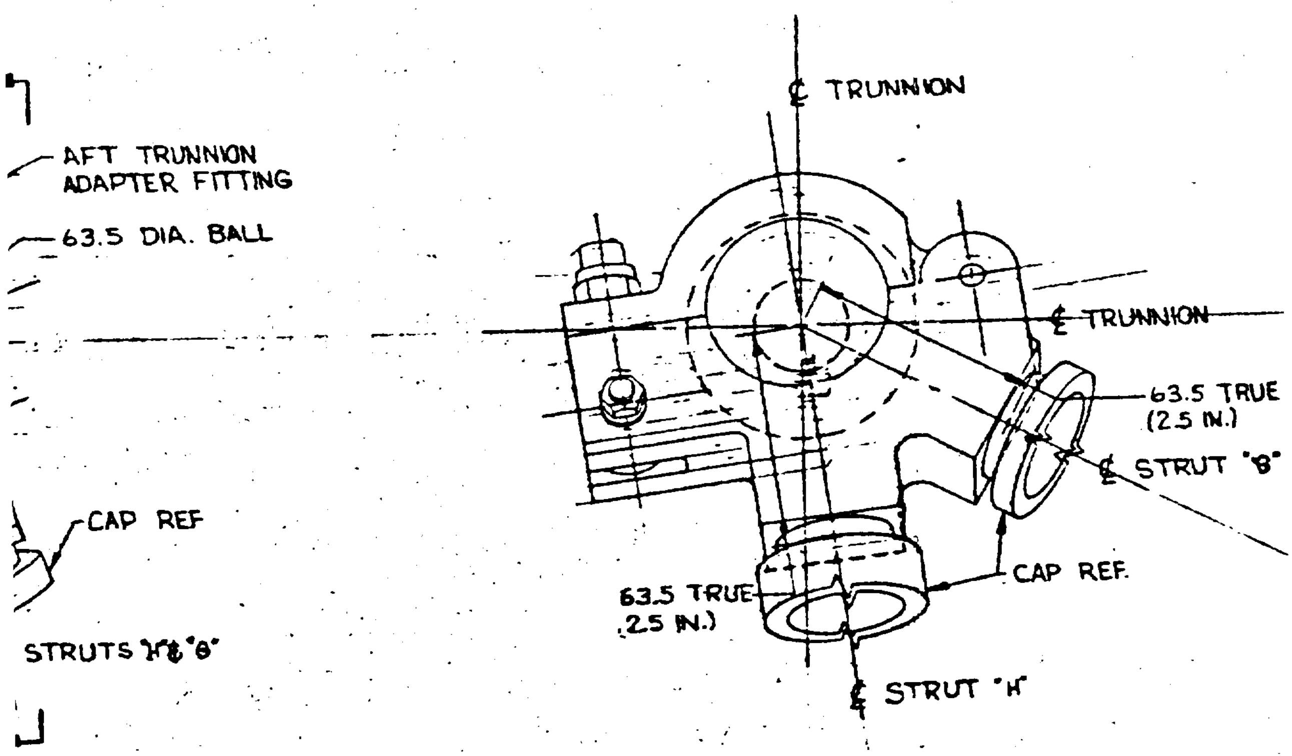
FWD. TRUNNION
ADAPTER FITTING

TRUE
L)

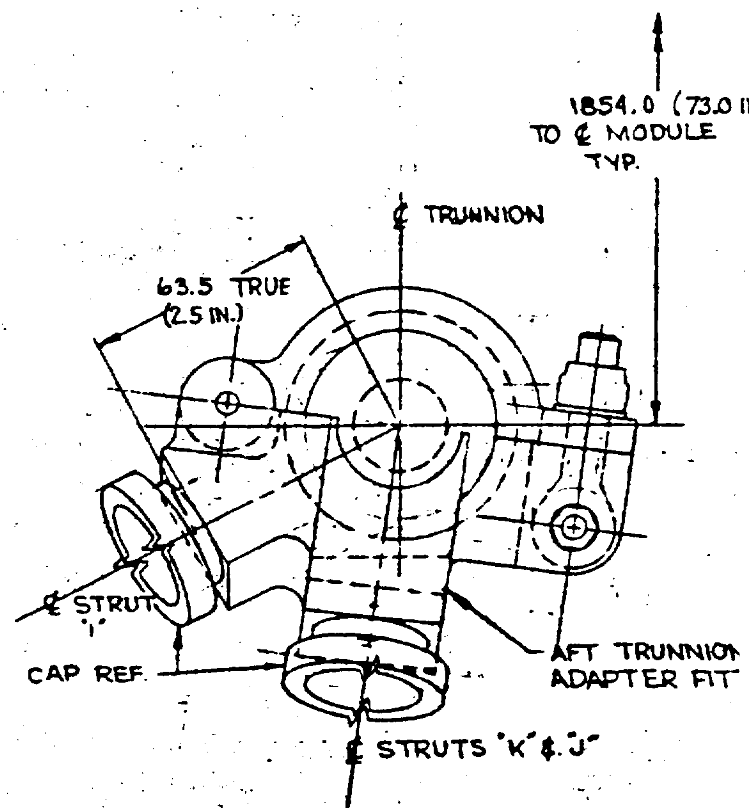



VIEW R SH. 1
VIEW LOOKING FORWARD

RING FRAME



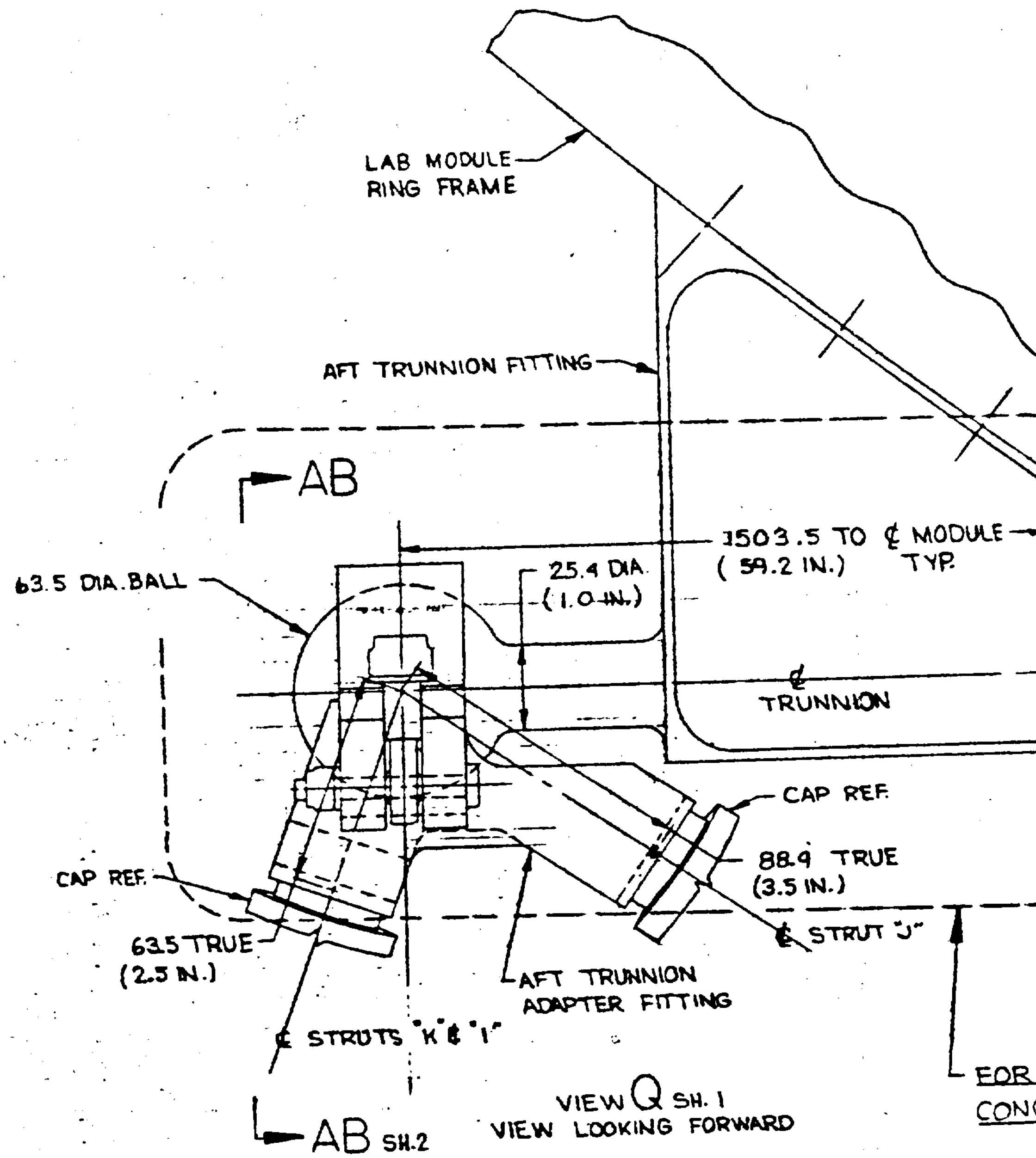

VIEW A-A SH.2



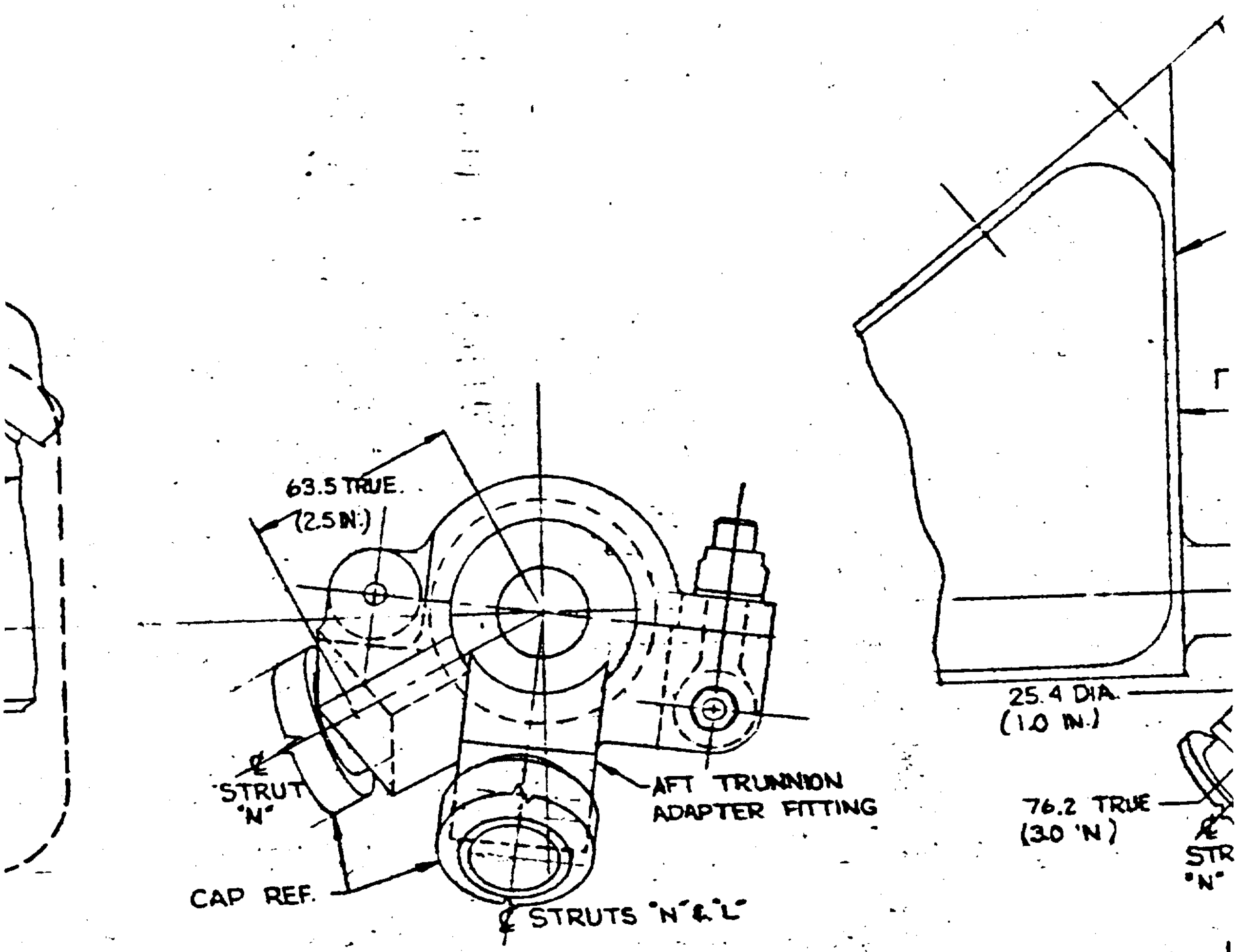
VIEW AB-AB SH.2

N.)

ING

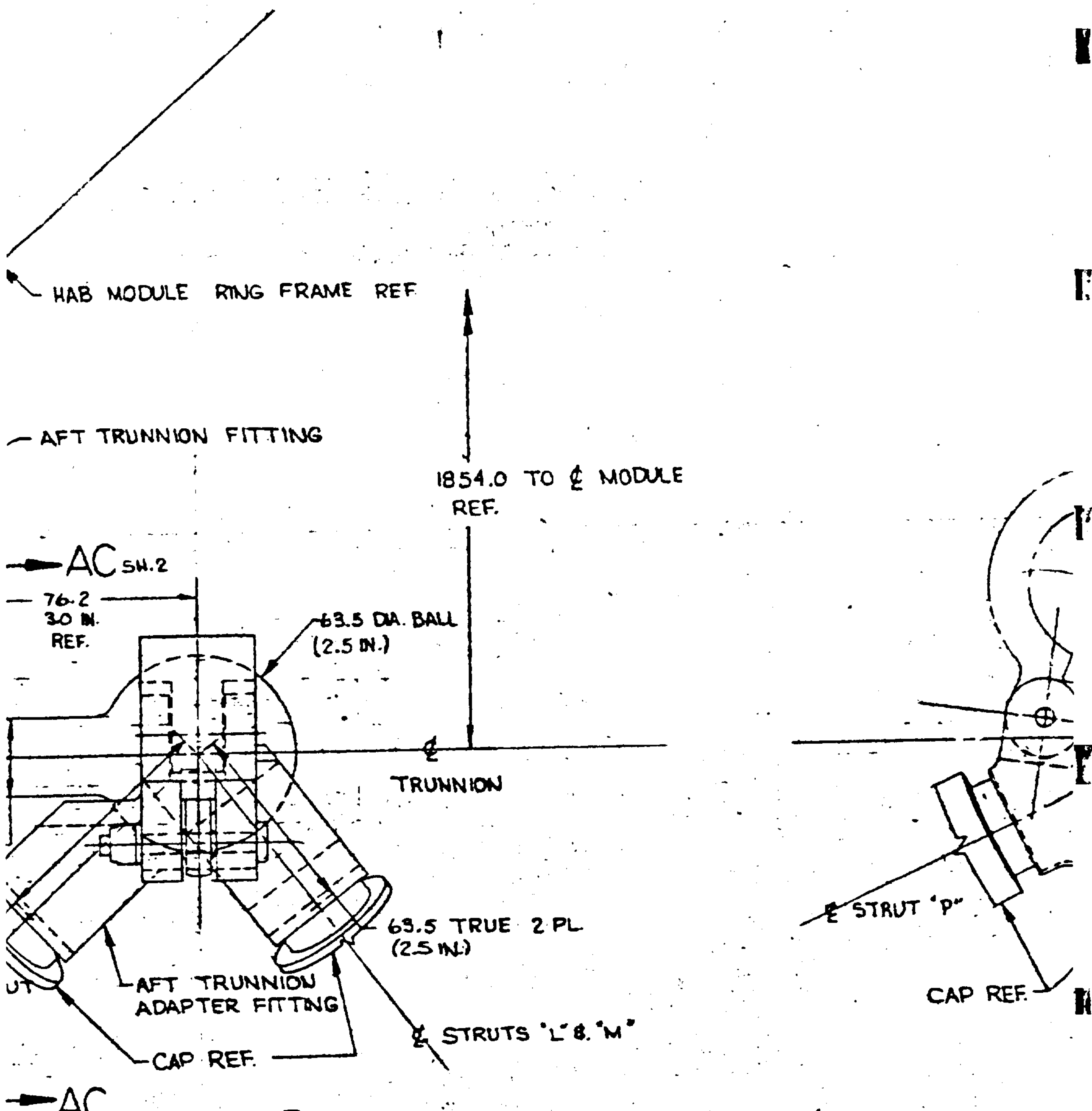


LAB MODULE RING FRAME
AFT TRUNNION FITTING
AB
1503.5 TO ₵ MODULE TYP.
( 59.2 IN.)
63.5 DIA. BALL
25.4 DIA.
(1.0 IN.)
₵ TRUNNION
CAP REF.
88.9 TRUE
(3.5 IN.)
CAP REF.
₵ STRUT "J"
63.5 TRUE
(2.5 IN.)
AFT TRUNNION ADAPTER FITTING
₵ STRUTS "K" & "I"
AB SH.2
VIEW Q SH. 1
VIEW LOOKING FORWARD
FOR
CONC

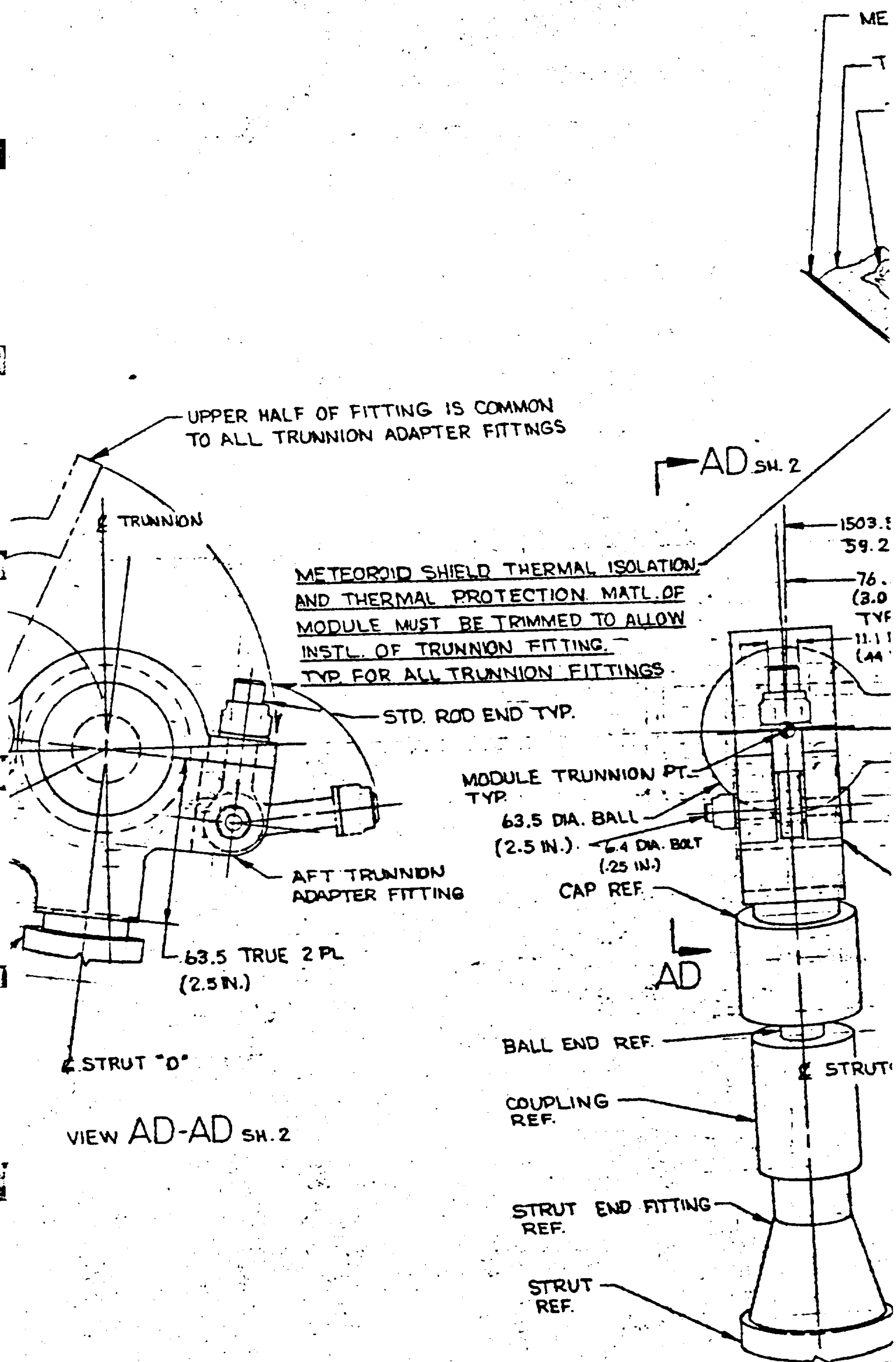



VIEW AC-AC SH. 2

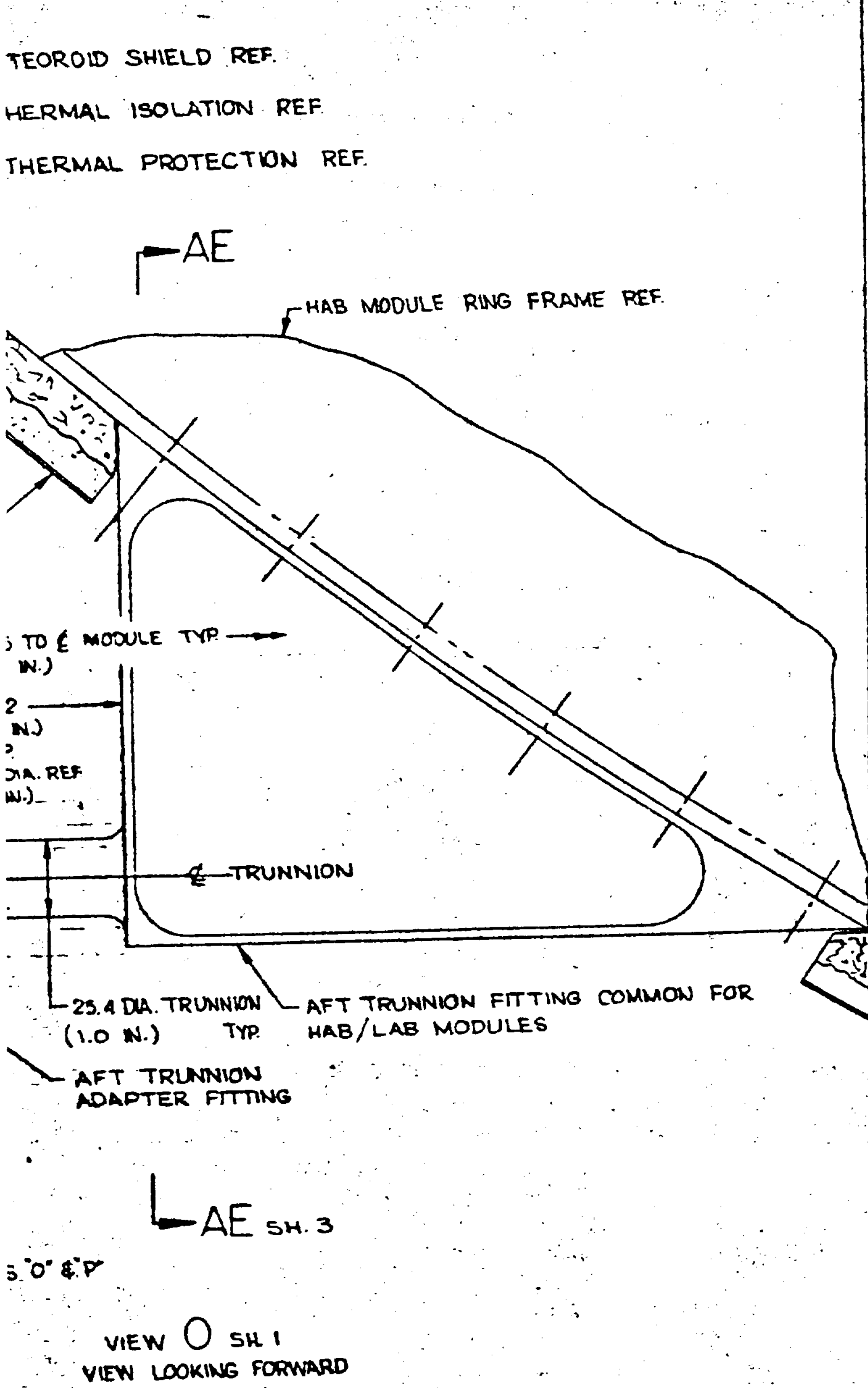
ALTERNATE TRUNNION ATTACH
EPT. SEE VIEW AF SH. 2




VIEW P SH.1
VIEW LOOKING FORWARD



ME
T
UPPER HALF OF FITTING IS COMMON
TO ALL TRUNNION ADAPTER FITTINGS
AD SH. 2
℄ TRUNNION
1503.5
59.2
METEOROID SHIELD THERMAL ISOLATION
AND THERMAL PROTECTION MATL. OF
MODULE MUST BE TRIMMED TO ALLOW
INSTL. OF TRUNNION FITTING.
TYP. FOR ALL TRUNNION FITTINGS
76.
(3.0
TYP
STD. ROD END TYP.
MODULE TRUNNION PT.
TYP.
63.5 DIA. BALL
(2.5 IN.)
6.4 DIA. BOLT
(.25 IN.)
CAP REF.
AFT TRUNNION
ADAPTER FITTING
63.5 TRUE 2 PL
(2.5 IN.)
AD
BALL END REF.
℄ STRUT "D"
℄ STRUT
COUPLING
REF.
VIEW AD-AD SH. 2
STRUT END FITTING
REF.
STRUT
REF.

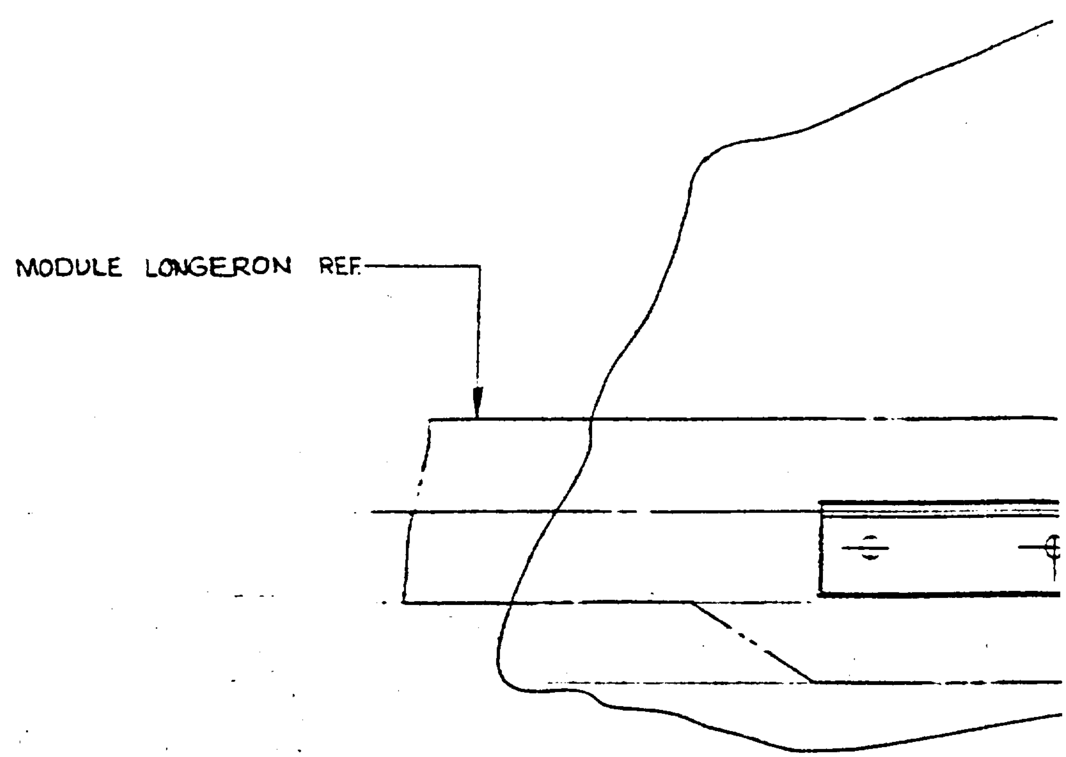


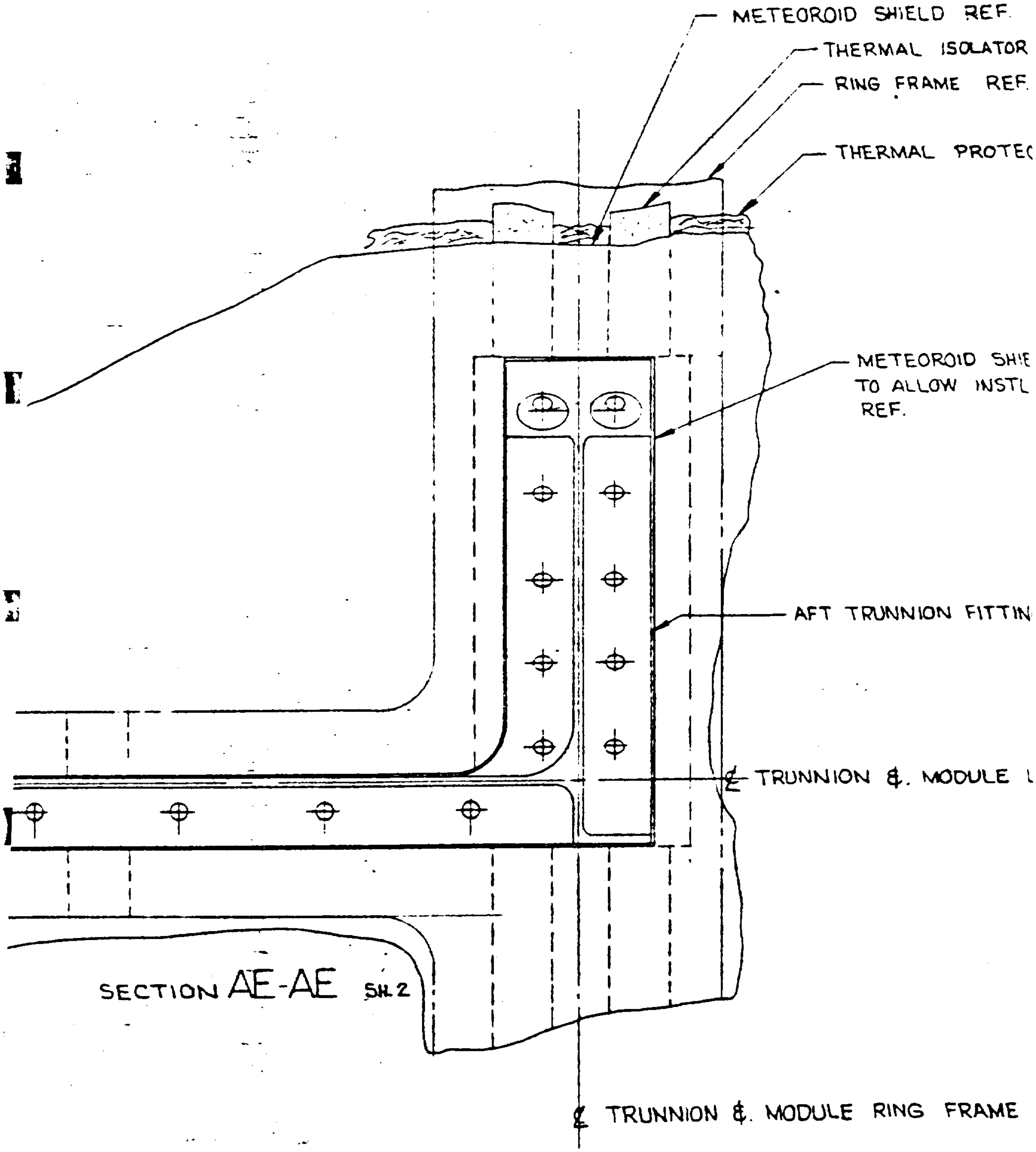

-B24-

B.R. ZOBEL
9-24-86

MODULE ATTACH CONCEPTS -
5 METER ERECTABLE TRUSS,
GO 41801

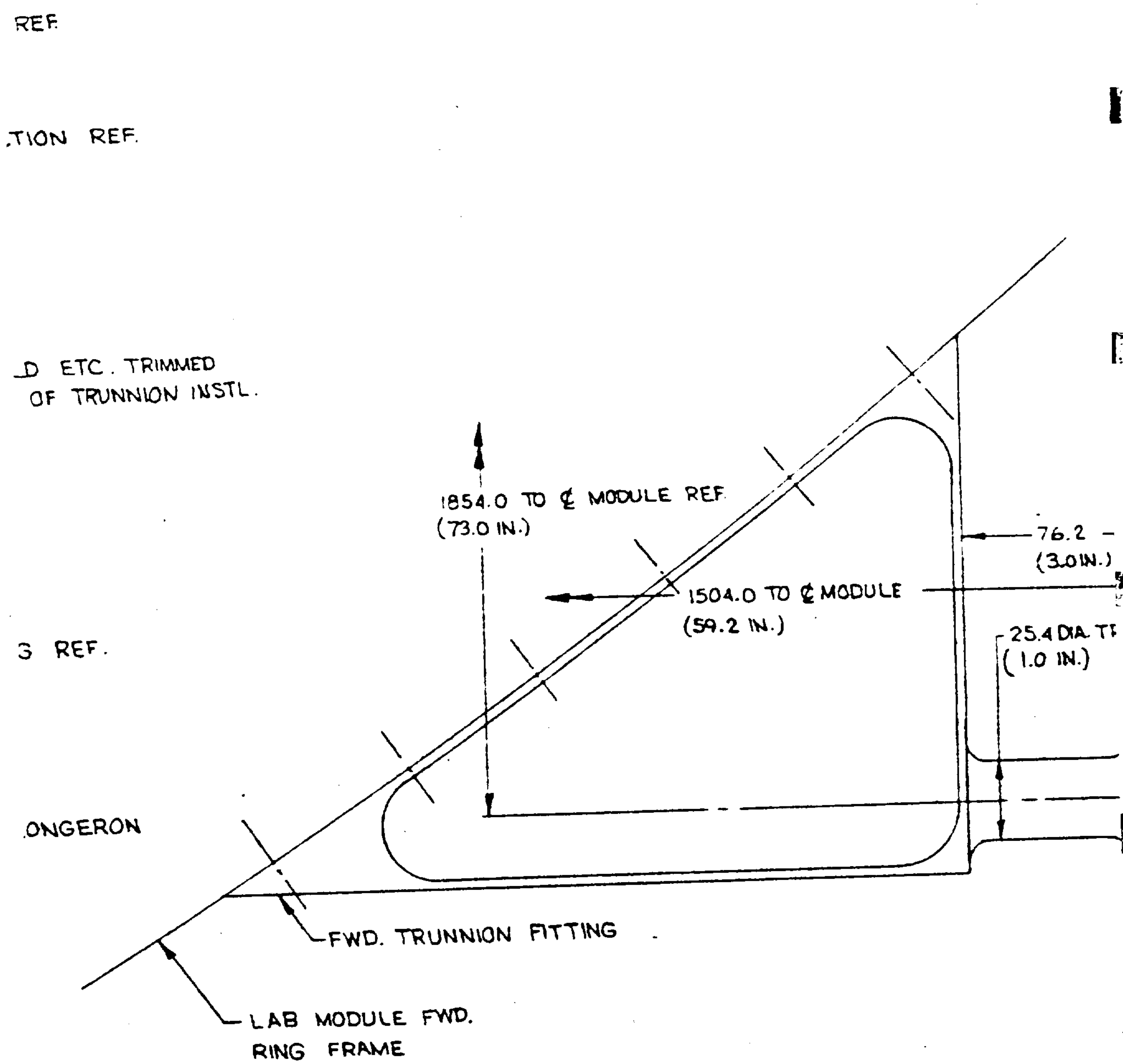
84321-449
SHEET 2


MODULE LONGERON REF

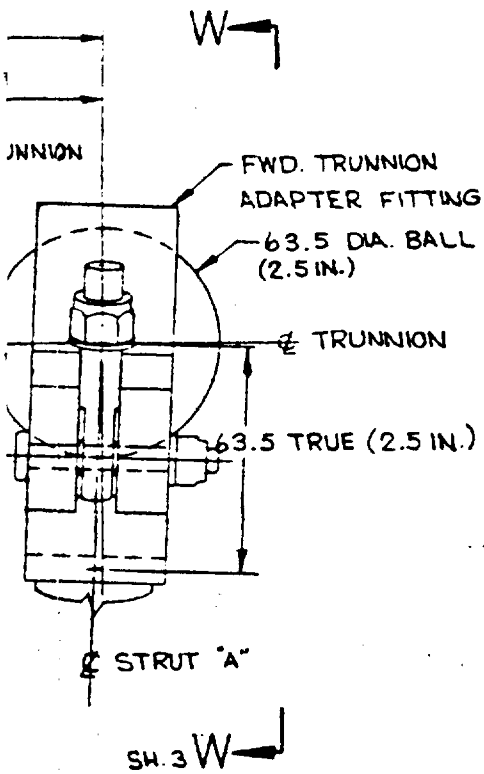


METEOROID SHIELD REF.
THERMAL ISOLATOR
RING FRAME REF.
THERMAL PROTEC
METEOROID SHIE
TO ALLOW INSTL
REF.
AFT TRUNNION FITTIN
℄ TRUNNION & MODULE
SECTION AE-AE SH.2
℄ TRUNNION & MODULE RING FRAME

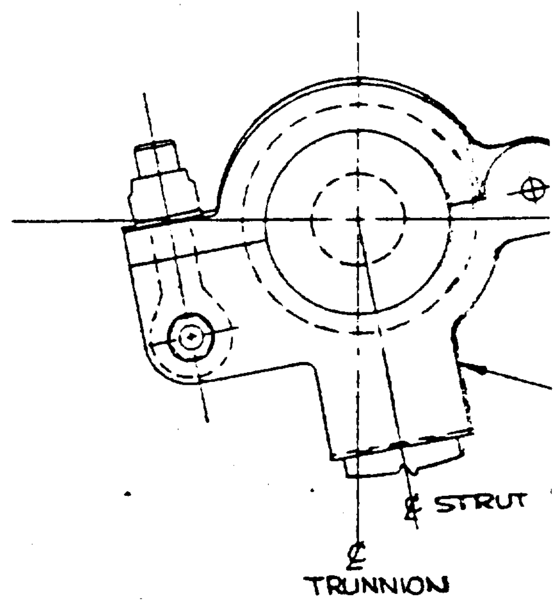
4



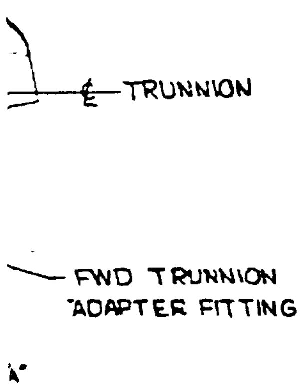

VIEW V
VIEW LOOKING

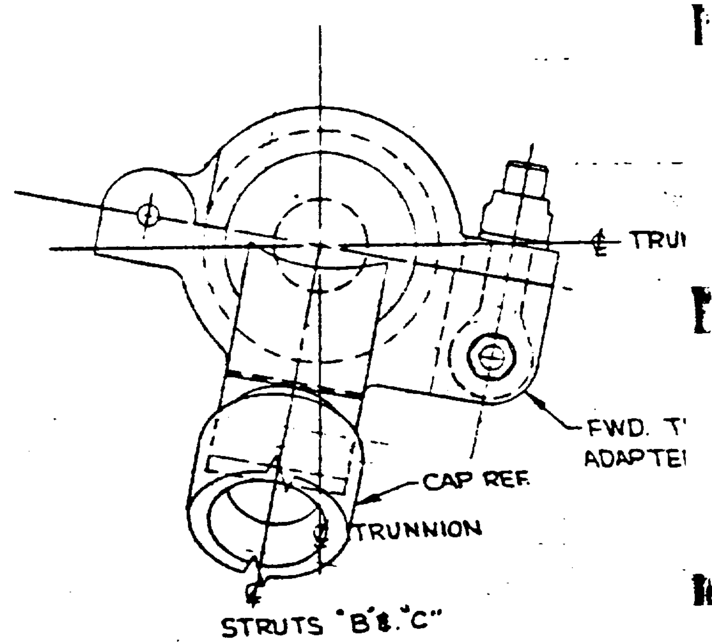



SH. 1
AFT

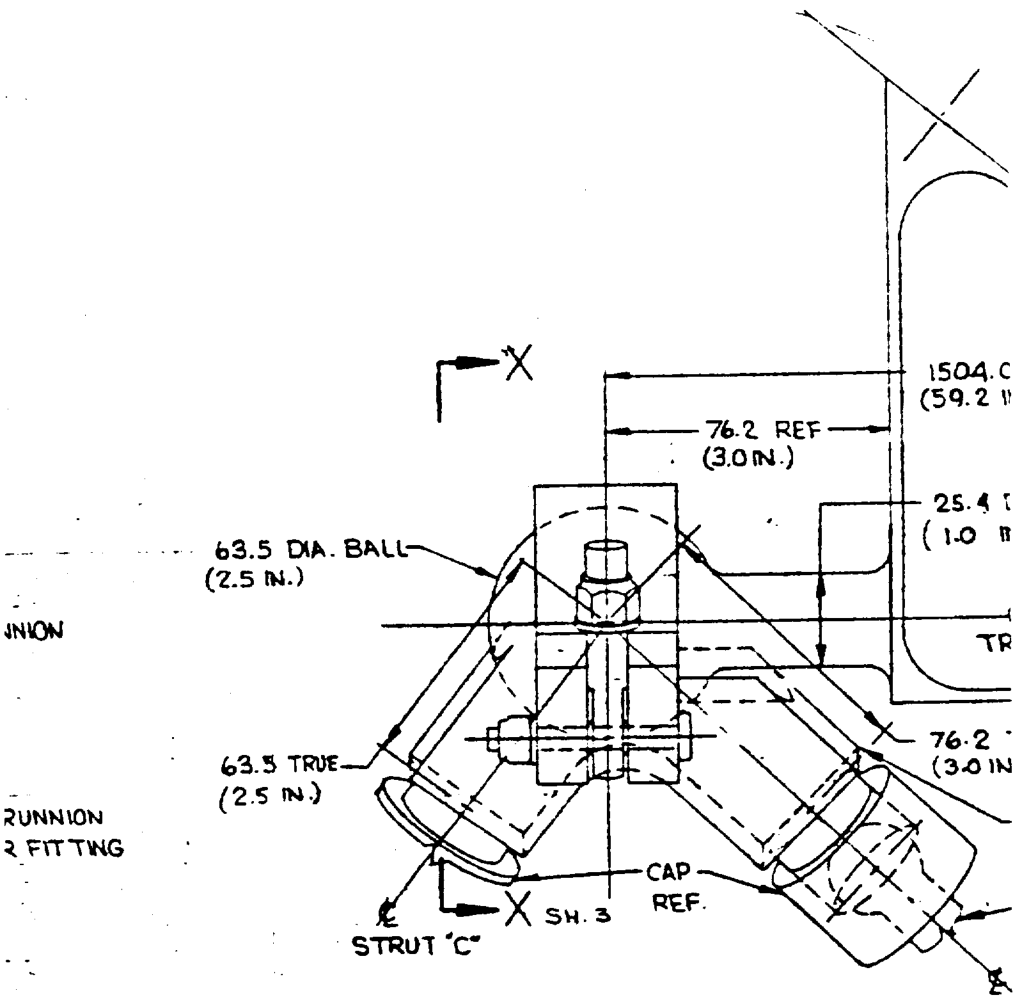



VIEW W-W SH. 3

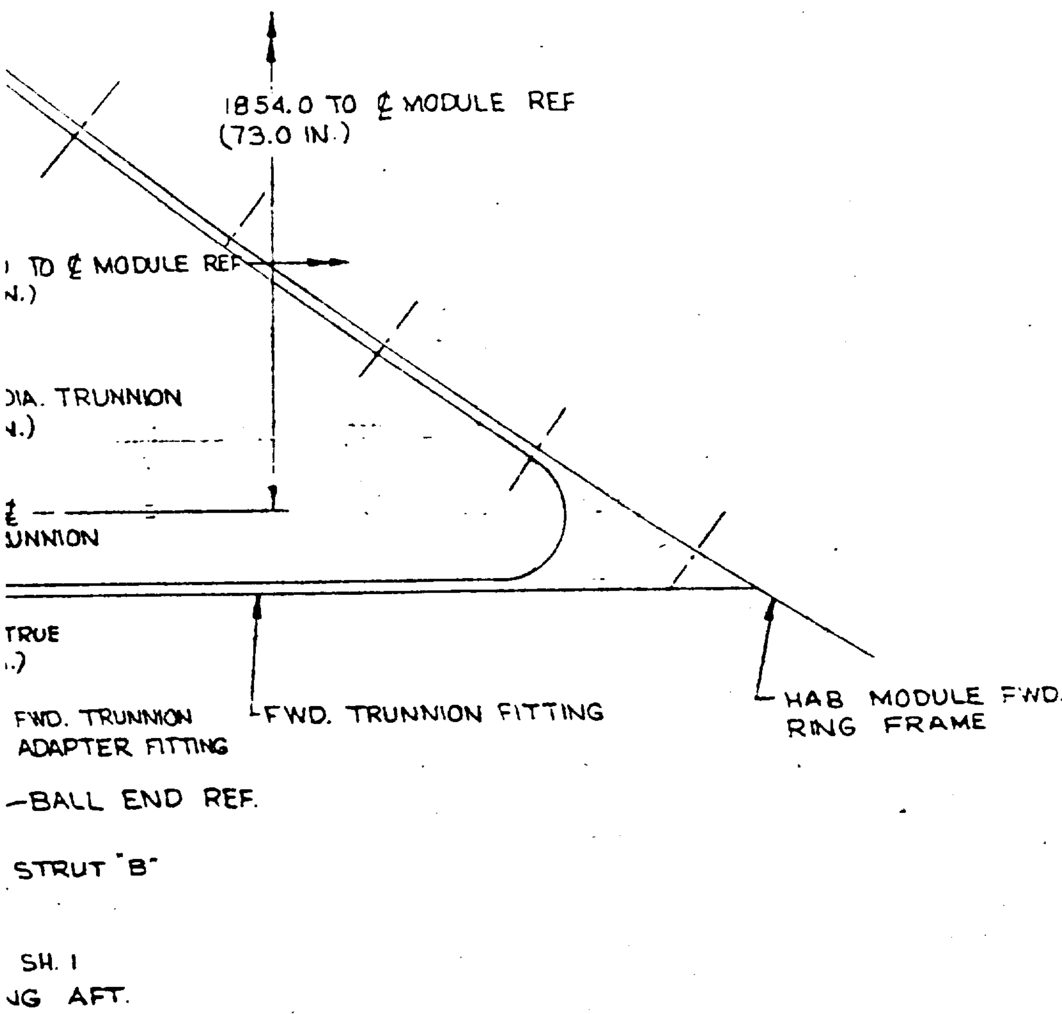

TRUNNION
FWD TRUNNION
ADAPTER FITTING


TRU
FWD. T
ADAPTE
CAP REF.
TRUNNION
STRUTS "B" & "C"

VIEW X-X SH. 3




VIEW U
VIEW LOOKI





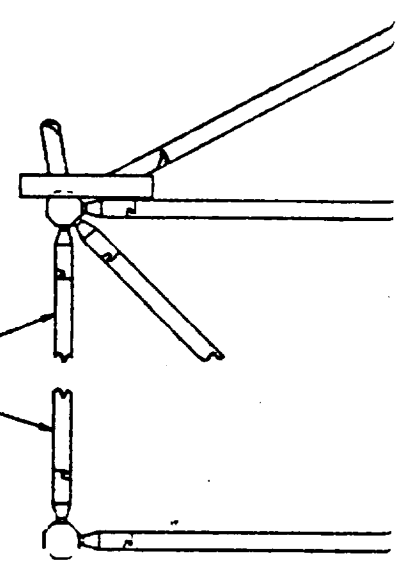

1/1 B. H.ZOBEL 9-24-86

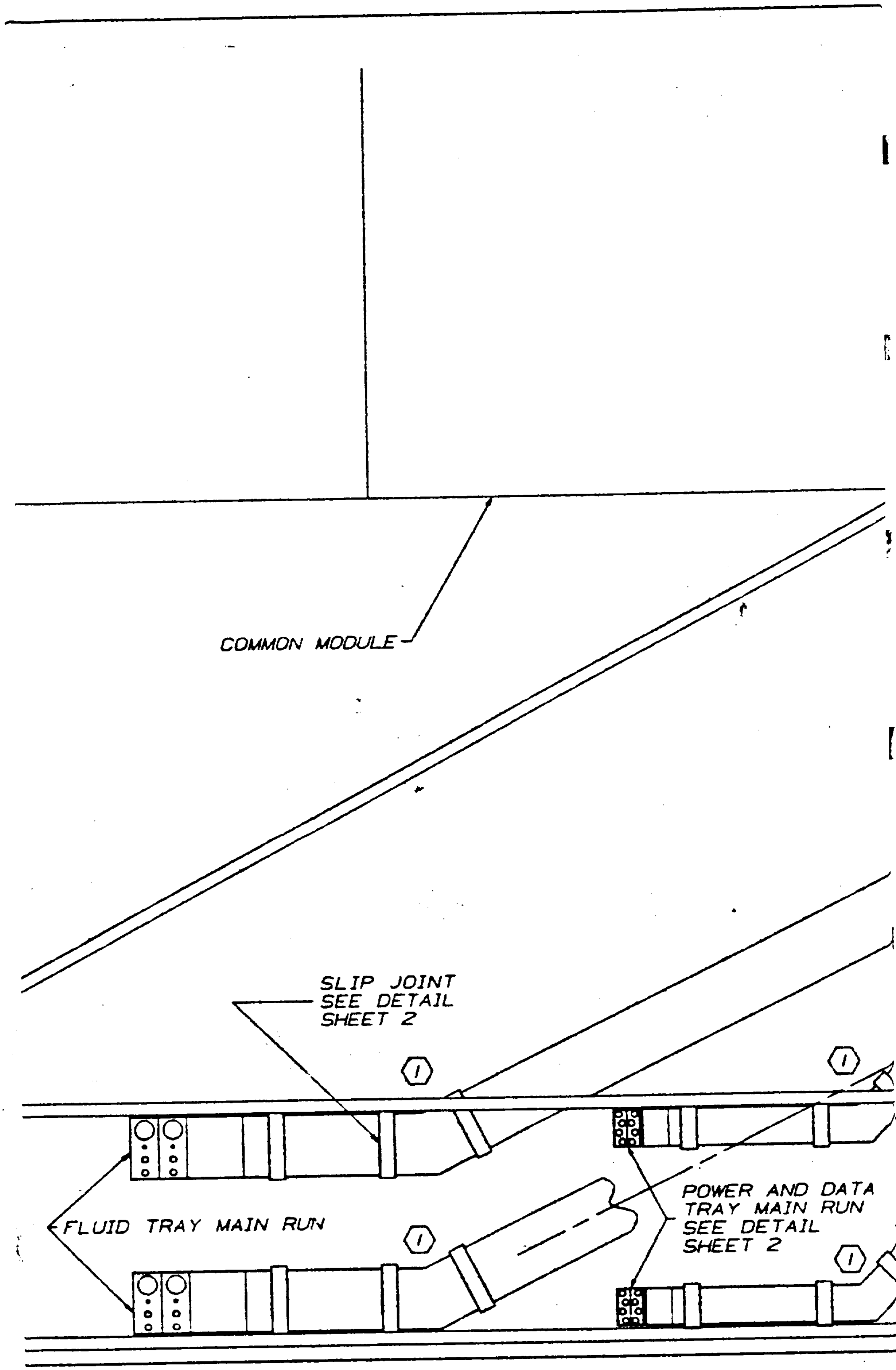
MODULE ATTA
5 METER EREC
GO 41801

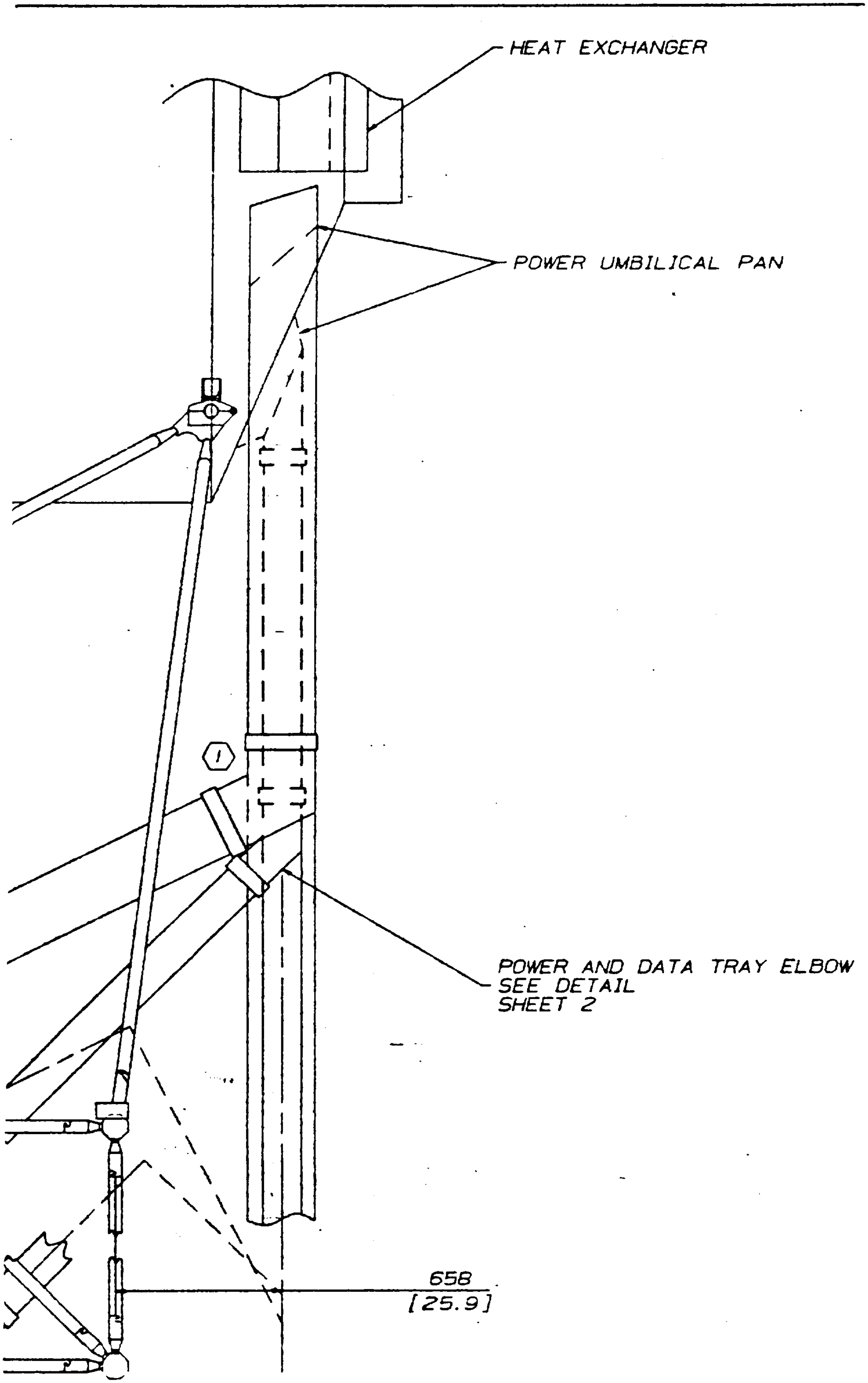
| | |
|---|---|
| ZOBEL<br>24-86 | Rockwell International |
| E ATTACH CONCEPTS-<br>ER ERECTABLE TRUSS,<br>01 | 84325-449<br>SHEET 3 |

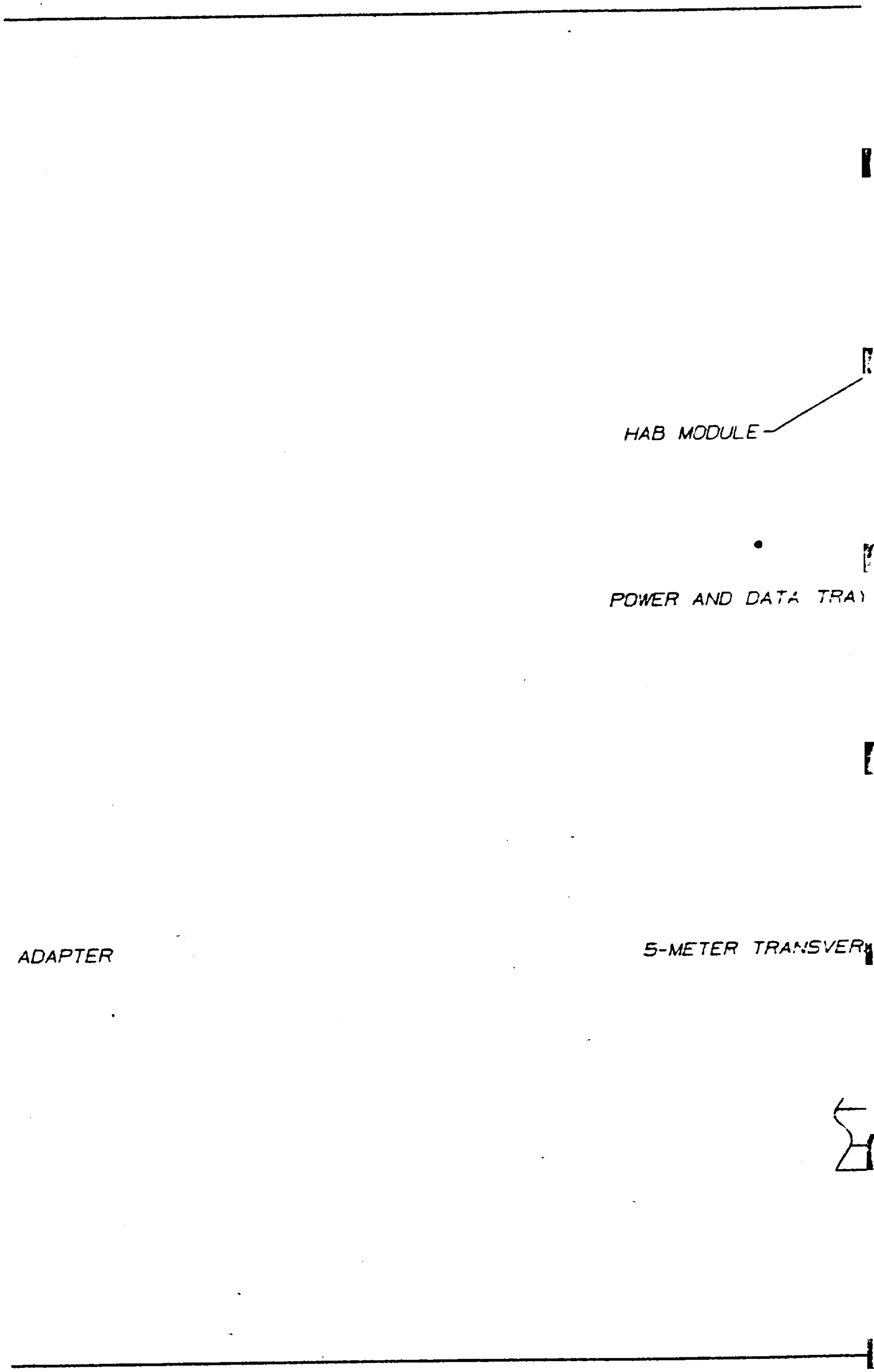
Utility Routing Concept, Module-to-5-Meter Truss

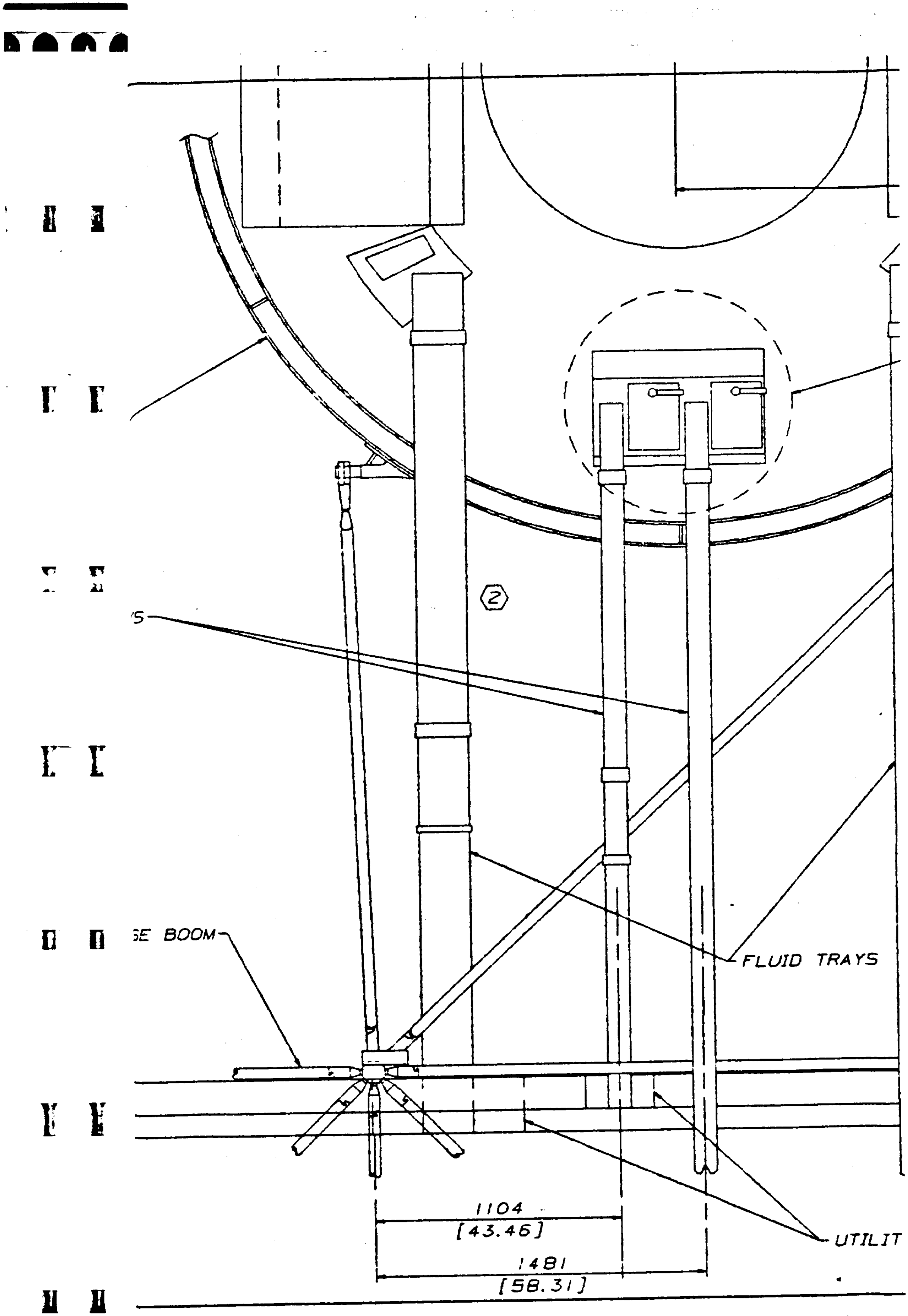
Drawing 29070-001


5-METER TRANSVERSE BOOM

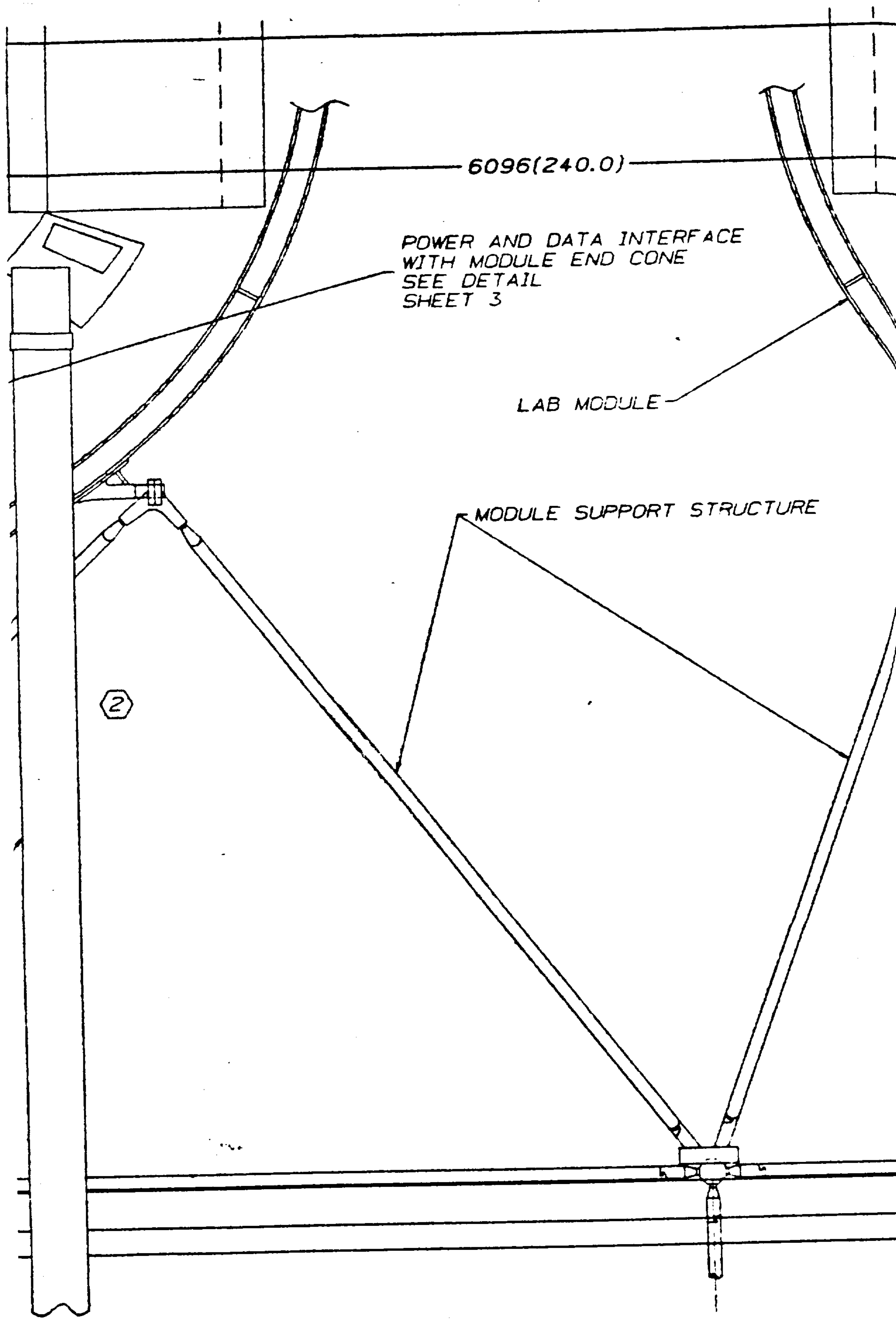

COMMON MODULE
SLIP JOINT
SEE DETAIL
SHEET 2
1
FLUID TRAY MAIN RUN
POWER AND DATA
TRAY MAIN RUN
SEE DETAIL
SHEET 2


HEAT EXCHANGER
POWER UMBILICAL PAN
1
POWER AND DATA TRAY ELBOW
SEE DETAIL
SHEET 2
658
[25.9]


HAB MODULE
POWER AND DATA TRA
ADAPTER
5-METER TRANSVER

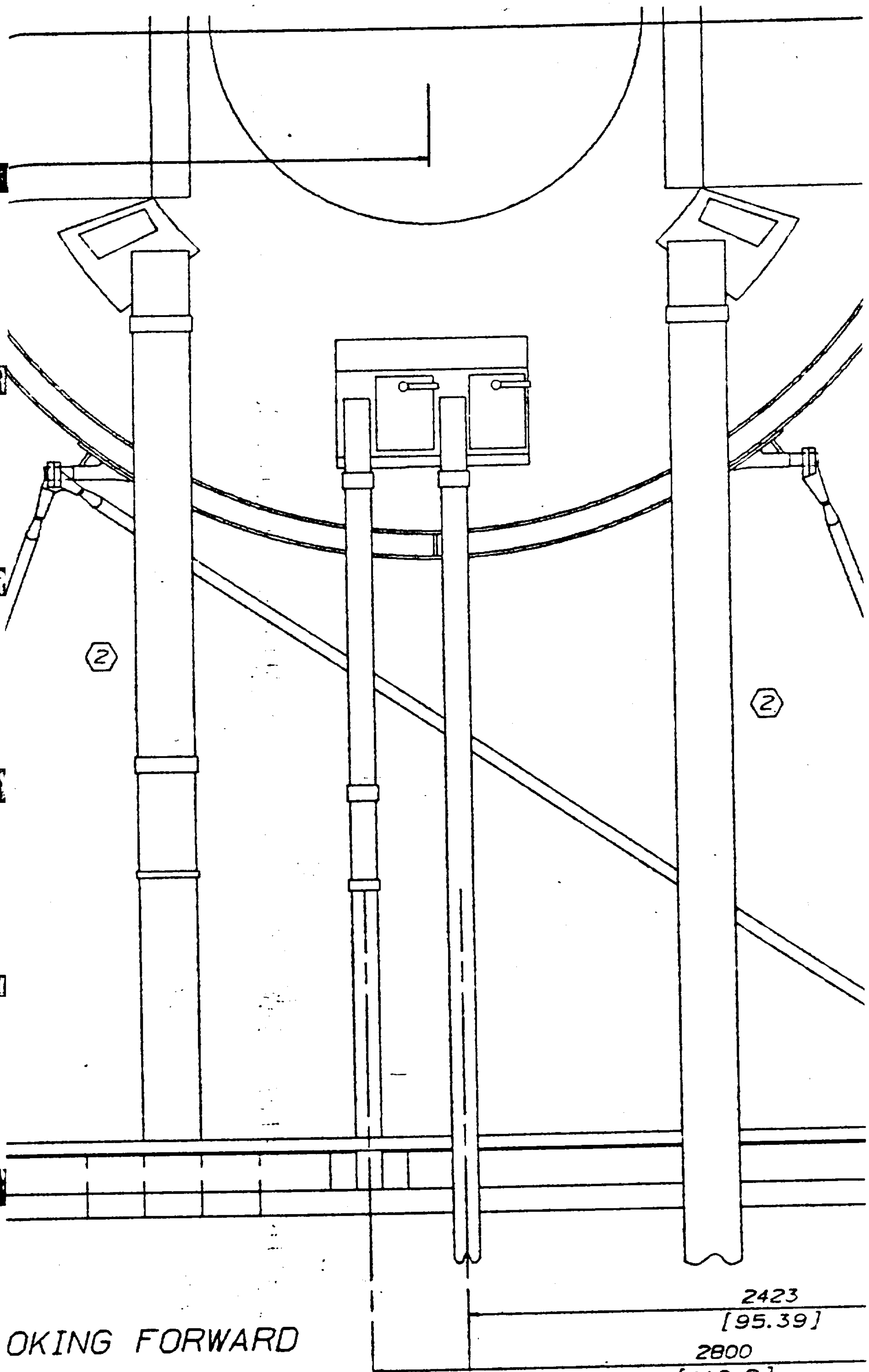


⟨2⟩
YS
SE BOOM
FLUID TRAYS
UTILIT
1104
[43.46]
1481
[58.31]



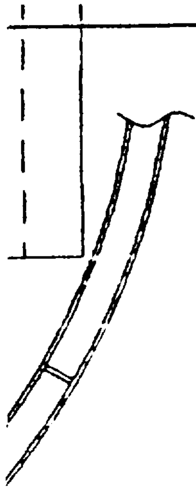

TY TRAY TEE ADAPTER

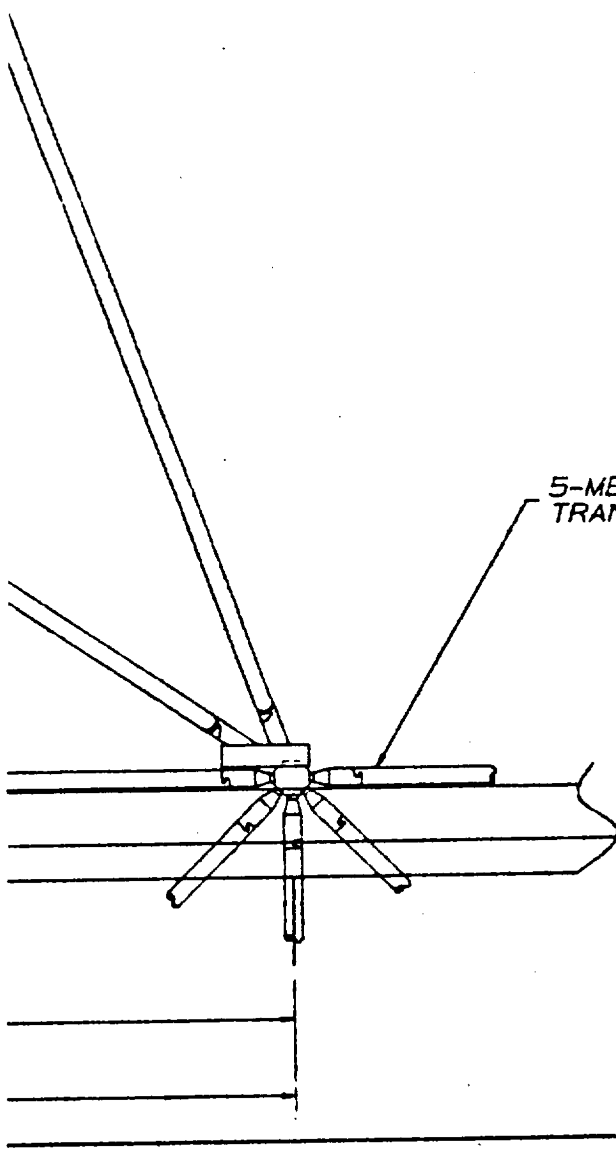
VIEW LC
SCALE




OKING FORWARD

: 1/10






NOTES: UNLESS OTHERWISE

10. SIZE AND LOCA
LOCATION OF F

9. UTILITY TRAY E
MAIN UTILITY

8. LOCATION OF U
FUTURE SPACE

7. THE ENTIRE UTI
PAYLOAD BAY D
ANGLES SHOWN.
FLUID LINES W

6. ALL ALUMINUM S

5. SHEET METAL C
ALUMINUM ALLO

4. CORNER RADII

3. SHARP EDGES

2. DIMENSIONS AN

1. ALL DIMENSIONS
BY THE VALUE

10. SIZE AND LOCATION OF HEAT EXCHA
LOCATION OF FLUIDS TRAYS DEPENI

9. UTILITY TRAY ELBOW ADAPTER ANGLI
MAIN UTILITY RUNS.

8. LOCATION OF UTILITY MAIN RUNS O.
FUTURE SPACE STATION DESIGN ST

7. THE ENTIRE UTILITY TRAY CAN BE
PAYLOAD BAY DURING LAUNCH AND
ANGLES SHOWN. ELECTRICAL AND
FLUID LINES WILL BE INSTALLED C

6. ALL ALUMINUM SURFACES SHALL BE

5. SHEET METAL CONSTRUCTION USING
ALUMINUM ALLOY UNLESS OTHERWISE

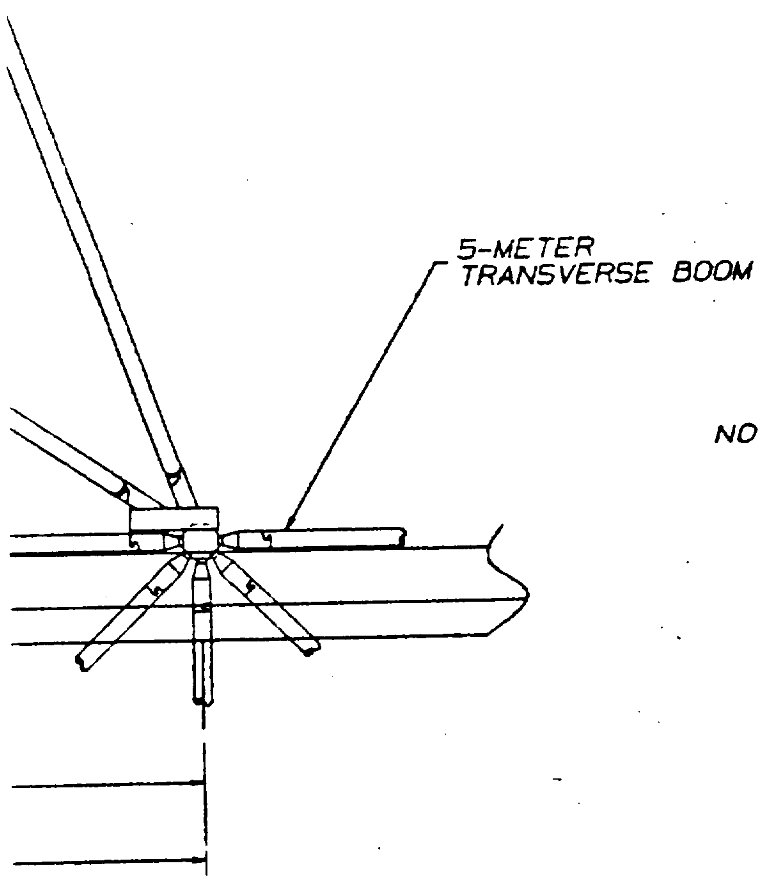
4. CORNER RADII 6.4 (0.25)

3. SHARP EDGES ROUNDED 0.25 (0.01

2. DIMENSIONS AND TOLERANCES PER

1. ALL DIMENSIONS ARE IN MILLIMETE
BY THE VALUE IN INCHES.

NOTES: UNLESS OTHERWISE SPECIFIED



NGER NOT KNOWN AT THIS TIME.
DENT ON FINAL LOCATION.

ES DEPENDENT ON LOCATION OF

N TRUSS WILL BE DETERMINED IN
UDIES.

STORED FLAT ALONG THE ORBITER
POSITIONED ON ORBIT INTO THE
DATA LINES INSTALLED ON ORBIT.
N THE GROUND.

ANODIZED AND TEXTURIZED.

3 1.0 (0.040) THICK 6061-T6
E NOTED.

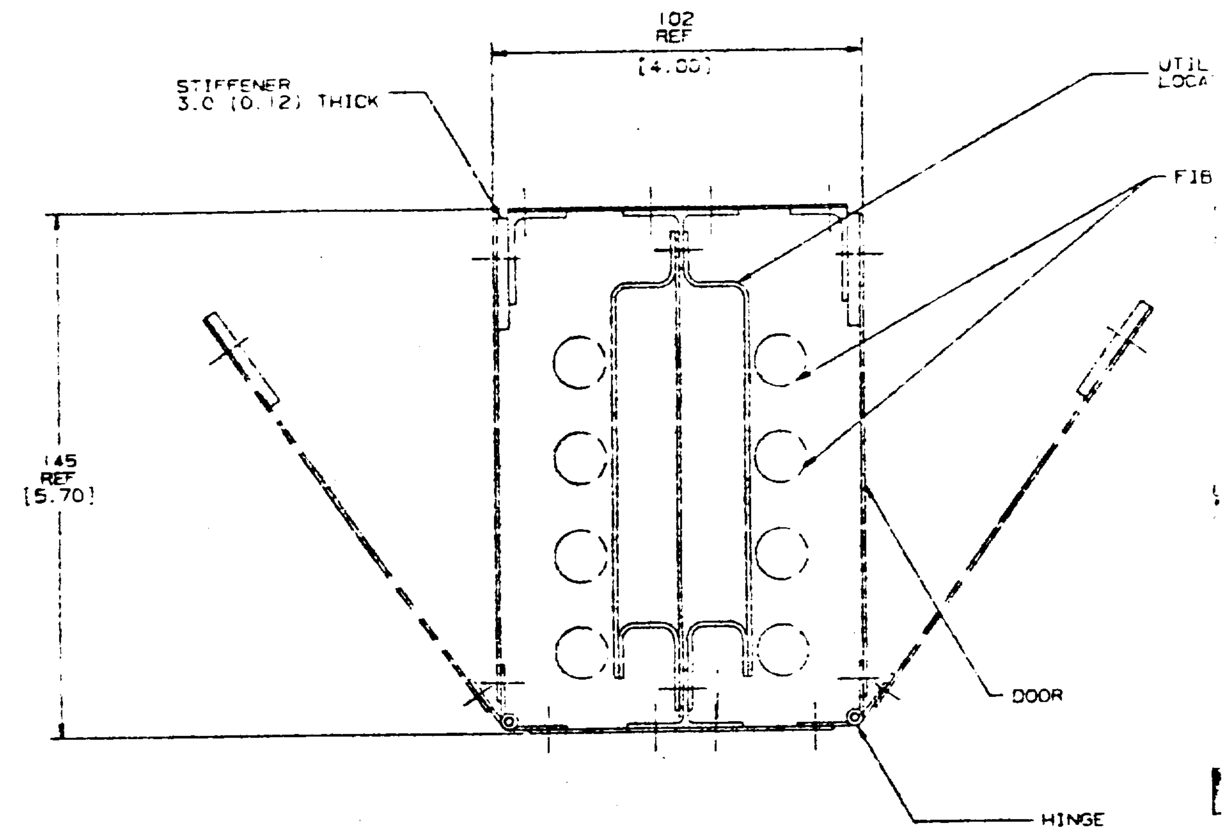
D)

ANSI Y14.5 - 1973

RS, FOLLOWED IN PARENTHESES

| | | | | |
|---|---|---|---|---|
| BY | RYAN PIERSON 7-29-86 | Rockwell International | Space Station Division 12214 Lakewood Boulevard Downey, CA 90241 | |
| BY | | UTILITY ROUTING CONCEPT, MODULES-TO-5 METER TRUSS | | |
| IGN | | | | |
| ESS | | | | |
| P | | | | |
| GHTS | | | | |
| RMAL | | | | |
| CT. | | DRAWING NO. | SHEET | REVISION |
| ES | | 29070-001 | 1 OF 3 | SCALE: NOTED |

2-29070-4182 -30000-100 CAD/CAM DCN-

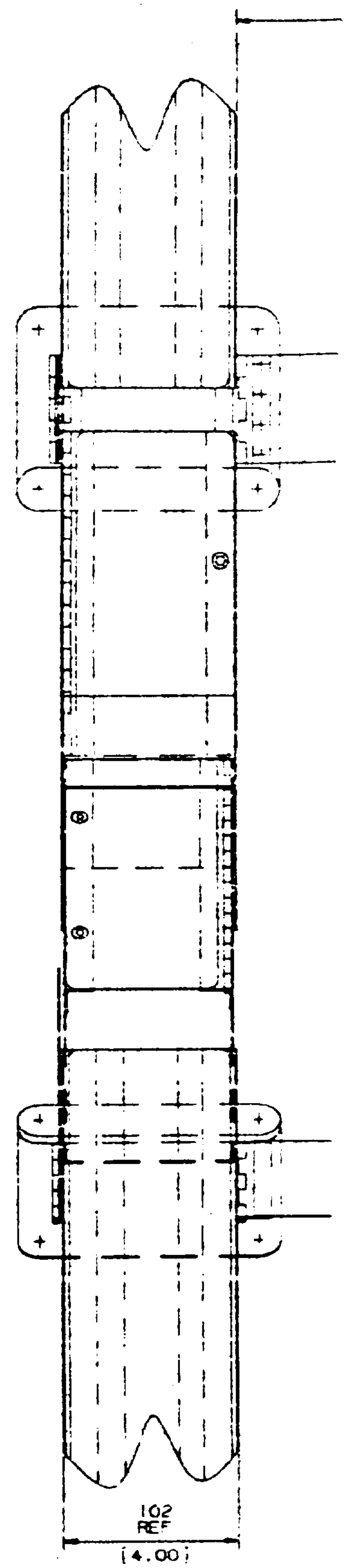


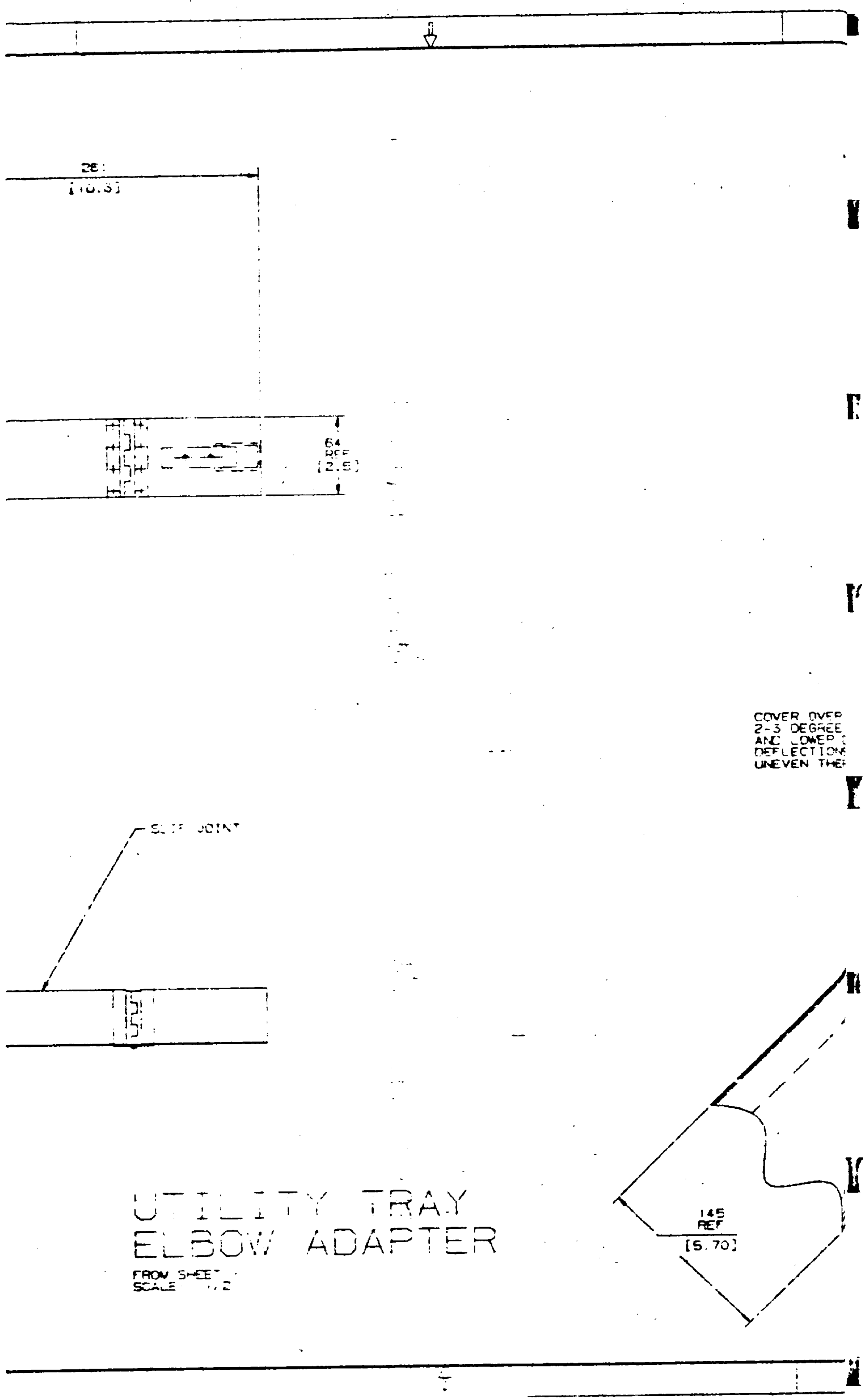

POWER AND DATA
MAIN RUN CROSS SECTIO

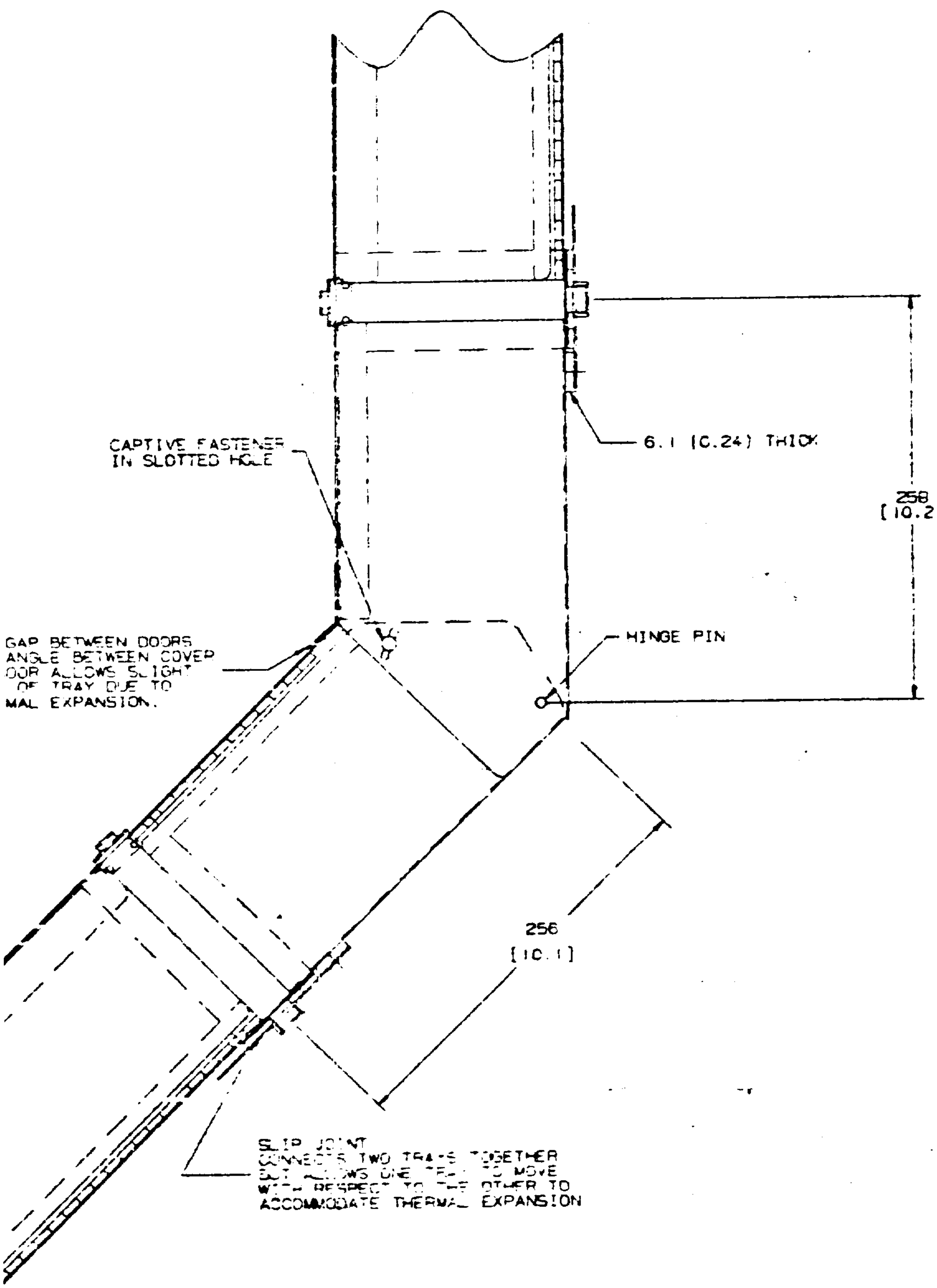
FROM SHEET 1
SCALE: FULL

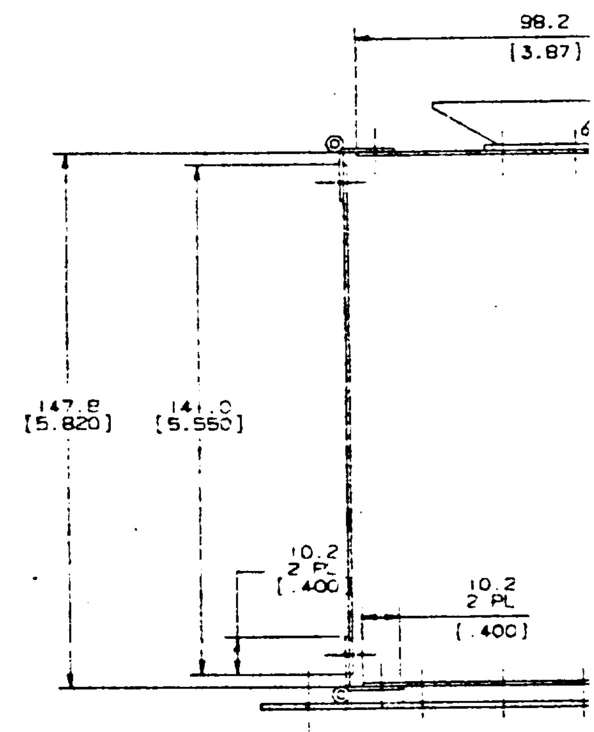
ITY LINE SUPPORT STRUCTURE
TED DISCRETELY

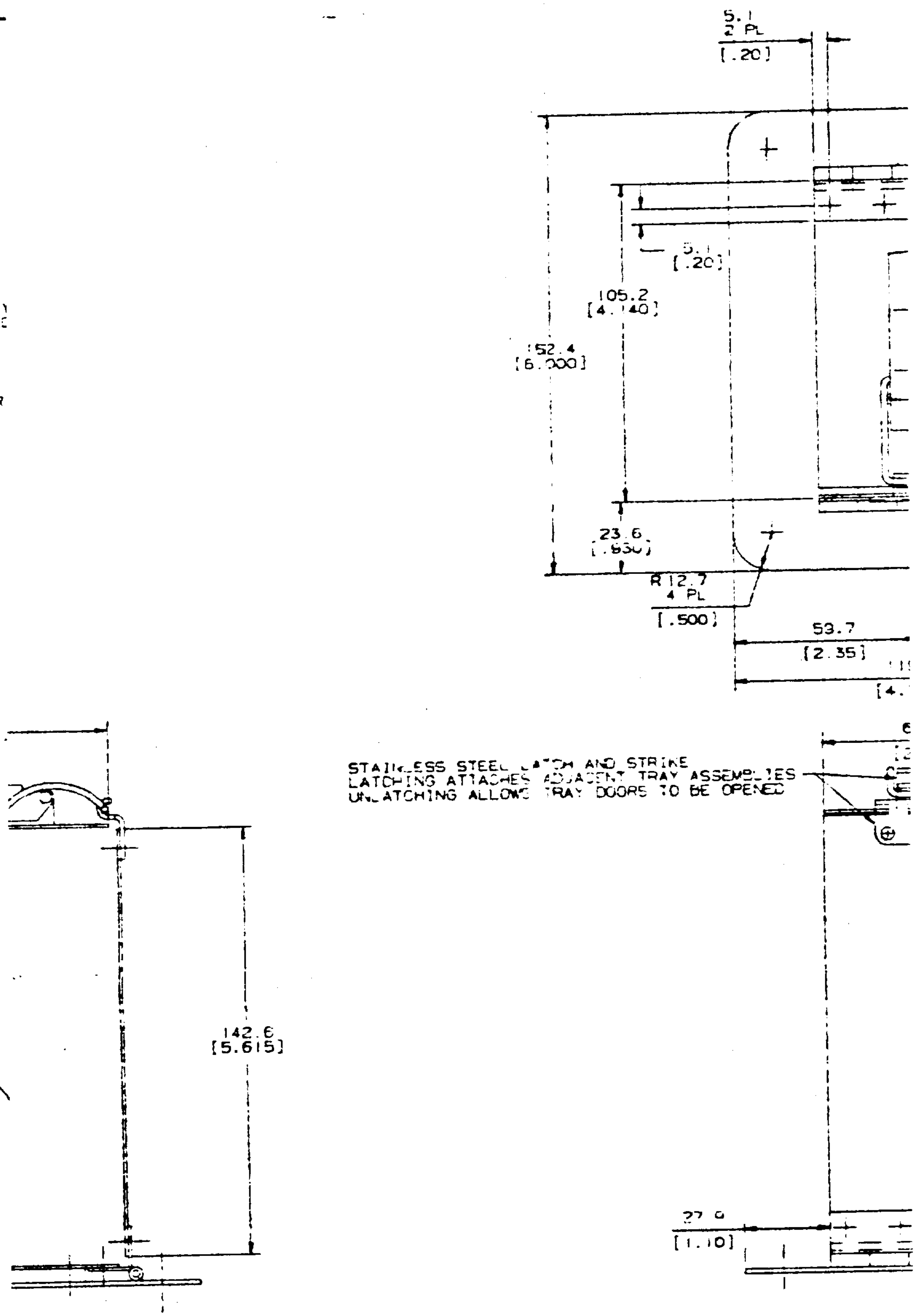
ER OPTIC BUNDLE OR POWER CABLE



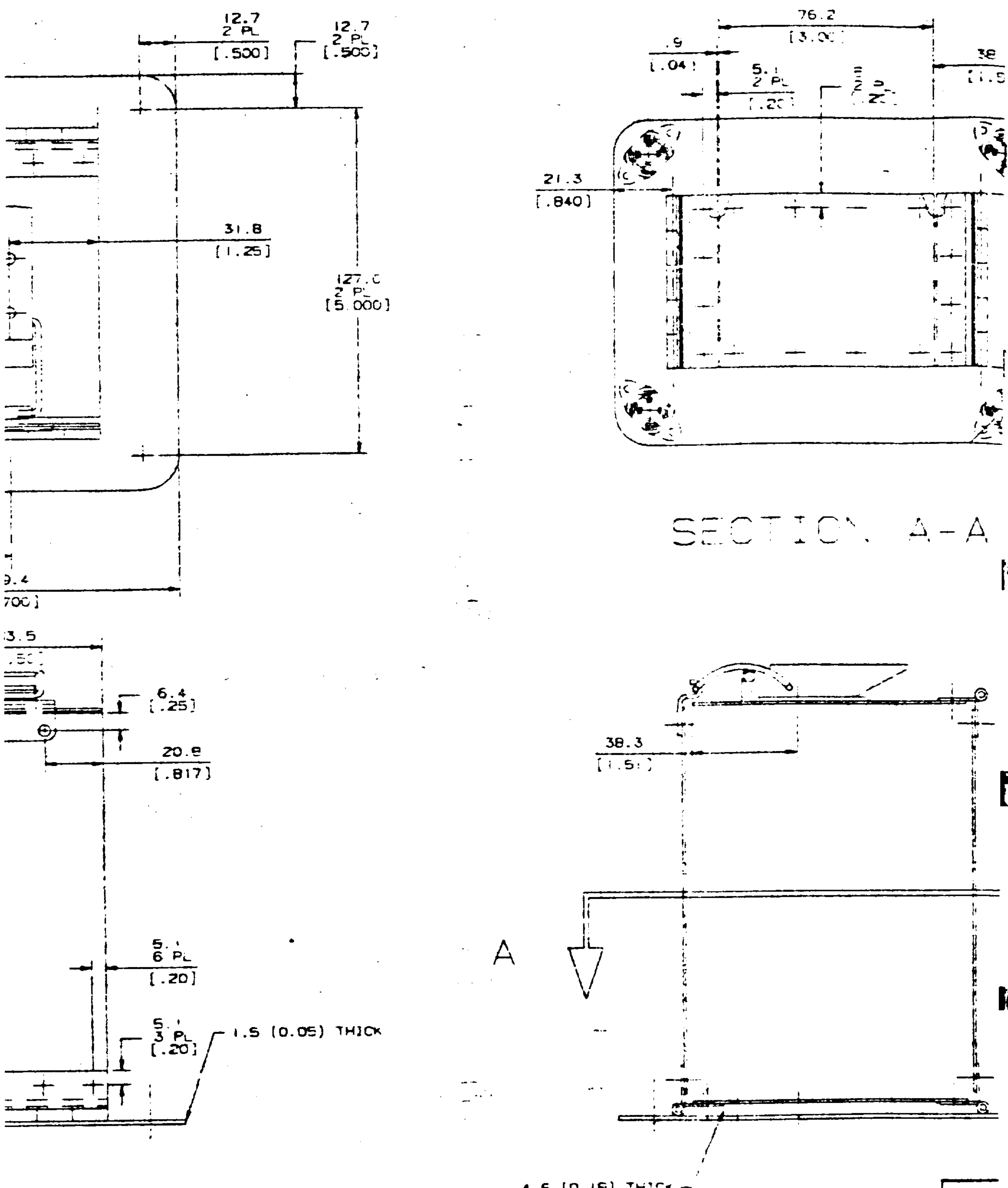

64
REF
[2.5]
COVER OVER
2-3 DEGREE
DEFLECTION
UNEVEN
145
REF
[5.70]
UTILITY TRAY
ELBOW ADAPTER
FROM SHEET
SCALE


CAPTIVE FASTENER
IN SLOTTED HOLE
6.1 (0.24) THICK
258
[10.2]
GAP BETWEEN DOORS
ANGLE BETWEEN COVER
DOR ALLOWS SLIGHT
OF TRAY DUE TO
MAL EXPANSION.
HINGE PIN
256
[10.1]
SLIP JOINT
ACCOMMODATE THERMAL EXPANSION


98.2
[3.87]
147.8
[5.820]
141.0
[5.550]
10.2
2 PL
[.400]
10.2
2 PL
[.400]

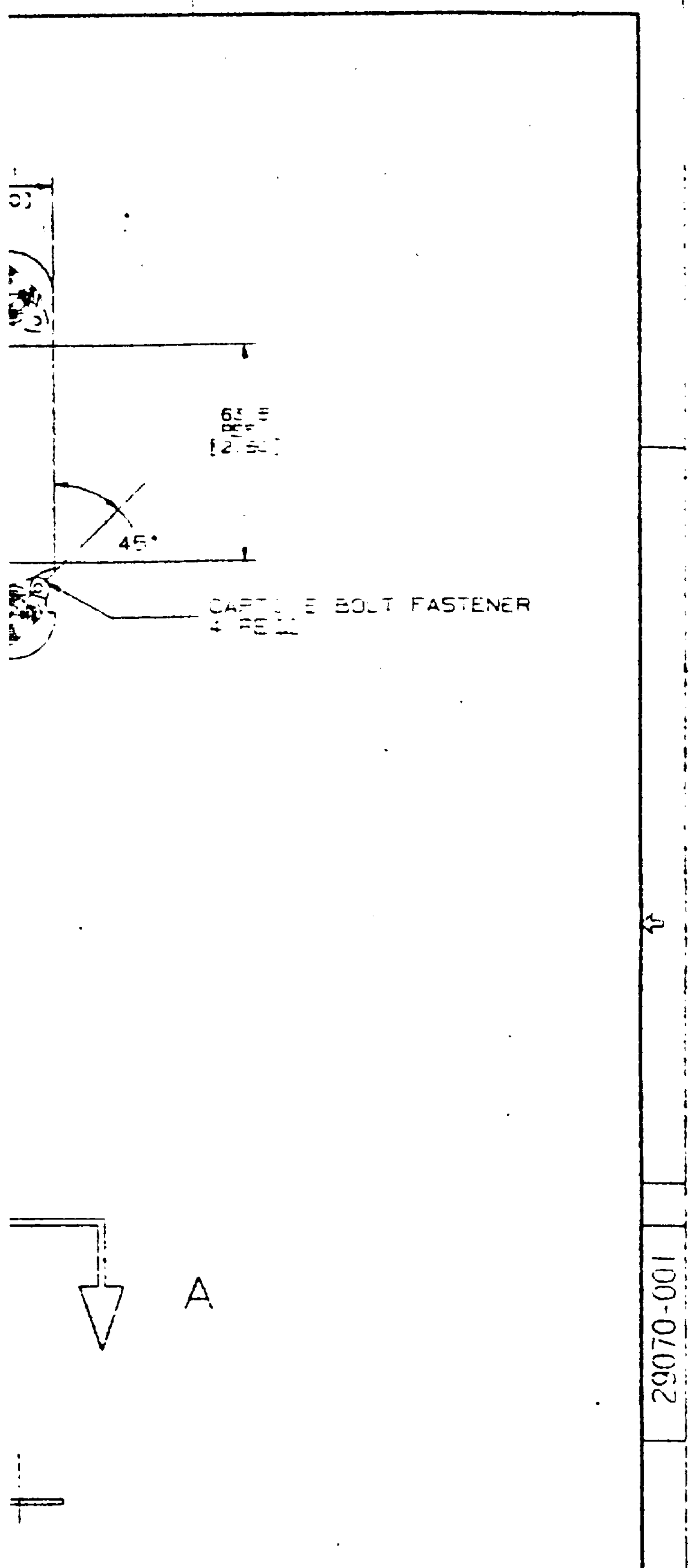



POWER AN
SLIP JOI
FROM SHEET
SCALE: FULL




D DATA TRAY
NT

-EZ3-




Rockwell International
Space Station Systems Division

RYAN PIERSON 10-02-86

APPROVED BY

UTILITY ROUTING CONCEPTS -
MODULES TO 5-METER TRUSS

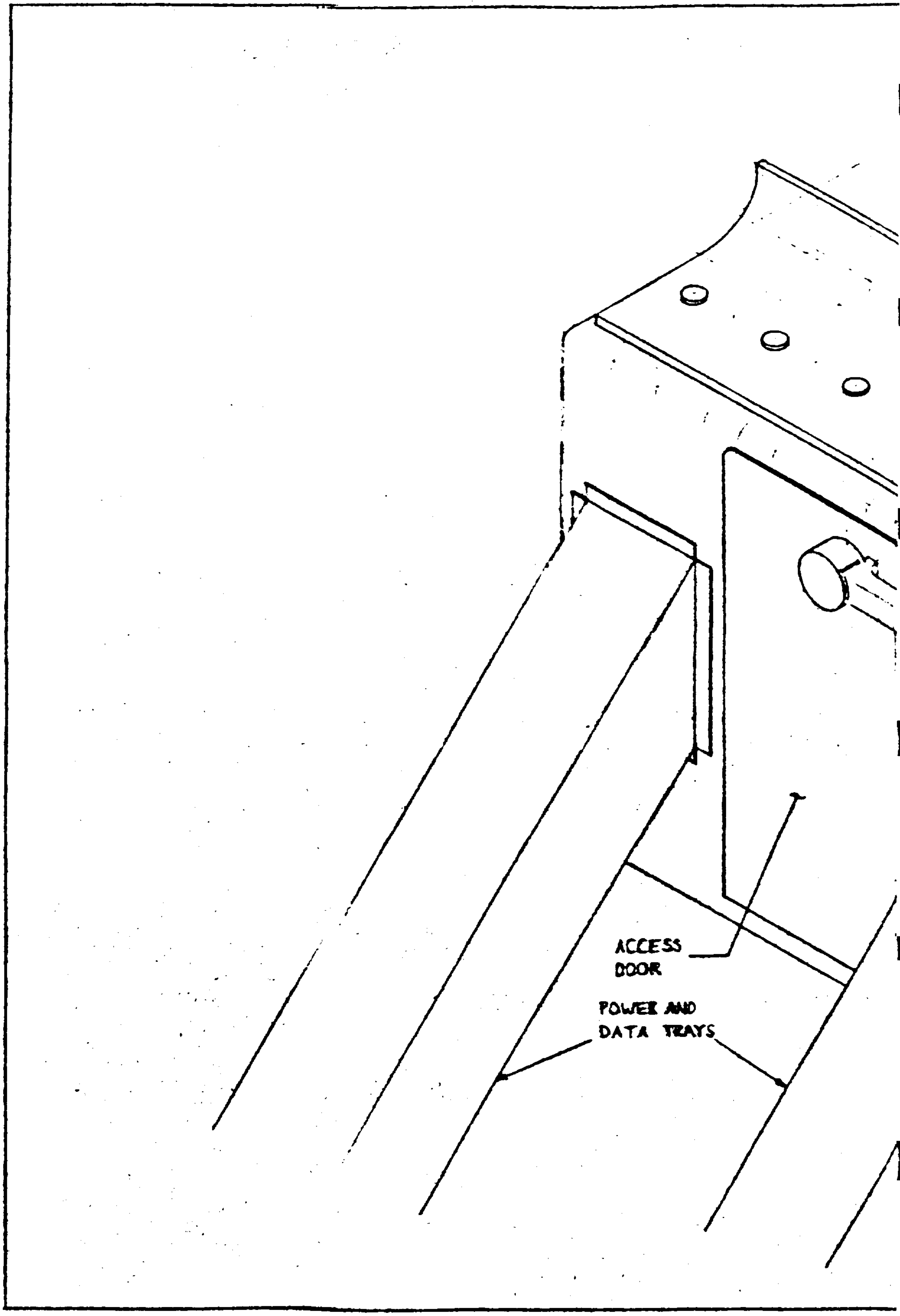
SIZE CODE IDENT NO. DRAWING NO.

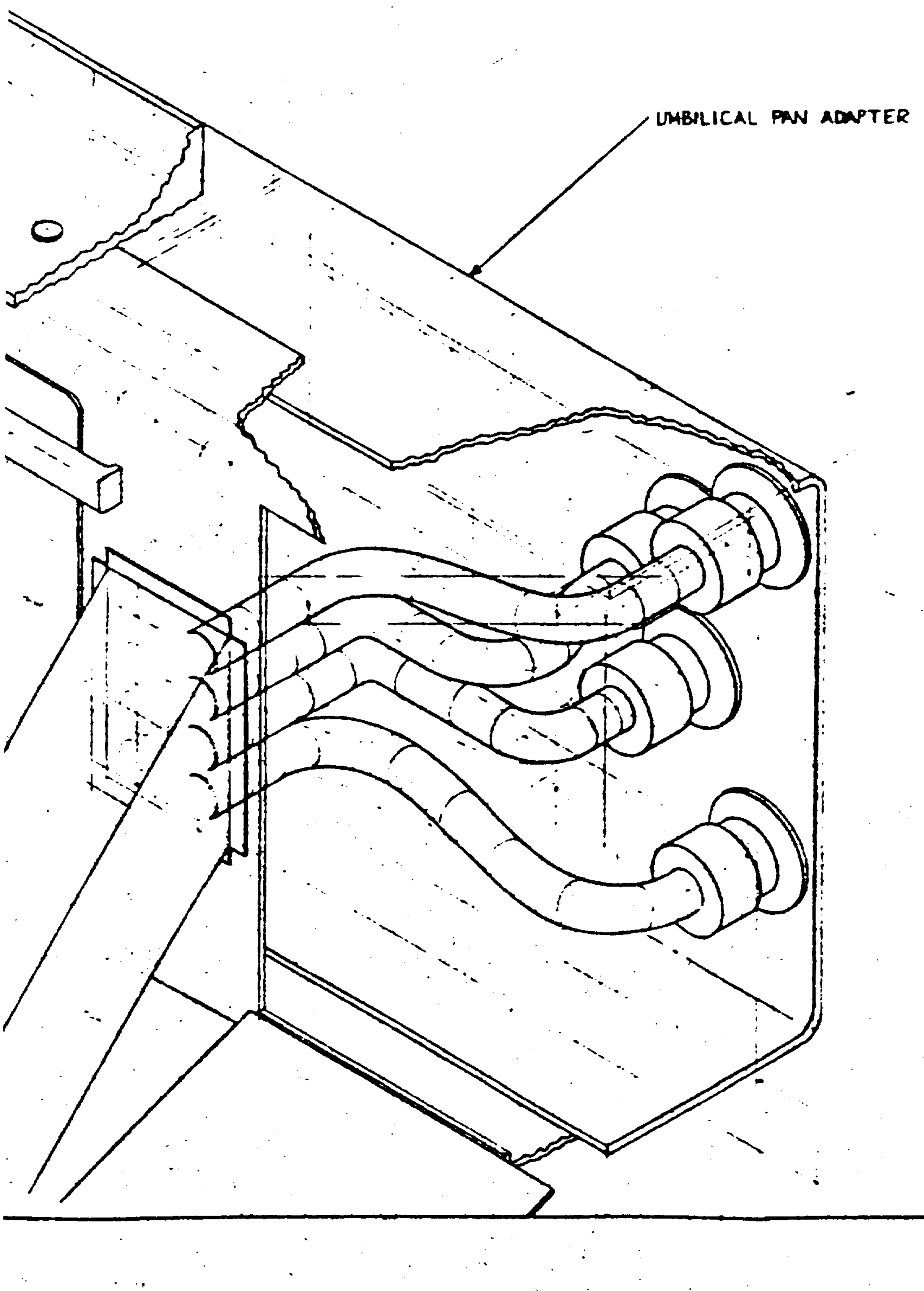
29070-001

SCALE

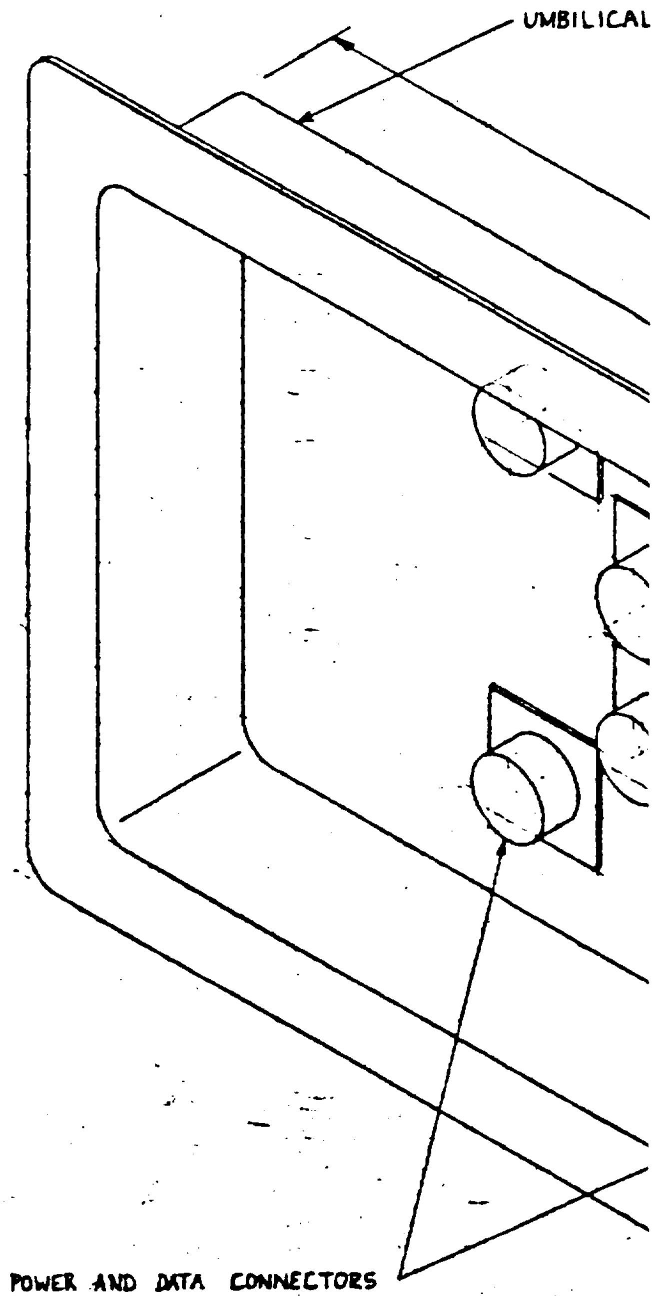
SHEET 2 OF 3

CAD/CAM


ACCESS DOOR
POWER AND DATA TRAYS



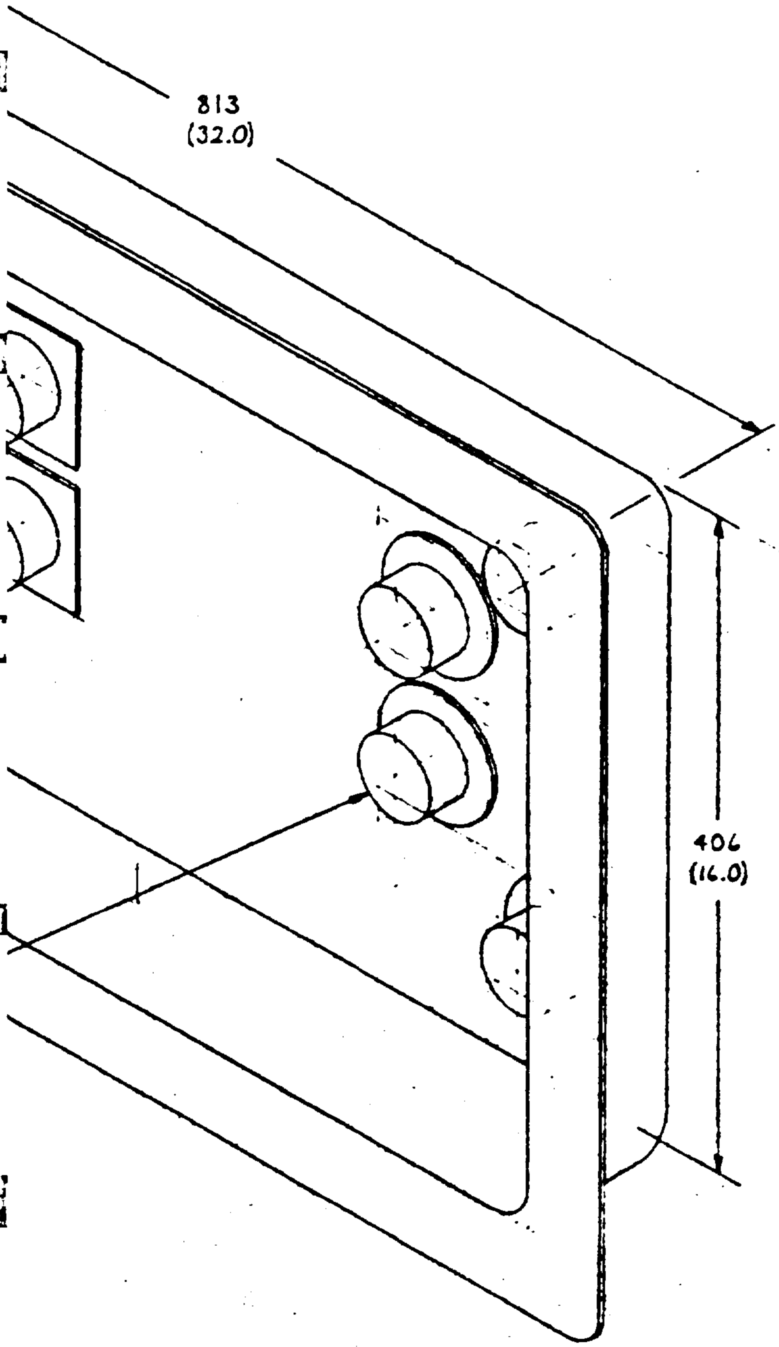

PC
FR(




)WER UMBILICAL ATTACHMENT DEVICE

)M SHEET I

PAN



| | | | |
|---|---|---|---|
| DR BY | T. MARINO | 9-15-8 | [illegible] Corporation<br>[illegible] Division<br>[illegible] |
| CHK BY | | | UTILITY ROUTING CONCEPTS-<br>MODULES TO 5-METER TRUSS |
| APPROVED BY | | | |
| | | CODE IDENT NO.<br>03953 | 29070-001 |
| | | SCALE [illegible] | SHEET 3 OF 3 |

B29-