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DESIGN, DEVELOPMENT, AND DEMONSTRATION OF AN EASY-FIX METHOD FOR RE-DEPLOYING DAMAGED TACTICAL SHELTERS

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This report documents a program which was conducted to design develop, and demonstrate a structural "Easy-Fix" system. This system could be used to evacuate structurally damaged non-operational tactical shelters using external helicopter airlift capabilities. Various concepts and material systems were evaluated, and a prototype Easy-Fix kit for an S-280 B/G tactical shelter was designed, fabricated, and tested to demonstrate the system concept.

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DESIGN, DEVELOPMENT AND DEMONSTRATION OF AN EASY-FIX METHOD FOR REDEPLOYING DAMAGED TACTICAL SHELTERS

PREFACE

The effort documented in this report was performed by the University of Dayton Research Institute (UDRI), Dayton, Ohio, 45469, under Contract F33615-85-C-5094, entitled, "Technical Support for Tactical Shelters," for the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio 45433. Air Force Administrative Direction and technical support was provided by Mr. Robert Urzi, AFWAL/MLS.

The work described herein was conducted during the period from January 1986 to March 1987. Project supervision was provided through the Materials Engineering Division of the University of Dayton Research Institute with Mr. Dennis Gerdeman, Supervisor. Mr. D. Robert Askins was the Project Engineer directing the overall activities. Technical effort was accomplished by Mr. D. R. Bowman, Applied Mechanics Group, Aerospace Mechanics Division. The author wishes to acknowledge the significant contributions of B. S. West, UDRI, G. J. Stenger, UDRI, T. J. Helmick, UDRI, and Mr. Mario Pieri, Natick Research and Development Center.

This report was submitted by the author for publication in August 1987.

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Tactical shelters are susceptible to a variety of types of in-service damage. This can result from battle damage, handling/transport damage, and environmental damage, and can be of a structural or functional nature. Structural damage consists of damage of sufficient extent to walls, roof, floor, or frame that transportability of the shelter is jeopardized.

EASY-FIX is a concept for providing the means to evacuate structurally damaged, non-operational shelters using helicopter external airlift capabilities. The University of Dayton conducted an EASY-FIX shelter concept feasibility study under Contract F33615-84-C-5079 as reported in AFWAL-TR-85-4070, Section 5. The objective of that study was to evaluate the feasibility of the EASY-FIX concept and to investigate the potential for utilizing the EASY-FIX structural members for supporting shelter armor.

That investigation resulted in the definition of a structural concept that provided the potential for meeting both the EASY-FIX evacuation and the armor support objectives within the constraints established by the study ground rules and guidelines. Several material systems were evaluated, namely steel, aluminum, metal matrix composite, and polymeric composite, and all provided acceptable individual member and total system weights for the shelter under consideration. The proposed concept was characterized by simplicity and versatility. Assembly was projected to be easily accomplished by two persons with no special training or tools required. Details regarding fitting design, tension member location and attachment, and the optimum number of components for maximizing flexibility and minimizing complication were not finalized in that report.

The objective of this effort was two-fold: first, to design and fabricate a hardware system to meet the EASY-FIX requirements, and second, to demonstrate the use of this hardware on a government-furnished S-280 B/G shelter (basic nominal dimensions 12 feet long, 7.5 feet wide, and 7.5 feet high), see Figure 1.

2. DESIGN, REQUIREMENTS, AND CONCEPTS

This program utilized the results of the feasibility study as a starting point. A number of design concepts were considered during the conduct of the feasibility study. Based on these, the concept shown in Figure 2 was selected as being simpler, more versatile, and easier to effect than other candidate concepts. Therefore, the University of Dayton pursued further development and refinement of this concept. However, some effort was expended in re-evaluating other promising design concepts, particularly for larger shelters.

As an initial step in the design process, the ground rules and guidelines from the feasibility study were reviewed and modified as required. After review of the feasibility study design requirements and objectives, several alternative Easy-Fix deployment concepts were defined: The Easy-Fix system could be (1) part of the basic shelter package, attached to and deployed with the shelter; (2) part of a support group inventory transported to the shelter site when needed; (3) a combination of 1 and 2 with some Easy-Fix kits deployed with shelters where required, and with some kits maintained as part of a support group inventory.

The advantages and disadvantages of each of the concepts are listed below.

(1) Easy-Fix system to be part of basic shelter package (that is, to be a package attached in some way to the shelter at all times).

Advantages

- The Easy-Fix hardware could be utilized to help support shelter armor.

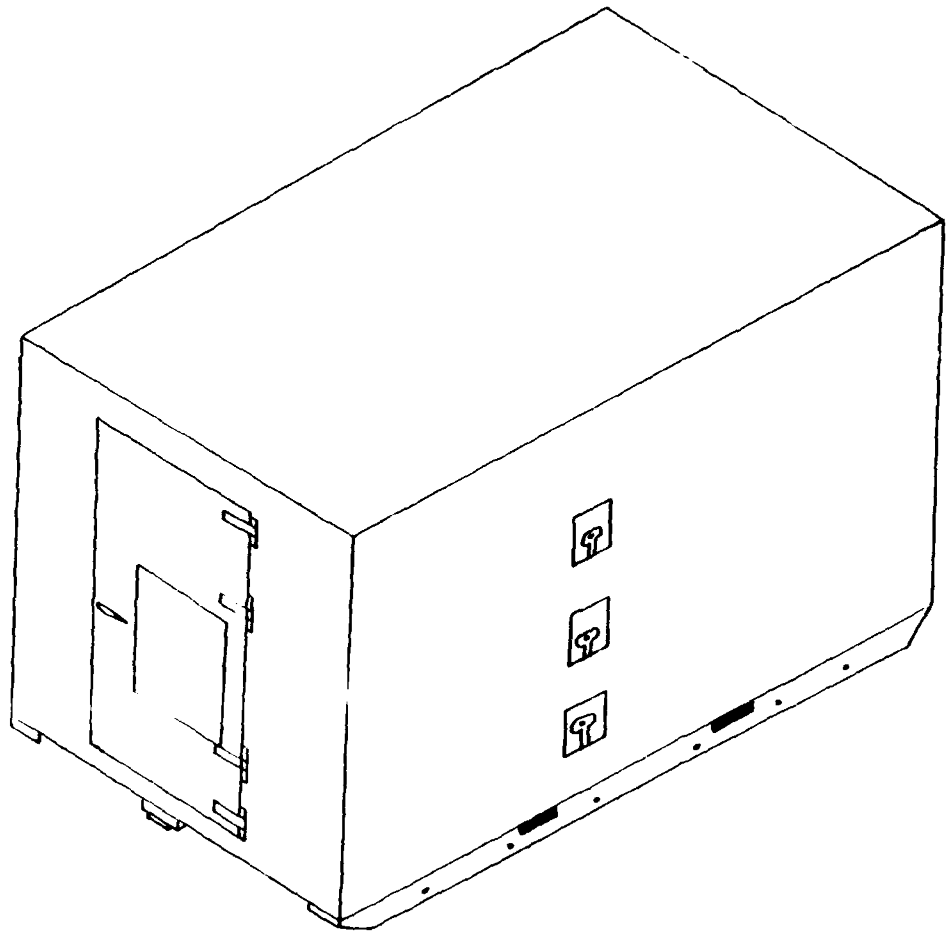

Figure 1. The S-280 B/G Tactical Shelter.

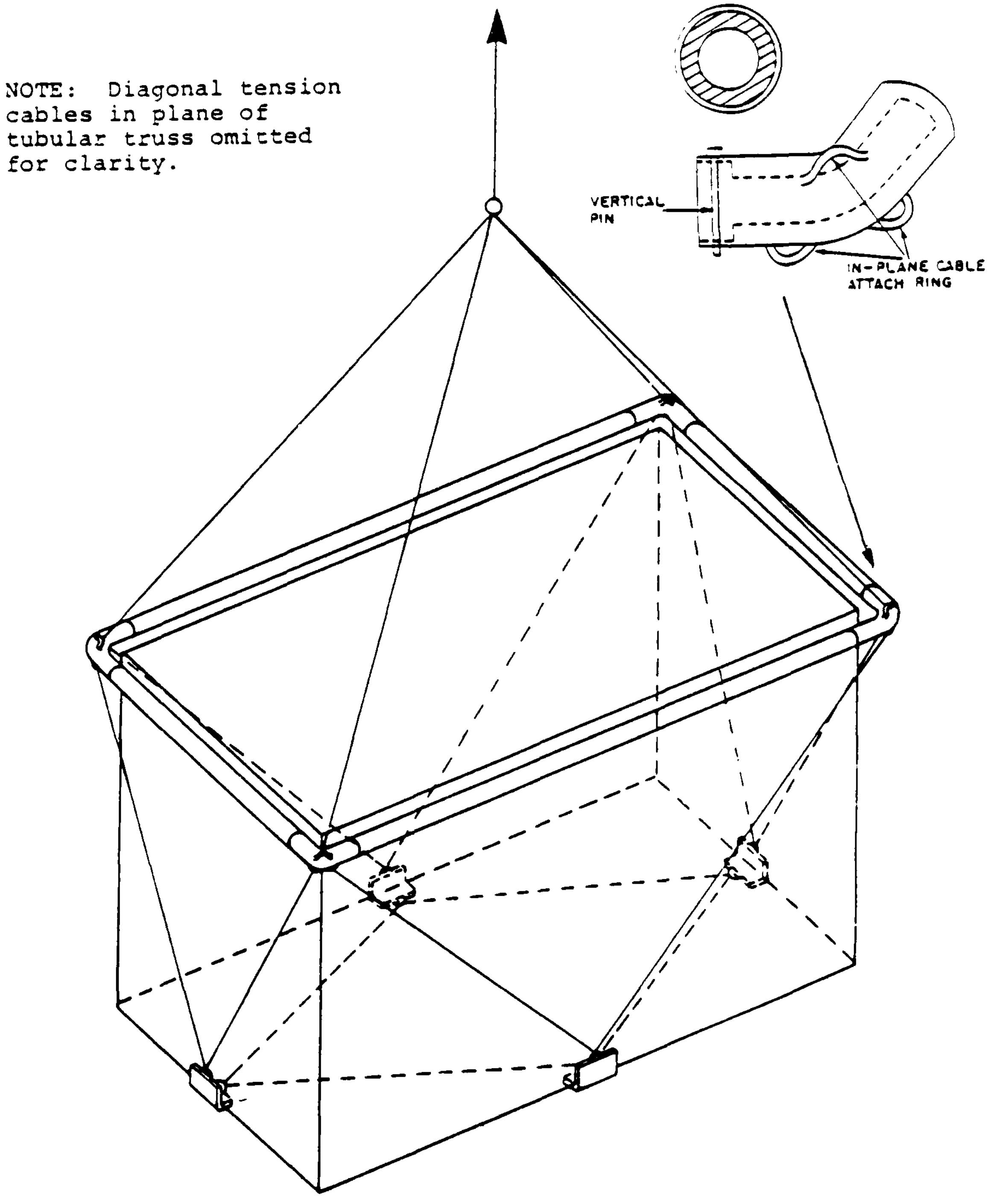

Figure 2. Easy-Fix Concept from Feasibility Study.

- If the Easy-Fix package is with the shelter, it is immediately accessible to be set up, assuming parts have not been lost or damaged. If a group of shelters are together, parts to make up whole Easy-Fix kits could be scavenged from hopelessly damaged shelters or from shelters which are not damaged.

Disadvantages:

- The possibility of damage to Easy-Fix is high if stored external to the shelter and unprotected. This could be battle damage, handling damage, etc. As mentioned above, shelter groups might be unaffected by Easy-Fix damage, however lone shelters would have no Easy-Fix equipment redundancy, and damage of Easy-Fix would require the shelter to be abandoned or spare parts to be flown in.

- External storage of Easy-Fix presents a shipping, handling, and storage problem for the shelter units.

- Storage of Easy-Fix with the shelter would reduce the shelter payload by approximately 10%.

(2) Easy-Fix system to be part of a support group inventory.

Advantages:

- Shelters would not have to carry the Easy-Fix system at all times, which would reduce shipping, handling, and storage problems, as well as save weight.

- Easy-Fix would not be damaged when the shelter is damaged.

- Manufacturing of Easy-Fix equipment would be limited to some percentage of total shelters, with each area or support group assigned a number of Easy-Fix packages dependent on the number of shelters and the likelihood of damage to shelters in their area.

- Easy-Fix hardware would be independent of shelter armoring, reducing the need for special hardware to mount the Easy-Fix to the shelter and the armor. Armor structure could then be designed to minimize weight and maximize function. In addition, the shelter armor must withstand large g-loads during transport. These g-loads will require a very special support system for the armor, which could be designed more easily and efficiently if it did not involve any of the Easy-Fix structure.

Disadvantages:

- If Easy-Fix packages are not standard equipment for the shelter, they must be taken to the shelter, erected, and then a helicopter must come to fly them out. This requires that Easy-Fix packages be available for use and not lost or misplaced over the years.

(3) Easy-Fix system to be shipped out with the shelters as standard equipment or stored elsewhere and transported to the shelter when required.

Advantages:

- This alternative allows the greatest flexibility in Easy-Fix usage. Deployment can be dependent on expected need and projected shelter environment.

In light of these arguments UDRI proceeded with alternative 3. The Easy-Fix kit was designed to be carried with the shelter or stored elsewhere and transported to the shelter in the event of damage. The armor support structure will be independent of Easy-Fix, and provisions can be made for storage of Easy-Fix behind the armor; however, the limitations involved in deploying the Easy-Fix kit with the shelter should be realized and emphasized.

Although it is possible to store the Easy-Fix kit behind the external armored panels on the shelter sides (if the shelter is armored), various components of the Easy-Fix Kit would require the armor to be spaced out from the shelter twelve inches or more. This would require special consideration for armor support system design, and additional shipping and handling problems would be caused by this large armor offset. No other suitable method of attaching Easy-Fix externally to the shelter exists which would protect Easy-Fix from damage and not create shipping and handling problems. Therefore, UDRI suggests that if Easy-Fix is required to be deployed with the shelter, it be packaged separately and shipped unattached to the shelter in a suitable crate. The Easy-Fix system weight is approximately 600 pounds (plus packaging). The kit could be placed in a crate of approximate dimensions 13'x1.5'x1.5'. The overall length of the crate* could be reduced to approximately 9 feet by making the longer (12') compression tubes in two pieces. In the field, it could be placed near the shelter, protected in a trench for example. If the shelter would be deployed on a truck or mobilizer, transport of the Easy-Fix package with the shelter might be difficult and protection of the kit from attack damage during transport could be difficult.

The primary function of this effort was to develop and demonstrate the Easy-Fix concept. The resulting Easy-Fix kit can be utilized as needed. Minimal further effort was expended to develop methods of deploying Easy-Fix with the shelter.

3. DESIGN INTEGRATION, GROUND RULES, AND GUIDELINES

Integration of the EASY-FIX concept into the requirements of the shelter system was very important. Compatibility with these varied requirements impose constraints on the design. Ground rules and guidelines used for the S-280 EASY-FIX design are listed as follows.

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*It may be more advantageous to package the Easy-Fix Kit in several different crates to reduce the difficulty in moving the kit.

- Any damaged shelter to which EASY-FIX is applied is no longer a functionally operational shelter, and upon application there will be no entry into or egress out of the shelter.

- Shelter armor will be removed before effecting EASY-FIX,and will not be in place during the EASY-FIX evacuation.

- There will be no electrical power at the shelter site.

- No special or exotic tools will be required to effect EASY-FIX.

- Available field personnel will be assumed to possess no specialized mechanical skills or knowledge for evaluating structural integrity.

- Materials, tools, and capability for making localized structural repairs is not a part of the EASY-FIX concept.

- No modification to existing shelters for attachment of EASY-FIX structural components will be made.

- EASY-FIX shelter evacuation will be effected using helicopter airlift with Class 1 slinging provisions per MIL-STD-209F.

- Concept demonstration will be limited to consideration of the loaded S-280B shelter. Shelter dimensions are taken as 12 feet long, 7.5 feet wide, and 7.5 feet high.

- The S-280B shelter maximum shipping weight is taken as 6,400 pounds.

- The weight of the shelter and its contents are assumed to be uniformly distributed over the floor area of the shelter.

- The weight of all EASY-FIX structural members, fittings, and hardware shall not exceed ten percent of the shelter maximum shipping weight.

- The weight of the individual EASY-FIX structural components shall not exceed 120 pounds to facilitate two person handling.
- Shelter will be assumed to rest on a relatively level surface or be in a position such that the forklift openings (if they exist) and the openings between the skids at the shelter ends are accessible for EASY-FIX implementation and for jack usage.
- Shelter air conditioning units will be discarded or pulled into the shelter prior to implementation of EASY-FIX.
- EASY-FIX will be designed to be stored with the shelter or elsewhere.
- EASY-FIX structure will be independent of armor support structure.
- EASY-FIX concept will be capable of being effected by two persons in one eight hour period.

4. DESIGN CONSIDERATIONS

4.1 Structural Concepts

A number of structural concepts were considered, some of which made use of the existing shelter structural members and lifting eyes. These approaches, however, had inherent disadvantages that are not compatible with the stated ground rules. The most important of these disadvantages are:

(1) A detailed assessment of the structural integrity of individual shelter components by on-site personnel is required,

(2) EASY-FIX structural members must be integrated into the undamaged shelter structure through special fittings and attachments,

(3) Bending stresses could be introduced into the EASY-FIX members where attach points, lifting eye, and truss-element force vectors could not be constrained to intersect at a common point, and

(4) System complexity becomes excessive.

Based on these considerations the concept depicted in Figure 3 was selected for development. Structurally, the system reacts the applied loads as a truss. The tubular members form an independent framework at the top of the shelter and react the compressive loads. Tension members are used to transfer the loads resulting from the shelter weight into the tubular framework corner joints. These tension members pass underneath the shelter, forming a basket.

Provisions for helicopter airlift are similar to those used for the basic shelter. The only difference is the use of lift rings on the tubular framework corner fittings instead of the shelter lift rings. Tension cables connect the diagonal corners of the tubular frame to maintain in plane stability. Vertical pins connect the tubular framework corner elbows to the straight tubular frame members. This prevents out-of-plane warping due to rotation of the tubular frame corner members.

4.2 Design Loads

The design loads for helicopter airlift are defined in Paragraph 5.1.1.1 of MIL-STD-209F. For equipment weighing less than 20,000 pounds, the working load is equal to the maximum shipping weight multiplied by 3.2.* All slinging components,

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*Applies to equipment with a maximum shipping weight to maximum projected frontal area ≥ 60 lbs/ft^2. For the shelter under consideration, this ratio equals $6400/(12 \times 8) = 66.7$ lbs/ft^2.

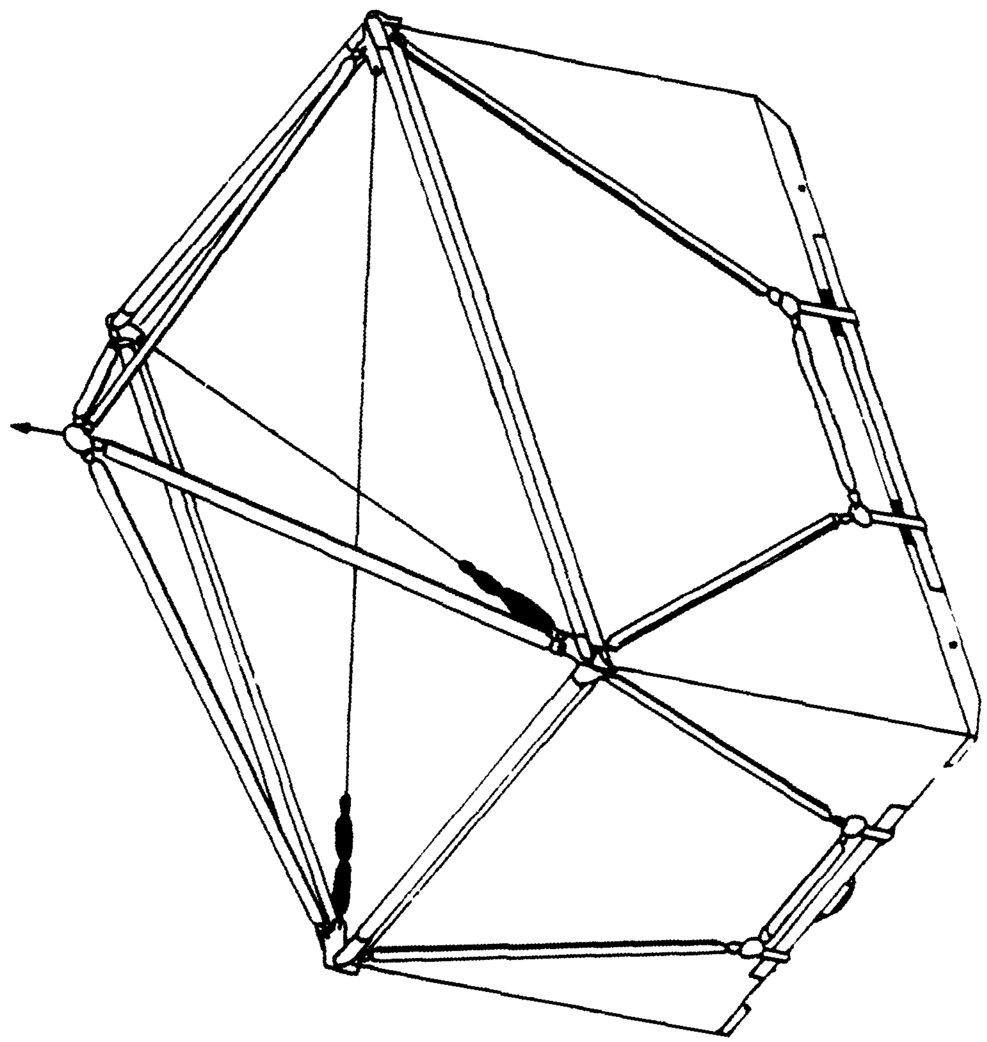


Figure 3. Easy-Fix Design Concept.

including the connection and structural members, are required to withstand their proportionate share of this working load withoutpermanent deformation. In addition, they are required to have an ultimate strength not less than 1.5 times the working load.

The working loads for an assumed worst case loading condition are depicted in Figure 4. The sling apex is over the center of gravity (assumed to be the geometric center of the shelter). The true angle of each sling leg is taken as 45 degrees from the vertical (the maximum angle permitted by MIL-STD-209F). The total shelter weight is conservatively assumed to be supported by cables attached to the center of the long side of the shelter.

This arrangement results in the most critical buckling load for the 12 foot long tubular compression members. The equivalent static working load for the EASY-FIX system is

$$P_{working} = 3.2 \times 6{,}400 = 20{,}480 \text{ lb}$$

Structural component member designations are shown in Figure 5, and the resulting working loads and ultimate design load for the EASY-FIX components are summarized in Table 1.

Table 1

Easy-Fix Loads Summary

Member	Working Load (kips)	Required Minimum Safety Factor	Ultimate Design Load (kips)
AB, AC, AD, AE	7.24	5	36.20
BE, CD	-8.10	1.5	-12.15
BC, DE	-4.76	1.5	- 7.14
CH, DI, BG, EF	6.4	5	32.00
BJ, CK, EL, DM	5.47	5	27.35
GH, FI, KM, JL	5.12	5	25.60

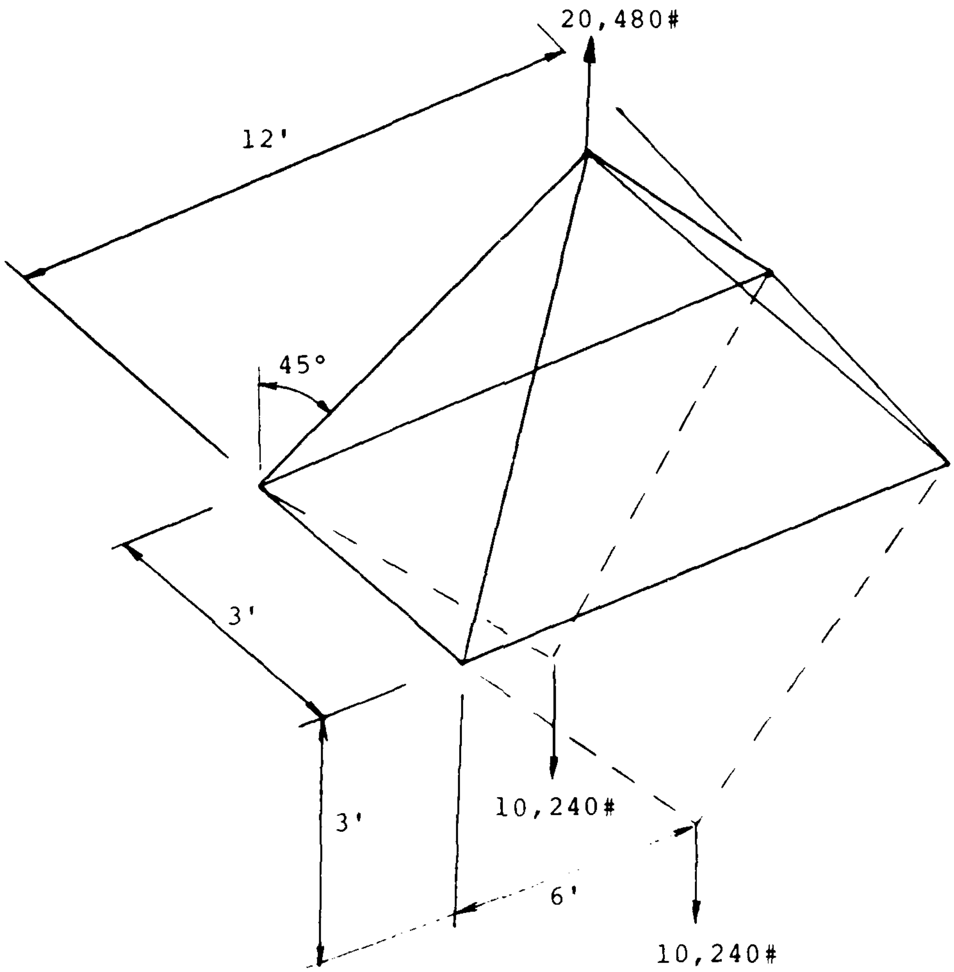


Figure 4. Easy-Fix Loads Diagram.

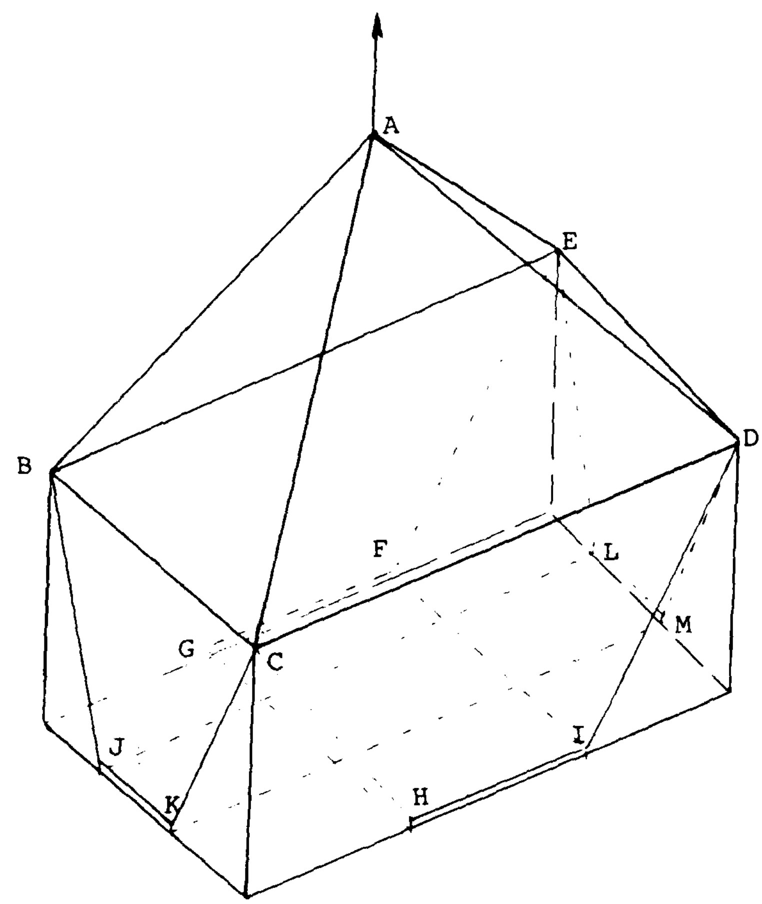


Figure 5. Component Member Designations.

4.3 Material Systems

Four representative material systems for the tubular compression members were selected for evaluating the feasibility of the EASY-FIX concept. They are A-36 steel, 6061-T6 aluminum alloy, DWAL 20 (a SIC/6061-T6 metal matrix composite produced by DWA Composite Specialties, Inc.), and a high modulus GR/EP system. These systems are not exhaustive of material system possibilities. However, they cover a broad range with respect to weight and cost and provide a good basis for evaluating feasibility. Easy-Fix system tension members could be steel, Kevlar, fiberglass, nylon, or polyester cable, rod, or strap.

4.4 Structural Evaluation

Since the 12-foot-long tubular compression members will fail catastrophically when the buckling load is reached, they were designed using the Euler buckling formula for long columns:

$$P_{cr} = \frac{\pi^2 EI}{\ell^2}$$

From the loads analysis, P_{cr} = 12,150 lbs for the 12 foot long tubular compression members using a safety factor of 1.5. Solving Euler's equation for the required stiffness gives

$$(EI)_{req'd} = \frac{P_{cr}\ell^2}{\pi^2}$$

Using this equation and assuming the members to be thin walled cylindrical tubes yields the results summarized in Table 2.

Some perturbation about the sizes listed in Table 2 would be required for weight optimization of a given material system. However, the weights shown are representative for each material system and reflect the weight difference to be expected as

TABLE 2

TACTICAL SHELTER EASY-FIX COMPRESSION TUBE EVALUATION

Material System	E_x (ksi)	σ_y (ksi)	$I_{req'd}$ (in^4)	Dia. (in)	t_{wall} (in)	A (in^2)	I_{act} (in^4)	L/r	σ_{act} (ksi)	ρ (#/in^3)	Wt. (#/ft)	Wt. Total	Cost ($/#)	Total Cost ($)
Steel	29×10^3	36	0.88	2.5	0.188	1.31	0.92	176	8.92	0.283	4.64	55.7	0.45	25
A-36					0.25	1.77	1.44	159	6.88		6.01	72.1		32
				2.75	0.156	1.28	1.08	157	9.53		4.32	51.9		23
					0.188	1.51	1.25	158	8.05		5.14	61.7		28
				3	0.120	1.09	1.13	141	11.19		3.69	44.3		20
					0.125	1.13	1.17	142	10.76		3.76	45.2		20
Aluminum	10×10^3	37	2.553	3	0.375	3.09	2.72	154	3.93	0.100	3.64	43.7	1.3-1.8	68
					0.500	3.93	3.19	160	3.09		4.62	55.4		86
				3.5	0.216	2.23	3.02	124	5.45		2.62	31.5		49
					0.250	2.55	3.39	125	4.76		3.00	36.0		16
				4.0	0.125	1.52	2.86	105	7.98		1.79	21.5		33
					0.250	2.94	5.20	108	4.12		3.46	41.5		64
DWAL 20	18.5×10^3	65.2	1.38	3.0	0.188	1.66	1.64	145	7.32	0.09	1.79	21.5	35-75	1180
(30 V/O					0.250	2.16	2.06	151	5.63		2.33	28.0		1540
SIC				3.5	0.125	1.32	1.89	120	9.20		1.43	17.1		940
6061-T6					0.188	1.95	2.68	123	6.23		2.10	25.3		1392
Al)				4.0	0.083	1.02	1.96	104	11.90		1.20	17.3		952
					0.120	1.27	2.76	105	9.54		1.72	20.6		1130
E-30	22×10^6	72	1.16	3.0	0.188	1.66	1.65	143	7.32	0.06	1.20	14.3	30-45	536
GR/EP					0.250	2.16	2.06	148	5.63		1.56	18.7		701
70% 0°				3.5	0.125	1.33	1.89	121	9.17		0.96	11.5		431
30% ±45°					0.188	1.95	2.68	123	6.23		1.40	16.8		630
				4.0	0.083	1.02	1.96	104	11.90		0.80	8.8		330
					0.125	1.52	2.86	105	7.98		1.09	13.1		491

P_{cr} = 12,150 lb.

$(EI)_{req'd}$ = 25.5 lb-in^2

L = 12 ft = 144 in.

a function of material system. System weights are shown in Table 3.

5. EASY-FIX PROTOTYPE KIT DESCRIPTION: MATERIALS AND SYSTEM COMPONENT CHOICES

The material system choices for the Easy-Fix demonstration components were chosen with several general guidelines. The materials should be proven (readily available and accessible technology), fairly easy to fabricate as a prototype, relatively inexpensive, relatively light weight, and representative of a system suited for mass production. Figure 6 shows the complete unassembled Easy-Fix Kit. Figures 7 and 8 illustrate the assembled Easy-Fix Kit used for demonstration. Figure 9 illustrates several component details. Mating components were color coded for ease of assembly.

5.1 Compression Tubes

An important consideration to be remembered when choosing member materials and sizes is that in the field the Easy-Fix components might possibly be used for purposes other than shelter removal. For instance, the compression tubes might be used as a lever to pry something, or might be handled roughly in one way or another. For this reason, a wall thickness of 0.25" was chosen for the 6061-T6 four-inch outside diameter tube used in the demonstration (providing a stiffness of twice that required to carry the ultimate compression load), providing a needed protection against abuse. In addition, the compressive loads in the tubes could increase significantly if the shelter tilts or leans excessively due to damage instabilities or uneven shelter payload loading, and because the corner fittings could not be designed such that all of the forces at the corner fitting were perfectly concurrent, some eccentricity of loading at the corner exists, creating a bending moment in the tubes.

Aluminum was chosen for weight savings and because it is readily available. The use of alternative material systems for

TABLE 3

EASY-FIX SYSTEM WEIGHT

Compression Tube Material System	Compression Tubes lbs.	Corner Fittings* lbs.	Tension Members** lbs.	Tension Member Fittings lbs.	Jacks lbs.	Misc. lbs.	Total Weight lbs.
A36 Steel 3" O.D. 2.75" ID	151	37	138	70	83	82	561
6061-T6 AL 4" O.D. 3.5" ID***	133	47	138	70	83	82	553
DWAL 20 30 V/O SIC/6061-T6 AL 3.5" O.D. 3.125" ID	84	42	138	70	83	82	499
E-30 GR/EP 70% - 0° 30% ± 45° 3.5" O.D. 3.125" ID	56	42	138	70	83	82	471

* 6061-T6 AL
** Nylon Straps and Steel Diagonal Tension Cables
*** Demonstrated System

Figure 6. The Unassembled Easy-Fix Kit.

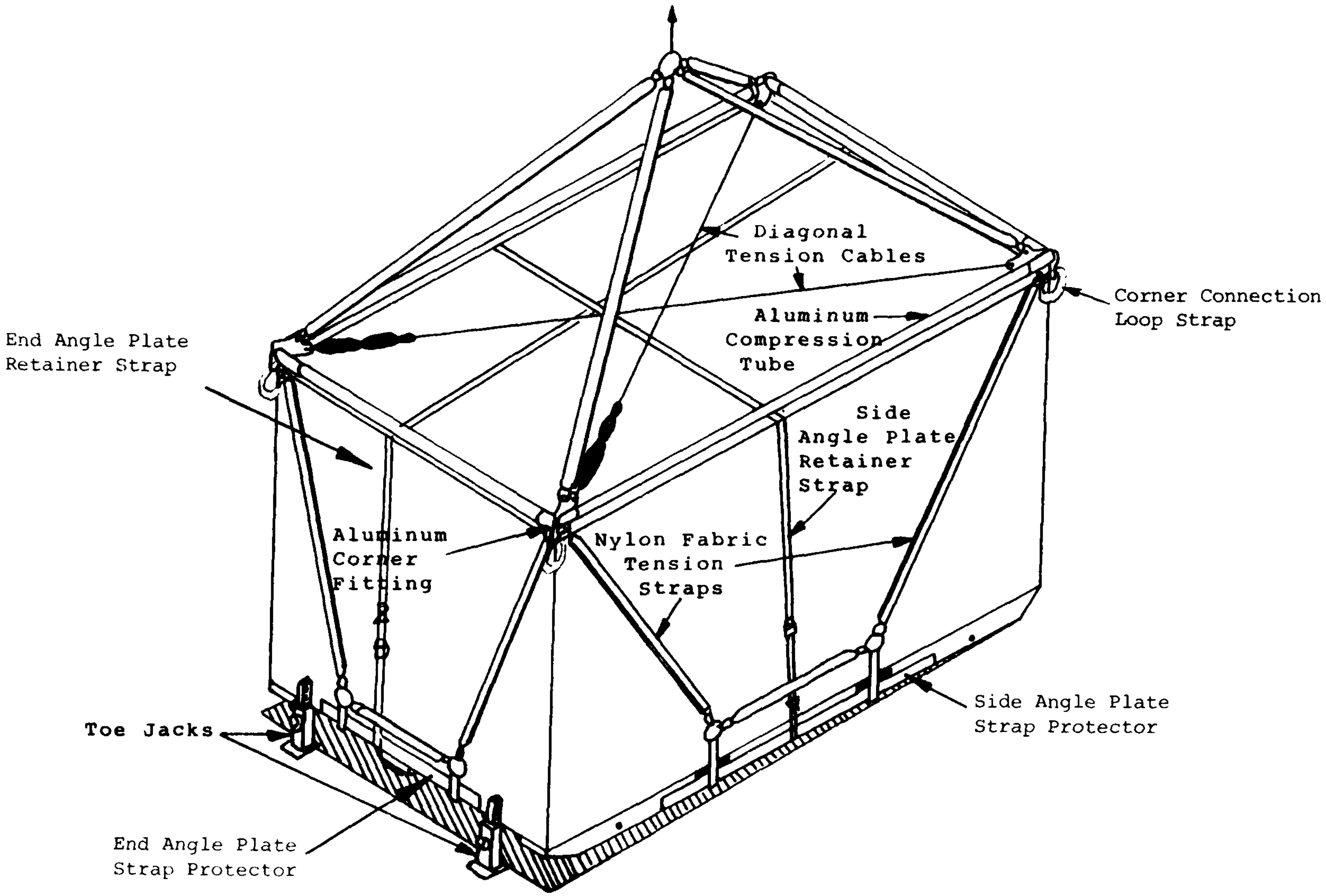


Figure 7. Easy-Fix Prototype Concept.

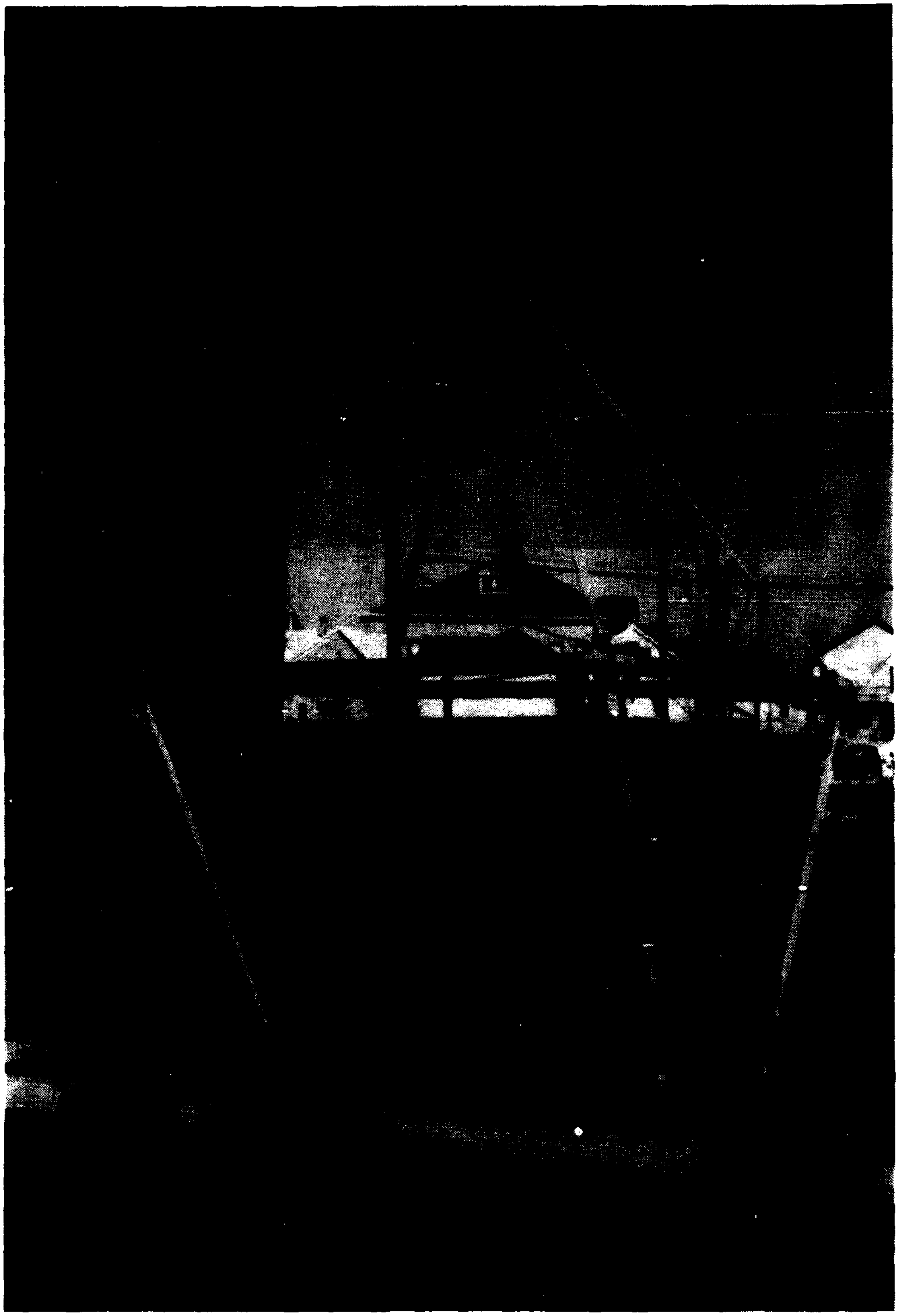
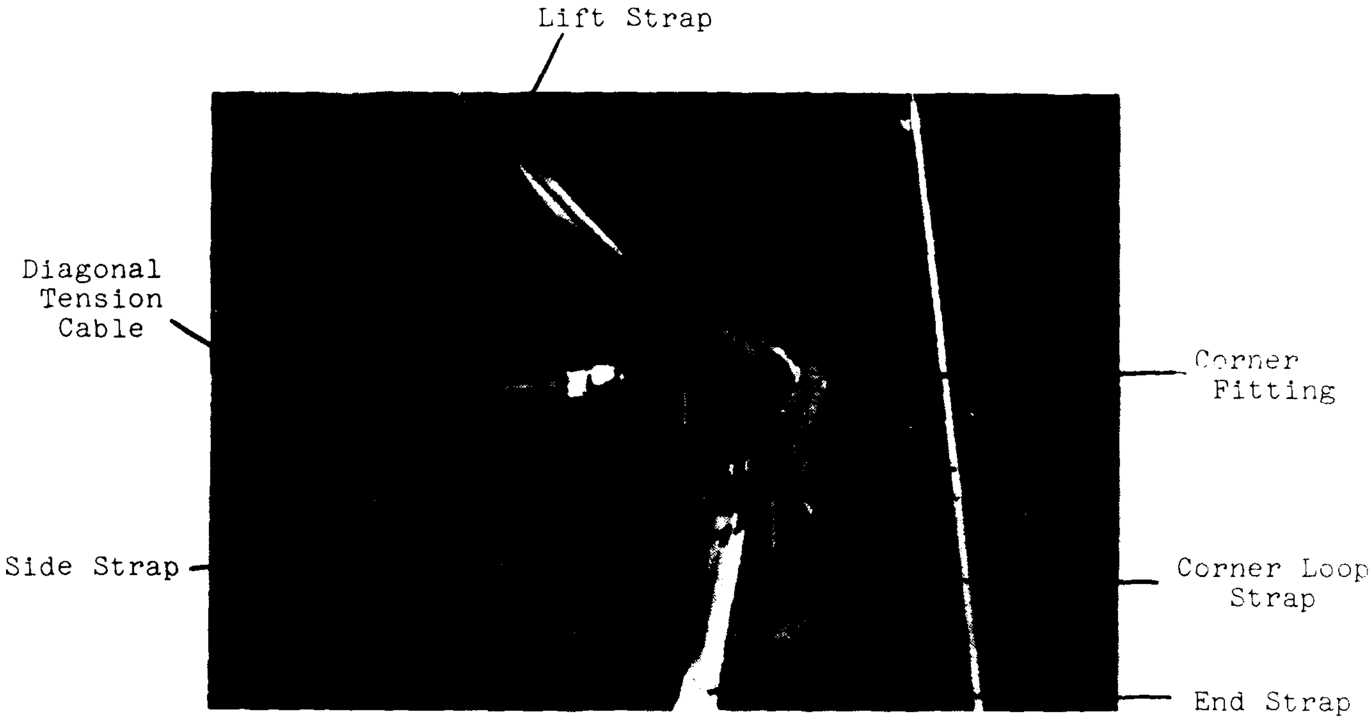
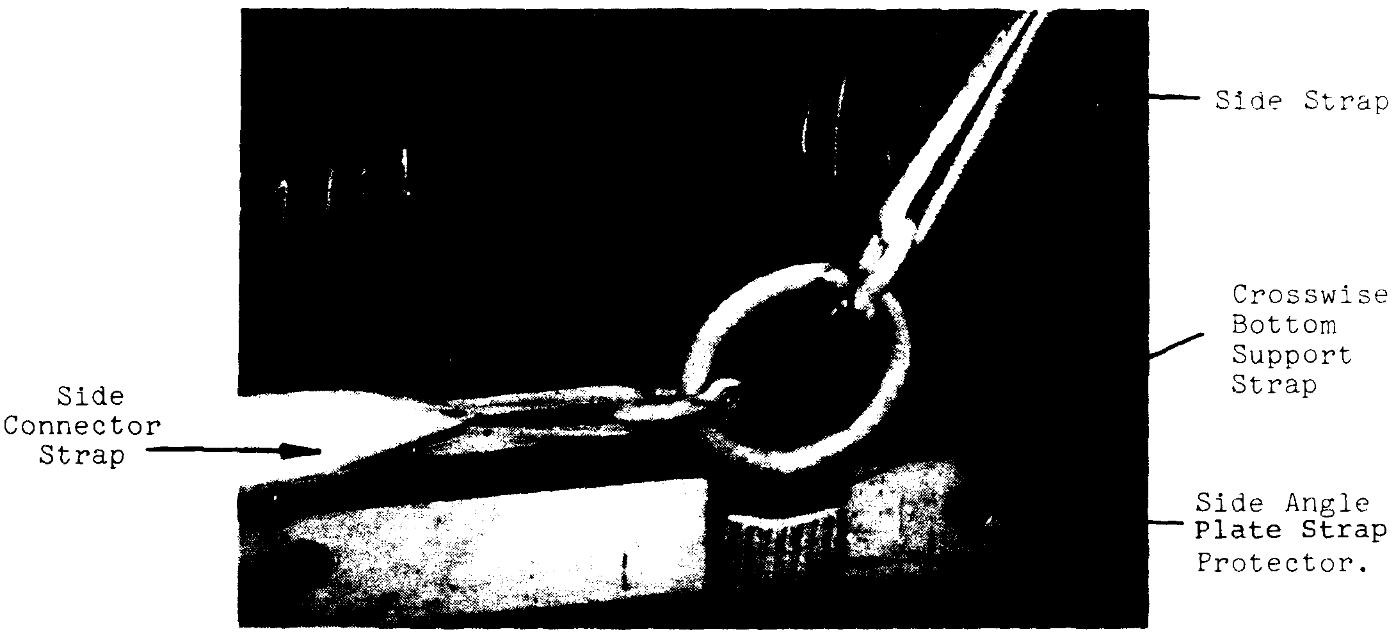


Figure 8. The Assembled Easy-Fix Kit.



Compression Tube Corner Fitting Attachment Detail



Side Angle Plate Attachment Detail

Figure 9. Easy-Fix Component Details

the compression tubes would save some weight, but the cost of these alternative materials at present is considered to be prohibitive. Minimal projected production cost data is available for the DWAL 20 and graphite/epoxy material systems. Best estimates were used to establish a cost range and the median cost was used to project the cost of a fabricated 12-foot-long tubular member. For damage tolerance, economy, and weight savings, an additional new structural material system which may merit review for usage in the compression members is fiber reinforced thermoplastics.

5.2 Compression Tube Corner Fittings

For the compression tube corner fittings, aluminum was chosen to save weight. Although aluminum is more expensive and more difficult to weld than steel, the differences are minor and the weight savings merited its usage. An in-depth study of the corner fittings using finite element or a similar design tool could produce a lighter weight corner fitting, but such an effort was not deemed necessary to meet the objectives of this program.

5.3 Tension Members

Tension members must be durable, easy to handle, and relatively light weight. Although possible material choices include steel, Kevlar, fiberglass, nylon, or polyester, and the tension members could be round or flat in cross-section, end fitting availability is very limited for all choices but steel cable and for nylon or polyester strap webbing. Nylon fabric straps were chosen for use as tension members instead of polyester fabric straps or wire rope. Nylon fabric straps have several advantages: (1) Nylon is more flexible than wire rope and can be bent around corners without kinking or strength loss; (2) nylon is handled and stored more easily than wire rope; (3) nylon is lightweight (both material and fittings); (4) nylon has a lower modulus than steel or polyester (nylon elongates 6-10% at design load), allowing redistribution and balancing of loads in the members, and due to the low modulus, nylon provides shock protection to the shelter during lift (reducing the actual g-loads experienced by the shelter). To increase durability, the bottom support straps were encased in a protective wrap. Steel wire rope was used for the two diagonal tension cables which keep the tubular frame from deforming in plane, to limit cable elongation and related frame distortion.

5.4 Additional Miscellaneous Equipment

Two standard toe jacks with handles were included in the Easy-fix package to facilitate elevation of the shelter and placement of the support straps. Aluminum plates were also included to increase the bearing area ("footprint") on the soil where needed.

Aluminum angle plate fittings were included to protect the support straps at the bottom edges of the shelter in the event of damage at those locations. These angle plates are held in place on the shelter with nylon straps.

Fiberglass extension rods were included to pull the straps underneath the shelter, so that personnel will not have to reach under the shelter. Two wrenches are included to tighten the jam nuts on the diagonal tension cable turnbuckles.

6. EASY-FIX SYSTEM CAPABILITY

6.1 Structural Capability

During the course of the program, conversations with responsible military personnel suggest that many shelters are overloaded in the field. As many as 80-90% may be overloaded up to 10,000 pounds total weight (maximum shipping weight for the S-280 shelters is 6,400 pounds), with several isolated reports of shelters loaded to 15,000 pounds. In response to this information, the Easy-Fix System structural capability is presented below.

Each structural component of the Easy-Fix kit is designed to have an ultimate strength equal to its proportionate share of the working load, as defined in Section 4.2, multiplied by the safety factor for that member type. For example, the working load for the compression tubes is 8,100 pounds. The chosen member will buckle at 24,750 pounds. The actual safety factor for that member is then 24750/8100 = 3.05. The required and actual safety factors used for each system component are shown in Table 4.

TABLE 4

SAFETY FACTORS

Component	Required Minimum Safety Factor	Actual Safety Factor
Compression Tubes	1.5	3
Nylon Straps	5	5
Steel Cables	5	5
Strap & Cable Fittings	5	5
Corner Fittings & Misc.	1.5	>2

The use of nylon straps increases the conservatism of the Easy-Fix design. Because of their flexibility, the nylon straps attenuate the shock transmitted to the shelter. The 3.2 factor used to determine the working load is a result of g-loads during helicopter lift. The use of nylon straps reduces the likelihood that the shelter will experience g-loads as high as 3.2.

6.2 Preliminary System Test

The main concern with an overload shelter is not that Easy-Fix might fail, but more likely, that the shelter floor structure might buckle.

Analysis of the S-280 B/G floor structure indicated that the stresses induced in the floor, when the shelter is lifted with the Easy-Fix Kit, are approximately equal to the stresses induced in the floor when the shelter is lifted by the corner lifting rings. In addition, analysis indicated that the floor should withstand the test load* of 17,500 lbs. with an actual safety factor of about 1.3, provided that the floor is undamaged (free of wrinkles, creases, or waviness, the foam core engineering properties have not deteriorated, and the foam/facing bond is as strong as the core tensile strength. Due to the age and condition of the S-280 B/G shelter test article, it was considered unwise to test at the proof load used for new shelters. Because of the uncertainties of the sandwich construction analysis, and in order to avoid the possibility of buckling the shelter floor during demonstration of the kit, UDRI instrumented the shelter during a preliminary system test at UD and obtained strain data for several different test loads below 17,500 lbs.

This preliminary system test was conducted at UDRI. The S-280 B/G tactical shelter was lifted by crane with both the standard lifting rings at the shelter upper corners and with the Easy-Fix kit assembly (see Figures 10 and 11). Testing was intended to be static. Crane lift speeds were kept to a minimum, to reduce the effects of g-loading. Water was used to load the shelter. Four layers of 6-mil plastic were used on the interior to contain the water. Sharp corners and protrusions inside the shelter were masked off with duct tape to prevent tearing of the liner. The interior area of the shelter was measured. For each load case, water was pumped into the shelter to a depth corresponding to a weight equal to the desired test load (see Figures 12 and 13). A transducer was placed in line between the shelter and the crane to determine actual system weight for each load case. Strain gages mounted at various critical floor and

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*The test load of 17,500 lbs. is a standard proof test load used by the government prior to acceptance of shelters on a new production contract. This 17,500 lbs. is in addition to the shelter dry weight of between 1,200 lbs. and 1,400 lbs.

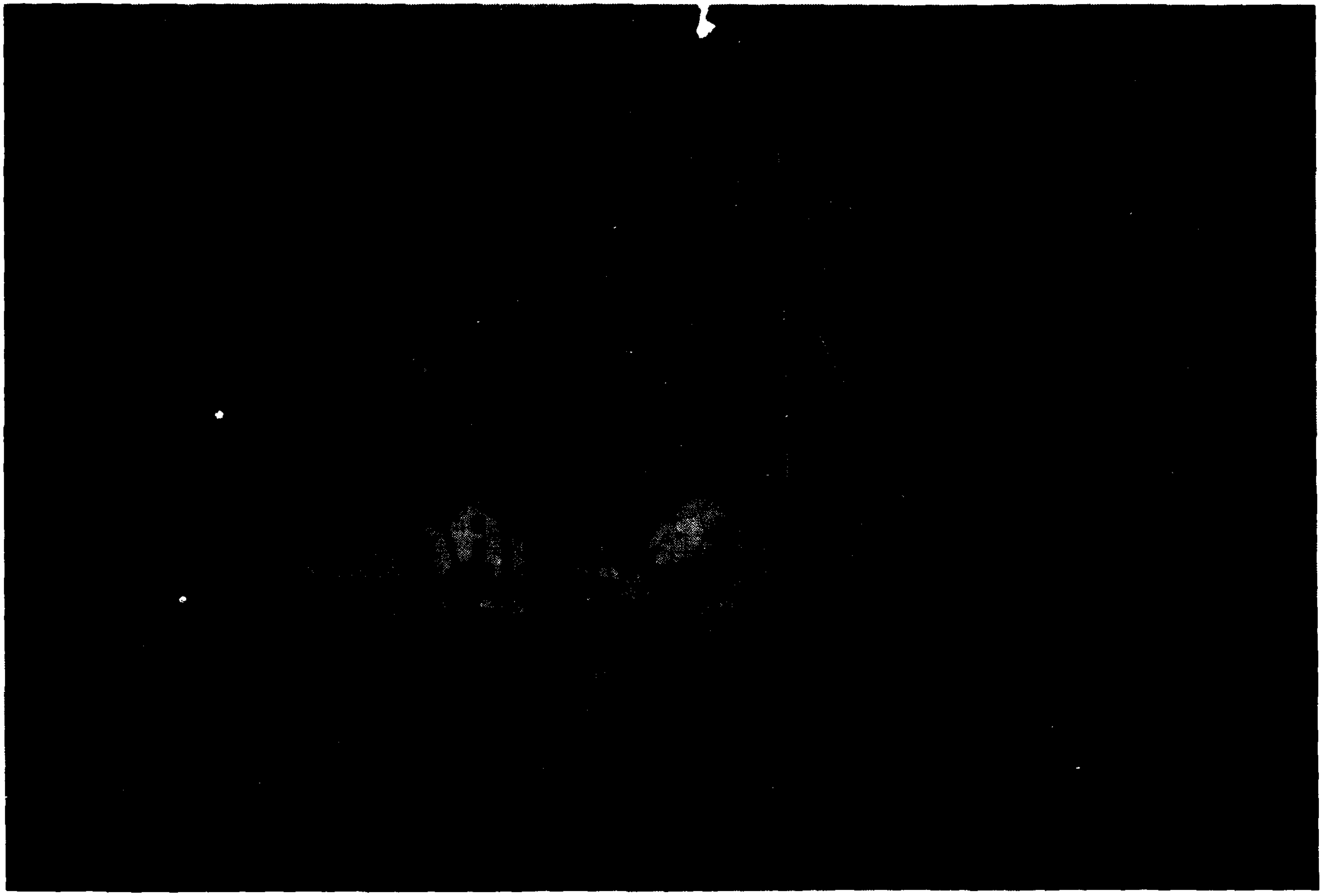


Figure 10. Easy-Fix Preliminary System Test Setup.

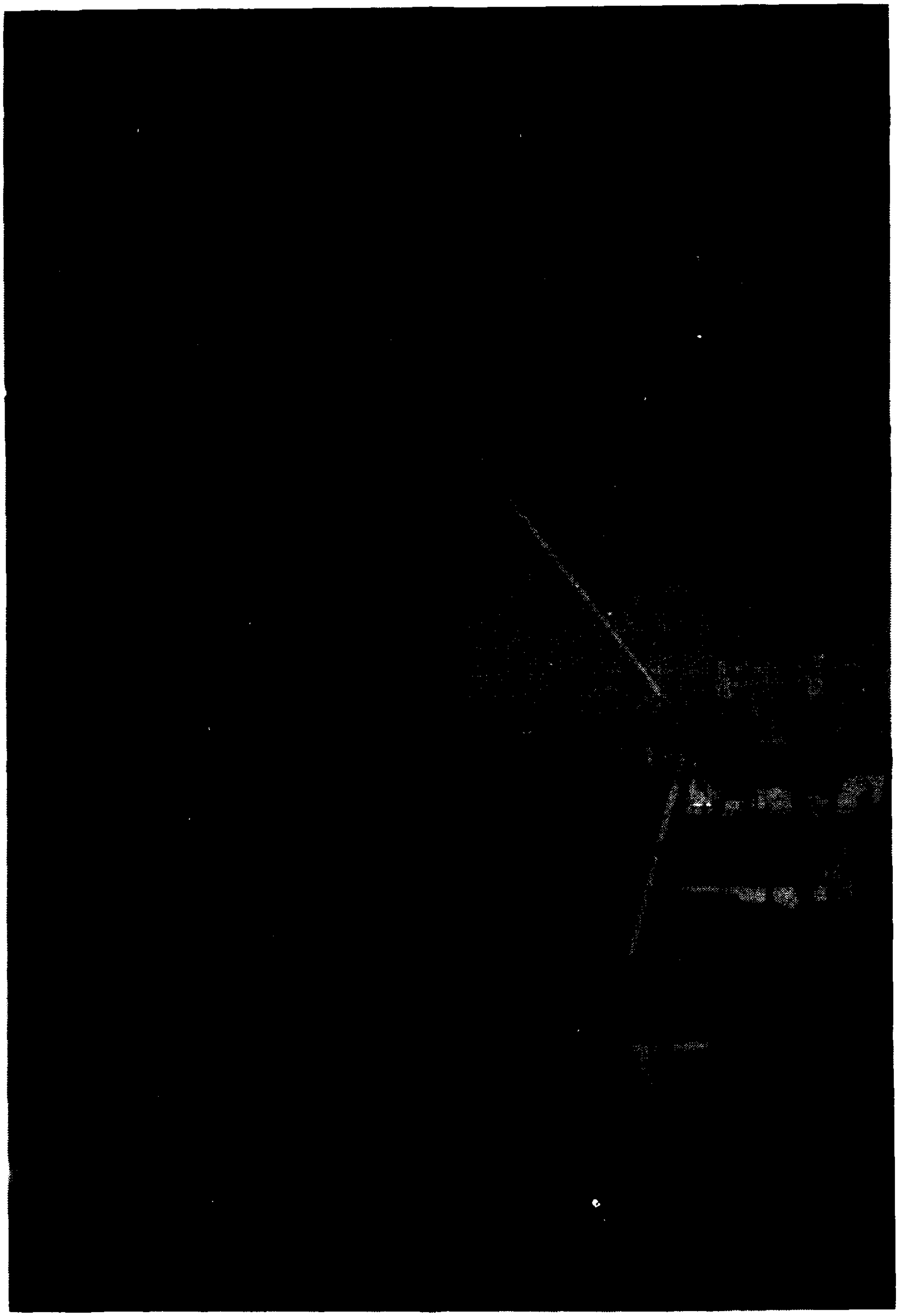


Figure 11. Easy-Fix Preliminary System Test--
Test Case #9, 10,000 lbs. Water.

Figure 12. Water Being Pumped Into the Shelter Interior.

Figure 13. Water Level for Tests #8 and 9, 30 in.

compression tube locations were used to monitor the system structural response.

Strain data from each test was analyzed and compared to theoretical expectations before more weight was added to the shelter. Table 5 lists the actual test loads. After completion of testing, the water in the shelter was pumped into a nearby catch basin. The purpose of this preliminary test was to compare the stress developed in the floor when the shelter is lifted with the standard upper corner lifting rings with the stress developed when lifting the shelter with Easy-Fix. In addition, the strain data obtained for different load increments allowed a prediction of ultimate shelter floor strength.

Strain gage locations on the shelter floor are shown in Figure 14. A summary of floor stresses at the different test loads is included in Table 6. The maximum stress (gages 5T and 7T) induced into the shelter floor when lifting the shelter with the upper corner lifting rings (Test #8) is about 5% lower than the stress induced into the floor when lifting the shelter with Easy-Fix (test #9). A comparison plot (for upper corner ring lift and Easy-Fix lift) of stress versus floor load at the most critical strain gage locations, 5T and 7T, is presented in Figure 15. Extrapolating to the proof test load of 17,500 lbs. produces a maximum floor stress of approximately 12,000 psi at gage 7T. The shelter floor failure mode would most likely be face wrinkling, which develops when either the foam core of the floor sandwich crushes, or the aluminum skin debonds from the core structure. The critical wrinkling stress is predicted to be 16,500 psi. Thus, lifting the shelter with Easy-Fix should not cause floor buckling with an undamaged and undegraded floor.

These results apply to the S-280 B/G shelter only. The newer S-280 C/G shelter has a redesigned floor, and buckling of an undamaged floor is not considered a problem.

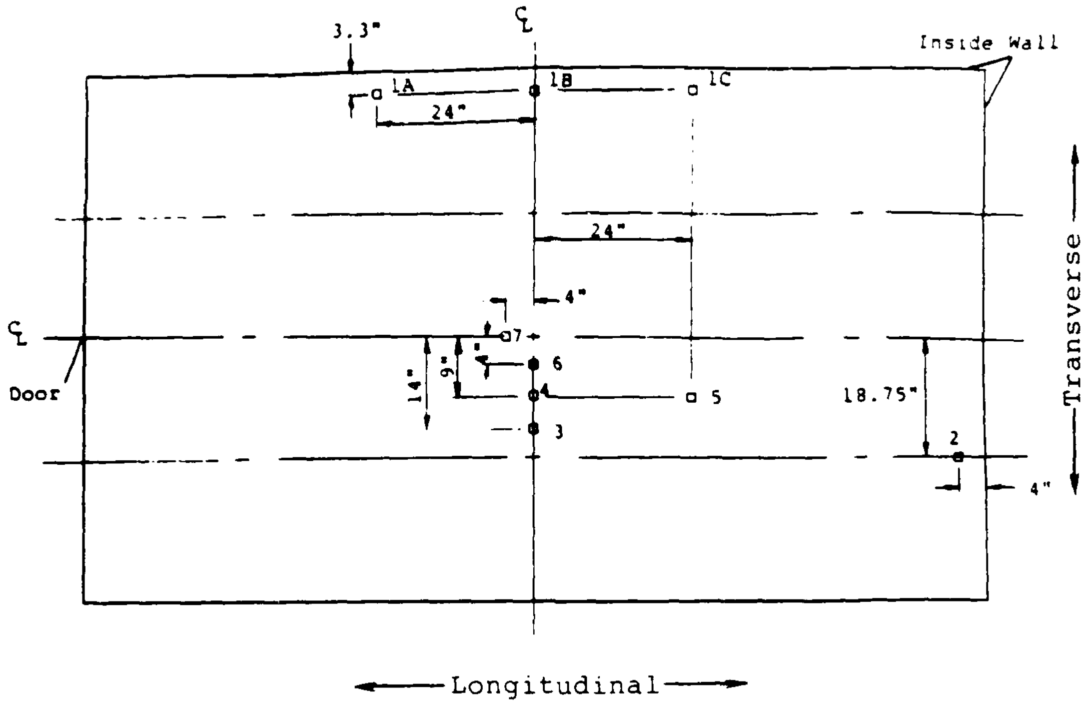
TABLE 5

ACTUAL LOADS USED FOR THE EASY-FIX PRELIMINARY SYSTEM TEST

Test No.	Method of Lift	Depth of Water in Shelter (inches)	Load on Shelter Floor (lbs.)	Shelter Weight (lbs.)	Easy-Fix Kit & Misc. Materials Weight (lbs.)	Total Weight (lbs.)
1	EF*	-	-	1280	670	1950
2	LR**	-	-	1280	670	1950
3	LR	≈ 7.6	2750	1280	670	4700
4	EF	≈ 7.6	2750	1280	670	4700
5	EF	≈12.7	4800	1280	670	6750
6	EF	≈20.3	7700	1280	670	9650
7	LR	≈20.3	7700	1280	670	9650
8	LR	≈30	10750	1280	670	12700
9	EF	≈30	10750	1280	670	12700

*Shelter lifted with Easy-Fix

**Shelter lifted with standard upper corner lifting rings.



NOTES:

1. Gages are Micro Measurement type CEA-13-125-UT-120.

2. These gages are 2-element rosettes, with one element installed longitudinal (L-gages), and one element installed transverse (T-gages).

Figure 14. Shelter Floor Strain Gage Locations

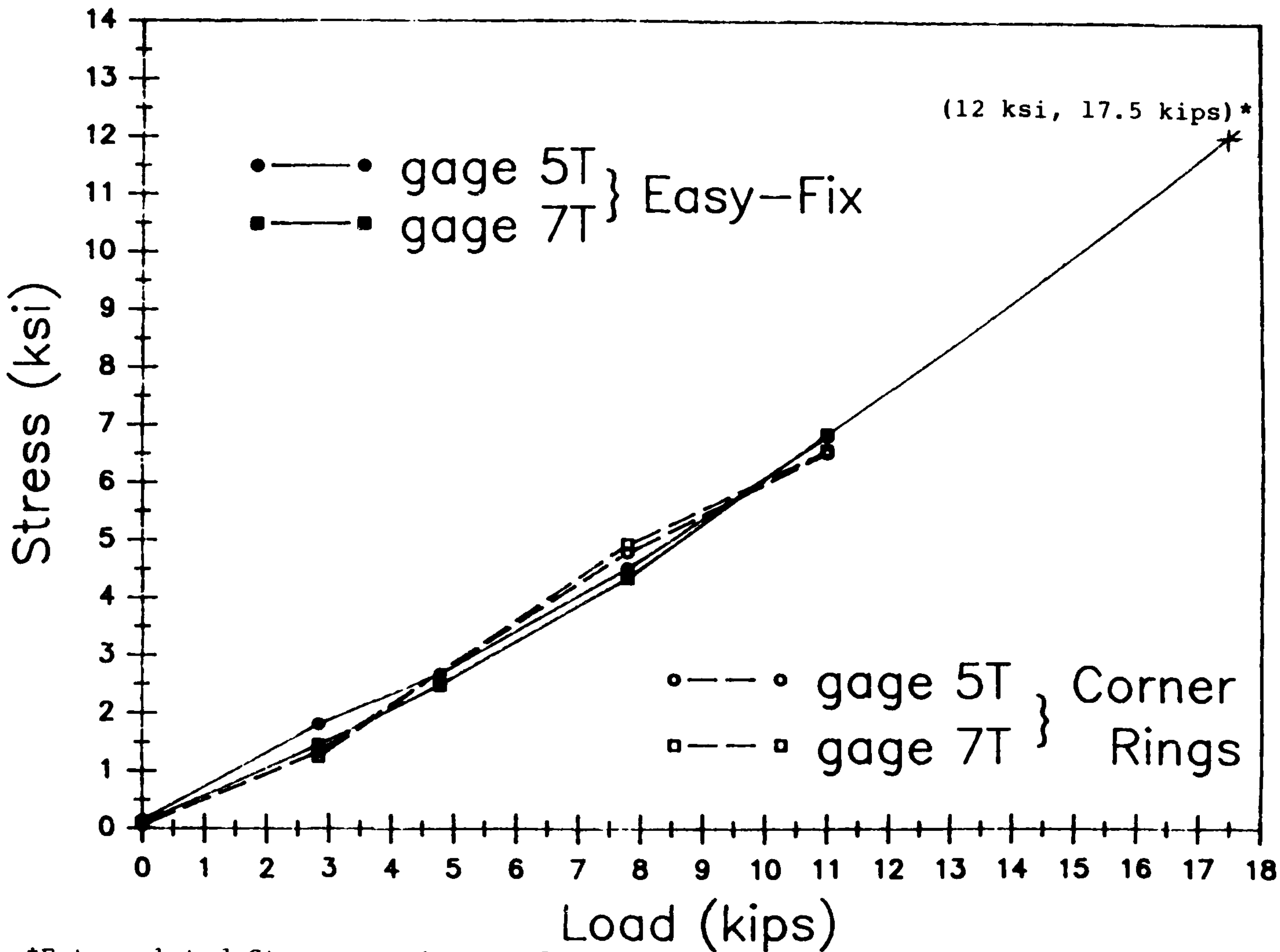
TABLE 6

SUMMARY OF FLOOR STRESSES

Test No. & Description	GAGE IDENTIFICATION																	
	1AL*	1AT**	1BL	1BT	1CL	1CT	2L	2T	3L	3T	4L	4T	5L	5T	6L	6T	7L	7T
1 EF (1960 lbs.)***	-116	-169	-120	-150	8	-82	-86	-19	60	0	-203	-158	-188	-143	-176	-139	-113	-98
2 LR (1960 lbs.)	199	-4	139	-124	150	-90	-30	150	158	203	-124	-71	-79	-56	26	19	41	34
3 LR (4700 lbs.)	-323	-195	-363	-368	-346	-279	-238	-52	-777	-540	-1013	-1295	-996	-1326	-999	-1187	-938	-1243
4 EF (4700 lbs.)	-227	-103	-628	-439	-624	-355	-614	-311	-779	-466	-1303	-1572	-1615	-1807	-1317	-1458	-1181	-1448
5 EF (6742 lbs.)	-336	-90	-697	-212	-939	-324	-737	-480	-1458	-888	-1847	-2353	-2096	-2664	-1879	-2242	-1659	-2472
6 EF (9650 lbs.)	-759	-127	-1378	-293	-1932	-672	-929	-447	-2889	-1785	-2941	-4075	-3315	-4514	-3134	-3974	-2779	-4348
7 LR (9650 lbs.)	-1105	-386	-1914	-896	-2383	-1094	-1367	-1190	-3171	-1794	-3187	-4481	-3463	-4790	-3311	-4349	-3135	-4932
8 LR (12700 lbs.)	-1658	-564	-2274	-999	-3069	-1585	-978	-3107	-4529	-2573	-4202	-6173	-4559	-6522	-4386	-5945	-3981	-6560
9 EF (12700 lbs.)	-1651	-841	-2503	-1326	-3231	-2009	-1116	-3223	-4717	-2745	-4585	-6451	-4994	-6808	-4558	-6102	-4307	-6349

*L - Gage element parallel to the length of the shelter (longitudinal)
**T - Gage element parallel to the width of the shelter (transverse)
***Total test weight; see Table 5 for more complete description of test

NOTE: Stress in psi.



*Extrapolated Stress at the Proof Test Load

Figure 15. Maximum Stress vs. Load for Shelter Floor

For a damaged or environmentally degraded floor, analysis indicates that buckling, if it occurs, will not be catastrophic because the lifting slings will provide needed support for a damaged floor which may buckle upon lifting or has already buckled from prior damage. Floor buckling is not considered a system failure as long as Easy-Fix supports the structure. While it is important to minimize further damage to the shelter, the primary function of Easy-Fix is to salvage the contents of a damaged shelter. Consequently, additional damage to the shelter which does not appreciably affect the contents, and does not jeopardize removal of the shelter, is tolerable.

Analysis of the strain data indicated that the compression tubes are not carrying pure axial loads, but that bending is being introduced into the tubes by the eccentricity of the loads at the corner fittings. The maximum stress recorded in the compression tubes was -2400 psi for test #9, indicating that bending loads present are not critical. A summary of maximum compression tube stress for each test is presented in Table 7. Extrapolation to the test load of 17,500 lbs. produces a maximum stress of only -3820 psi, which is well below the critical buckling stress of -8418 psi for the long compression tubes.

TABLE 7

MAXIMUM COMPRESSION TUBE STRESS

Test #4	-1120 psi
#5	-1560 psi
#6	-2000 psi
#9	-2400 psi

6.3 Assembly Test

One of the ground rules listed in Section 3 was that it should be possible for two persons to assemble the Easy-Fix kit in one - eight hour period. To test compliance with this ground rule, two undergraduate students were given the Easy-Fix assembly/installation manual which is included in Appendix A and the Easy-Fix kit, and were told to read the manual and assemble the kit. Figures 16 and 17 illustrate two steps in this task. They completed the entire task in two hours. One student was a male, height 6'0"; the other student was a female, height 5'4". At the time of this assembly test, no crate had been constructed for the Easy-Fix kit. The assembly recommends standing on the crate for certain stages of the assembly procedure, so a small 18" tall trash can was used to simulate a crate by the female student. The male student was tall enough that he required nothing to stand on.

7. EASY-FIX KIT CRITIQUE

After completion of the prototype Easy-Fix Kit, and the subsequent preliminary test and assembly of the kit by undergraduate students, several minor improvements were conceived. The toe jacks chosen for the prototype kit are five ton jacks (35 pounds each) with steel 36" - 1 1/4" O.D. lever bars, (5 lbs. each). Possibly aluminum toe jacks and lever bars could be substituted for these jacks to save weight. The 7/8" diameter forged steel hitch pins which connect the corner fittings and the compression tubes could be replaced with 7/8" diameter 7075-T6 aluminum pins to save weight. To reduce the size of the crate required for the Easy-Fix kit, a center tube connection splice could be designed such that the longer (12') compression tubes could be made in two pieces. A small two or three step aluminum step ladder would be helpful during assembly of the kit; however, it would not be absolutely necessary because the Easy-Fix kit crate or crates could be used to stand on. Because the shackles used

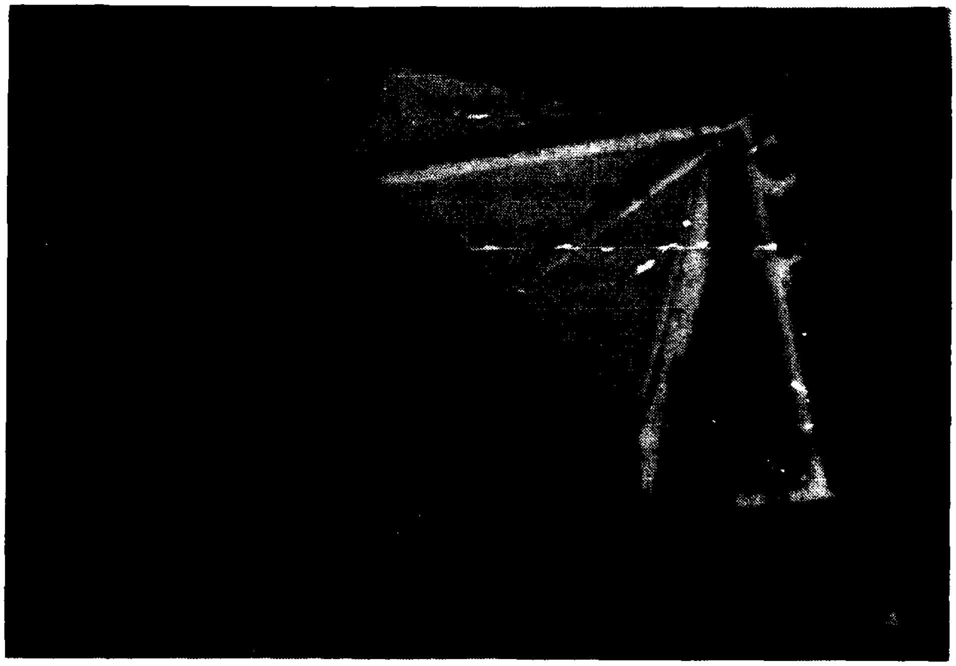


Figure 16. Aerial View of Compression Tube Framework Assembly.

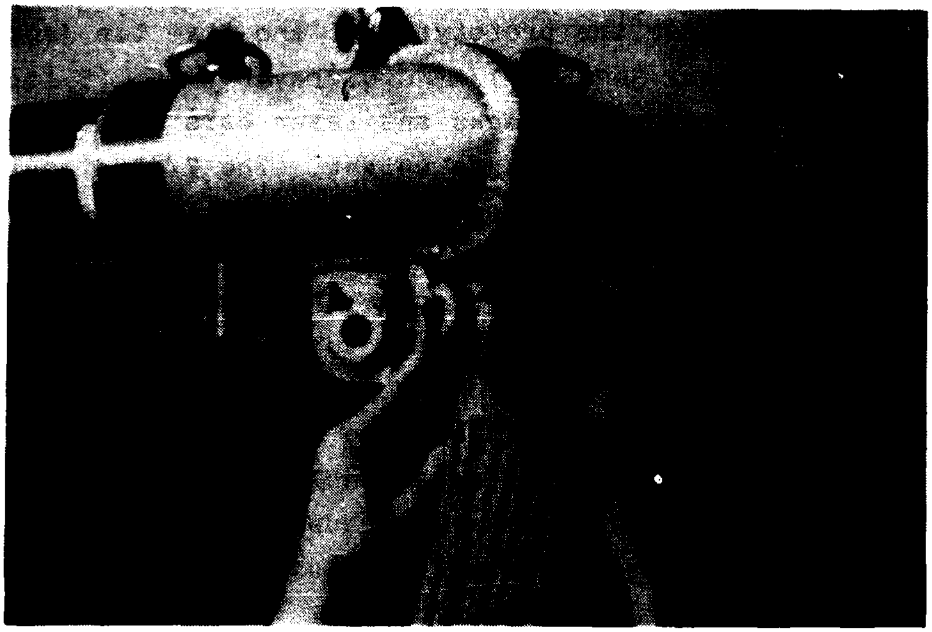


Figure 17. Corner Connection Strap Assembly.

with the nylon straps are forged, they are somewhat rough and may abrade the nylon. To eliminate this problem, the shackles could be rubber coated, and in addition, this rubber coating could also be used as part of the color coding process.

8. LIMITS TO THE EASY-FIX KIT USAGE

Easy-Fix is designed to transport damaged tactical shelters by helicopter. However, for reasons of economy and complexity, Easy-Fix is not appropriate for usage when damage exceeds certain limits.

Basic Damage Assumption

If enough of the shelter remains such that the Easy-Fix kit can be implemented, it is likely that those remains can be airlifted with Easy-Fix. But, an obviously unstable system may create greater danger than worth, and should probably be left behind or destroyed. It is believed that if damage is sufficient to make the use of Easy-Fix impossible or treacherous, it is highly likely that little remains in the shelter worth salvaging.

Easy-Fix can be used when:

(1) The shelter understructure (floor) is undamaged and means are available to secure the remaining upper structure with the upper corner fittings or other means, such that the shelter is stable in flight.

(2) The shelter understructure is damaged, but enough structure remains to allow support of the shelter with the support straps. If there is damage along the bottom of the shelter near or at the location of the lifting straps, which pass under the shelter, the shelter may still be removed with Easy-Fix if the strap is not bearing against jagged edges which might cut the strap (the bottom support straps are encased in a protective wrap, however, caution should still be used at sharp edges.) If the bottom edges are undamaged or slightly damaged, the aluminum angle should bridge any minor problem areas.

(3) Easy-Fix may be used as long as at least one pair of the bottom support straps are carrying load (the system is designed to work with either or both sets of straps running lengthwise and widthwise.) However, even if it appears that only one pair of the straps, either those running lengthwise or widthwise, will actually carry load, all sets should be erected to provide extra support should the load shift, or should the damaged shelter deform. Also, the large stretch inherent to nylon will provide the possibility of load distribution between the crosswise and lengthwise straps.

Damage Conditions which will prevent Easy-Fix usage

Two conditions may exist which will prevent Easy-Fix usage: (1) damage which prevents actual assembly of the Easy-Fix kit around the shelter, (2) damage which results in the shelter being severed into separate pieces near the midpoint.

9. CONCLUSIONS

This investigation resulted in the definition of a structural concept and the design and assembly of a system that meets the EASY-FIX evacuation objectives within the constraints established by the study ground rules and guidelines.

Several material systems were evaluated and all provide acceptable individual member and total system weights for the shelter under consideration. Consideration of longer and/or heavier shelters could alter this result.

The proposed concept is characterized by simplicity and versatility. Assembly of Easy-Fix is easily accomplished by two persons with no special training or tools required.

No major problem areas with respect to implementing this system have been defined. The design used for demonstration is detailed in Appendix B.

REFERENCES

(1) Askins, D. R., "Evaluation of Materials and Technical support for Tactical Shelters," AFWAL-TR-85-4070, April 1987.

(2) MIL-STD-209F, September 1984.

APPENDIX A

EASY-FIX ASSEMBLY/INSTALLATION MANUAL
FOR THE S-280 TACTICAL SHELTER

UDR-TM-87-07

EASY-FIX ASSEMBLY/INSTALLATION MANUAL FOR THE S-280 TACTICAL SHELTER

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PREFACE

The effort documented in this report was performed by the University of Dayton Research Institute (UDRI), Dayton, Ohio, 45469, under Contract F33615-85-C-5094 entitled, "Technical Support for Tactical Shelters," for the Materials Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio 45433. Air Force administrative direction and technical support was provided by Mr. Robert Urzi, AFWAL/MLS.

The work described herein was conducted during the period from January 1986 to March 1987. Project supervision was provided through the Materials Engineering Division of the University of Dayton Research Institute with Mr. Dennis Gerdeman, Supervisor. Mr. D. Robert Askins was the Project Engineer directing the overall activities. Technical effort was accomplished by Mr. D. R. Bowman, Applied Mechanics Group, Aerospace Mechanics Division.

BACKGROUND

Military tactical shelters are susceptible to a variety of types of in-service damage. This can result from battle damage, handling/transport damage, and environmental damage, and can be of a structural or functional nature. Structural damage consists of damage of sufficient extent to walls, roof, floor, or frame that transportability of the shelter is jeopardized.

Easy-Fix is a concept for providing the means to evacuate structurally damaged, non-operational shelters using helicopter external airlift capabilities. This assembly/installation manual is for a prototype Easy-Fix Kit developed to airlift S-280 B/C and C/G tactical shelters.

This Easy-Fix Kit provides the means to evacuate structurally damaged shelters using helicopter external airlift capabilities. However, Easy-Fix is not appropriate for usage when damage exceeds certain limits. If it is possible to assemble the Easy-Fix Kit around the damaged shelter and the shelter is stable as judged by common sense, it may be airlifted.

NOTES:

1. Read this entire instruction manual before beginning installation. The safety and effectiveness of this assembly, when implemented, is dependent on careful assembly as shown in this instruction manual.

2. If, however, the shelter has sustained severe damage, then the assembly procedures will have to be altered. When this is necessary, care should be taken to ensure that:

   (a) the nylon straps are not placed over sharp or jagged edges that could cut the straps during lift or transport.

   (b) the shelter is well supported and stable within the kit. This should be carefully evaluated during initial lift by the helicopter and any required adjustments to nylon strap locations should be made before transport.

3. Easy-Fix is designed to be erected with a minimum of two people. However, the use of three people would reduce assembly time.

4. Many of the parts are color coded. During assembly, attention should be paid to the color coding and when two color coded parts are brought together, the color code on one part should match the color code of the other part.

Step 1. Remove Easy-Fix equipment from crate. Check inventory list to determine if all Easy-Fix parts are included. During inventory, place similar components together to allow easy assembly.

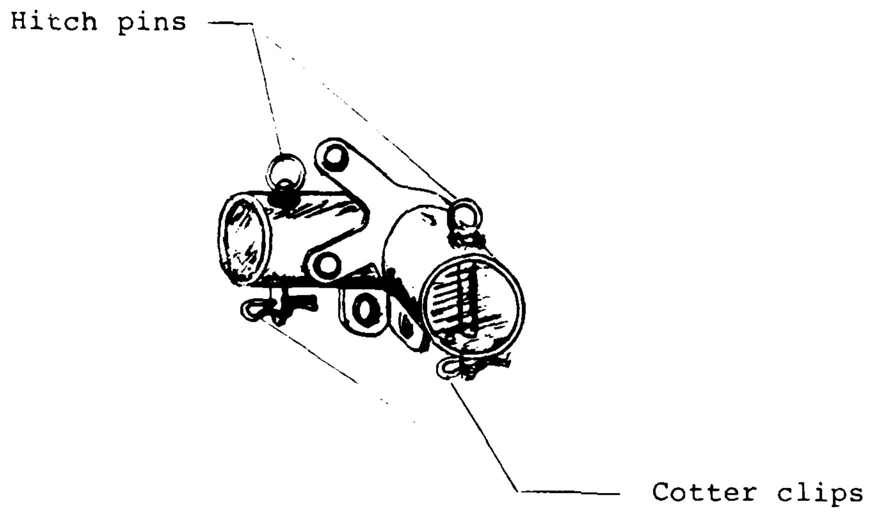
EASY-FIX MATERIAL INVENTORY LIST

1. 4" diameter aluminum compression tubes:

   2 - 12' long - ends color coded green

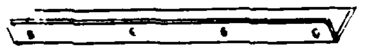
   2 - 7' long - ends color coded blue

2. Aluminum corner fittings - four total including two hitch pins with cotter clips per corner fitting.

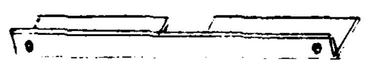


3. Aluminum angle plate strap protectors:

   2 - 6' long angles for shelter sides



   2 - 6' long angles with leg cut-outs for shelter ends



4. Tension cables

2 - 13' long steel cables with turnbuckle and clevis on one end and clevis on other end

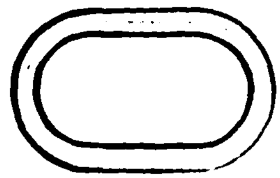
2 - wrenches for tightening turnbuckles

5. Nylon straps:

NUMBER	DESCRIPTION	LENGTH AND WIDTH
1	Khaki green angle plate retaining strap with hook, ring, and ratchet buckle	30' x 1 3/4"
1	White angle plate retaining strap with hook, ring, and ratchet buckle	40' x 1 3/4"
4	Top lifting straps, shackle end fittings color coded brown	105" x 3"
4	Side straps, one shackle color coded green, and one shackle yellow	79.5" x 3"
4	End straps, one shackle blue, one shackle red	69" x 3"
2	Side connector straps, both shackle end fittings yellow	36" x 3"
2	End connector straps, both shackle end fittings red	28" x 3"
2	Bottom support straps with ring end fittings red	160" x 4"
2	Bottom support straps with ring end fittings yellow	101" x 4"
4	Corner connection loop straps, both shackle end fittings black	10" x 3"

6. Lift Ring

1 - Master link lifting ring color coded brown



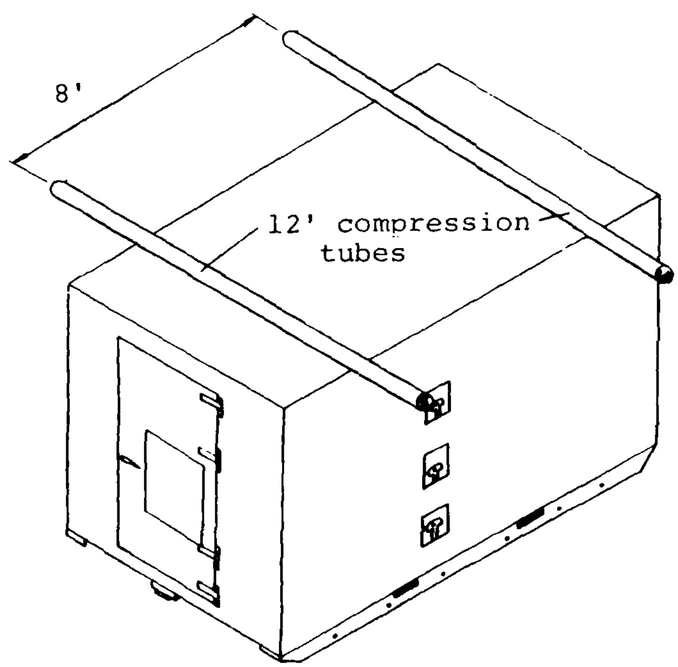
7. Toe jacks

2 - toe jacks with lever bars and aluminum
8" x 8" x 1/2" jack support plates

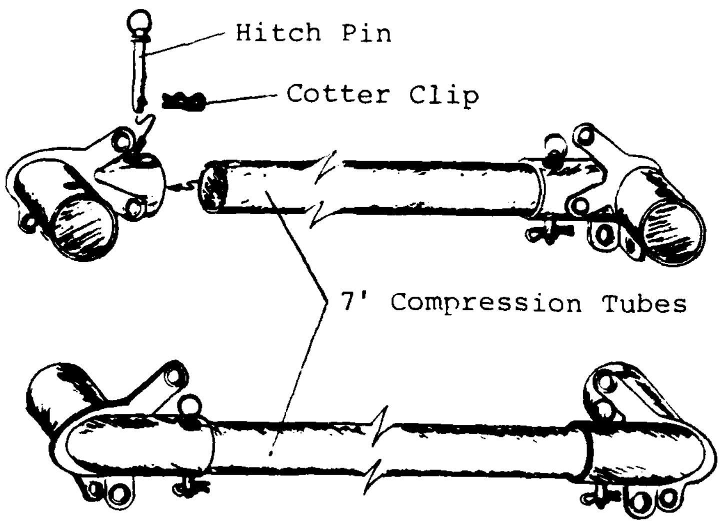
8. Fiberglass extension rods

3 - 4' fiberglass extension rod sections with one 18" light wire chain and hook assembly. These join together to form a 12' rod.

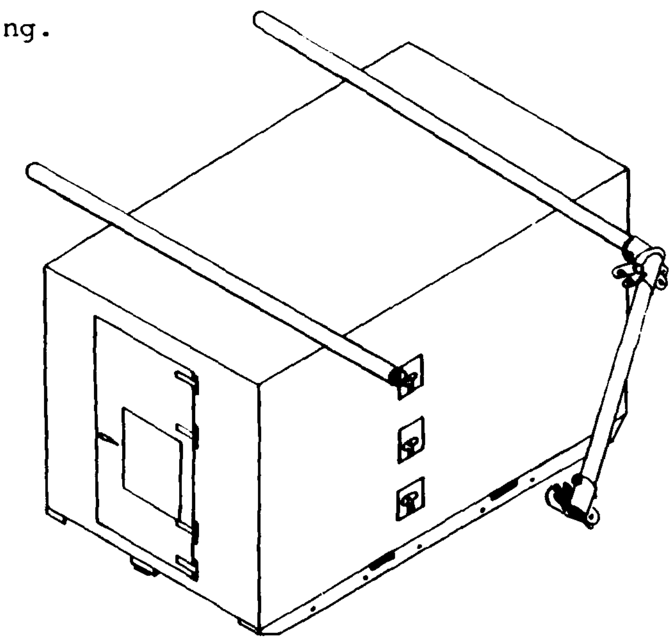
Step 2. Place the two - 12' long compression tubes (color coded green) cross wise across the top of the shelter as shown Space the tubes about 8' apart. If the shelter roof is not level, the tubes may need to be blocked in place so that they do not roll off of the shelter.



Step 3. Assemble the end fittings on both of the shorter compression tubes (color coded blue), as shown. Note that the fittings are color coded blue. Place hitch pin in place through corner fitting and compression tube and secure with cotter clip. Make sure hitch pin goes through the hole in the compression tube.

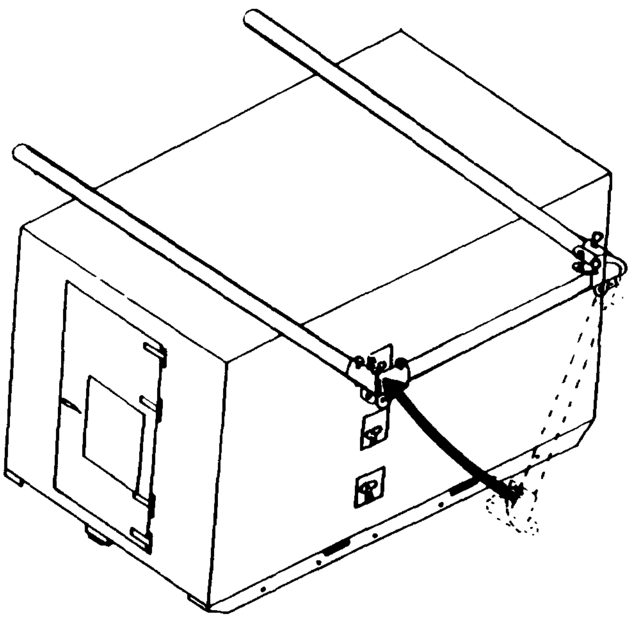


Step 4. Using one of the end compression tube assemblies from Step 3, slip one corner fitting of this assembly onto one of the long compression tubes which is on top of the shelter. Install hitch pin and cotter clip to secure fitting.

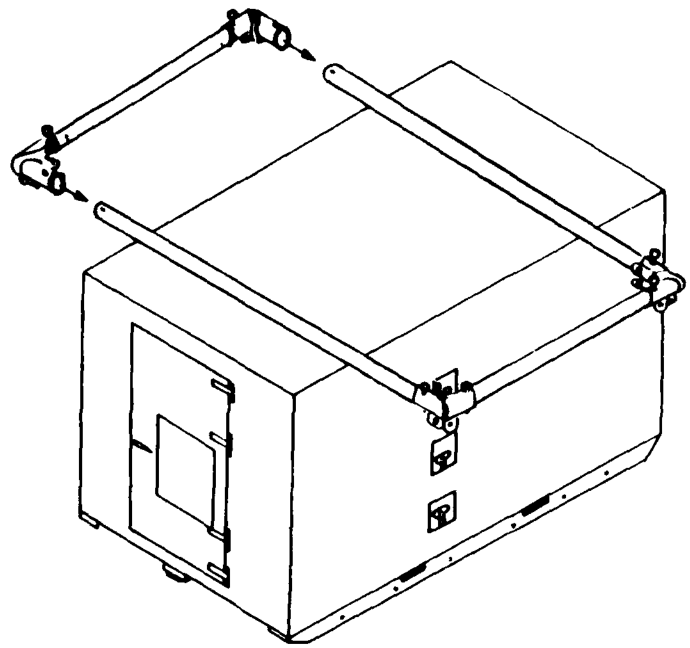


Step 5. Rotate end compression tube assembly to the horizontal position. Insert other long compression tube into the corner fitting. Secure with hitch pin and cotter clip. When this assembly is completed it should be pushed closer to the shelter so that it does not tip off.

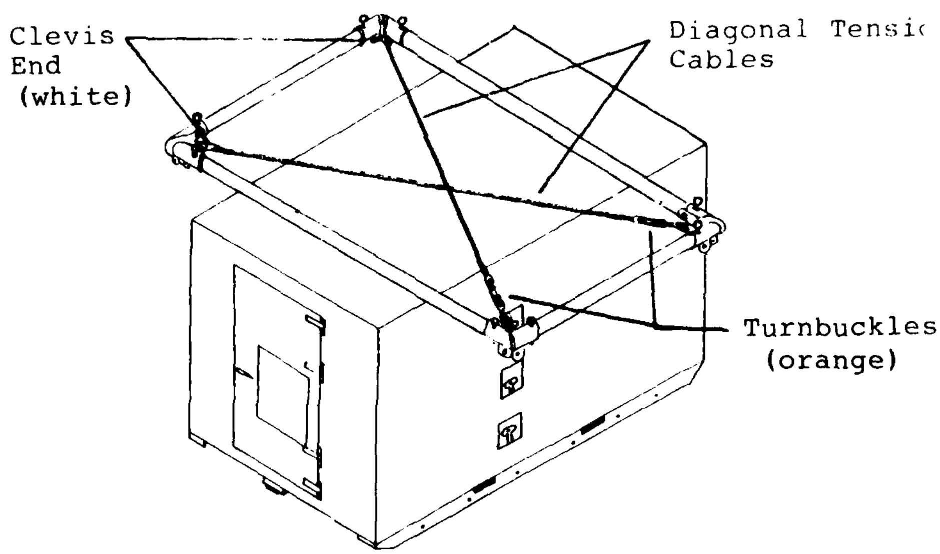
NOTE: If the shelter roof will support a man, this step may be accomplished more easily with one person on the roof and one on the ground. The person on the ground should be the taller of the two people. In addition, the crate may be used to stand on to make assembly easier. (If someone is on the roof, this person should hold the assembly so it does not tip off.)



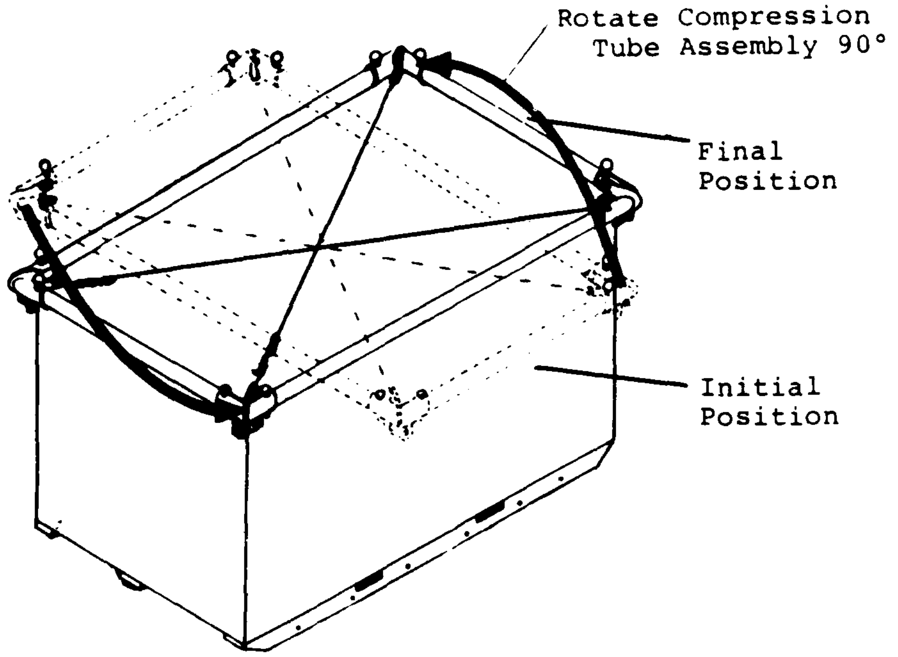
Step 6. Attach second end compression tube assembly as shown. Secure with hitch pins and cotter clips.



Step 7. Install diagonal tension cables. Install the clevis end first, and then install the turnbuckle end as shown. Tighten the turnbuckles evenly (alternating back and forth between the two turnbuckles) <u>by hand, DO NOT USE WRENCHES TO TIGHTEN</u>. Then use the wrenches to tighten the jam nuts against the turnbuckles. <u>CAUTION</u>: the tubular compression framework must be balanced on the shelter roof, and care should be used when installing the diagonal cables not to put weight on the framework which might cause it to slide off the shelter.

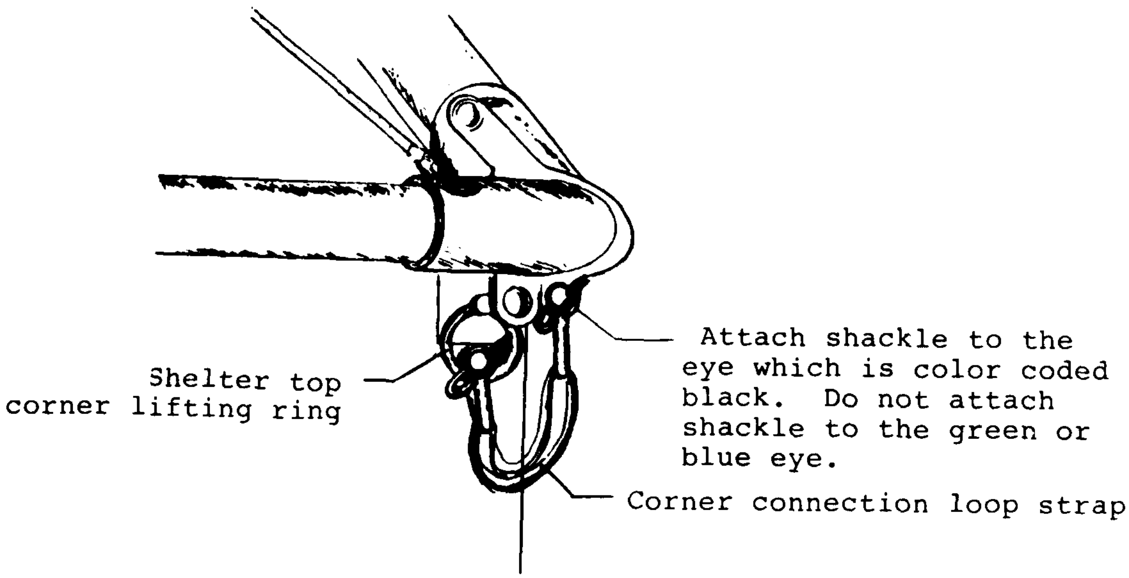


Step 8. Check to be sure that all hitch pins and cotter clips are in place, then rotate compression tube assembly approximately 90° such that the long compression tubes are parallel to the shelter.

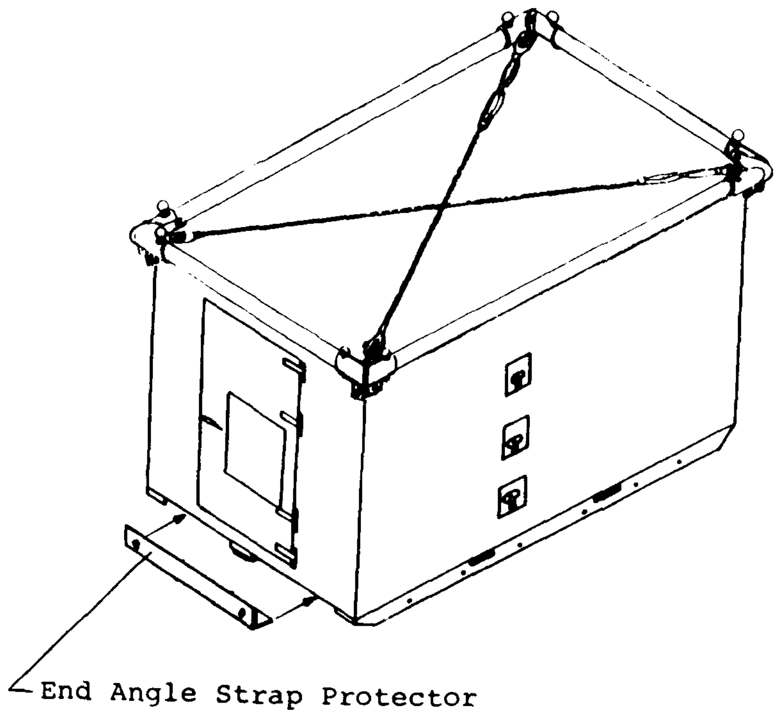


NOTE: This step must be completed very carefully. Do not allow the assembly to become off-balance as it is rotated around the corners, or it may slip over a corner, become unbalanced, and slide off the shelter.

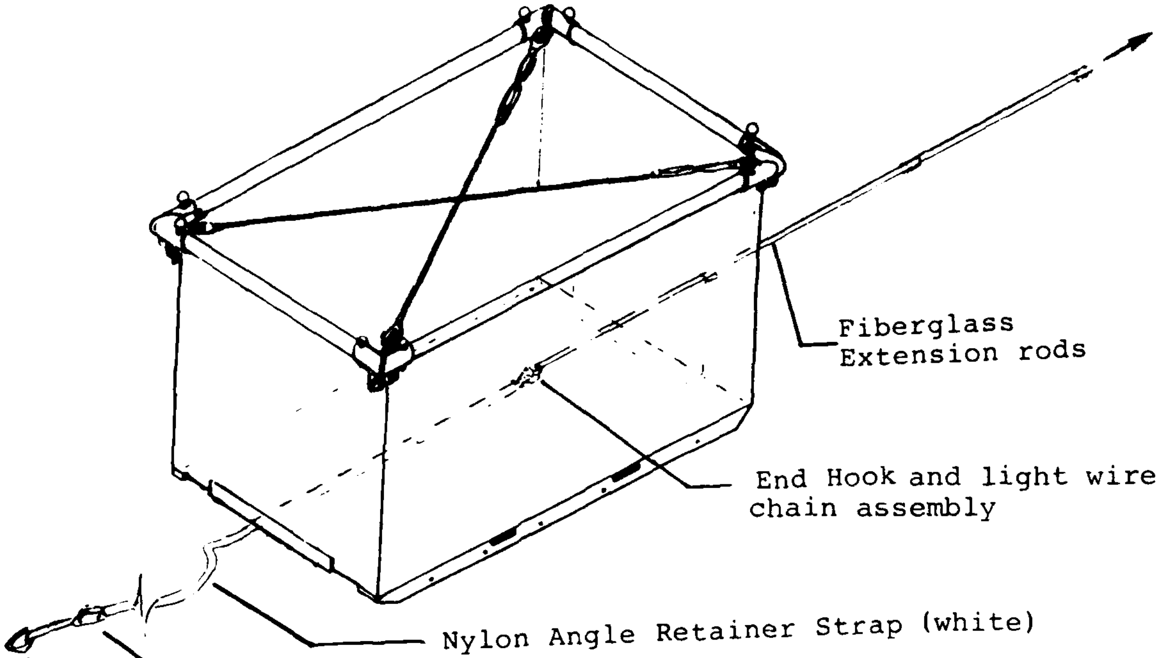
Step 9. Assemble the four corner connection loop straps (10"x3" color coded black). One shackle end fitting attaches to the shelter top corner lifting ring. The other shackle end fitting attaches to the aluminum corner fitting at the eye which is also color coded black.



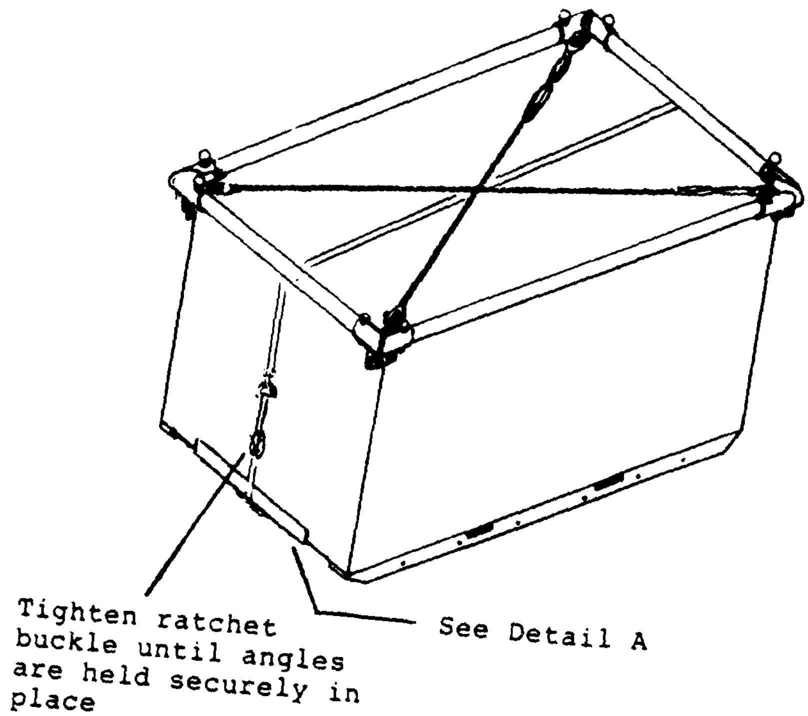
Step 10. Place the 6' end angle strap protectors (with cutouts) as shown below. If the shelter is buried in earth and it is not possible to dig out enough to place the angles and the bottom support straps, proceed to Step 13.

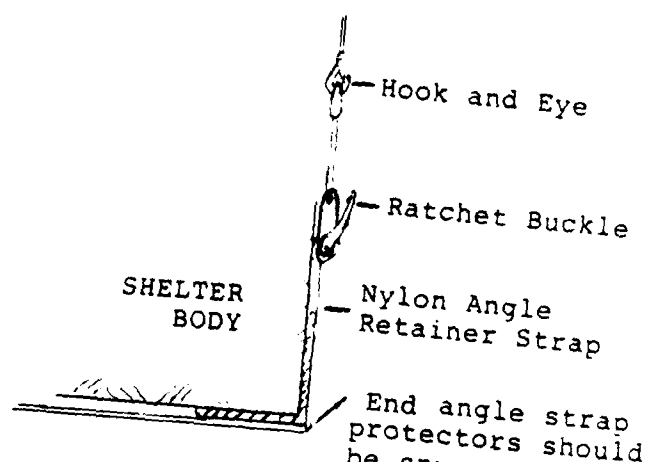


Assemble fiberglass rod sections into single 12' rod with light wire chain and end hook assembly, and pull the hook end of the 40' white, 1 3/4" wide nylon strap with a ratchet buckle underneath the shelter along either side of the center skid.



Pass the hook end of the white 40'x1-3/4" nylon strap assembly under the compression tube framework, under the diagonal tension cables, and over the shelter so that the hook end and the delta ring (eye) end are together. With one person at each end of the shelter, center the end angle strap protectors and the angle retainer strap. Each person should hold the angle up tightly against the shelter end while the person who is next to the ratchet assembly attaches the hook and eye, and tightens the strap with the ratchet to secure the angles in place (see detailed sketches on next page).

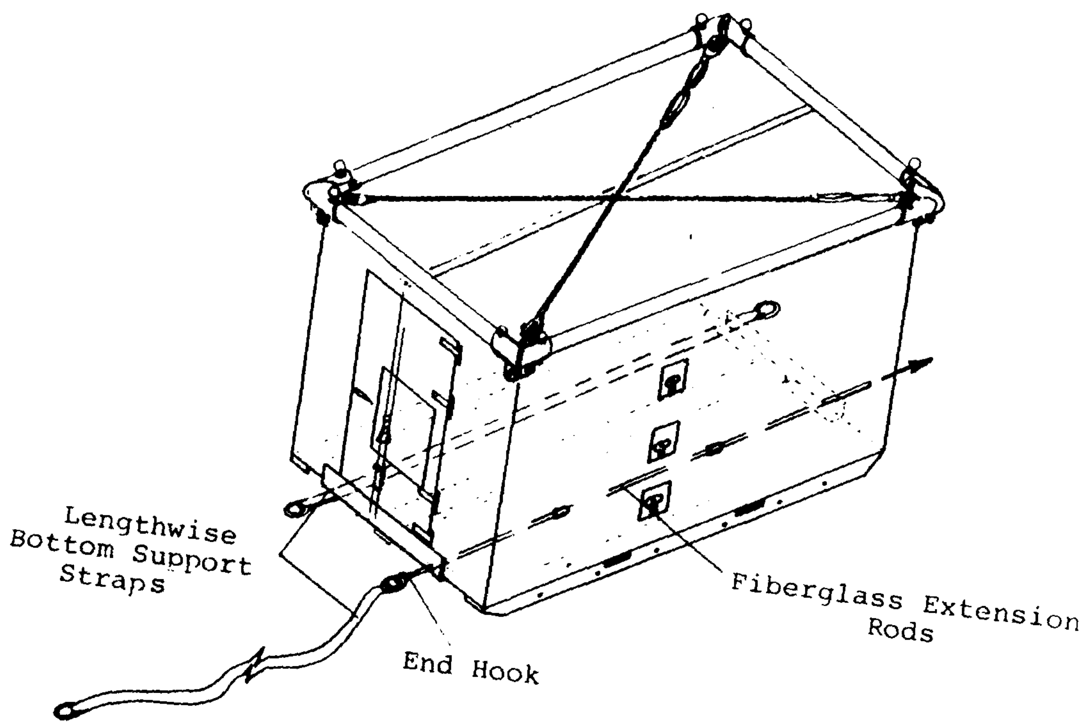

Tighten ratchet buckle until angles are held securely in place
See Detail A


Hook and Eye
Ratchet Buckle
SHELTER BODY
Nylon Angle Retainer Strap
End angle strap protectors should be snug against the shelter

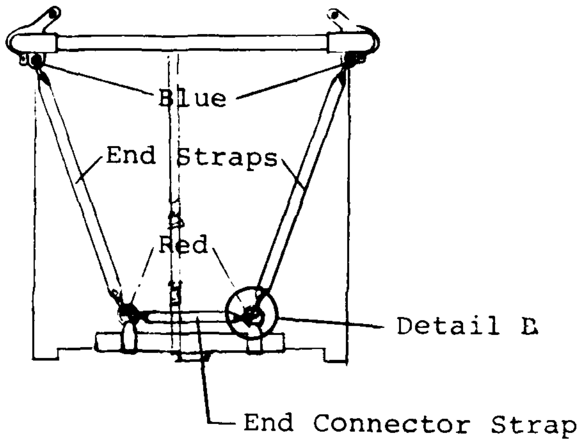
DETAIL A

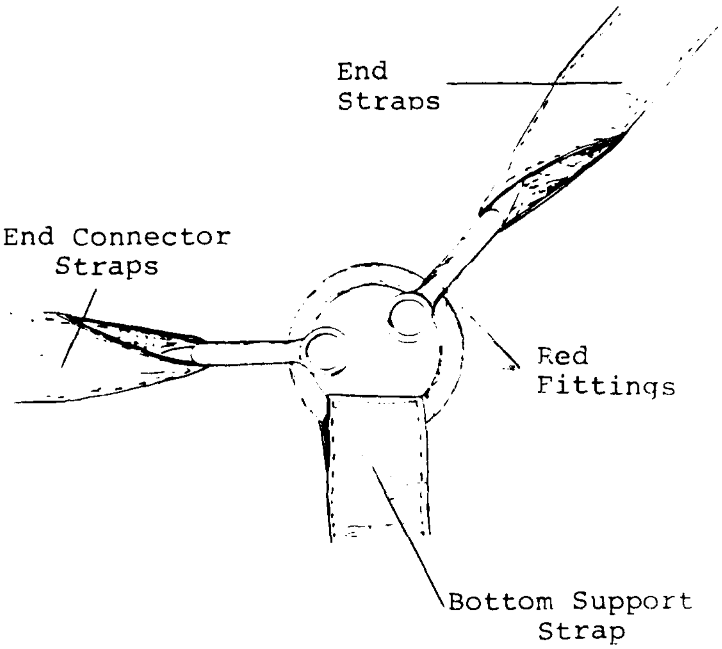
Step 11. Use the fiberglass rods with end hook to pull support straps (158" with red colored end rings) under shelter as shown.

IMPORTANT: In this step and all following steps make sure that straps are not twisted.



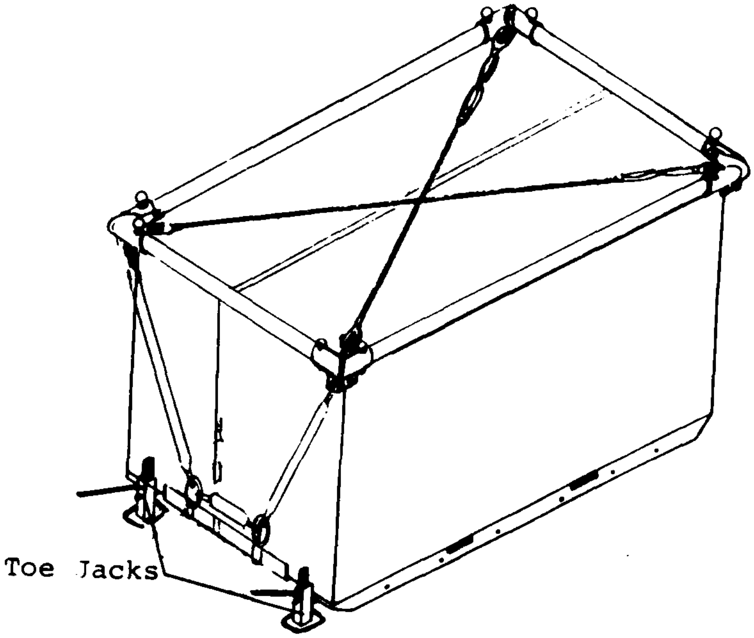
Step 12. Attach bottom support straps, end straps and end connector straps to each other as shown below at each end of shelter. Attach end straps to blue eyes on aluminum corner fittings of framework around top of shelter as shown below. Match colors at each fitting.



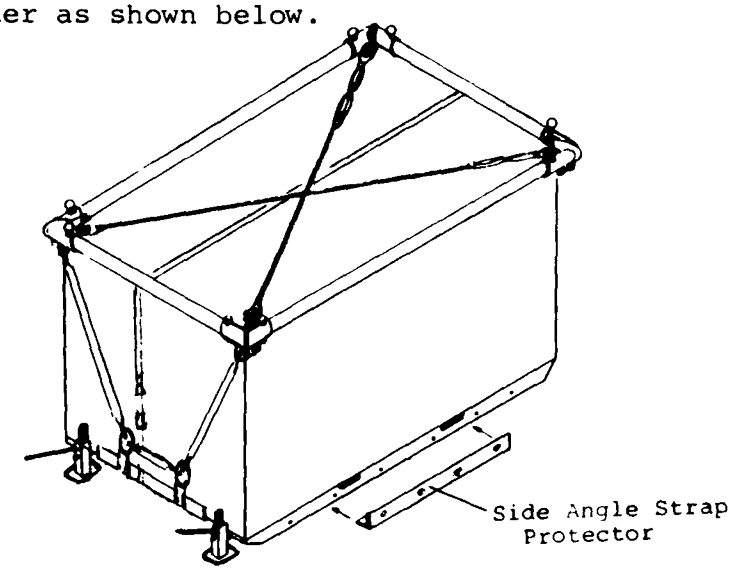


DETAIL B

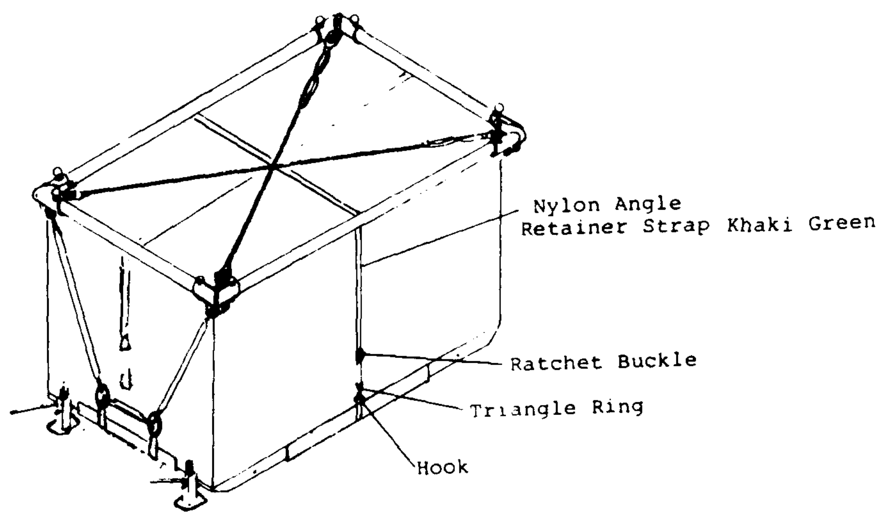
Step 13. Locate toe jacks under one shelter end. If possible, use jacks as near to outside skids as possible, see sketch. If shelter damage prevents placement of jacks as shown in the sketch, a suitable alternate location may be selected. If soil surface is unsuitable for jacking (soft, muddy, etc.), use 8" x 8" x 1/2" aluminum plate beneath jack to increase stability. Using one person per jack, evenly jack shelter end up approximately 10". If one or both of the end angle strap protectors from Step 10 could not be installed, install now following the instructions for Step 10. Pull support straps under shelter as described and shown in Step 11. Attach end straps and end connector straps as shown in Step 12.

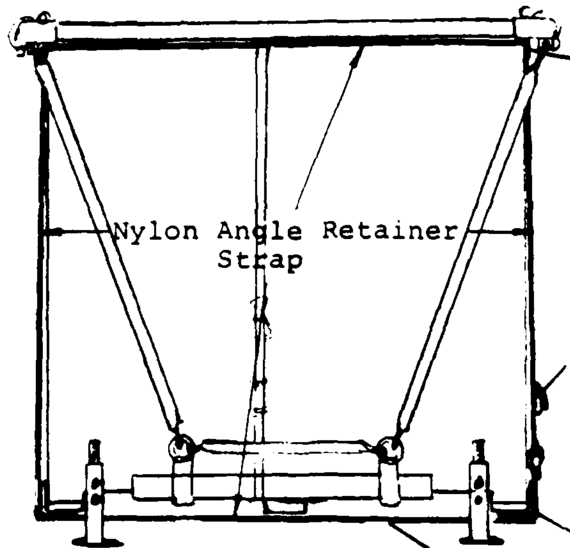


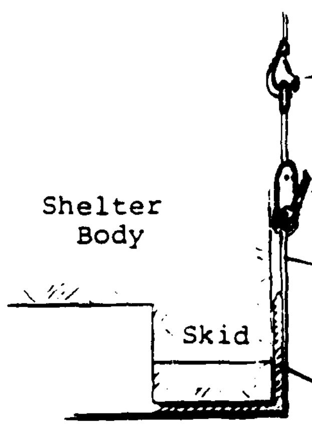
Step 14. Place one 6' side angle strap protector on each side of shelter as shown below.



Use 12' fiberglass rod with hook to pull the hook end of the khaki green 30'x1-3/4" wide nylon strap with a ratchet buckle underneath the shelter. Make sure strap is beneath the two 4" wide support straps which were placed in Step 11. Pass the hook end of the nylon strap assembly under the compression tube framework, under the diagonal tension cables, and over the shelter so that the hook end and the delta ring (eye) end are together. With one person at each side of the shelter, center the side angle strap protectors and the angle retainer strap. Each person should hold the angle up snugly against the skid while the person who is next to the hook, eye, and ratchet assembly attaches the hook and eye, and tightens the strap with the ratchet to secure the angles in place (see detailed sketches on next page).

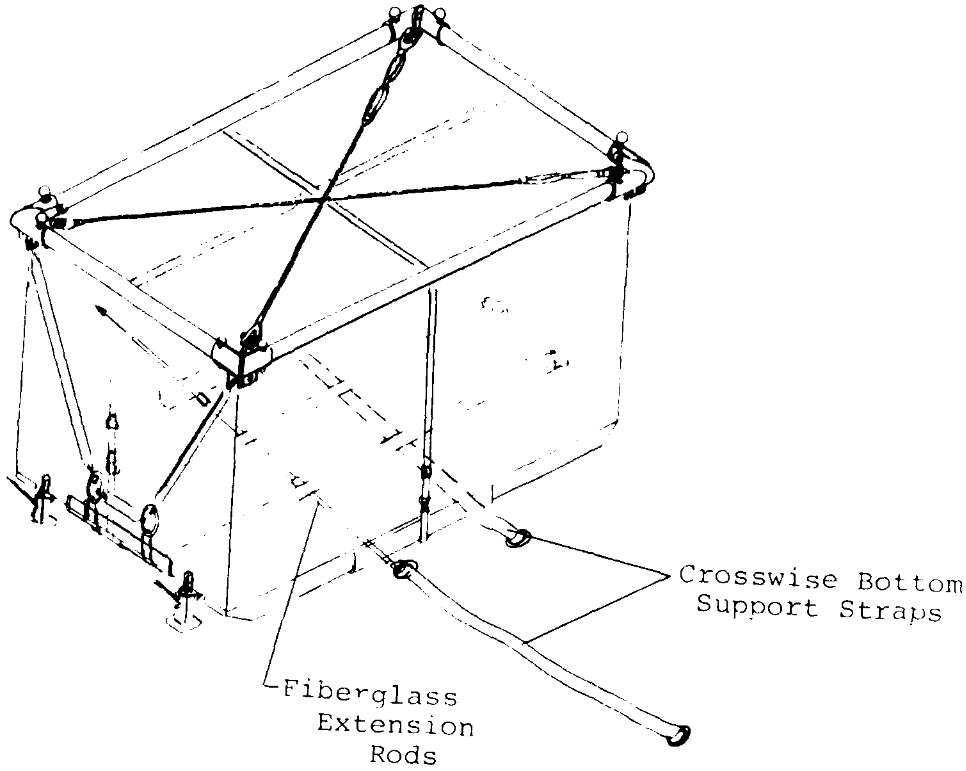



pass strap under compression tubes and diagonal tension cables
Nylon Angle Retainer Strap
Tighten Ratchet Buckle until angles are held securely in place
See Detail C
Note that the Nylon Angle Retainer Strap must be underneath the lengthwise Support Straps

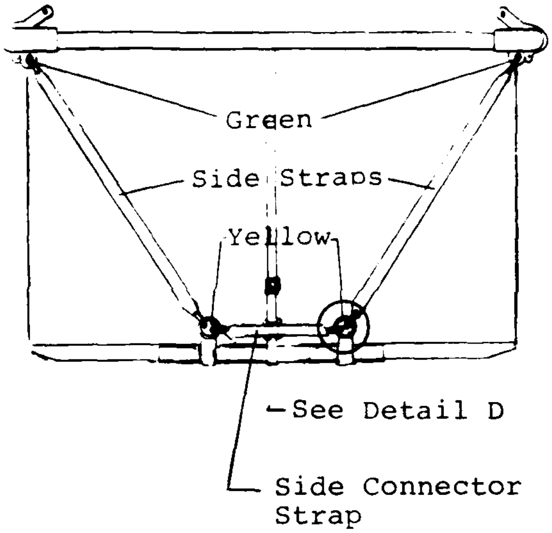

Hook and Eye
Ratchet Buckle
Shelter Body
Skid
Nylon Angle Retainer Strap
Side Angle Strap Protectors should be snug against skids

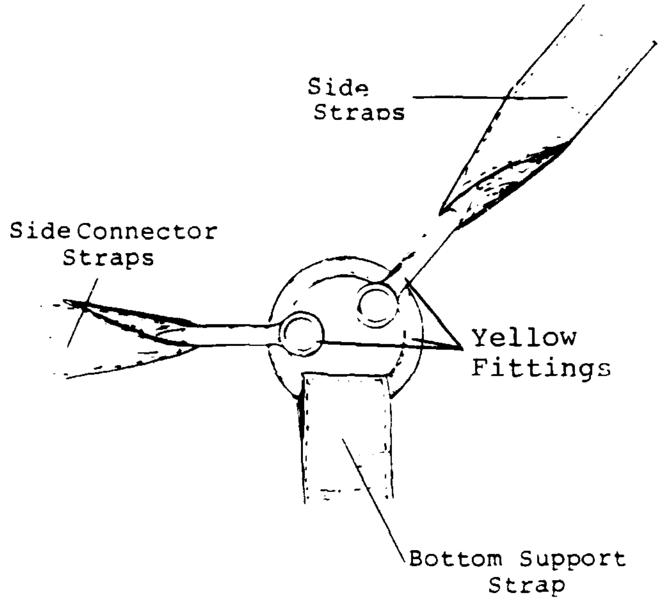
Detail C

Step 15. Using the fiberglass extension rods and the end hook, pull bottom support straps (101" x 4" with yellow colored end rings) under the shelter. Make sure these straps pass beneath the lengthwise bottom support straps placed in Step 11.



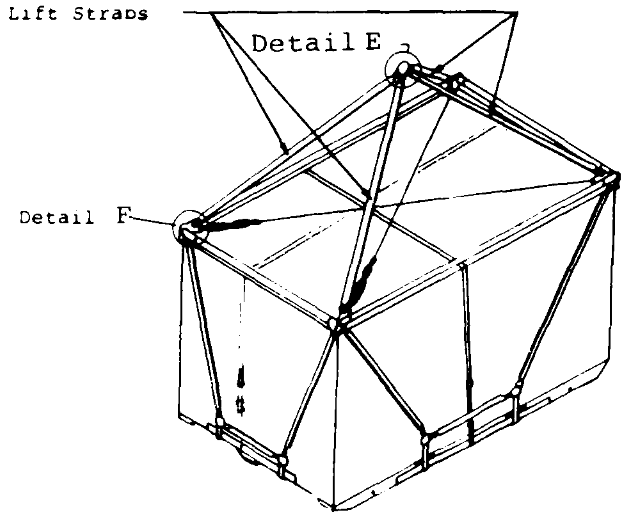
Step 16. Attach crosswise bottom support straps, side straps, and side connector strap to each other as shown below. Connect side straps to green eyes on aluminum corner fittings of framework around top of shelter as shown below. Match colors at each fitting.

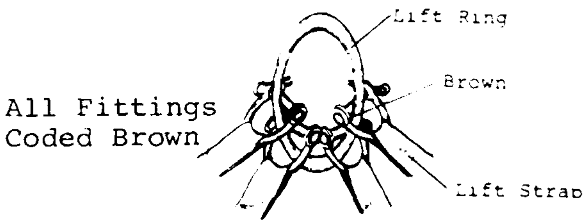




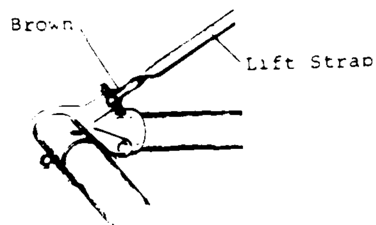
DETAIL D

Step 17. Assemble the four lift straps. The lift straps should be attached to the lift ring, so that they are not crossed or tangled. Attach the other ends of the four lift straps to the four brown eyes on the aluminum corner fittings of the framework around the top of the shelter as shown below.





Detail E



Detail F

Step 18. Check all connections to be certain that all shackles and cotter clips are installed correctly. Check diagonal steel tension cables; they should be taut, but not excessively tight.

Step 19. During lifting with the helicopter, radio contact or hand signal communications should be maintained with the pilot so that the pilot may be warned if the shelter begins to fail in the Easy-Fix Kit, or if the shelter is not stable enough to be transported.

APPENDIX B

PROTOTYPE EASY-FIX KIT COMPONENTS LIST AND DRAWINGS OF NON STANDARD COMPONENTS

REQUIRED NYLON WEB PRODUCTS

Item	UDRI* Designation	Quantity	Length	Type	Wireco/Web Slings Stock No., Description	Crosby Group, Inc. End Fitting
1**	GH	2	101"	4" single ply nylon	-1-904 101"x4" of nylon webbing with type 4 nylon wear pad wrap over entire length	S-643 weldless rings O.D.=5.75", I.D.=4" Stock diameter=7/8" Ring stock #10-13780
2**	KM	2	160"	4 single ply nylon	-1-904 160"x4" of nylon webbing with type 4 nylon wear pad wrap over entire length	S-643 weldless rings, O.D.=5.75", I.D.=4", stock diameter=7/8", ring stock #10-13780
3	CH	4	79.5"	3" 2 ply nylon	EET-2-603 79.5"x3" of nylon webbing	Stock #10-18115 3-1/4 ton anchor shackle, round pin, galvanized
4	AC	4	105"	3" 2 ply nylon	EEF-2-903 105"x3" of nylon webbing	10-18133 4-3/4 ton anchor shackle, round pin, galvanized
5	HI	2	36"	3" single ply nylon	EET-1-403 36"x3" nylon webbing	10-18115 2-1/4 ton anchor shackle, round pin, galvanized
6	JK	2	28"	3" single ply nylon	EET-1-603 28"x3" nylon webbing	10-18115 3-1/4 ton anchor shackle, round pin, galvanized
7	CK	4	69"	3" 2 ply nylon	EET-2-603 69"x3" nylon webbing	10-18115 3-1/4 ton anchor shackle, round pin, galvanized
8	CCLS***	4	10"	3 " 2 ply nylon	EN-2-901 10"x3" nylon webbing	10-18115 3-1/4 ton anchor shackle, round pin, galvanized

*See Figure 5 for component member designations.

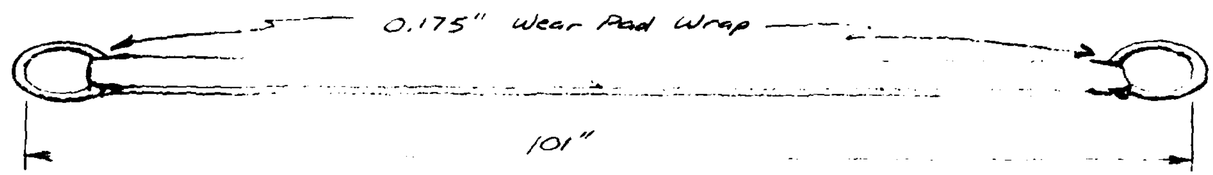
**See Drawing Number EF-001 for these non-standard strap assemblies.

***Corner connection loop strap. See pages 47 and 53.

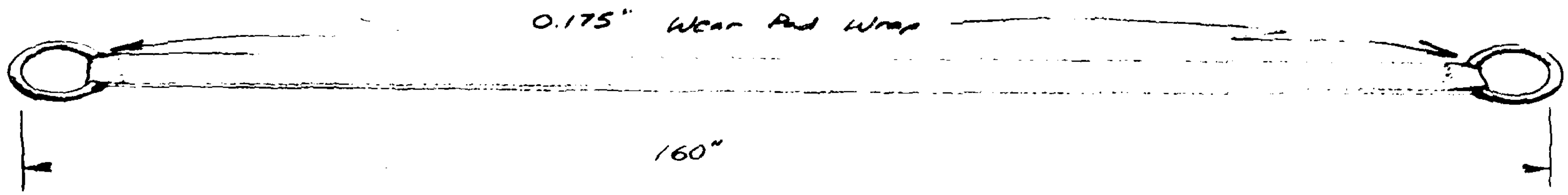
ADDITIONAL COMPONENTS

NUMBER REQUIRED	DESCRIPTION
	Non Standard
1	End angle plate retainer strap assembly, see drawing No. EF-002
1	Side angle plate retainer strap assembly, see drawing No. EF-003
2	Diagonal tension cable assembly, see drawing No. EF-004
2	End angle plate strap protectors, see drawing No. EF-005
2	Side angle plate strap protectors, see drawing No. EF-005
2	End compression tubes, see drawing No. EF-006
2	Side compression tubes, see drawing No. EF-006
4	Compression tube corner fittings, see drawing Nos. EF-007, EF-008, EF-009, EF-010
	Standard
8	7/8" dia. x 6-1/4" forged steel hitch pins
52	Cotter clips to replace cotter pins in all of the shackles
2	8"x8"x1/2" 6061-T6 Al jack support plates
2	5 ton toe jacks (TK Simplex, Model 86A) and lever bars
1	Master link (Accoloy Kuplex II No. 5983-10003 Stock No. K-3)
3	4' fiberglass chimney cleaning rods with threaded end fittings
1	18" light wire chain and latching eye hook assembly
2	1-3/8" open end wrenches

Item 1 - CROSSWISE BOTTOM SUPPORT STRAP - UDRI DESIGNATION GH



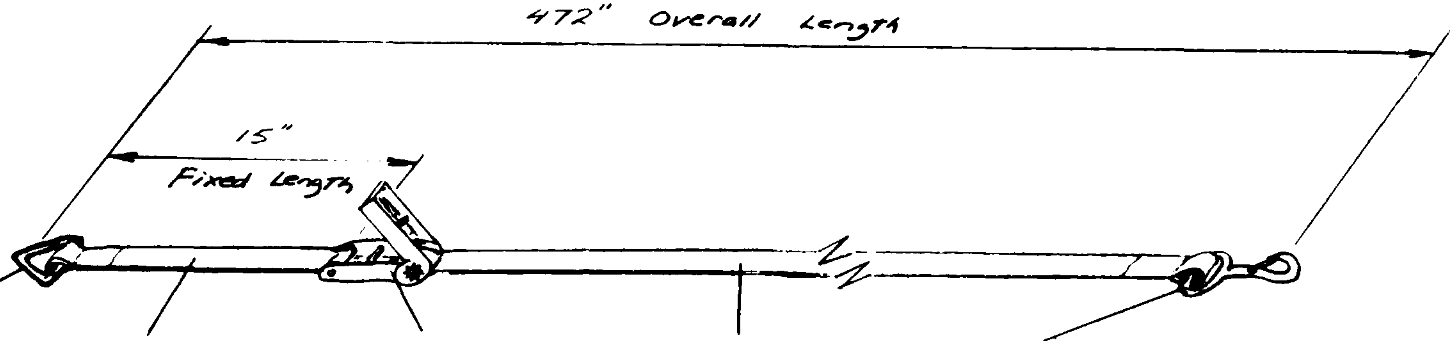
Item 2 - LENGTHWISE BOTTOM SUPPORT STRAP - UDRI DESIGNATION KM



Notes:

1) Quantity Required - 2 of each per Easy-Fix Kit.
2) Material & Supplier Information listed on Required Nylon Web Products sheet.

UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY-FIX BOTTOM SUPPORT STRAPS	
APRIL 27, 1981	NO SCALE
Dr. DAN BOWMAN	DWG. No. EF-001

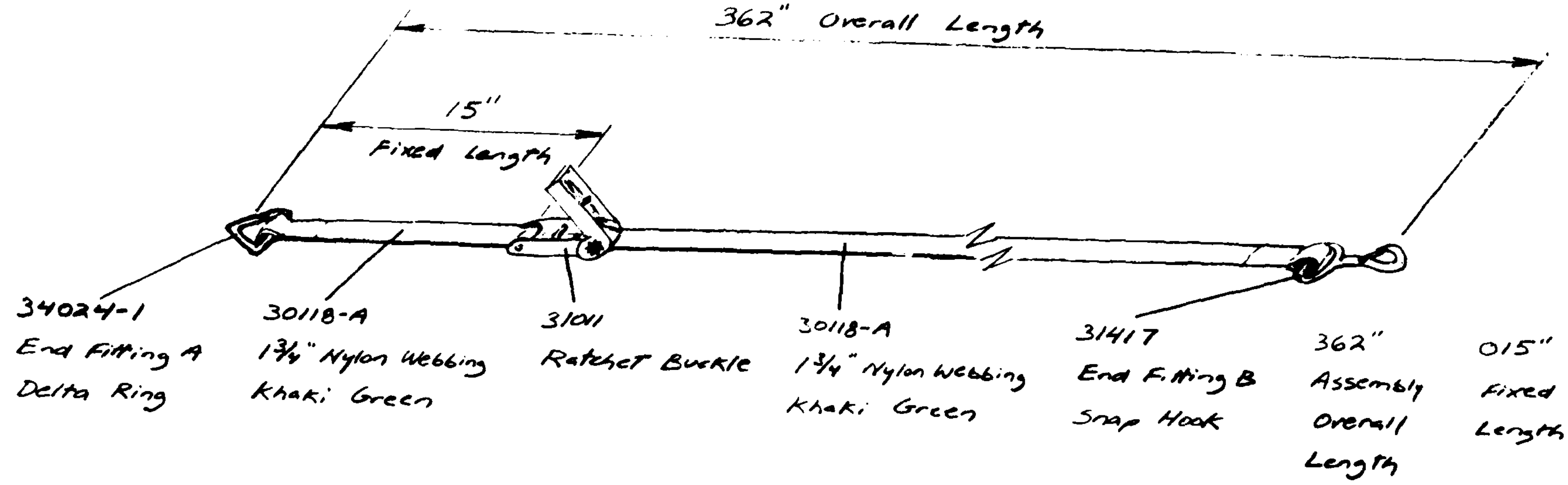


34024-1	30118-G	31011	30118-G	31417	472"	015"
End Fitting A	1¾" Nylon Webbing	Ratchet Buckle	1¾" Nylon Webbing	End Fitting B	Assembly	Fixed
Delta Ring	Gray		Gray	Snap Hook	Overall	Length
					Length	

Notes:

1) Quantity Required - 1 per Easy-Fix kit
2) Supplier: Samsel Supply Co.
   Cleveland, OH

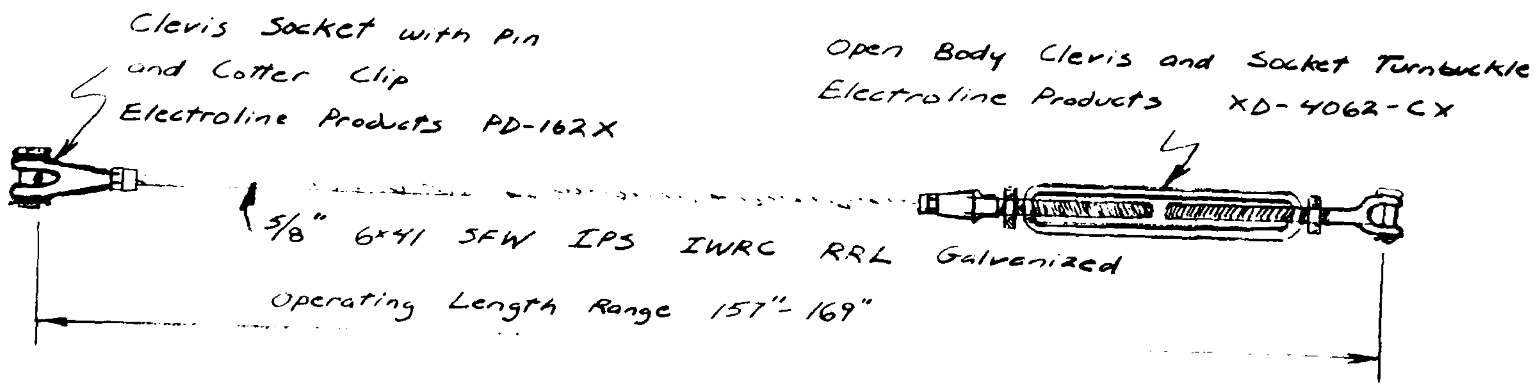
UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY-FIX END ANGLE PLATE RETAINER STRAP ASSEMBLY	
MARCH 31, 1987	NO SCALE
Dr. DAN BOWMAN	DWG NO. EF-002



Notes:

1) Quantity Required - 1 per Easy-Fix kit
2) Supplier: Samsel Supply Co.
Cleveland, OH

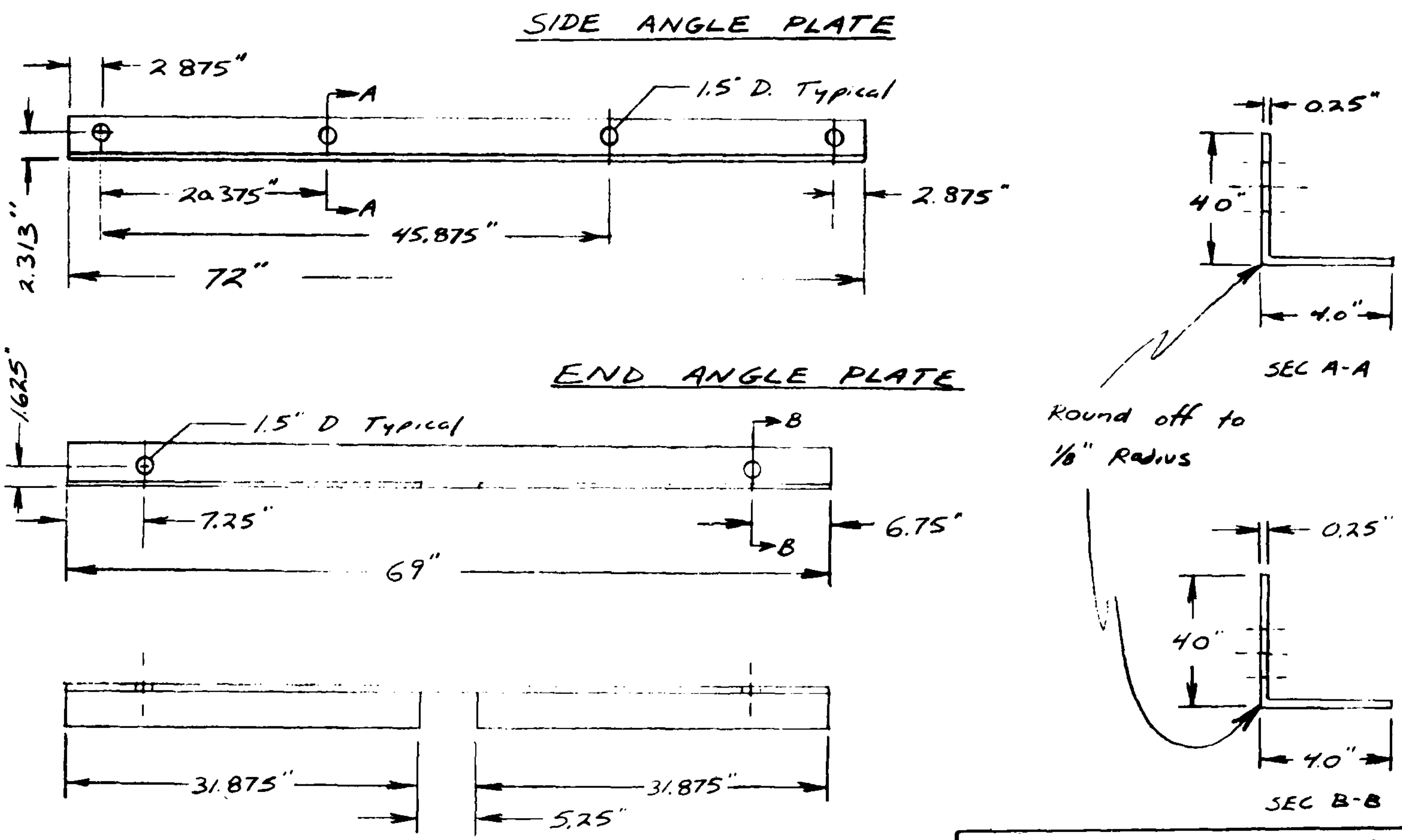
UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY-FIX SIDE ANGLE PLATE RETAINER STRAP ASSEMBLY	
MARCH 31, 1987	NO SCALE
Dr I AN BOWMAN	DWG NO. EF-003



Notes:

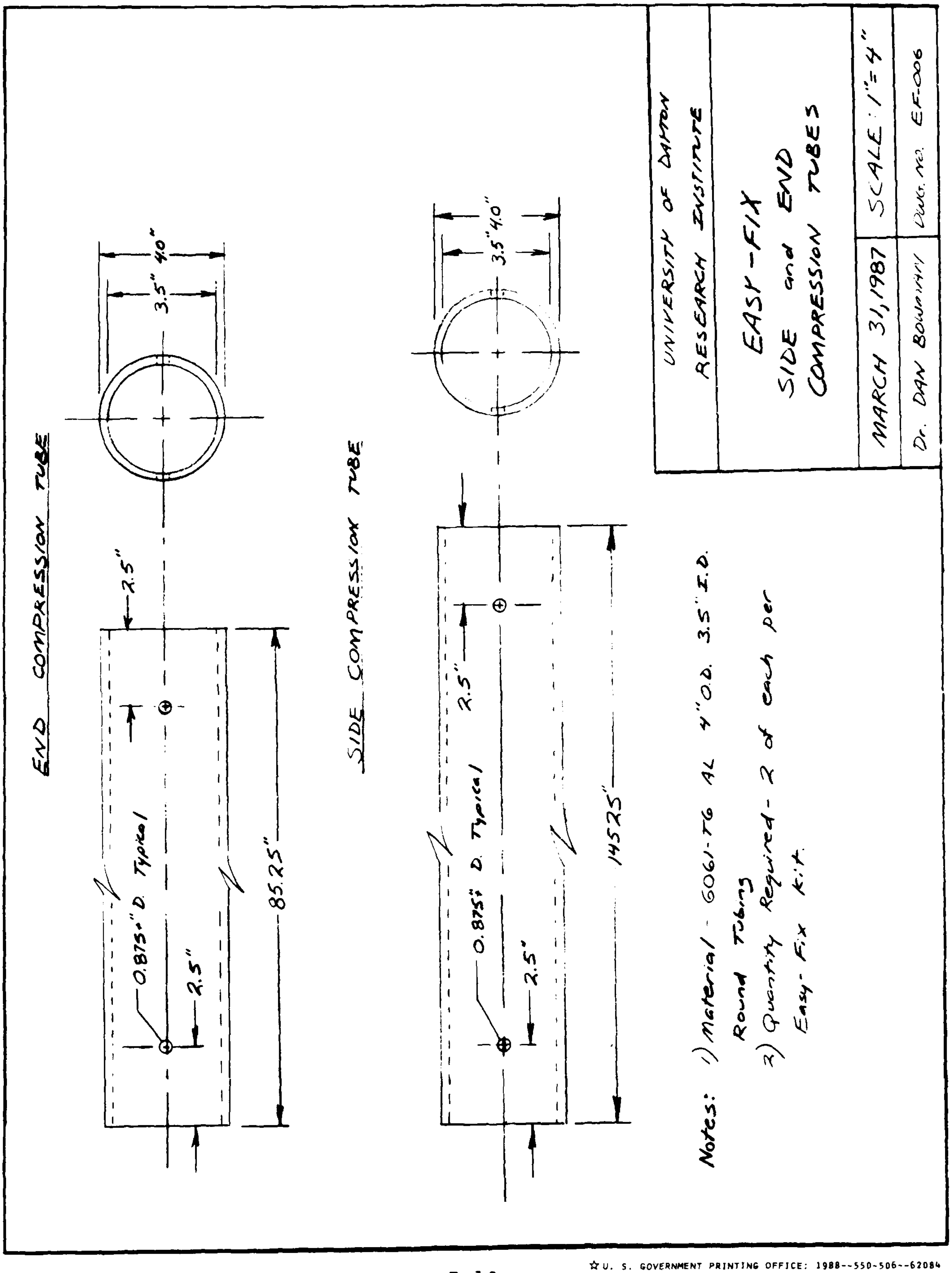
1) Quantity Required - 2 per Easy-Fix Kit
2) Substitution of end fittings from other manufacturers is acceptable if the substituted fittings are of equivalent geometry and strength.

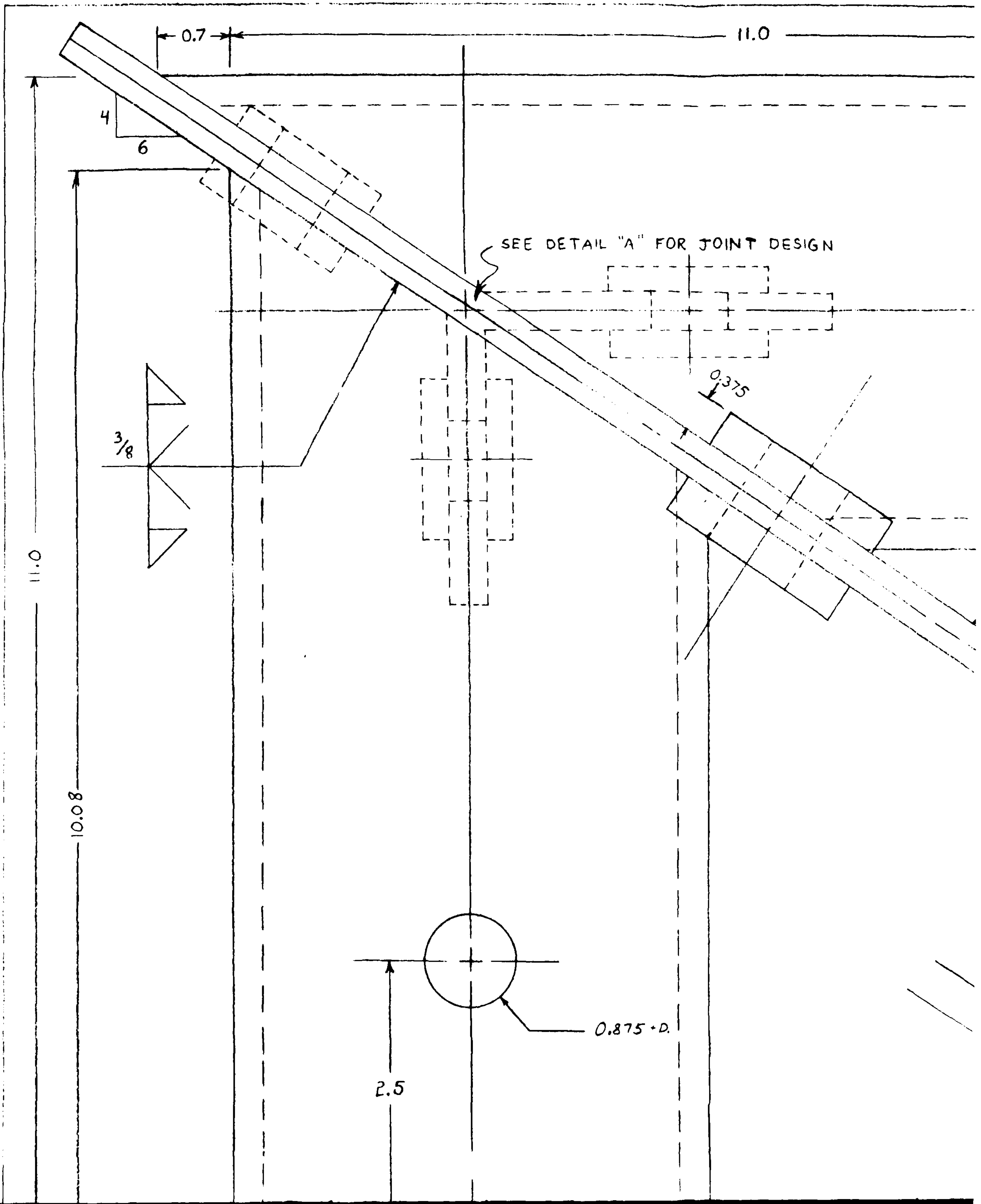
UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY - FIX	
DIAGONAL TENSION CABLE ASSEMBLY	
MARCH 31, 1987	NO SCALE
Dr. DAN BOWMAN	DWG. NO. EF-1204



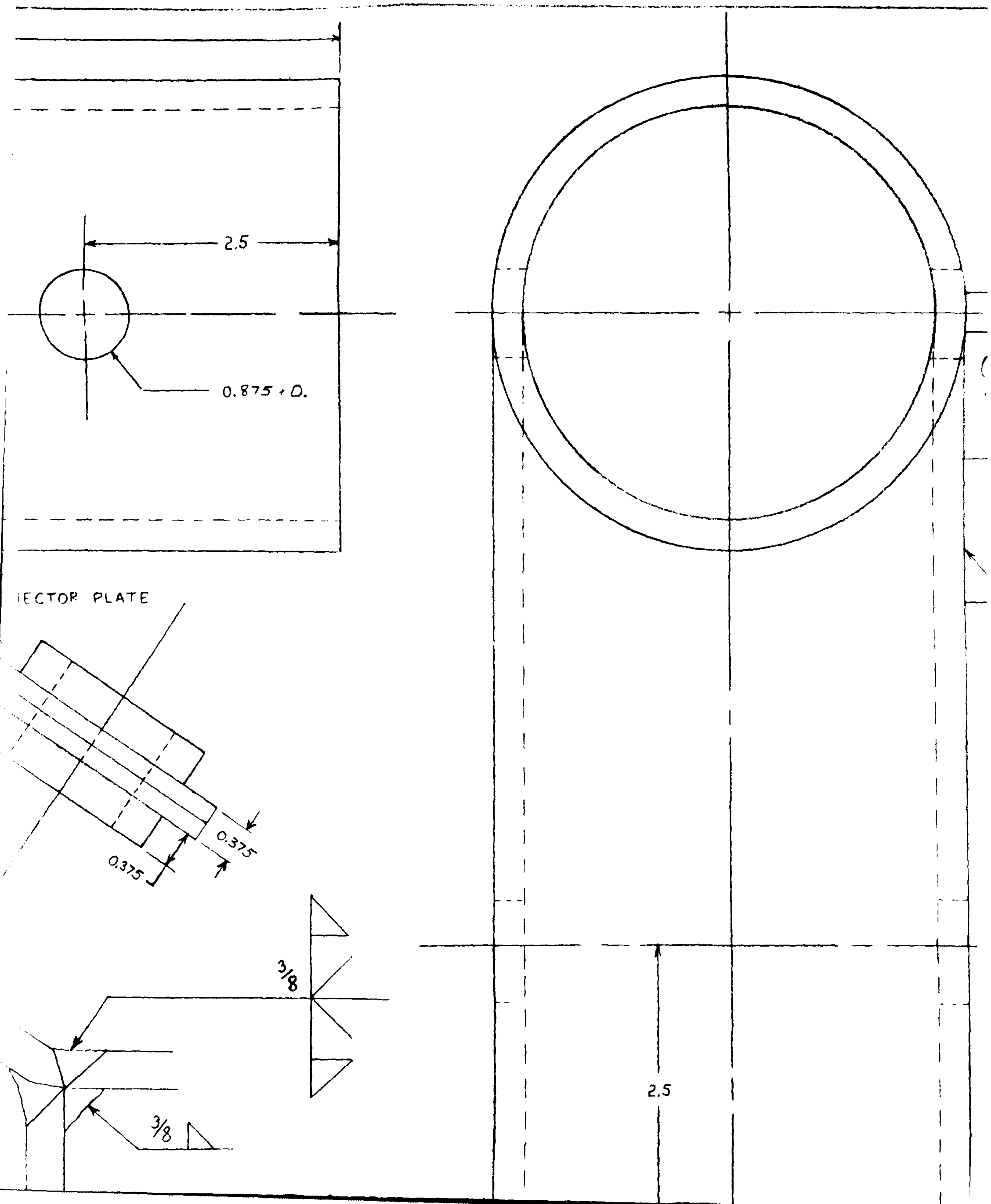
Note: 1) Material - 6061-T6 AL 4x4x1/4 Angle
2) Quantity Required - 2 of each per Easy-Fix kit

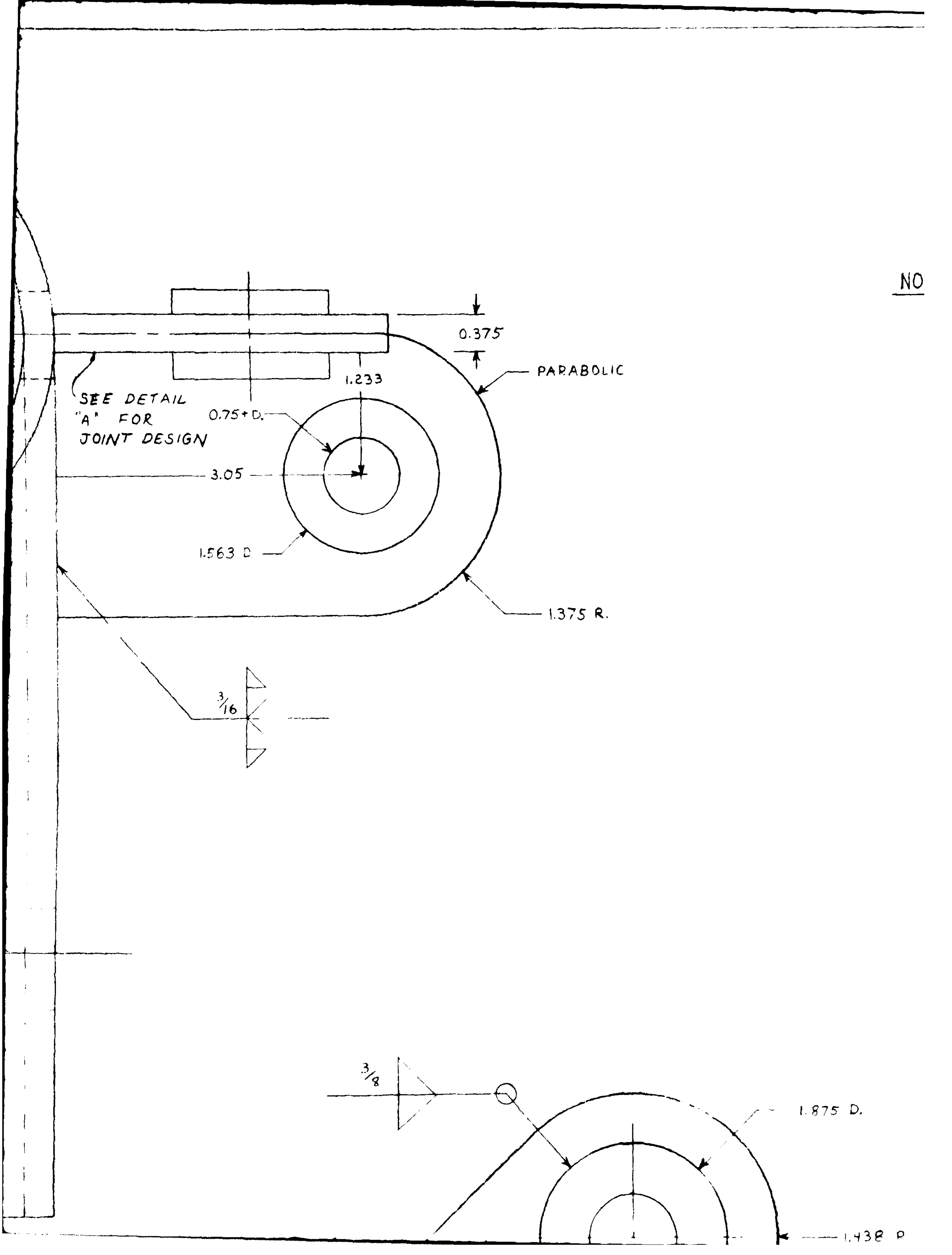
UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY-FIX SIDE and END ANGLE PLATE STRAP PROTECTORS	
MARCH 31, 1987	SCALE: 1" = 1.5"
Dr DAN BOWMAN	Dwg. No. EF-005


UNIVERSITY OF DAYTON
RESEARCH INSTITUTE
EASY-FIX
SIDE and END
COMPRESSION TUBES
MARCH 31, 1987
SCALE: 1"=4"
Dr. DAN BOWMAN
DWG. NO. EF-006
END COMPRESSION TUBE
3.5" 4.0"
2.5"
0.875" D. Typical
2.5"
85.25"
SIDE COMPRESSION TUBE
3.5" 4.0"
2.5"
0.875" D. Typical
2.5"
145.25"
Notes: 1) Material - 6061-T6 AL 4" O.D. 3.5" I.D.
Round Tubing
2) Quantity Required - 2 of each per
Easy-Fix kit.



0.7
11.0
4
6
SEE DETAIL "A" FOR JOINT DESIGN
0.375
3/8
11.0
10.08
0.875 ⌀D.
2.5

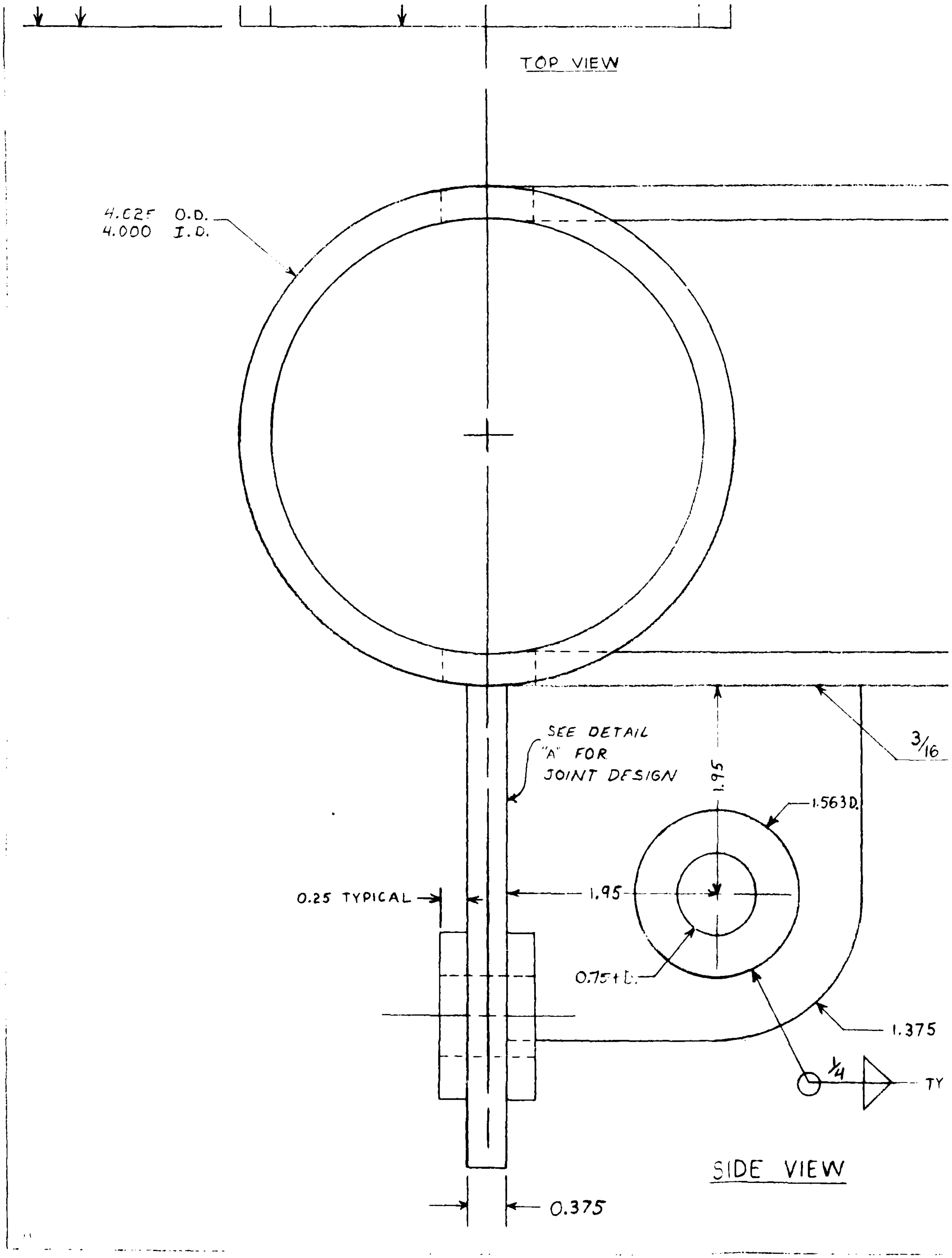

2.5
0.875 + D.
ECTOR PLATE
0.375
0.375
3/8
3/8
2.5



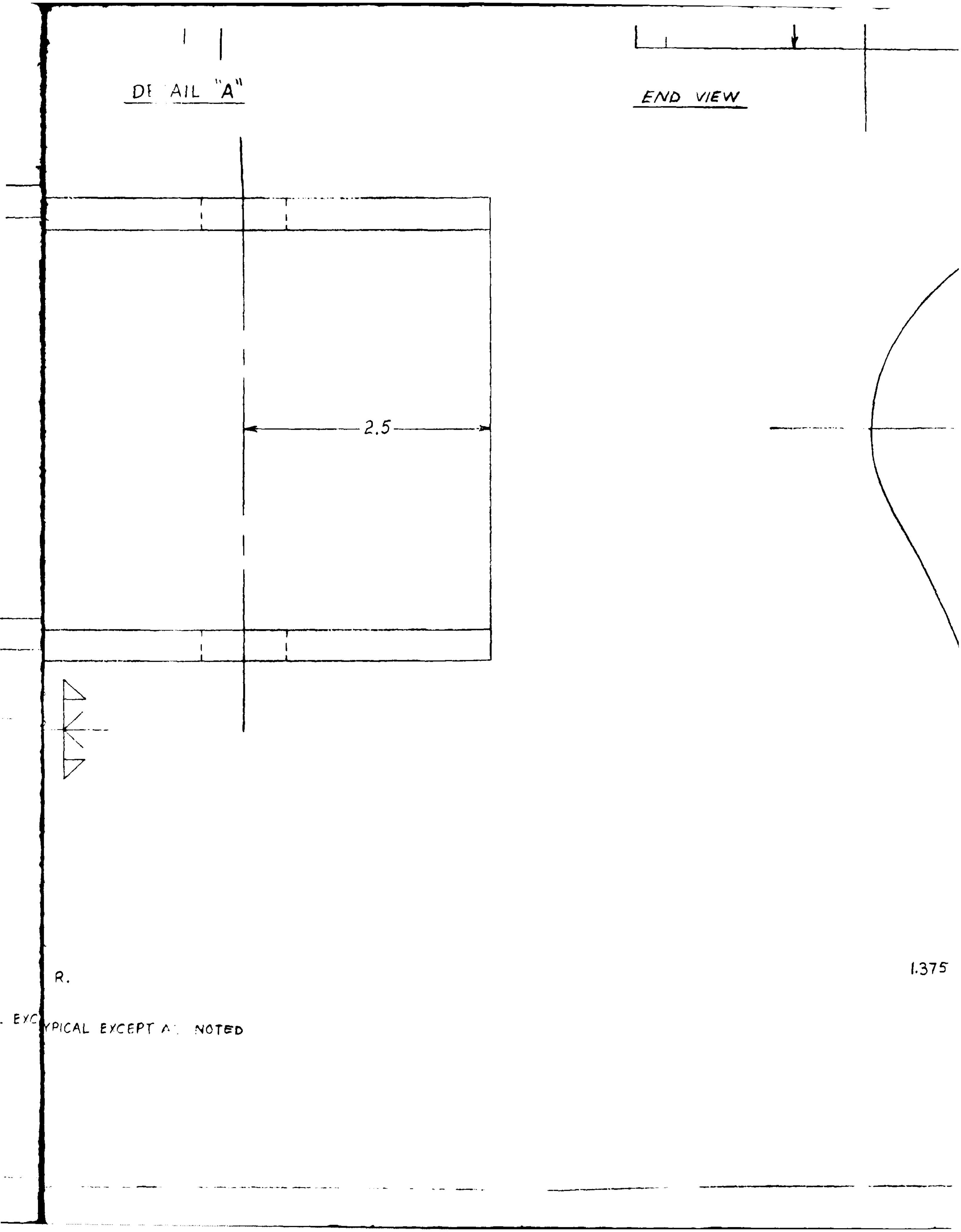
NO
0.375
PARABOLIC
1.233
SEE DETAIL "A" FOR JOINT DESIGN
0.75+D.
3.05
1.563 D
1.375 R.
3/16
3/8
1.875 D.
1.438 R

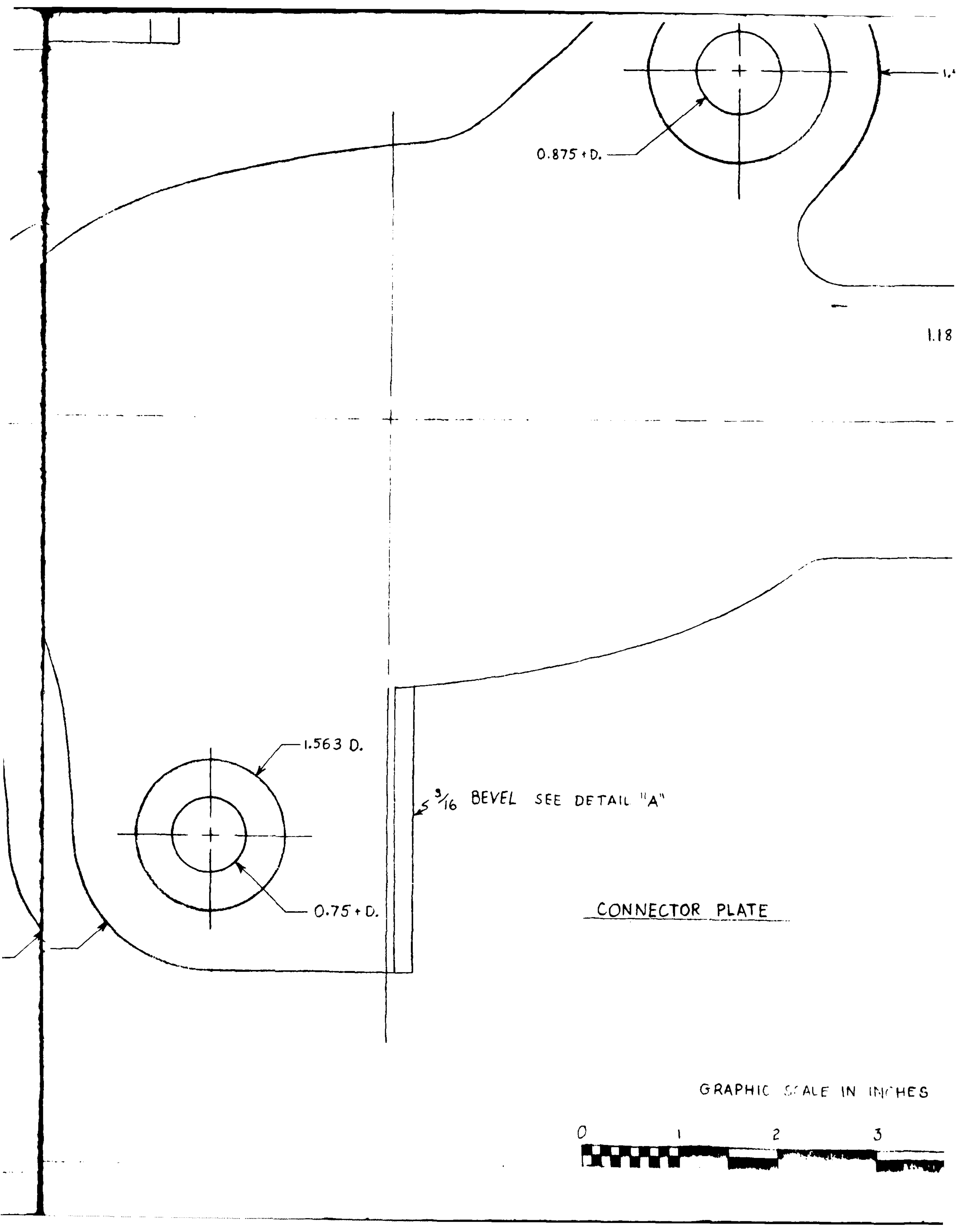
NOTES:

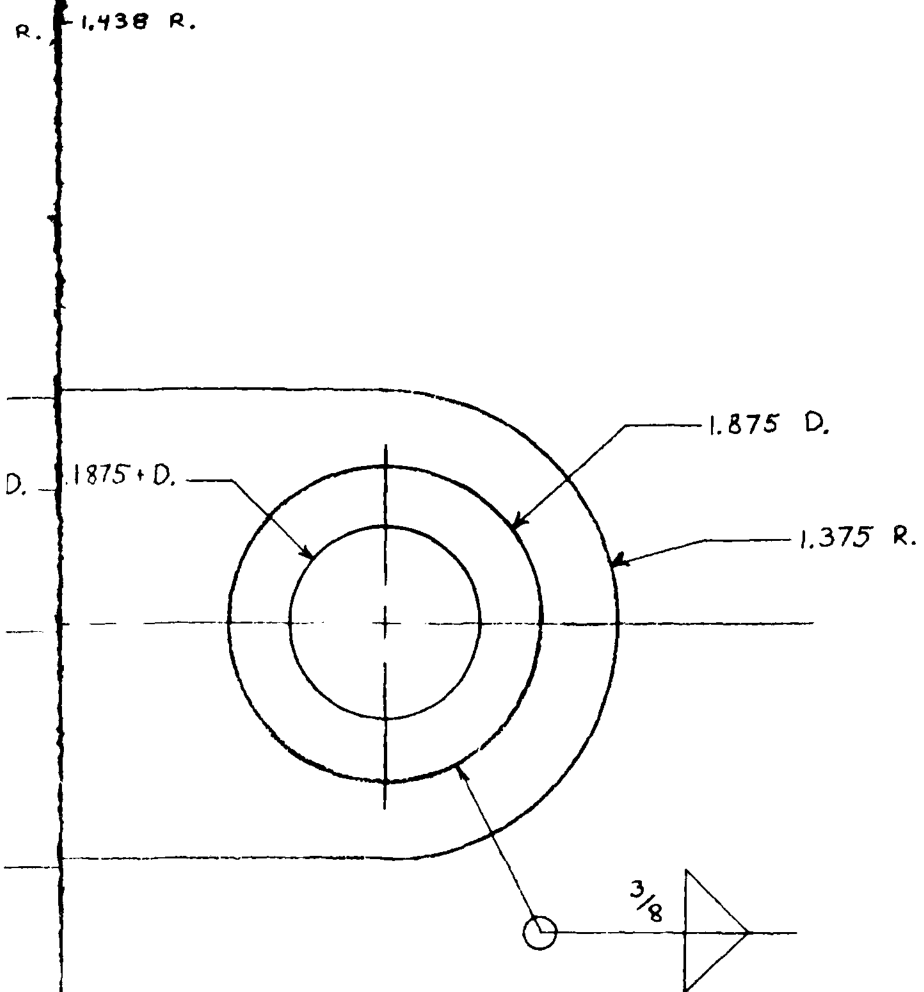
1.) MATERIAL - 6061-T6 AL TYPICAL
2.) $4\frac{5}{8}$" O.D. TUBE MILLED DOWN FROM 5" O.D.
3.) REINFORCING DISKS ARE TO BE WELDED IN PLACE BEFORE HOLES ARE DRILLED.
4.) TUBE I.D. MAY REQUIRE MILLING TO ALLOW CLEARANCE FOR 4" O.D. COMPRESSION MEMBER.
5.) CONNECTOR PLATE IS OMITTED FROM SIDE AND END VIEWS FOR CLARITY.
6.) ALL WELDING TO BE IN ACCORDANCE WITH MIL-STD-8604: USE 4043 FILLER WIRE.
7.) AFTER FABRICATION OF EACH CORNER FITTING IS COMPLETED, THE FITTINGS SHALL BE REHEAT TREATED TO RESTORE THE WELD AFFECTED ZONE TO THE ORIGINAL T-6 CONDITION. PARTS SHALL BE HEAT TREATED TO T-4 CONDITION BY HEATING TO 985°F FOR 2 HOURS AT TEMPERATURE IN ROOM TEMPERATURE WATER. PARTS SHALL THEN BE HEAT TREATED TO T-6 CONDITION BY HEATING TO 320°F FOR 18 HOURS AT TEMPERATURE AND AIR COOLING. ALL HEAT TREATING SHALL BE IN ACCORDANCE WITH MIL-H6088.



TOP VIEW
4.025 O.D.
4.000 I.D.
SEE DETAIL
"A" FOR
JOINT DESIGN
3/16
1.95
1.563 D.
0.25 TYPICAL
1.95
0.751 D.
1.375
1/4
TY
SIDE VIEW
0.375


DE AIL "A"
END VIEW
2.5
1.375
R.
. EXC YPICAL EXCEPT A NOTED


0.875 + D.
1.18
1.563 D.
3/16 BEVEL SEE DETAIL "A"
0.75 + D.
CONNECTOR PLATE
GRAPHIC SCALE IN INCHES
0 1 2 3

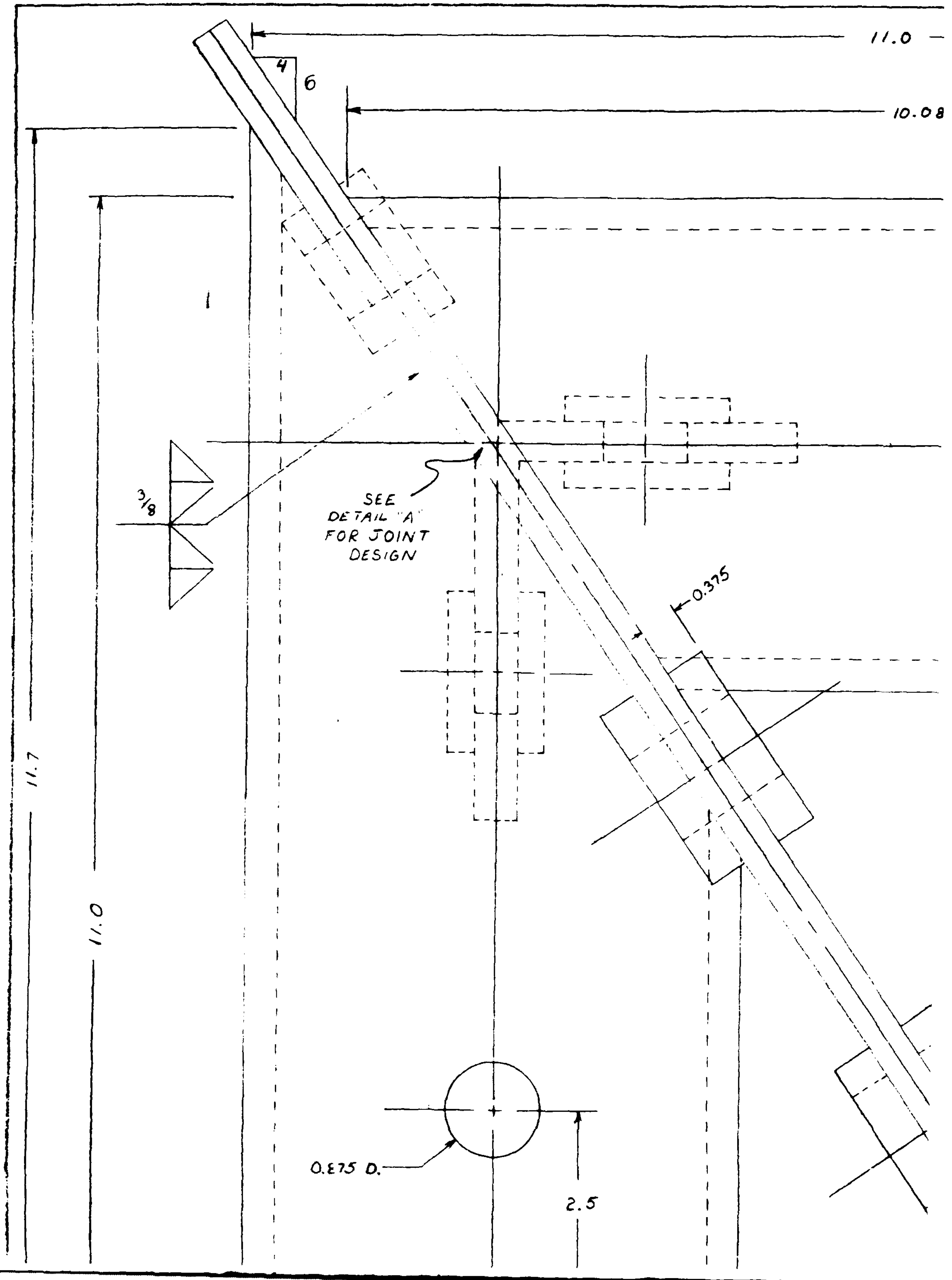


UNIVERSITY OF DAYTON
RESEARCH INSTITUTE

EASY - FIX
COMPRESSION TUBE
CORNER FITTING # 2

JANUARY 14, 1987 DWG. NO. EF-008

Dr. & Ckd. DAN BOWMAN | SCALE: 1/1



11.0
4
6
10.08
1
3/8
SEE DETAIL "A" FOR JOINT DESIGN
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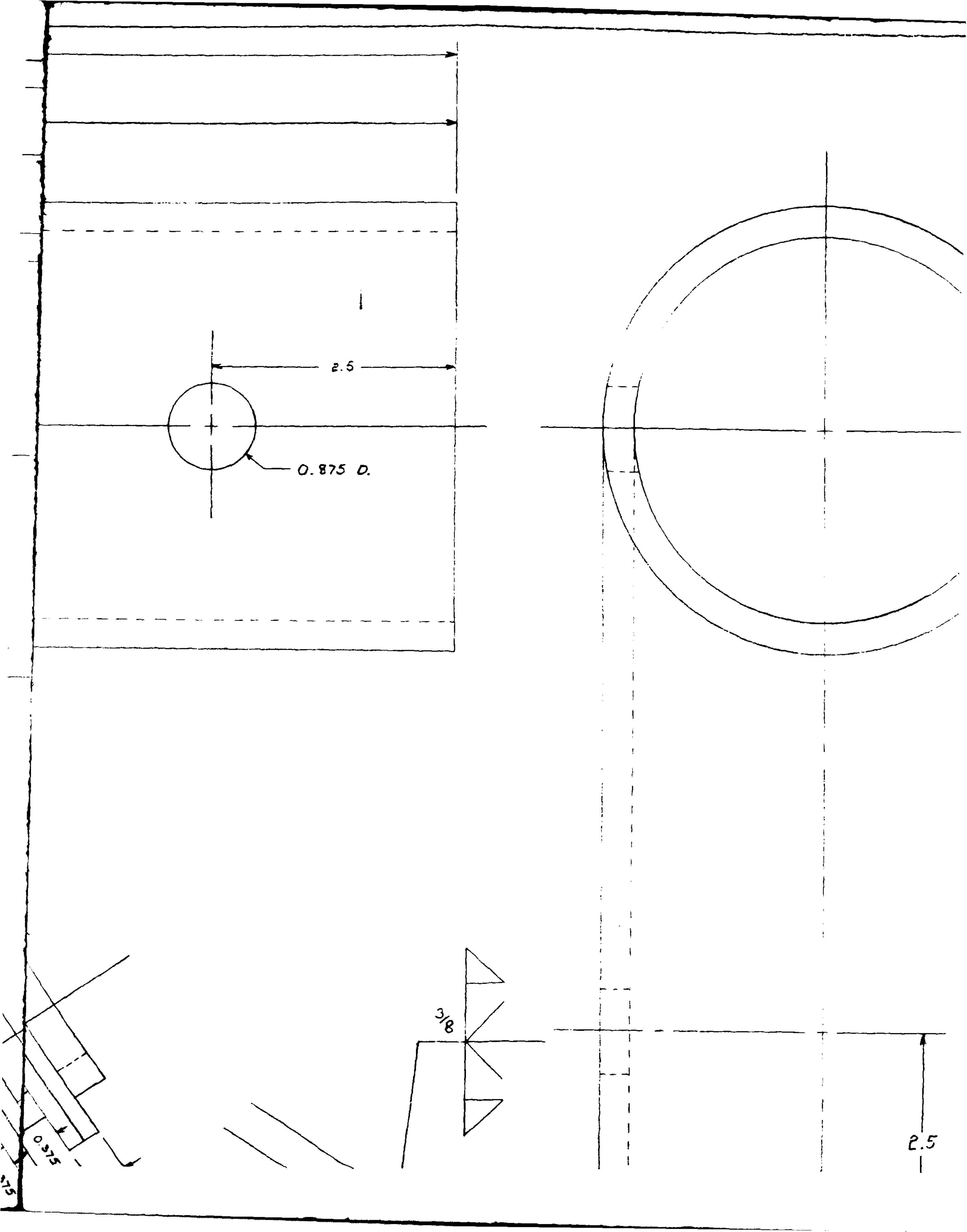
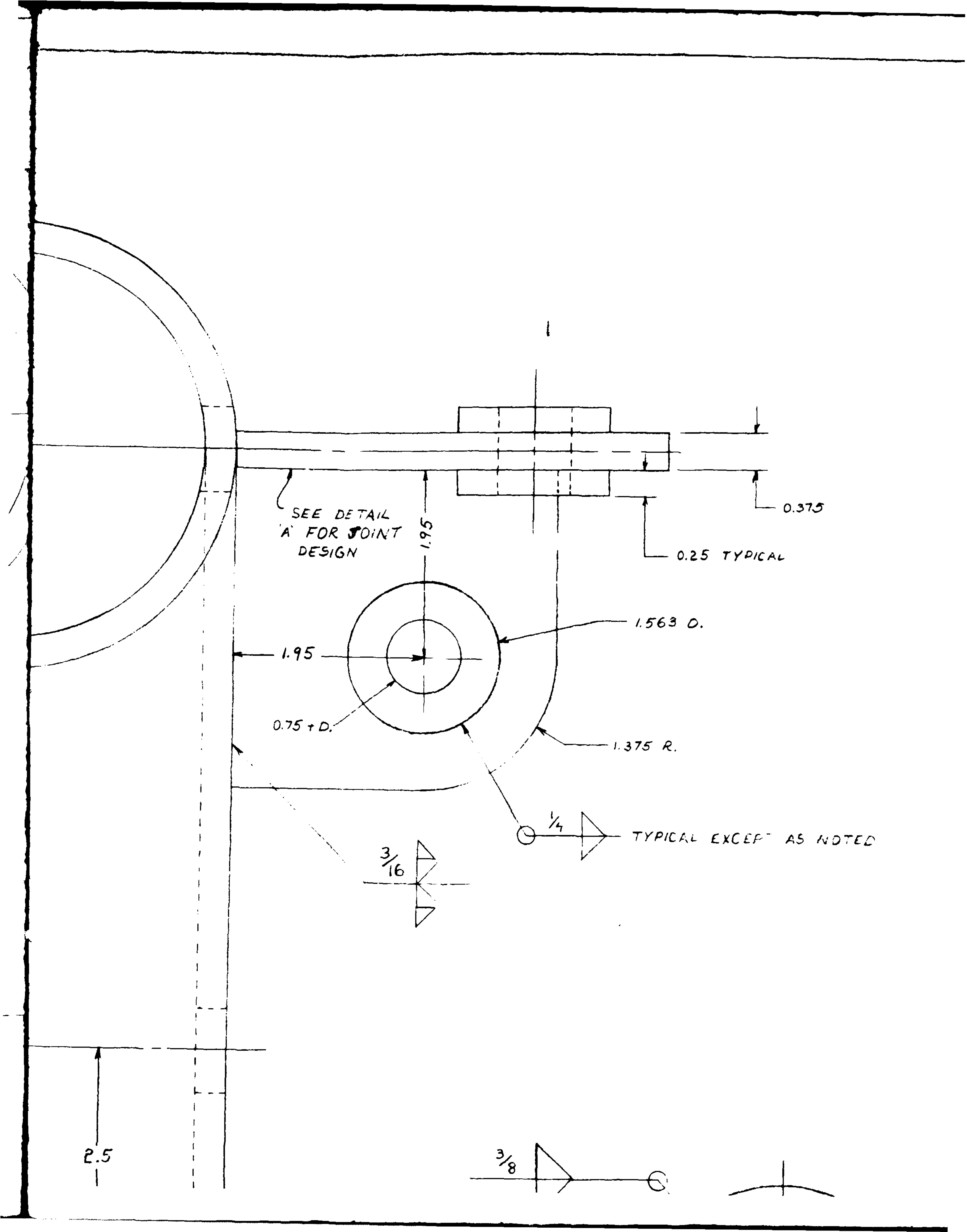
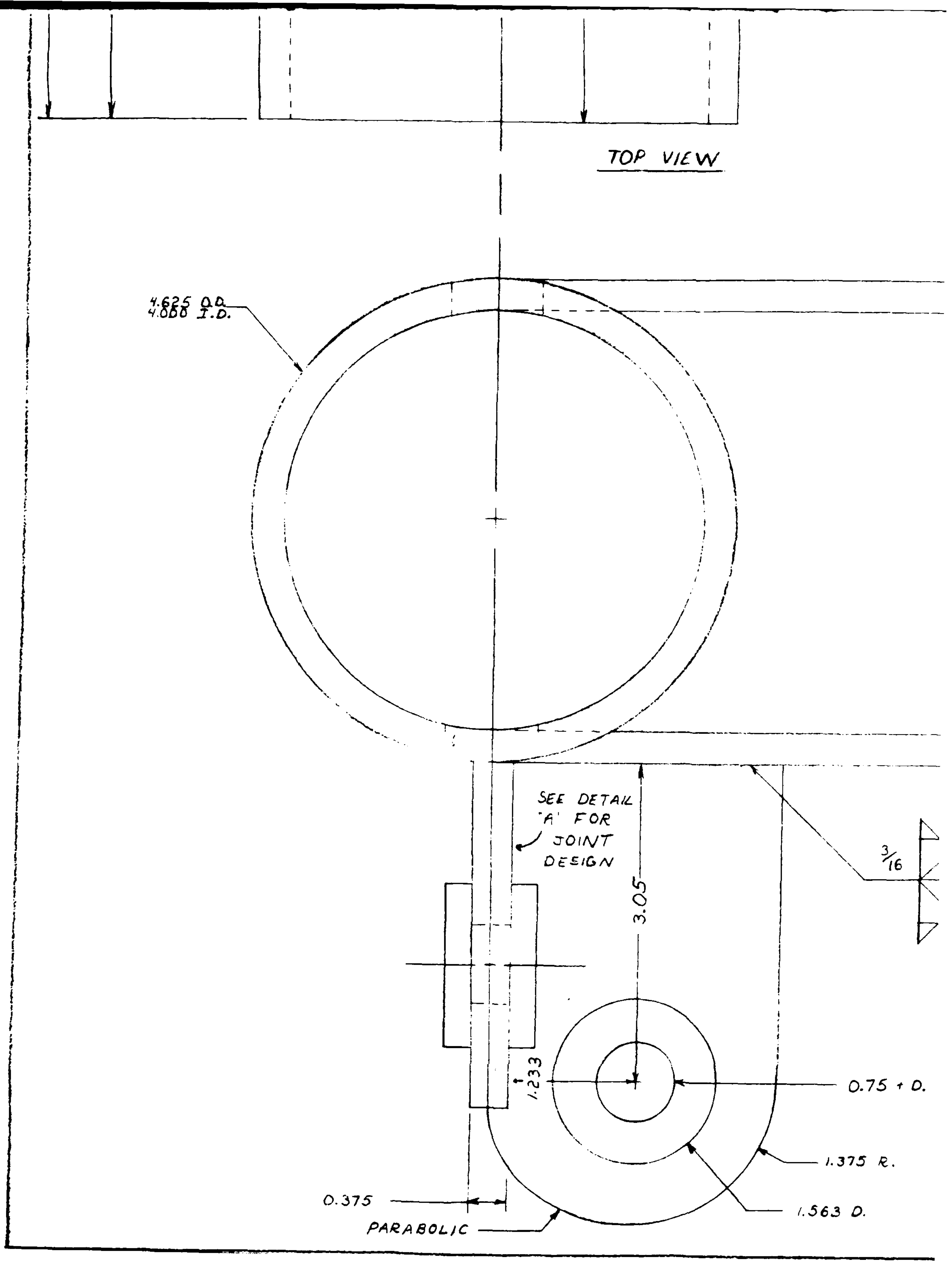
11.7
11.0
0.875 D.
2.5

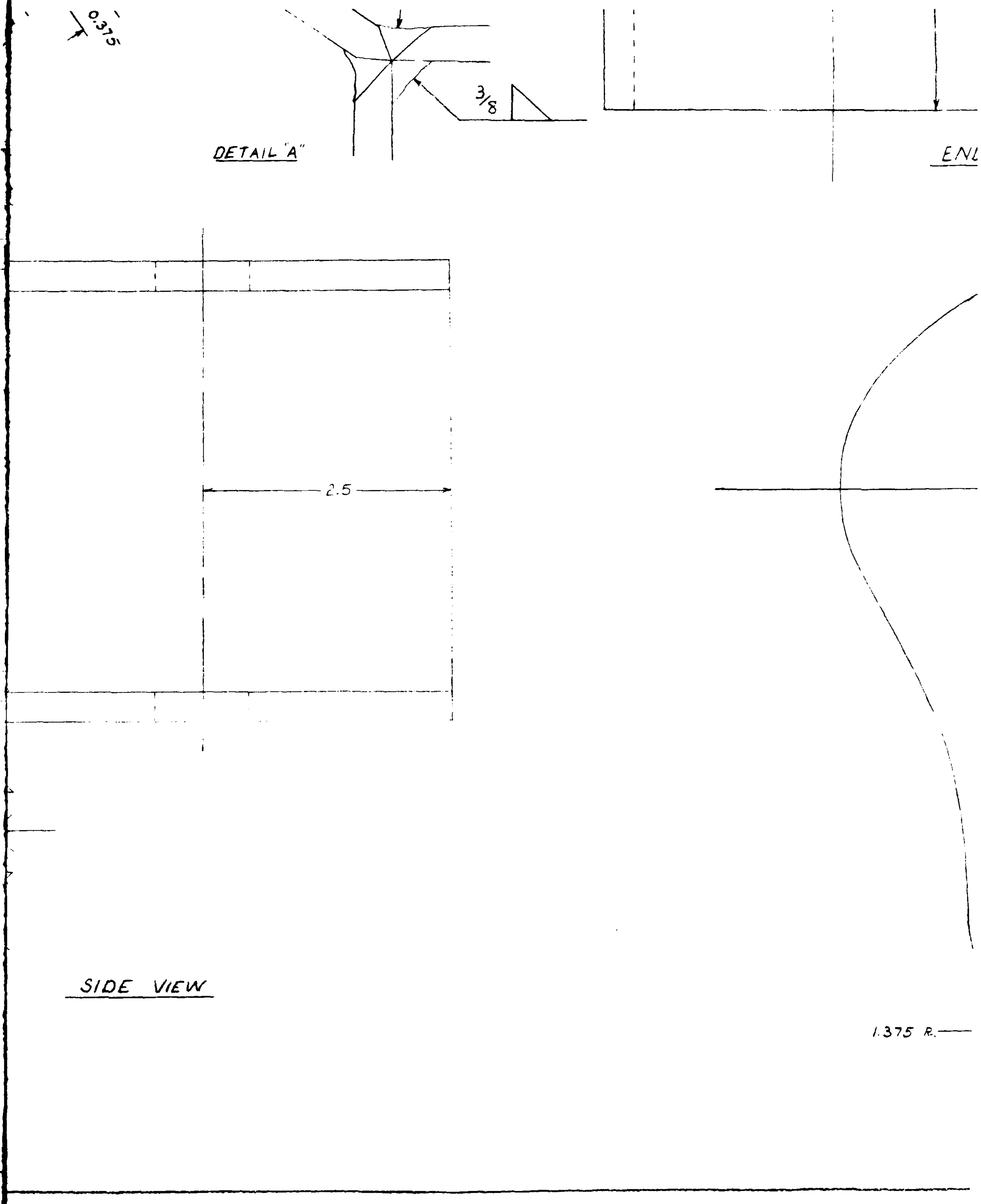


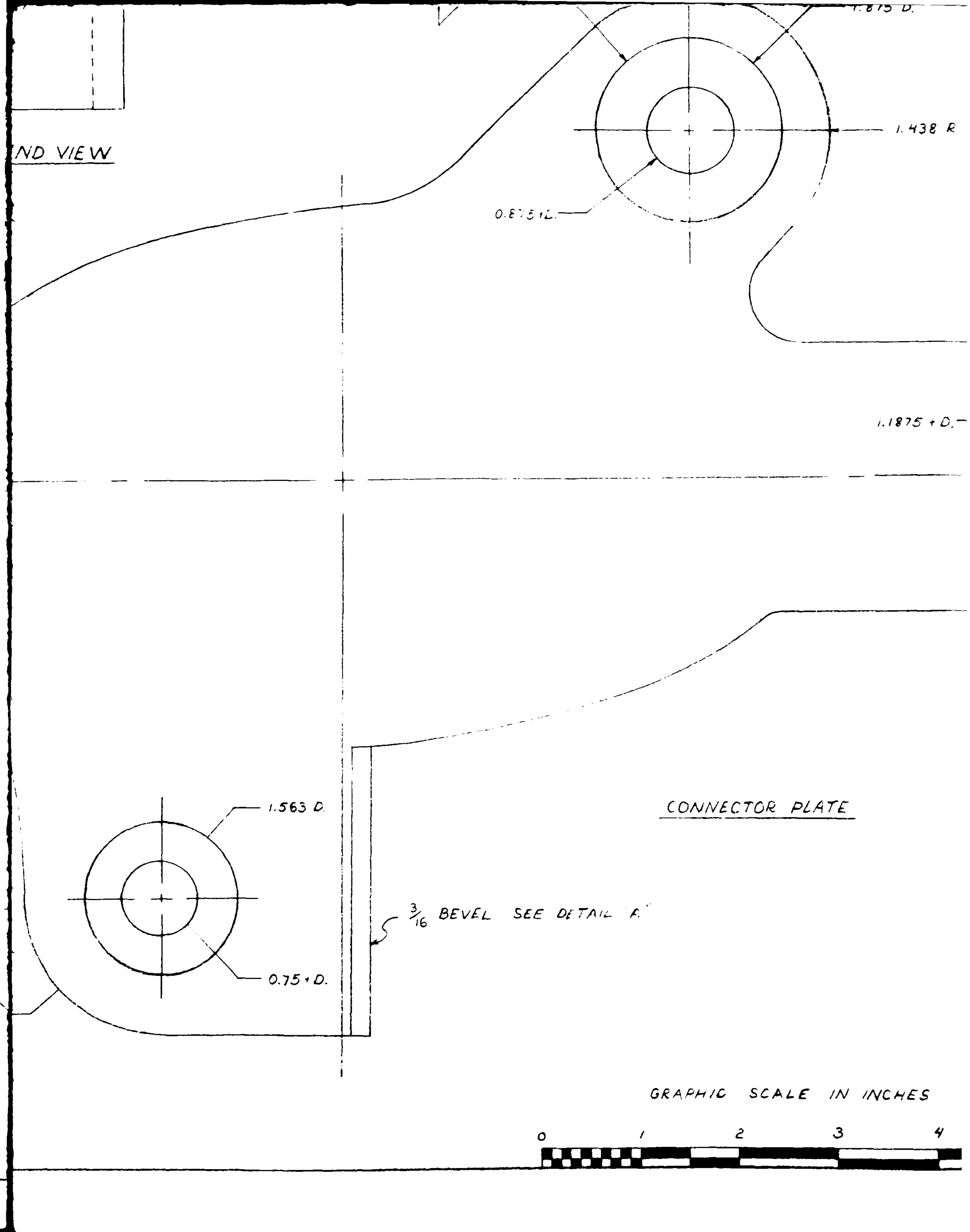
2.5
0.875 D.
3/8
0.375
2.5


1
SEE DETAIL 'A' FOR JOINT DESIGN
1.95
0.375
0.25 TYPICAL
1.563 D.
1.95
0.75 + D.
1.375 R.
1/4
TYPICAL EXCEPT AS NOTED
3/16
2.5
3/8

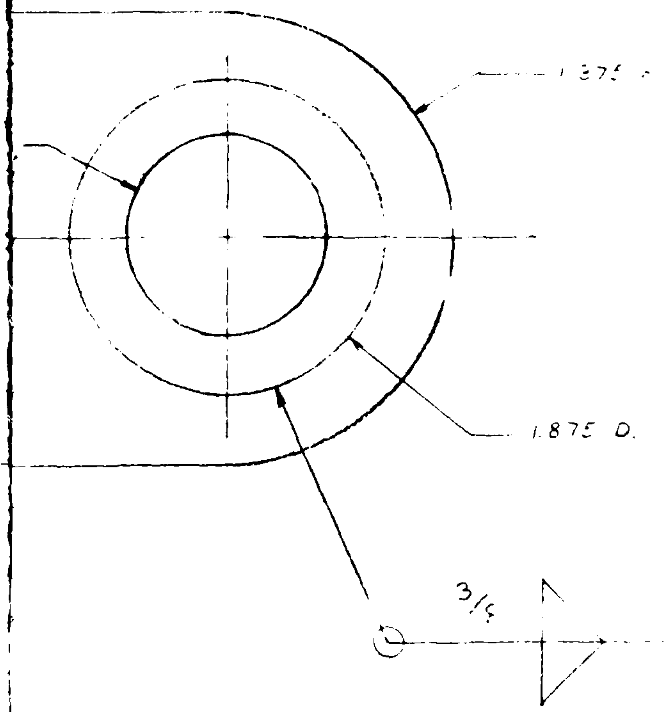
NOTES:
1) MATERIAL - 6061-T6 AL TYPICAL.
2) $4\frac{1}{8}$" O.D. TUBE MILLED DOWN FROM 5" O.D.
3) REINFORCING DISKS TO BE WELDED IN PLACE BEFORE HOLES ARE DRILLED.
4) TUBE I.D. MAY REQUIRE MILLING TO ALLOW CLEARANCE FOR 4" O.D. COMPRESSION MEMBER.
5) CONNECTOR PLATE IS OMITTED FROM SIDE AND END VIEWS FOR CLARITY.
6) ALL WELDING TO BE IN ACCORDANCE WITH MIL-STD-8604 : USE 4043 FILLER WIRE.
7) AFTER FABRICATION OF EACH CORNER FITTING IS COMPLETED, THE FITTING SHALL BE REHEAT TREATED TO RESTORE THE WELD AFFECTED ZONE TO THE ORIGINAL T-6 CONDITION. PARTS SHALL BE HEAT TREATED TO T-4 CONDITION BY HEATING TO 985°F FOR 2 HOURS AT TEMPERATURE AND QUENCHING IN ROOM TEMPERATURE WATER. PARTS SHALL THEN BE HEAT TREATED TO T-6 CONDITION BY HEATING TO 320°F FOR 18 HOURS AT TEMPERATURE AND AIR COOLING. ALL HEAT TREATING SHALL BE IN ACCORDANCE WITH MIL-H6088.


TOP VIEW
4.625 O.D.
4.000 I.D.
SEE DETAIL 'A' FOR JOINT DESIGN
3.05
3/16
1.233
0.75 + D.
1.375 R.
1.563 D.
0.375
PARABOLIC


0.375
3/8
DETAIL "A"
END
2.5
SIDE VIEW
1.375 R.



ND VIEW
1.438 R
0.875 D.
1.1875 + D.
1.563 D.
3/16 BEVEL SEE DETAIL A
0.75 + D.
CONNECTOR PLATE
GRAPHIC SCALE IN INCHES
0 1 2 3 4

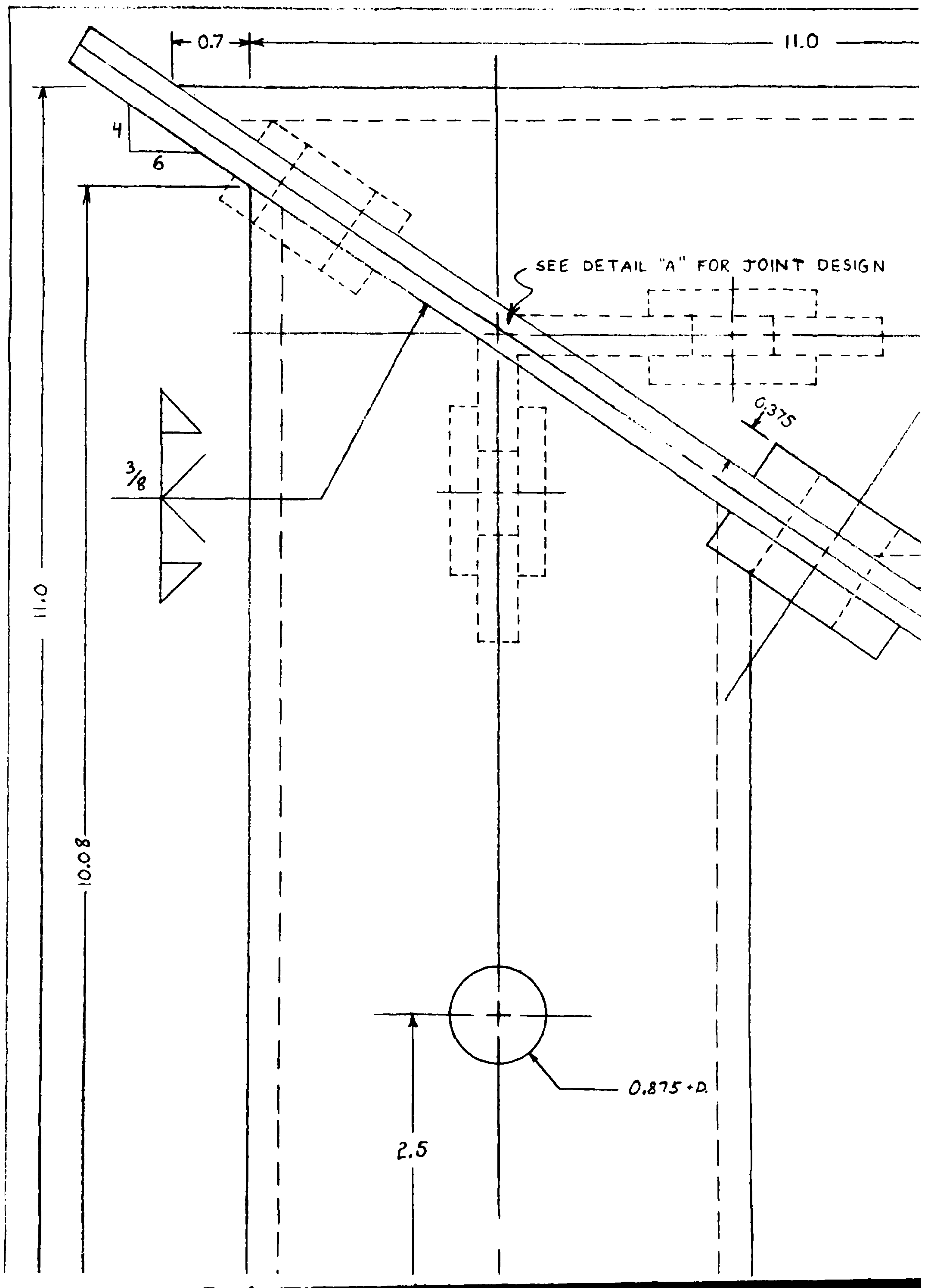


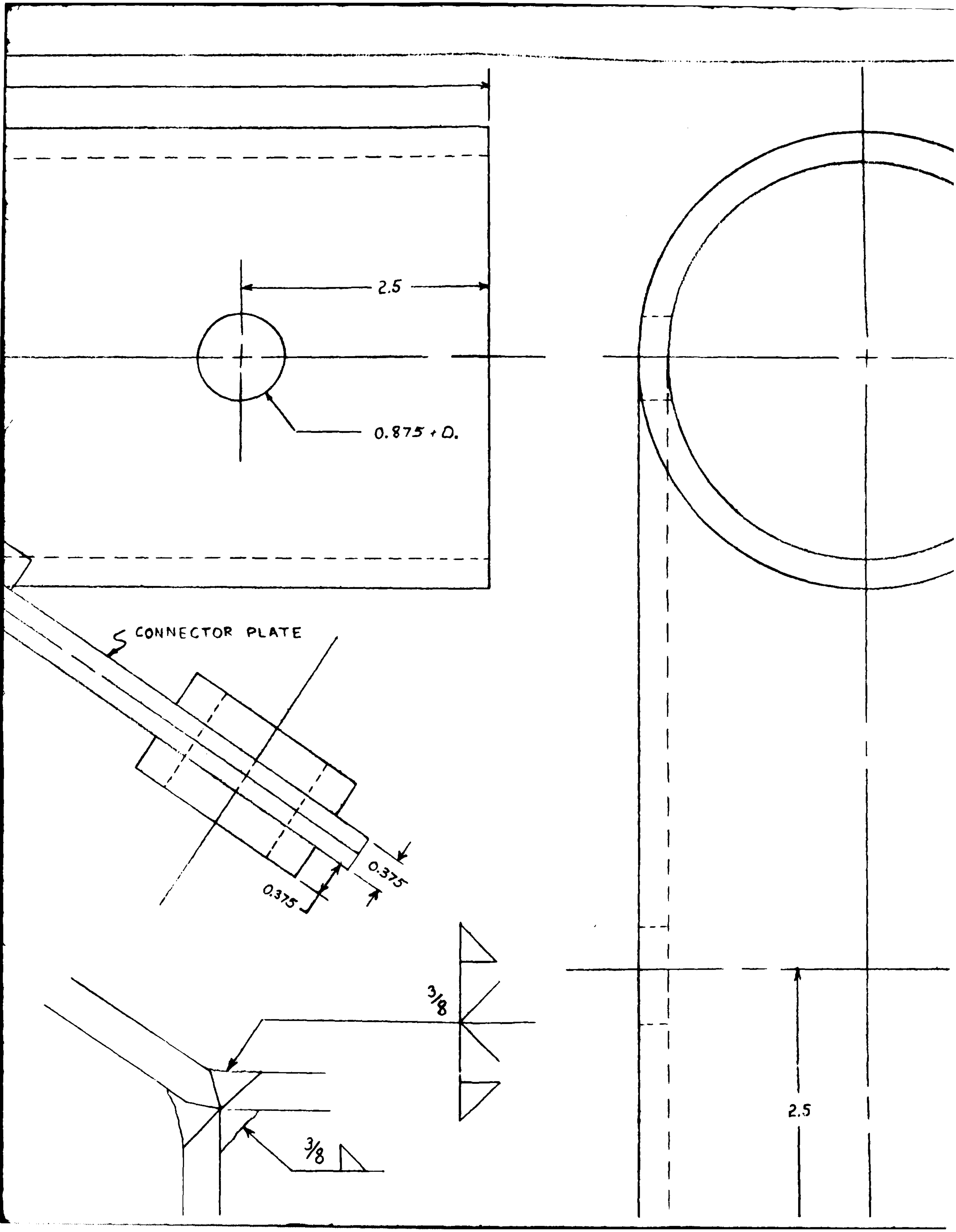
UNIVERSITY OF DAYTON
RESEARCH INSTITUTE

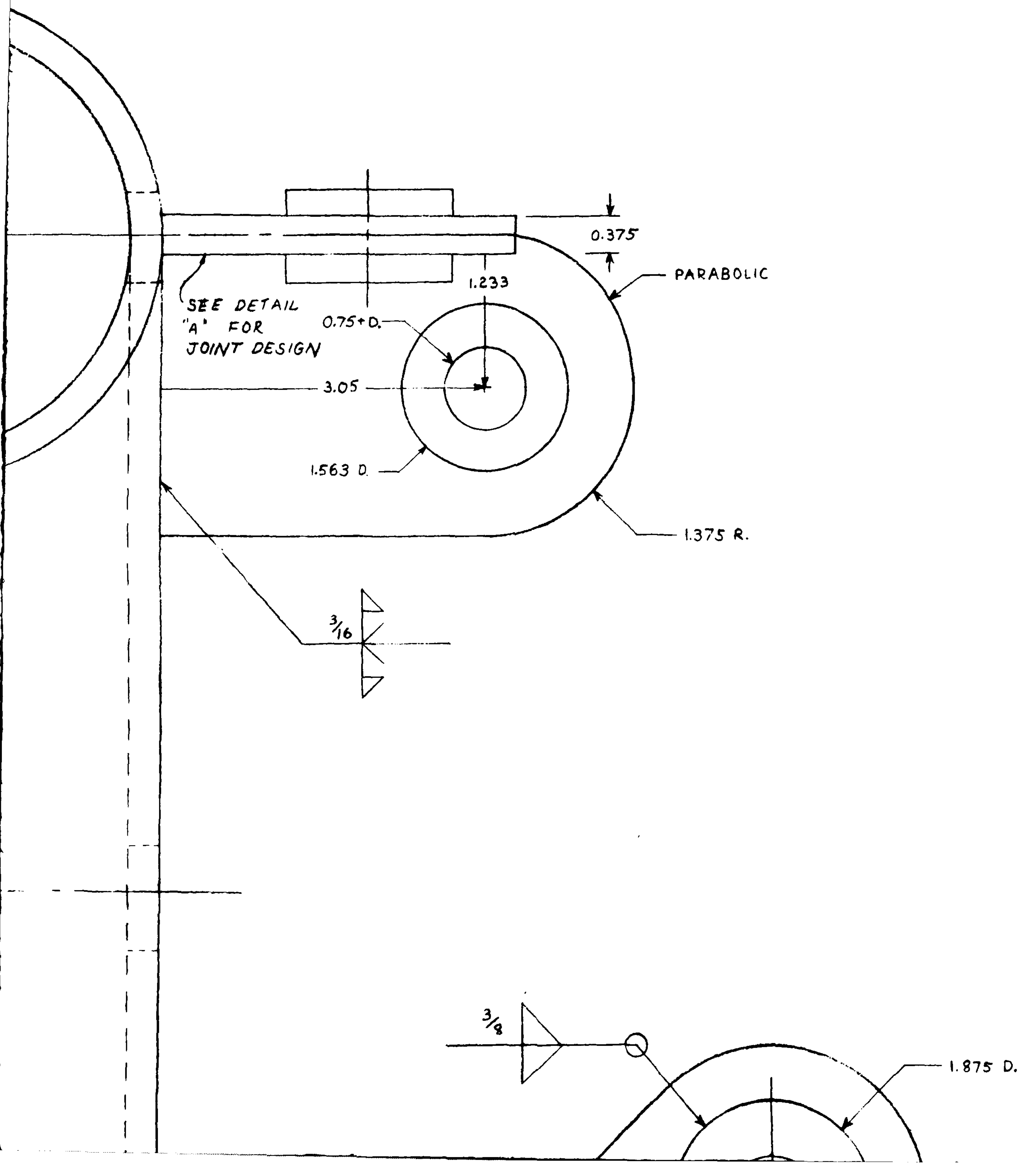
EASY-FIX
COMPRESSION TUBE
CORNER FITTING # 4

JANUARY 14, 1987

Dr. & Ckd. DAN BOWMAN | SCALE: 1/1

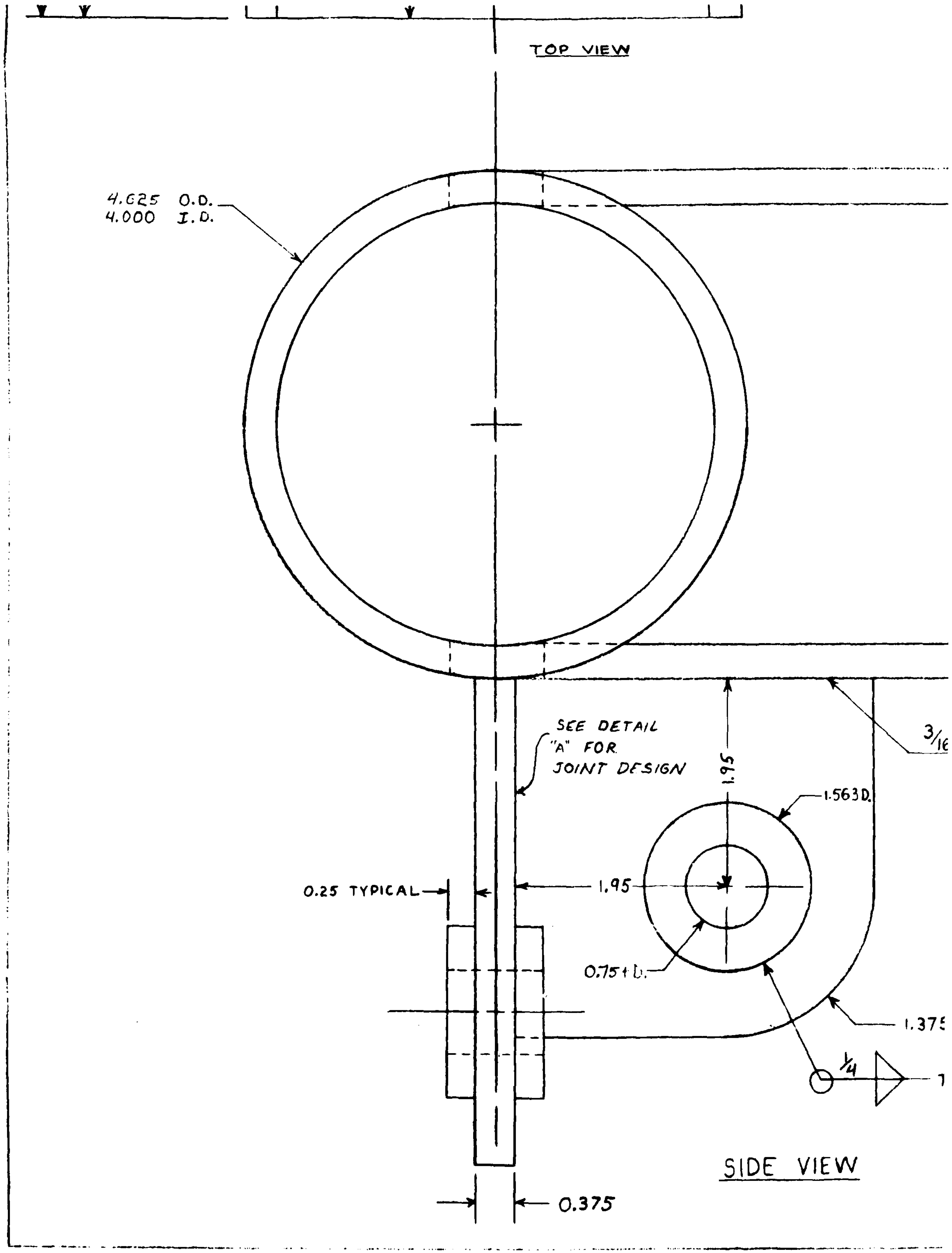

0.7
11.0
4
6
SEE DETAIL "A" FOR JOINT DESIGN
0.375
3/8
11.0
10.08
0.875 + D.
2.5

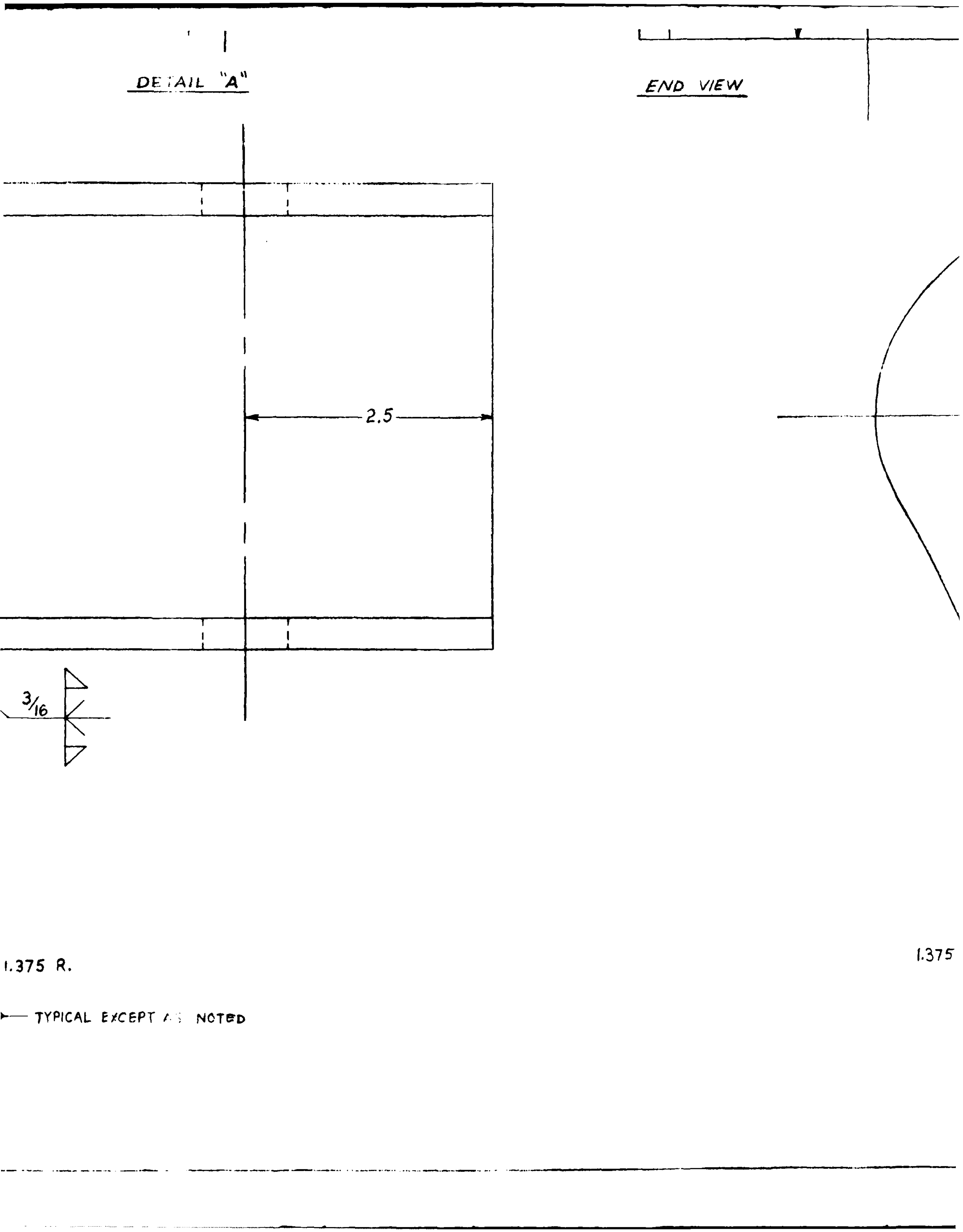

2.5
0.875 + D.
CONNECTOR PLATE
0.375
0.375
3/8
3/8
2.5


0.375
PARABOLIC
1.233
SEE DETAIL "A" FOR JOINT DESIGN
0.75+ D.
3.05
1.563 D.
1.375 R.
3/16
3/8
1.875 D.

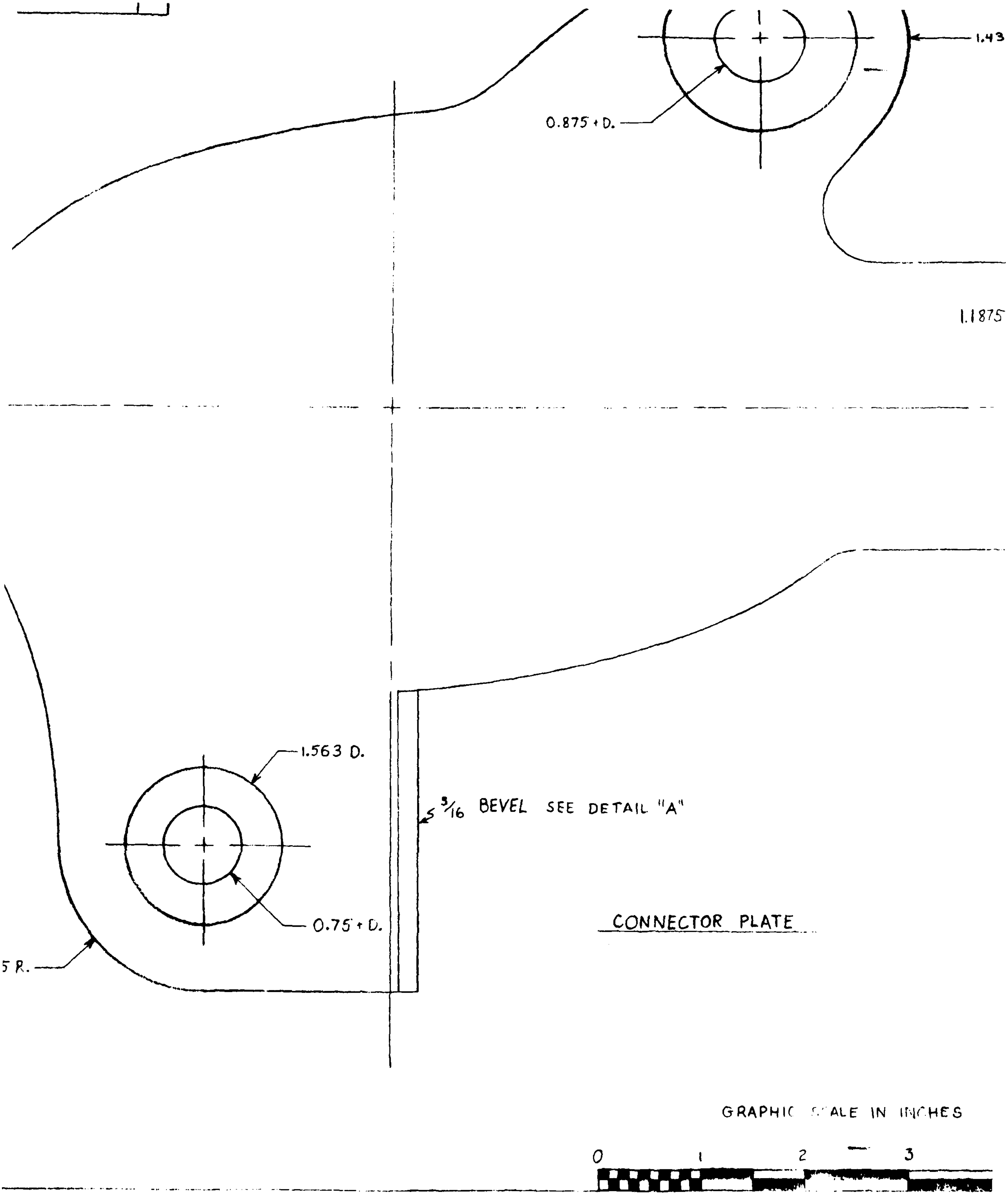
NOTES:

1.) MATERIAL- 6061-T6 AL TYPICAL
2.) 4$\frac{3}{8}$" O.D. TUBE MILLED DOWN FROM 5" O.D.
3.) REINFORCING DISKS ARE TO BE WELDED IN PLACE BEFORE HOLES ARE DRILLED.
4.) TUBE I.D. MAY REQUIRE MILLING TO ALLOW CLEARANCE FOR 4" O.D. COMPRESSION MEMBER.
5.) CONNECTOR PLATE IS OMITTED FROM SIDE AND END VIEWS FOR CLARITY.
6.) ALL WELDING TO BE IN ACCORDANCE WITH MIL-STD-8604: USE 4043 FILLER WIRE.
7.) AFTER FABRICATION OF EACH CORNER FITTING IS COMPLETED, THE FITTINGS SHALL BE REHEAT TREATED TO RESTORE THE WELD AFFECTED ZONE TO THE ORIGINAL T-6 CONDITION. PARTS SHALL BE HEAT TREATED TO T-4 CONDITION BY HEATING TO 985°F FOR 2 HOURS AT TEMPERATURE IN ROOM TEMPERATURE WATER. PARTS SHALL THEN BE HEAT TREATED TO T-6 CONDITION BY HEATING TO 320°F FOR 18 HOURS AT TEMPERATURE AND AIR COOLING. ALL HEAT TREATING SHALL BE IN ACCORDANCE WITH MIL-H6088.

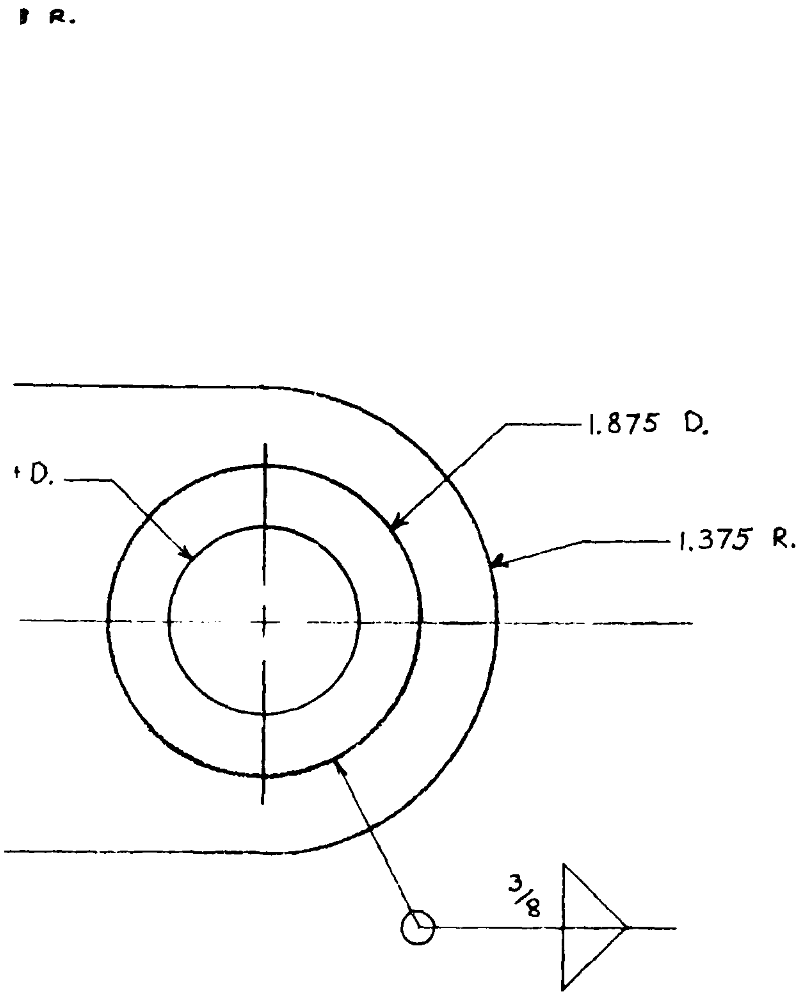

TOP VIEW
4.625 O.D.
4.000 I.D.
SEE DETAIL
"A" FOR
JOINT DESIGN
1.95
1.563 D.
0.25 TYPICAL
1.95
0.75 t D.
1.375
1/4
SIDE VIEW
0.375



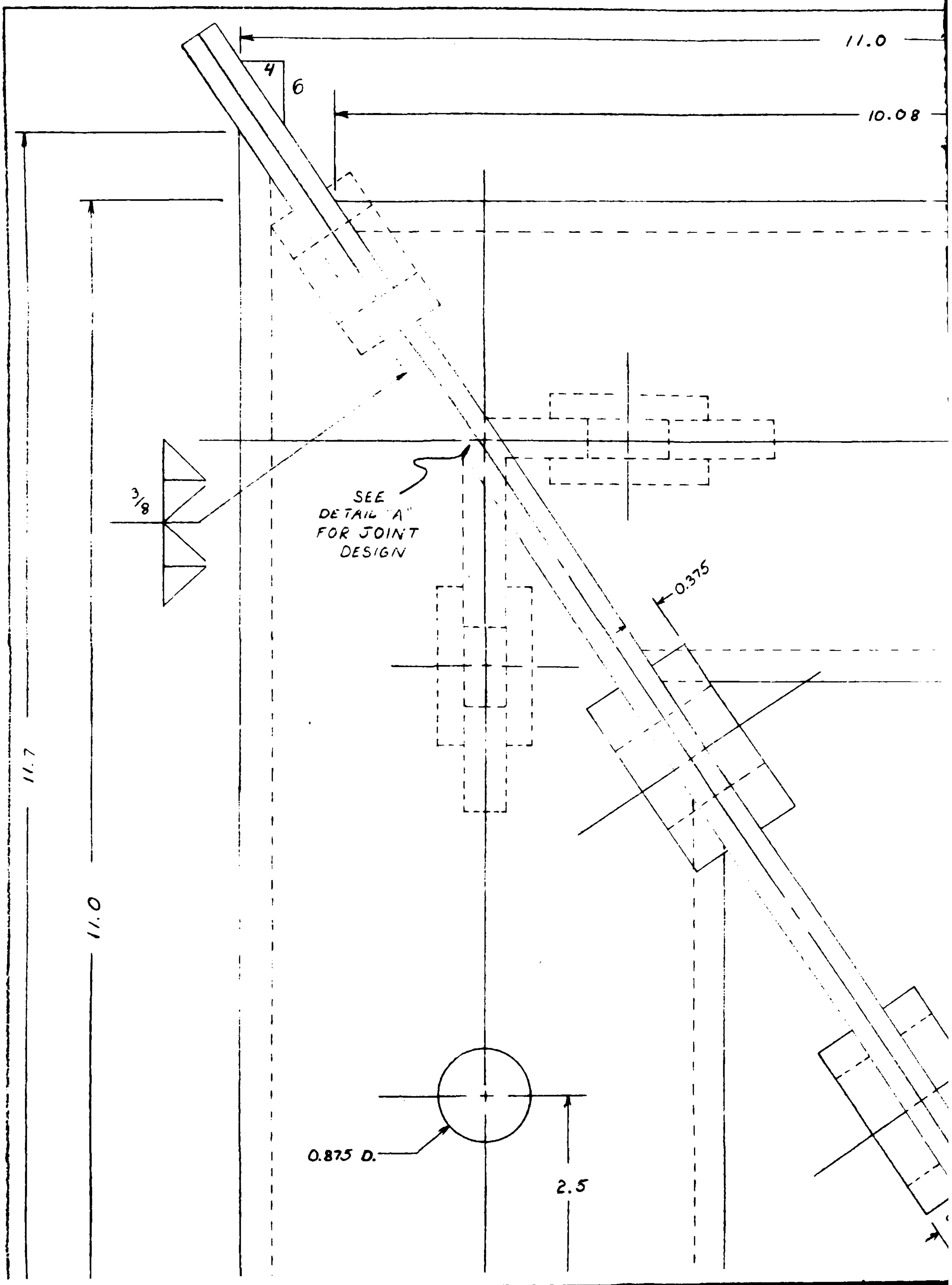
DETAIL "A"
END VIEW
2.5
3/16
1.375 R.
TYPICAL EXCEPT AS NOTED
1.375



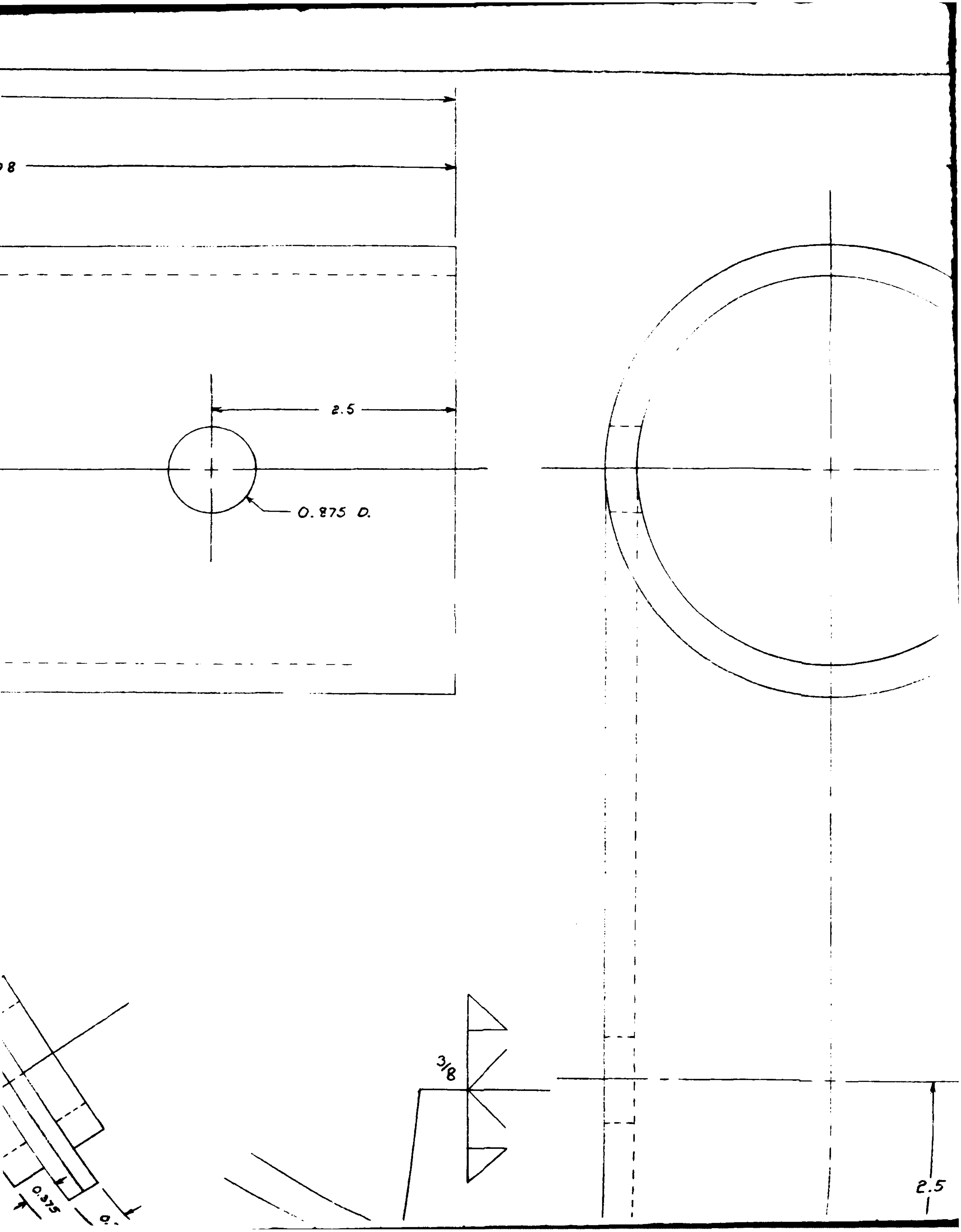
CONNECTOR PLATE

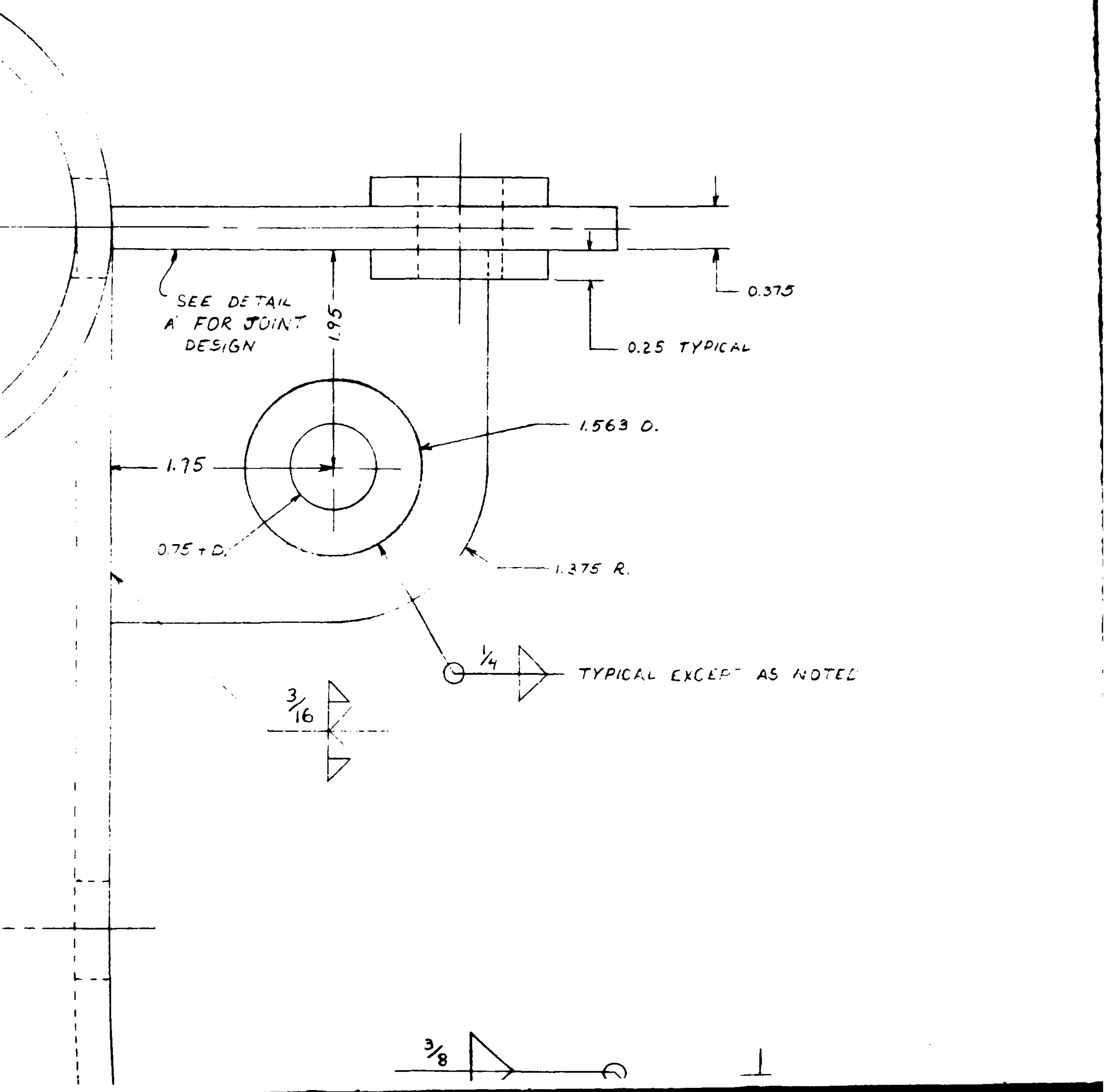


UNIVERSITY OF DAYTON RESEARCH INSTITUTE	
EASY - FIX COMPRESSION TUBE CORNER FITTING # 2	
JANUARY 14, 1987	DWG. NO. EF-008
Dr. & Ckd. DAN BOWMAN	SCALE: 1/1



11.0
10.08
4
6
11.7
11.0
3/8
SEE DETAIL "A" FOR JOINT DESIGN
0.375
0.875 D.
2.5

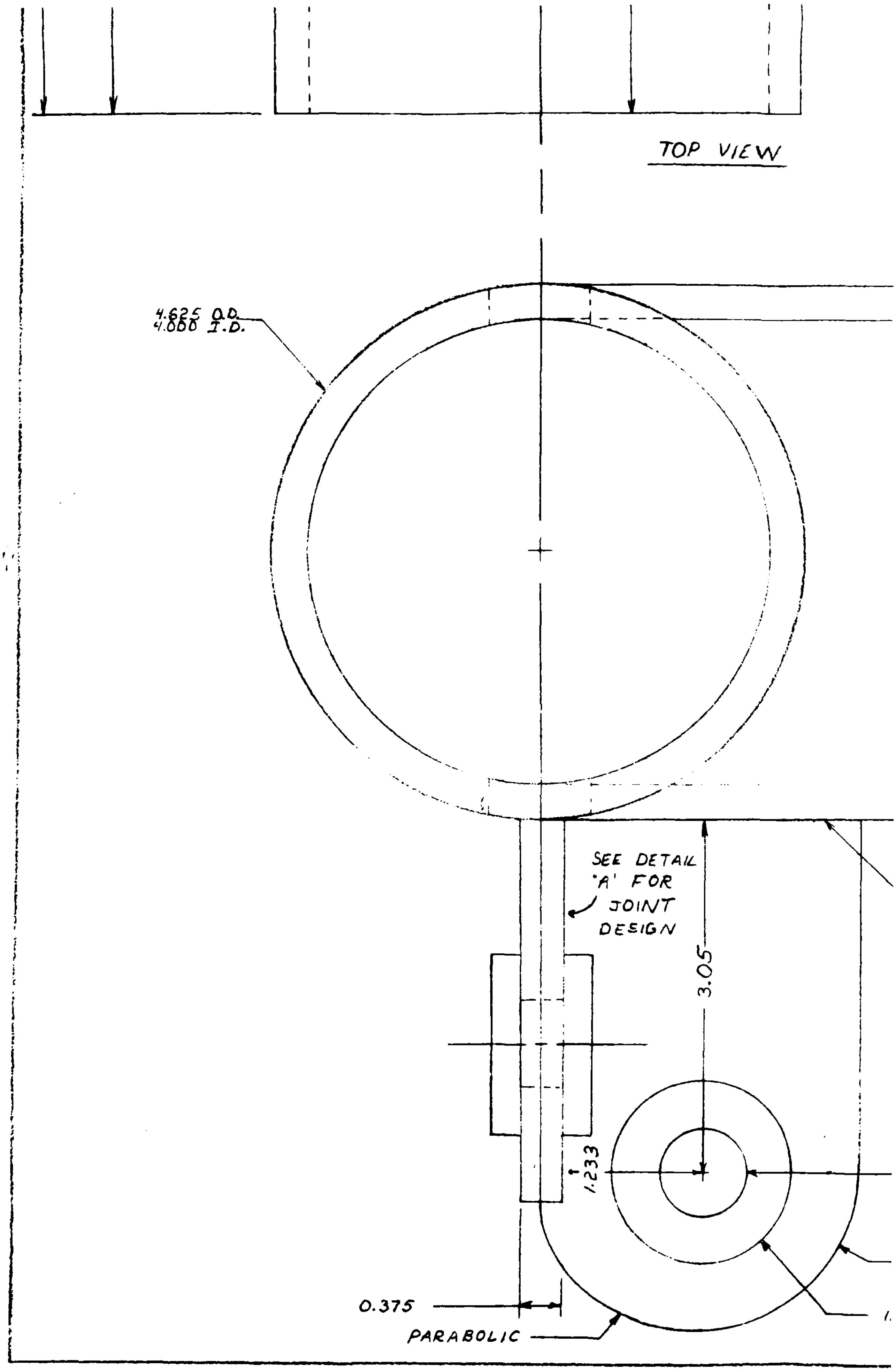

2.5
0.875 D.
3/8
0.375
2.5

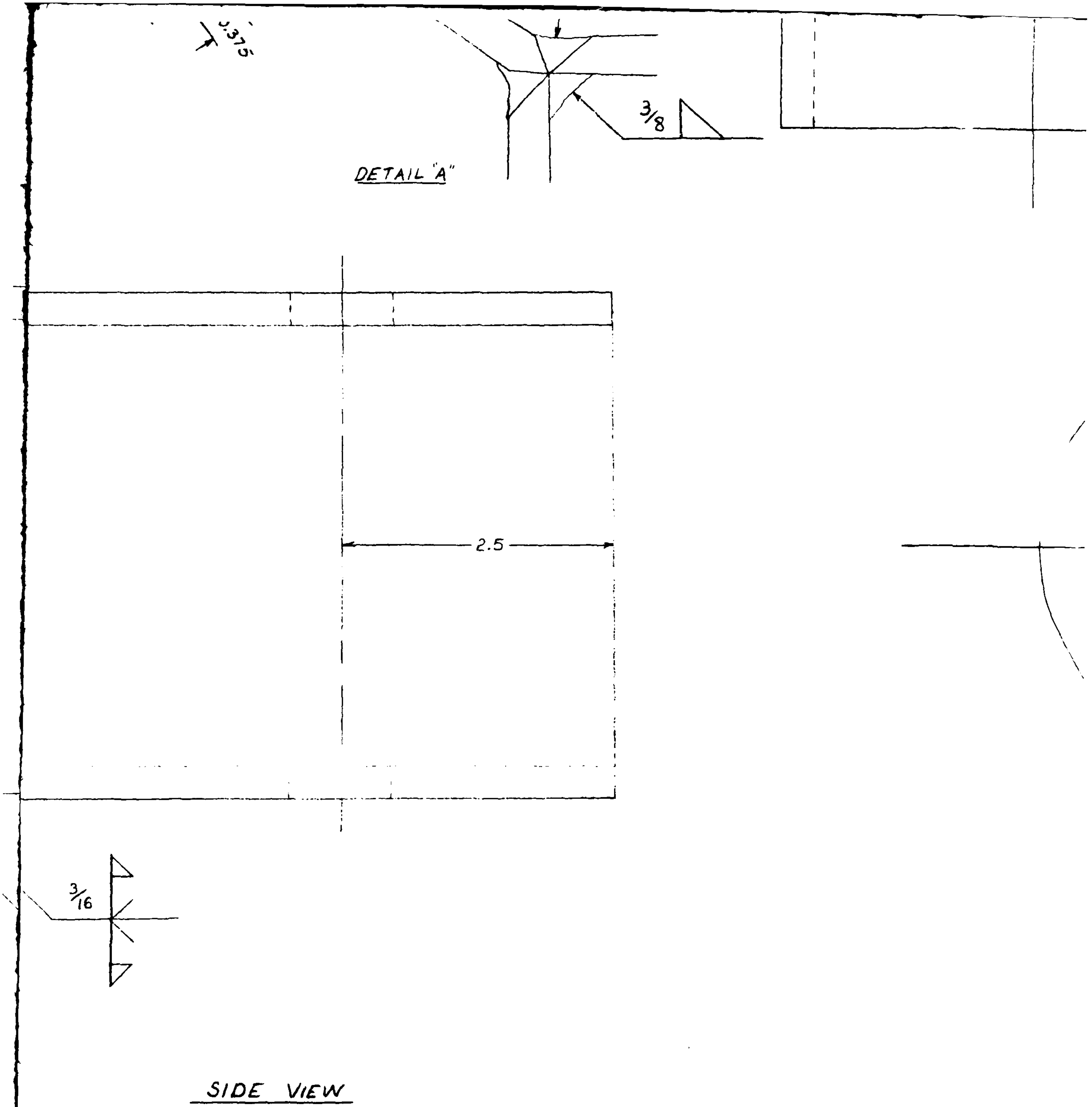


SEE DETAIL
A FOR JOINT
DESIGN
1.95
0.375
0.25 TYPICAL
1.563 D.
1.75
0.75 + D.
1.375 R.
1/4
TYPICAL EXCEPT AS NOTED
3/16
3/8

NOTES:

1) MATERIAL - 6061-T6 AL TYPICAL.
2) $4\frac{5}{8}$" O.D. TUBE MILLED DOWN FROM 5" O.D.
3) REINFORCING DISKS TO BE WELDED IN PLACE BEFORE HOLES ARE DRILLED.
4) TUBE I.D. MAY REQUIRE MILLING TO ALLOW CLEARANCE FOR 4" O.D. COMPRESSION MEMBER.
5) CONNECTOR PLATE IS OMITTED FROM SIDE AND END VIEWS FOR CLARITY.
6) ALL WELDING TO BE IN ACCORDANCE WITH MIL-STD-8E34 : USE [illegible] LER WIRE.
7) AFTER FABRICATION OF EACH CORNER FITTING IS COMPLET[illegible] FITTING SHALL BE RE[illegible] TREATE[illegible] RESTORE THE WELD AFFECTED ZONE TO THE ORIGINAL T-6 CONDITION. PARTS SHALL BE HEAT TREATED TO T-4 CONDITION BY HEATING T[illegible] 985°F FOR 2 HOURS AT TEMPERA[illegible] HING IN ROOM TEMPE[illegible]. PARTS SHALL THEN [illegible] TREATED TO T-6 CONDITION [illegible] O 320°F FOR 18 HOURS AT TEMPERATURE AND AIR COOLING. ALL HEAT TREATING SHALL BE IN ACCORDANCE WITH MIL-H6088.

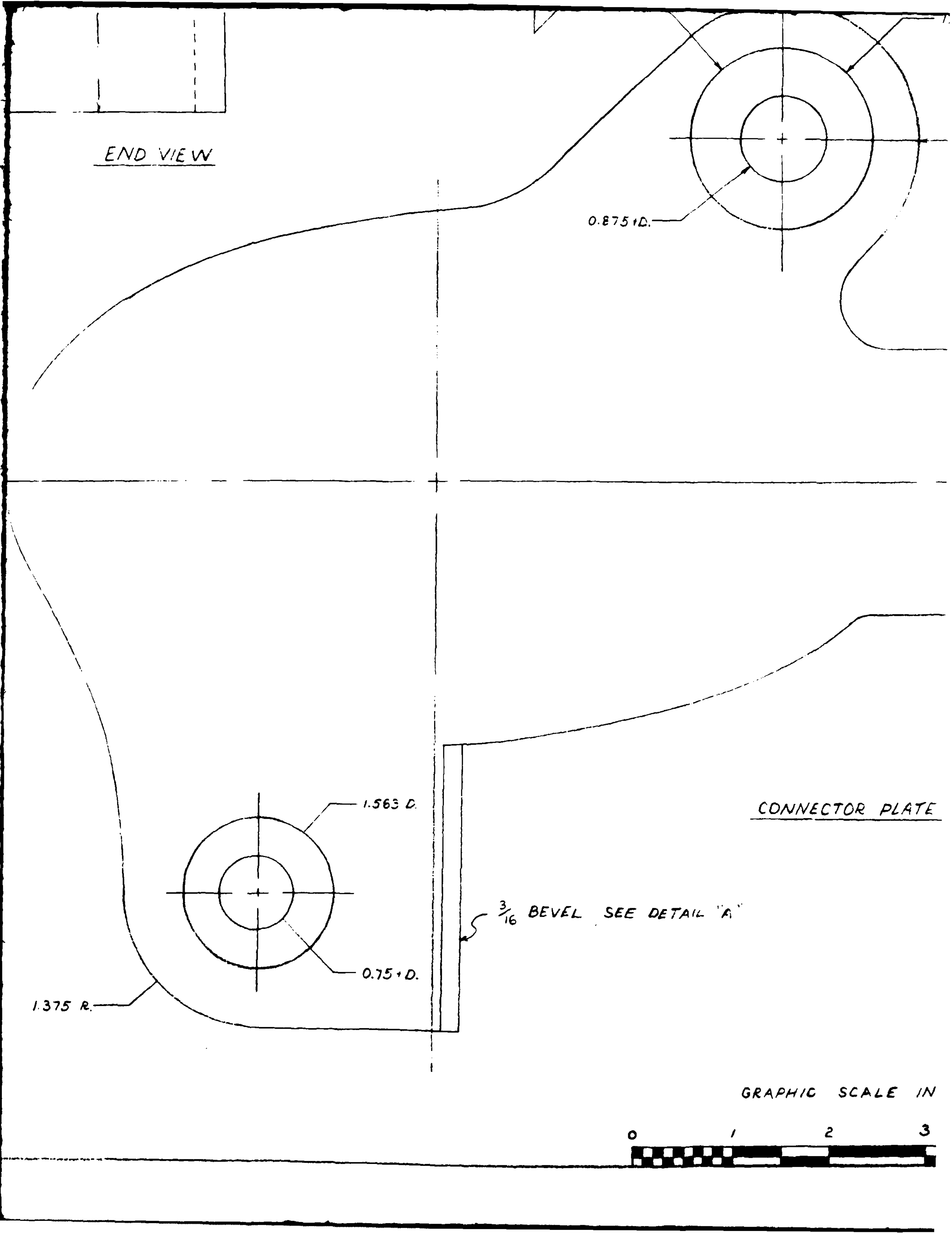

TOP VIEW
4.625 O.D.
4.000 I.D.
SEE DETAIL 'A' FOR JOINT DESIGN
3.05
1.233
0.375
PARABOLIC

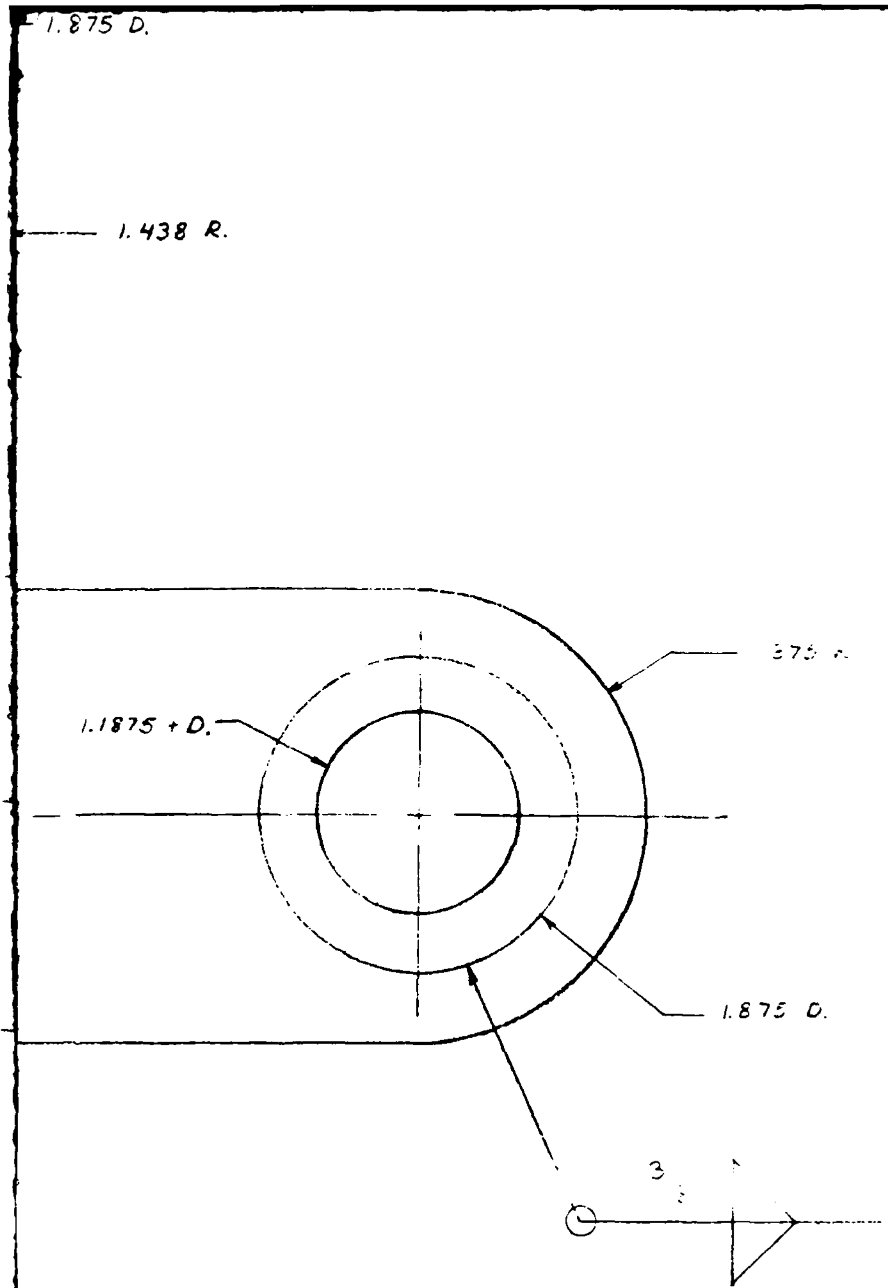


0.75 + D.

.375 R.

3 D.


END VIEW
0.875 + D.
1.563 D.
0.75 + D.
1.375 R.
3/16 BEVEL SEE DETAIL "A"
CONNECTOR PLATE
GRAPHIC SCALE IN
0
1
2
3



UNIVERSITY OF DAYTON
RESEARCH INSTITUTE

EASY-FIX
COMPRESSION TUBE
CORNER FITTING # 4

JANUARY 14, 1987

Dr. & Ckd. DAN BOWMAN | SCALE :

INCHES

4