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M.E. 366-J Embodiment Design Project

Portable Foot Restraint

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Abstract

During space shuttle operations, astronauts require support to carry out tasks in the weightless environment. In the past, portable foot restraints (PFR) with orientations adjustable in pitch, roll, and yaw provided this support for payload bay operations. These foot restraints however, were designed for specific tasks with a load limit of 111.2 Newtons. Since the original design, new applications for foot restraints have been identified. New designs for the foot restraints have been created to boost the operational work load to 444.8 Newtons and decrease setup times. What remains to be designed is an interface between the restraint system and the extra-vehicular mobility unit (EMU) boots. NASA provided a proposed locking device involving a spring-loaded mechanism. This locking mechanism must withstand loads of 1334.4 Newtons in any direction and weigh less than 222.4 Newtons.

This paper develops an embodiment design for the interface between the PFR and the EMU boots. This involves design of the locking mechanism and a removable cleat that allows the boot to interface with this mechanism. The design team used the Paul Beitz engineering methodology to present the systematic development, structural analysis, and production considerations of the embodiment design. This methodology provides a basis for understanding the justification behind the decisions made in the design.

Background and Statement of Problem:

Due to the weightless environment of space, astronauts require support to carry out their tasks. This means that a system of restraint is necessary to give them enough leverage to carry out even simple functions. NASA has previously addressed this problem with a portable foot restraining mechanism which can be moved about the payload bay.

However, tasks have been identified which require more and more leverage. It has become paramount that a new restraining mechanism be designed to meet this need.

NASA has developed a series of specifications for the new restraints. The means of restraint needs to be portable and lock into various sections within the payload bay. The amount of available space makes this necessary. The weight and volume must also be limited so that the PFR is indeed portable and does not take up much space while not in use.

The scope of the task the design team is limited to design of the interface between the PFR and the EMU boots. NASA provided a preliminary design for this locking mechanism for the team to develop. Due to the requirement of the PFR being portable, the locking mechanism is limited to a weight of 222.4 Newtons The dexterity of the astronauts will be retarded due to their EMU's so operation of the locking mechanism must be simple. Time constraints on missions also require that operation be quickly accomplished in a maximum of three steps. The locking mechanism must endure loads of 1334.4 Newtons with a safety factor of 1.4 in any direction to properly support the astronaut. Finally, since 8 units are required, the cost of the project is a factor. The prototype is limited to $350,000 and then $125,000 per actual unit. Therefore, to meet project cost ceilings, the system must work with the present EMU boots. The interface design must include a removable cleat that attaches to the boot and locks into the PFR. Other functional requirements are included in the specification sheet.

Scope and Limitations

The design of an improved PFR must solve certain problems. Clarification of these problems begins with the major function of the device, securing the astronaut's feet. The design must secure the feet in any direction and withstand a pull out force of 1868

Newtons (factor of safety included). The design must also allow for easy manipulation of the task, as the astronaut will be using the device while wearing an EMU.

Another problem that the design must solve is to produce an interface between the EMU boot and the proposed foot restraint. This requires that the design include a cleat to attach to the EMU boot. This cleat must be able to withstand all forces specified for the securing device without hindering agility.

There are several important issues to be considered in the design of a more effective PFR. First, the device must be sturdy. It will need to withstand not only the forces applied by the astronaut, but also the forces involved in take off and re-entry. The device must also be light, as the cost of sending mass into space is high. Also, NASA has existing standards for the geometry of the EMU boots to which the design must conform. In addition, the design can not damage or pinch the boots in any way, as this could lead to safety problems. The materials used in the design will also be of great importance. Finally, the device must operate in a wide range of temperatures (-171 to 111 degrees C) and be corrosion resistant.

The proposed embodiment design that follows will be limited to the design of the foot restraining mechanism and the cleat. These parts will interface with the existing NASA PFR support structures shown in the appendices.

Functional Description of Portable Foot Restraint

Embodiment Determining Requirements

The existing design for the portable foot restraint consists of a spring loaded mechanism analogous to a snow ski binding. NASA engineers want to incorporate this basic concept into a new, higher performance design. The new set of specifications NASA has developed for the portable foot restraint comprises the guidelines on which the following embodiment design will be based.

NASA has decided on a set of concept requirements to which the design of the portable foot restraint must adhere. First, the device must secure the astronauts foot with some sort of a spring loaded system. This is similar to the existing design but must be improved upon. Also the securing device must include a removable cleat which can be attached to the bottom of the EMU boot.

The specification requirements of the embodiment design can be seen by examining the attached specification list. Some of these warrant brief discussion.. The most important requirement of the new design is that it be able to withstand 1334.4 Newtons in any direction, without the astronauts foot slipping free. The existing design was weak in this area, and the astronauts often found it too easy to inadvertently unsecure their feet from the restraint. The new design must also be easy for the astronaut to manipulate while in an EMU. The quantification of this specification is that the user be able to work the device in three or less steps. The design must also conform to the existing EMU boot specifications, which affects the design of the cleat that must attach to the bottom of the boots. Finally, it is important that the device not damage or pinch the boot or any other portion of the EMU. The following design follows all of the constraints listed above as well as the specifications presented in the specification list.

Discussion of the Presented Embodiment Design

The embodiment design agreed upon by the design team is presented in Figures 1 through 22. These figures consist of a side and a top view of the restraining mechanism, a schematic of the restraint release system, and a side and top view of the cleat, and several views of the release and pulley mechanisms.

Embodiment Concept

Prior to discussing the details of the actual design it is important to discuss the concept proposed for the PFR. The first step is to secure the designed cleat (Figure 3) to the bottom of the EMU boot. The astronaut then places the front end of the cleat under the toe support (Part 1-B in Figure 1) and steps down with his or her heel. As the astronaut puts weight on his or her heel, the spring loaded securing pins (Part 5-A in

Figure 5) protruding from the sides of the heel clamp are forced outward. The pins are machined at a forty five degree angle as seen in Figure 8 (Part 8-C). As the astronaut steps down, his or her weight force is applied in both vertical and horizontal directions due to this geometry. This forces the pins to retract against a pair of internal springs (Part 6-A in Figure 6, Part 7-A in Figure 7). When the astronaut's foot is in its proper position, the springs eject the pins into the machined holes on either side of the cleat. This restrains movement of the foot in the vertical direction. Any movements in the horizontal direction are restrained by the combination of the toe support and the heel restraint.

To release his or her foot, the astronaut pushes a release button (Part 5-C in Figure 5) that is connected to the securing pins by a taught wire (shown in Figures 5-8). When the button is pushed, the securing pins are pulled back into their retracted positions, allowing the astronaut to free his or her foot. When the button is released, the springs expand and the securing pins are ejected to their original rest positions.

Discussion of Individual Embodiment Components

The discussion of the individual components involved in the proposed design begins with the base plate and restraining supports shown in Figure 1. The base plate (Part 1-A) must be designed to attach to the PFR work site interface. This is accomplished by bolting the plate through the extended flanges at either end of the base plate. Six quarter inch socket head cap screws (round heads) will be used as fastening mechanisms. These bolts, while being much stronger than necessary to secure the plate (see calculations), are easier to manipulate than weaker bolts. Their round head also allows them to fit nicely into round counterbored holes. The plate will be made of 6061 aluminum, which will withstand all foreseeable loads (see calculations). 6061 aluminum is also exceptionally machinable and can easily be fabricated from sheet stock, using a mill or drill press.

Attached to the base plate is the front toe support (Part 1-B) and the heel restraint (Part 1-C). Both pieces must be able to withstand the specified load and will be secured using quarter inch (1/4 -20) socket head cap screws. The material suggestion for the toe support is 6061 aluminum. This aluminum can be both machined or die cast, the two most likely methods of fabricating this difficult geometrical part. It is also strong enough to withstand the specified load.

The heel restraint can be seen in as part 1-C in Figure 1. This part will serve as the spring loaded restraint that will secure the astronaut's foot firmly in place. The restraint will be held to the base plate by five quarter inch (1/4-20) socket head cap screws. A material suggestion for this part is 6061 aluminum. Manufacturing of the part would involve milling the main geometry, then using electric discharge machining to produce the square holes on either side of the restraint.

Figure 3 shows a top and a side view of the proposed cleat design. The cleat is dimensioned to fit the existing specifications of the EMU boot. The important aspect of this cleat is that it must be able to mount to the bottom of the EMU boot and withstand the specified load. This will be accomplished with four socket head cap screws. These bolts will thread into the fiberglass plate found on the bottom of the EMU boot. The cleat could be made of 6061 aluminum which will be strong enough to withstand the load and not add a great deal of weight or bulk to the EMU. Also the aluminum will resist possible cold welding with the toe support.

Figures 4 through 8 show the release mechanism and the securing pins. A better drawing of the pin design is shown in Figure 16. These pins will be the most important part of the design, as they will secure the foot into place when they are ejected into the square holes on either side of the cleat. Not only must these pins be designed to withstand the specified load, they must also slide inside the holes machined in the heel restraint. This means metal to metal contact. Another important constraint of the pins is that they must be abrasion resistant, as they will be in sliding contact with the bottom of the cleat. The pins could be fabricated of anodized 6061 aluminum. Anodizing will improve surface hardness and increase abrasion resistance. The anodizing does cause minor expansion in the part however. If this expansion proves to be a problem, 303 stainless steel could be used instead.

Figures 6 and 7 show blowup views of the release button and the pulley system. These pulleys (Parts 6-B and 7-B) could be machined of a lightweight aluminum, either

3003 or 6061, and would be held on the support bar with dowel pins (Part 7-F) as shown in Figure 20. 6061 aluminum could be used as a material option for the button itself (Part 6-E). A suggestion for the wire used to retract the pins is 1.59 cm (1/16 in.) 7x7 aircraft wire. The wire will be connected to the securing pins by looping the wire around a hole machined in the pins (part 6-G) then fastening the wire back on itself with a crimp. Finally the spring (Parts 6-A and 7-A) could be made of piano wire and have a recommended spring constant of roughly 350 Newtons per meter.

The pulley system rests inside a sheet aluminum housing which is secured to the outside of the heel restraint as shown in Figure 4. Size 5 bolts (1/8 in.) will be used as fasteners to keep the housing in place, with angle brackets connecting the individual sides. This housing will encompass the wires and pulleys on all sides except the bottom, forming a protective shell.

Overall Design Analysis

It is the opinion of the design team that the proposed design satisfies the specifications setup by the NASA engineers. The calculations that follow show that the design presented will withstand the 1868 Newton force applied in any direction without a problem. The only possibility for failure due to this force would be caused by either internal or external cracks in the individual parts of the design. This type of defect could lead to unforeseen fast fracture. The use of aluminum to make the majority of the parts in the design will keep the overall weight low, well below the 222.4 Newton maximum, as well as offer good corrosion resistance. The aluminum also suffers little from thermal expansion. The presented design allows for use in less than three steps by the astronaut, and should not damage or pinch the EMU boots in any way. Finally, since the majority of the components of the design are readily available and should not prove difficult to fabricate, the overall cost of the proposed PFR will be low.

This proposed design has many advantages over the existing PFR design. First, the astronaut's feet will be secured much more firmly, and there should be no problem with them becoming inadvertently unsecured. The proposed design is also easy to use, requiring a minimal amount of steps to manipulate. Using socket head cap screws as fasteners should also facilitate the transportation of the device from position to position in the cargo bay. Finally, fabricating the device from a high strength aluminum alloy makes it lightweight and corrosion resistant.

The proposed design does have a contain a few drawbacks. The astronaut's feet will be firmly secured and he or she will not be able to pull them out until the button release is actuated. This could lead to possible safety problems. Also the cable release system is not as sturdy as the other components in the design proposal. The design team does not feel that the release system will pose any problems in terms of reliability, but it is the weakest portion of the device.

Calculations

As mentioned earlier, the specifications demand that the PFR withstand loads of up to 1868 Newtons in any direction (safety factor of 1.4 included). The design team therefore performed calculations confirming that the proposed design will withstand the designated loads.

Figure 23 shows the calculations addressing the bolts that attach the cleat to the EMU boots. These calculations were performed under the assumption that if a single bolt can support the required load, then obviously a group of the same type of bolts could do the same. Examination of the numbers shows that one grade five bolt will withstand the load in both tension and in shear. The actual design uses four socket head cap screws to secure the cleat to the bottom of the EMU boot. Since the proof strength of a socket head cap screw is superior to that of a grade five bolt, there should be no problem in supporting this load. To minimize the risk of failure due to unforeseen moments or fast fracture, four socket head cap screws will be used instead of one. The analysis discussed above can be applied to all loaded bolts in the proposed design. For this reason there will be no further calculations done on failure of the bolts.

Figure 24 shows calculations addressing fatigue loading of the bolts. Again the analysis is done using the physical properties of a grade 5 bolt. Since this bolt will withstand the fatigue loading, it is inherent that the socket head cap screws used in the existing design will also withstand fatigue loading.

The most important calculations for the PFR design are presented in Figure 25. These are the calculations addressing the viability of the securing pins that hold the astronaut's foot in place. In the calculation of the strength of the pins, the design team used a worst case scenario approach with respect to shear and bending. The system was considered as a cantilever beam with a point load of 1868 Newtons applied at the far end. The material properties used were that of 2024 aluminum (inferior in strength to the 6061 suggested). Also only the minimum height of the pin was used for cross sectional area calculations. The calculations show that the pin is satisfactory even in this worst case scenario, validating the soundness of this portion of the design.

Figure 26 shows the calculations with respect to the base plate of the PFR. This plate was analyzed against shear failure. Examination of the numbers show that even with the conservative analysis presented (one bolt was used instead of six), the plate withstood the specified load.

Figure 27 shows the calculations used for checking the choice of spring and spring constant. The value set for actuation of the button release mechanism was 7 Newtons. It can be seen that a spring constant of about 350 Newtons per meter is acceptable.

Other calculations are presented in Figures 28 through 30. These include analysis of the fiberglass plate on the bottom of the EMU boot, a calculation of mass, and a strength analysis of the wire used in the release system. Examination of these calculations validate the proposed design of the PFR.

Conclusion

It is the opinion of the design team that the proposed design detailed in this document satisfies all existing requirements listed in the attached specification list. The design should produce no difficulties in the areas of material availability or fabrication.

Future work involved in this design includes the production and testing of a working prototype to confirm the analysis completed. The present embodiment may prove to be over designed, and further analysis could be conducted to minimize material waste. Other analysis could be done to locate stress concentrations and possible failure positions using Finite Element Analysis. Also, more research could be conducted in the areas of effective manufacturing and material selection

References

Budinski, Kenneth, Engineering Materials: Properties and Selections (Englewood Cliffs, NJ, Prentice-Hall, 1992).

Juvinall, Robert, Fundamentals of Machine Component Design (New York, NY; John Wiley & Sons 1991).

Schey, John, Introduction to Manufacturing Processes (New York, NY; McGraw-Hill Inc., 1987).

Appendix A

Technical Drawings

In reference to the bolt holes shown in the following figures, the bolt holes shown in Figures 1,2, and three are for quarter inch socket head cap screws. The counterbored holes have been counterbored 0.75 cm. All of the screw holes in the rest of the figures are for size 5 bolts. The holes drilled into Part 5-C (Figure 5) for the size 5 bolts are drilled 0.5 cm into Part 5-C.

Quick Reference List of Parts and Figures

Figure Number	Part Number	Part Name
1	1 - A	Base Plate
	1 - B	Toe Support
	1 - C	Heel Restraint
2	2 - A	Base Plate
	2 - B	Toe Support
	2 - C	Heel Restraint
3	3 - A	Cleat
	3 - B	Cleat
4	4 - A	Aluminum Housing
	4 - B	Aluminum Housing
	4 - C	Aluminum Housing
	4 - D	Aluminum Housing
	4 - E	Aluminum Housing
	4 - F	Aluminum Housing
	4 - G	Alminum Housing
	4 - H	Pulley Support Flange
	4 - I	Pulley Support Flange
5	5 - A	Restraining Pins
	5 - B	Heel Restraint
	5 - C	Release Button
	5 - D	Pulley Support Flange
	5 - E	Pulley A
	5 - F	Pulley B
6	6 - A	Spring
	6 - B	Pulley
	6 - C	Wire
	6 - D	Restraining Pin
	6 - E	Release Button
	6 - F	Dowel Pins
	6 - G	Pulley A
7	7 - A	Spring
	7 - B	Pulley
	7 - C	Restraining Pin

8	8 - A 8 - B 8 - C	Release Button Pulley Restraining Pin
9		Aluminum Housing
10		Aluminum Housing
11		Aluminum Housing
12		Aluminum Housing
13		Aluminum Housing
14		Aluminum Housing
15		Wire/Pulley Housing Cover
16		Release Button Restraining Pin
17		Pulley Support Flange
18		Pulley Support Flange
19		Pulley Support Flange
20		Pulleys
21		L - Clamps
22		L-Clamps

Figure 1 - Foot Restraint

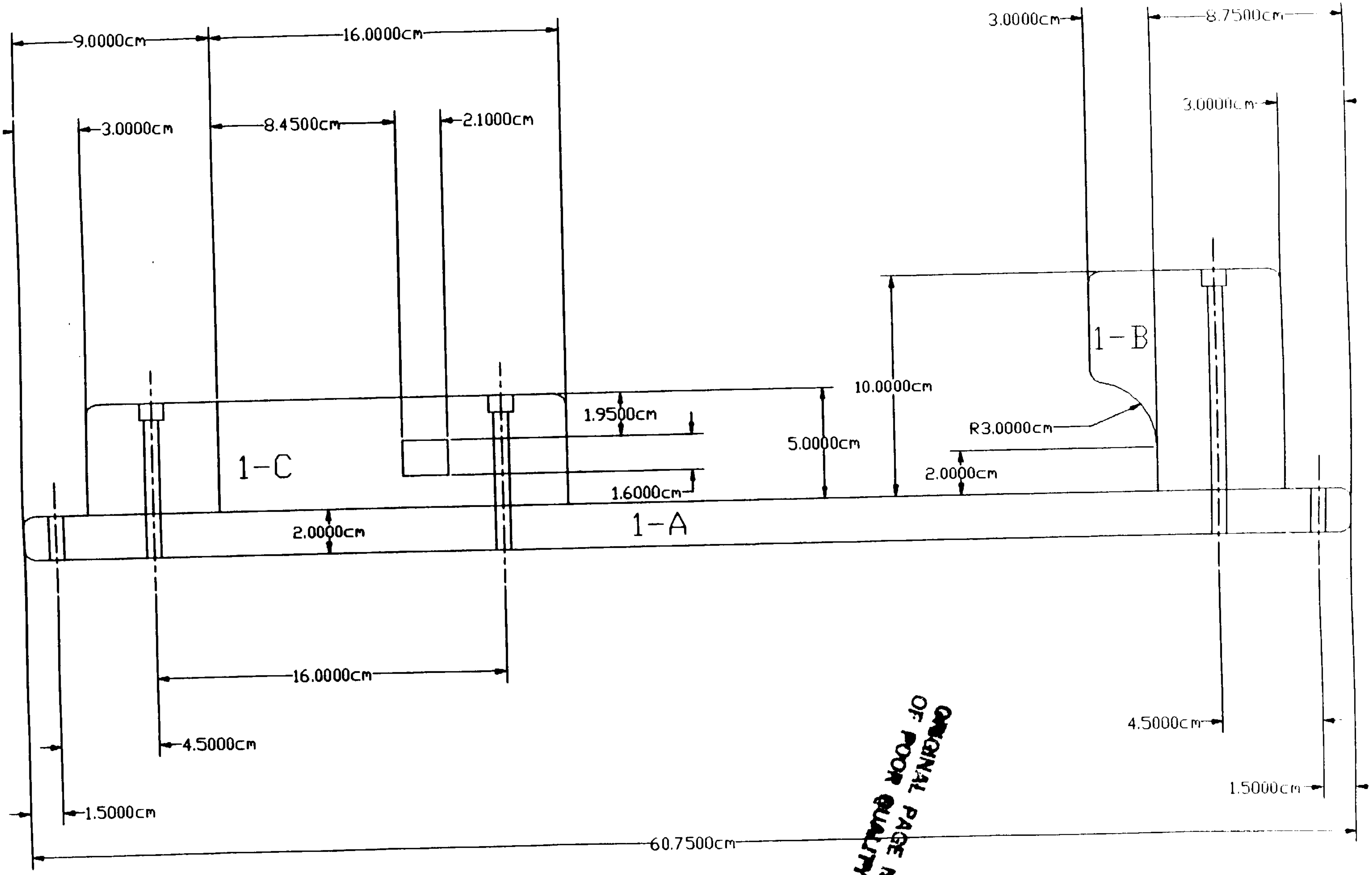


Figure 2 - Foot Restraint

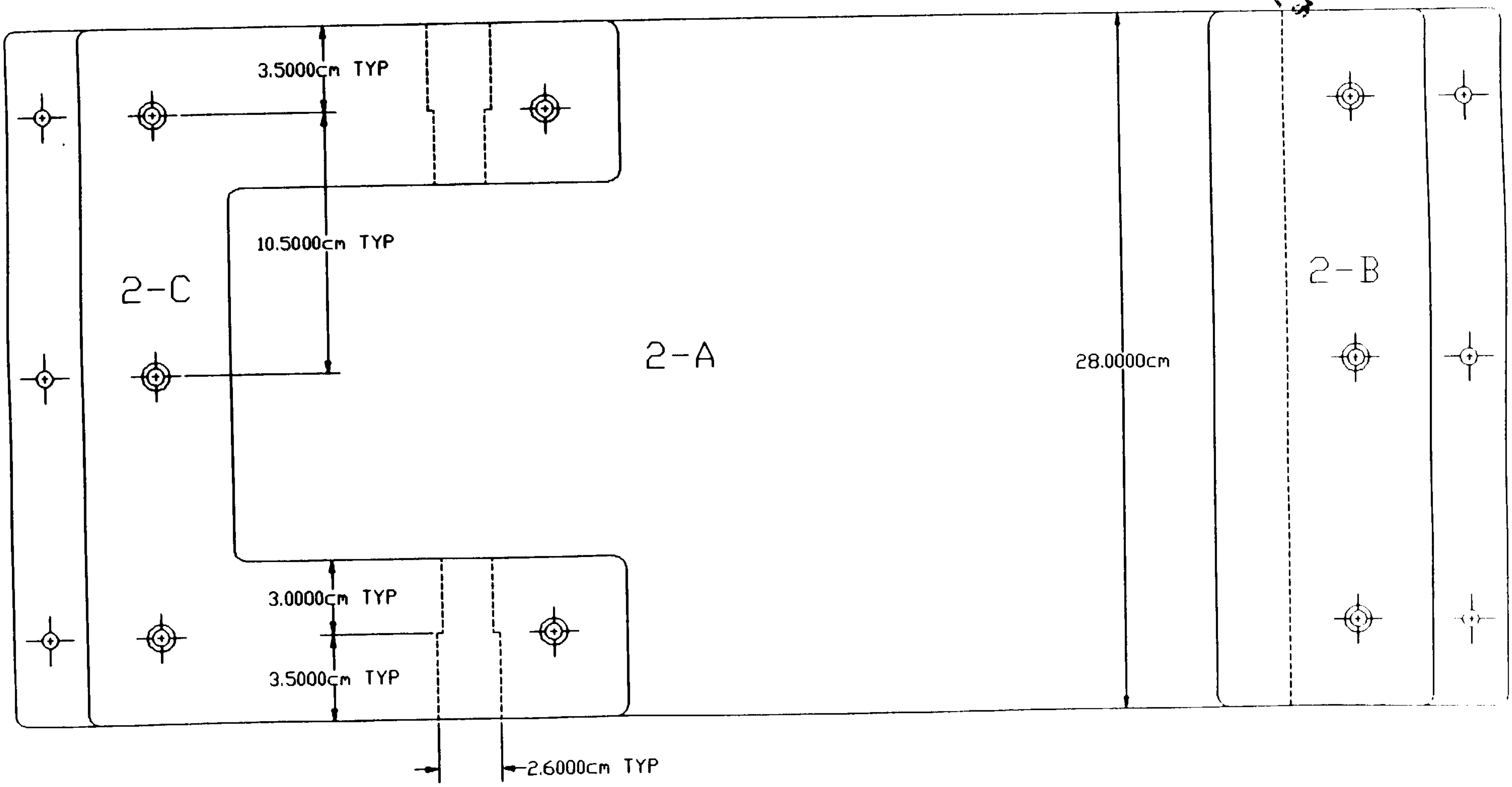


Figure 3 - Cleat

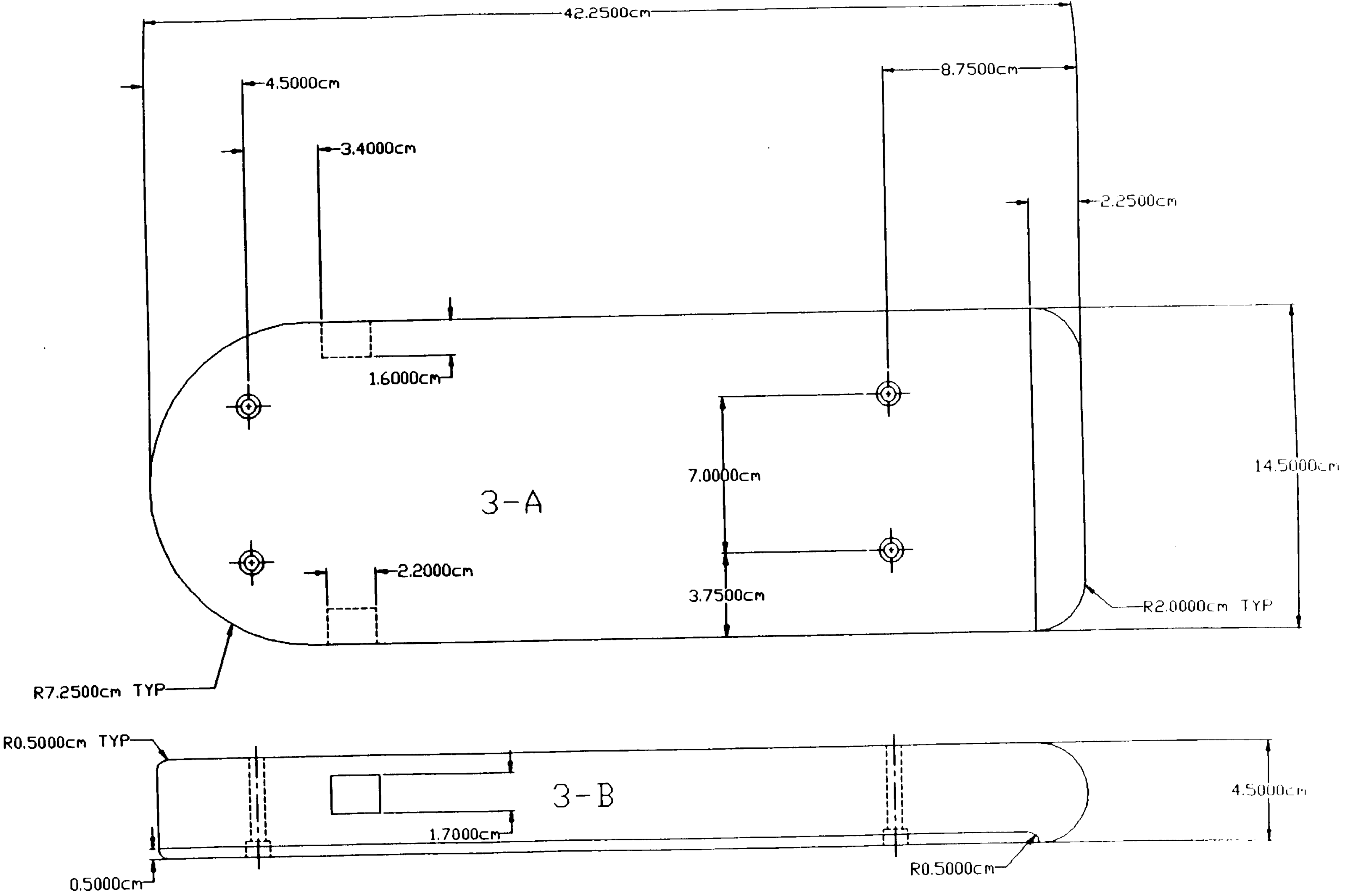
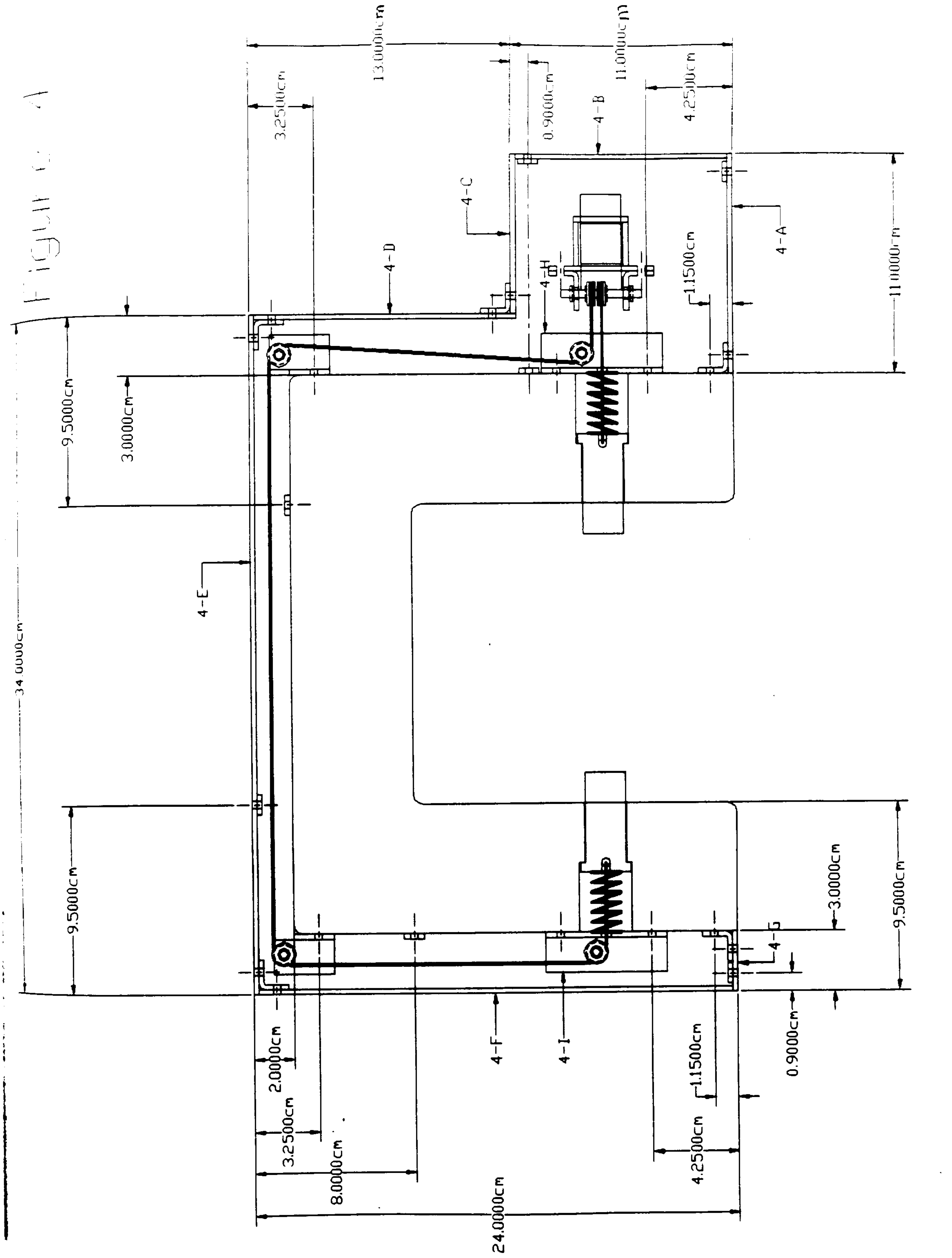


Figure A



4-A
4-B
4-C
4-D
4-E
4-F
4-G
4-H
4-I
13.0000cm
11.0000cm
0.9000cm
3.2500cm
4.2500cm
11.0000cm
1.1500cm
9.5000cm
3.0000cm
34.0000cm
9.5000cm
3.0000cm
9.5000cm
2.0000cm
3.2500cm
8.0000cm
24.0000cm
1.1500cm
4.2500cm
0.9000cm

Figure 5

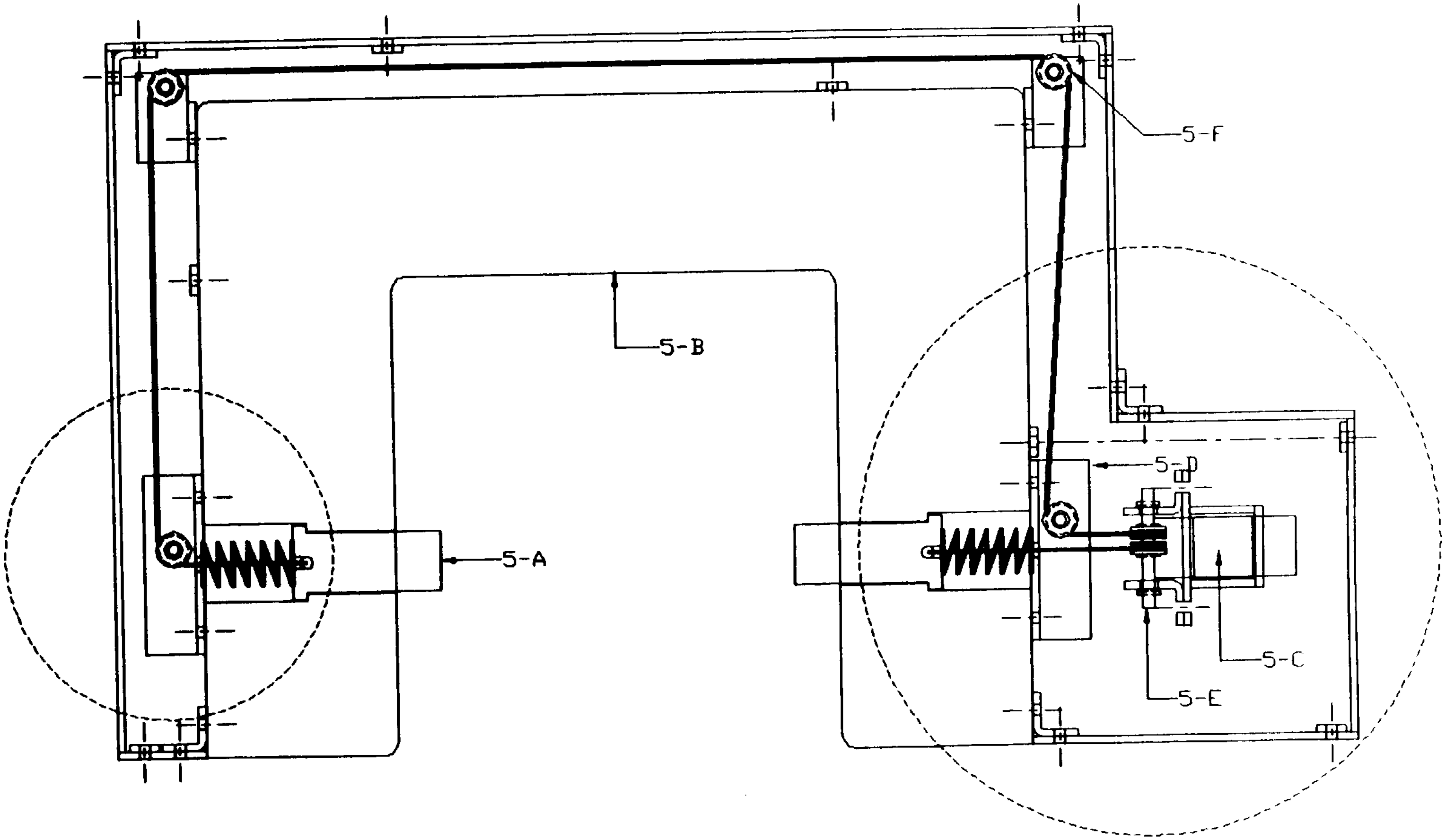


Figure 6

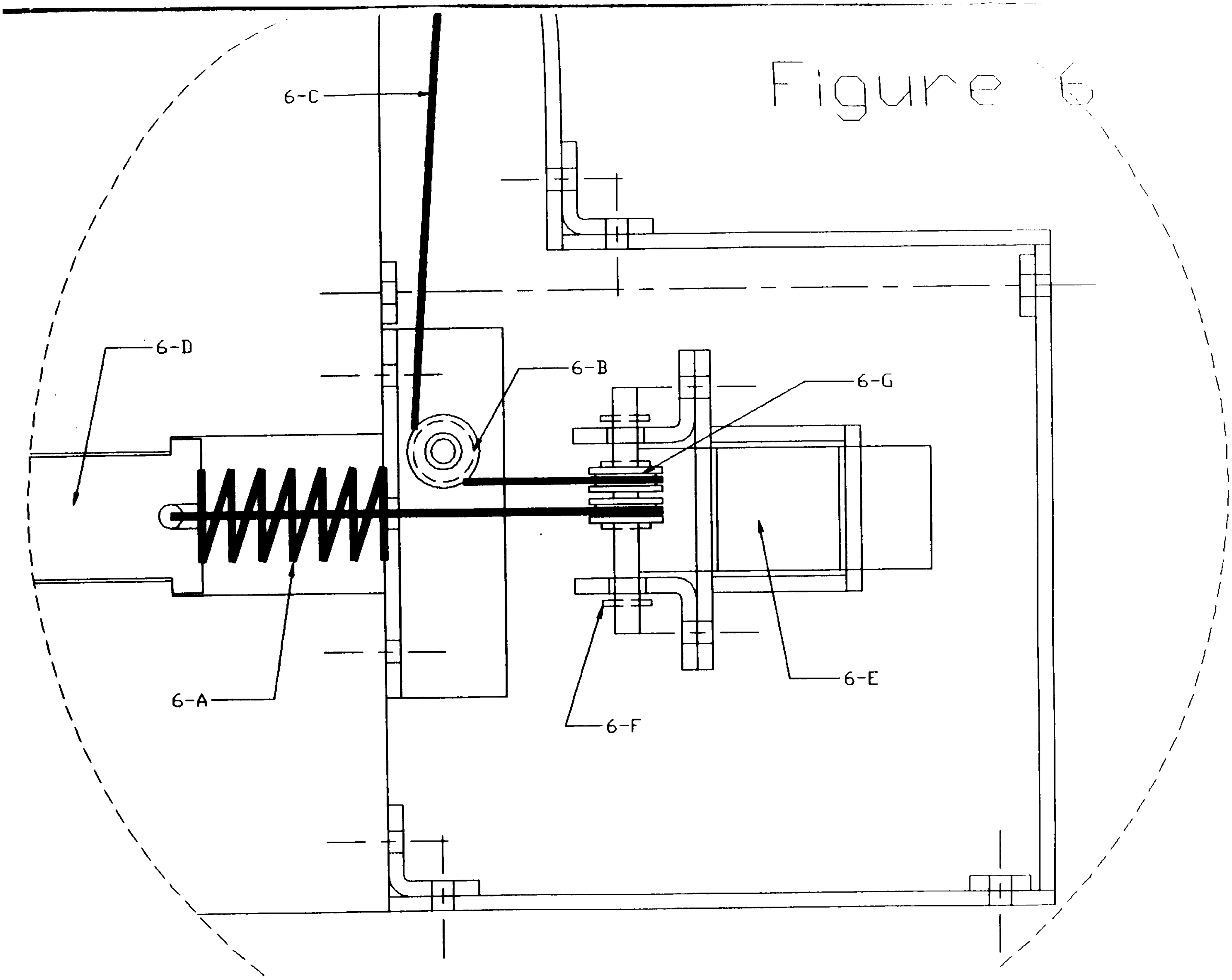


Figure 7

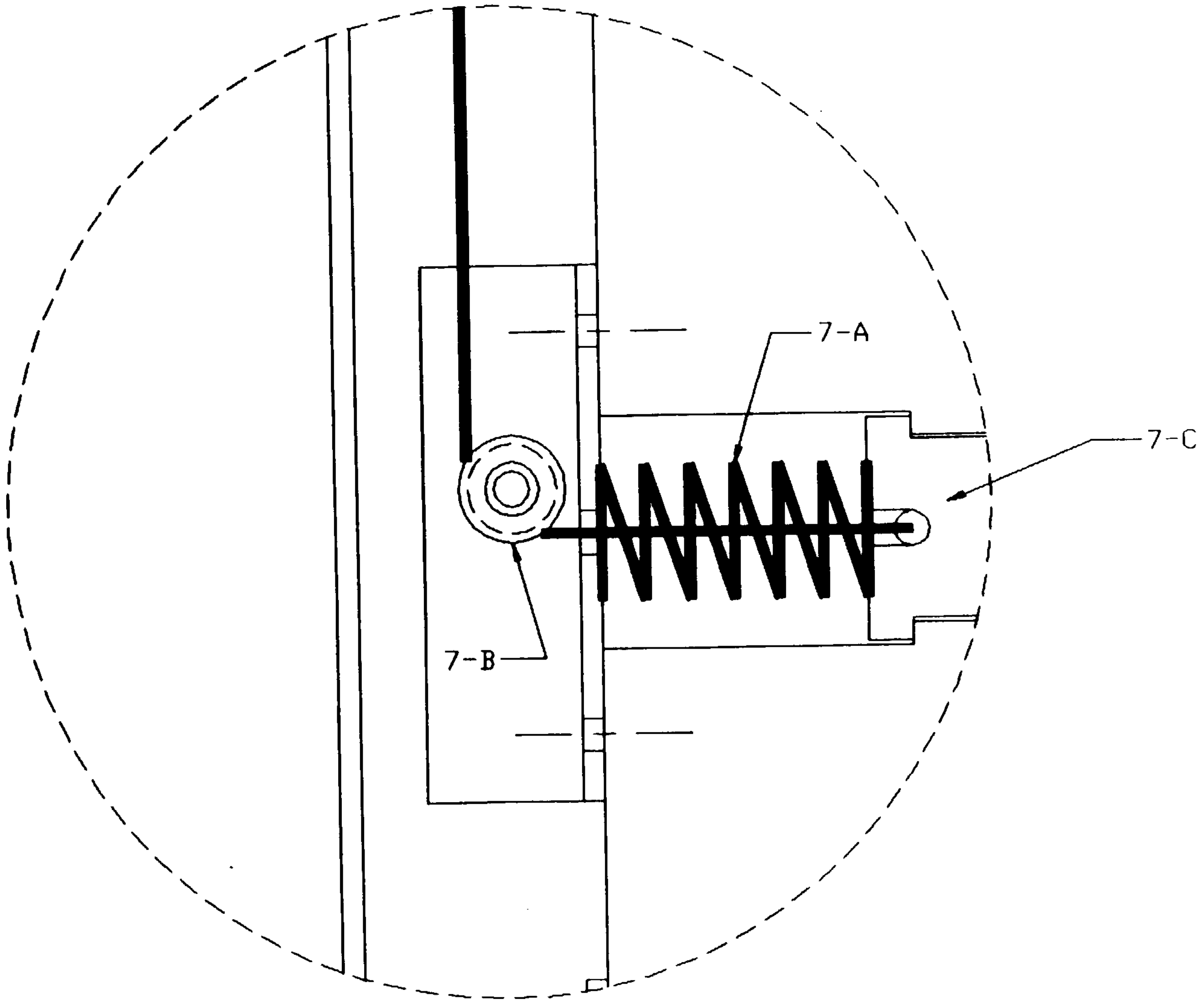
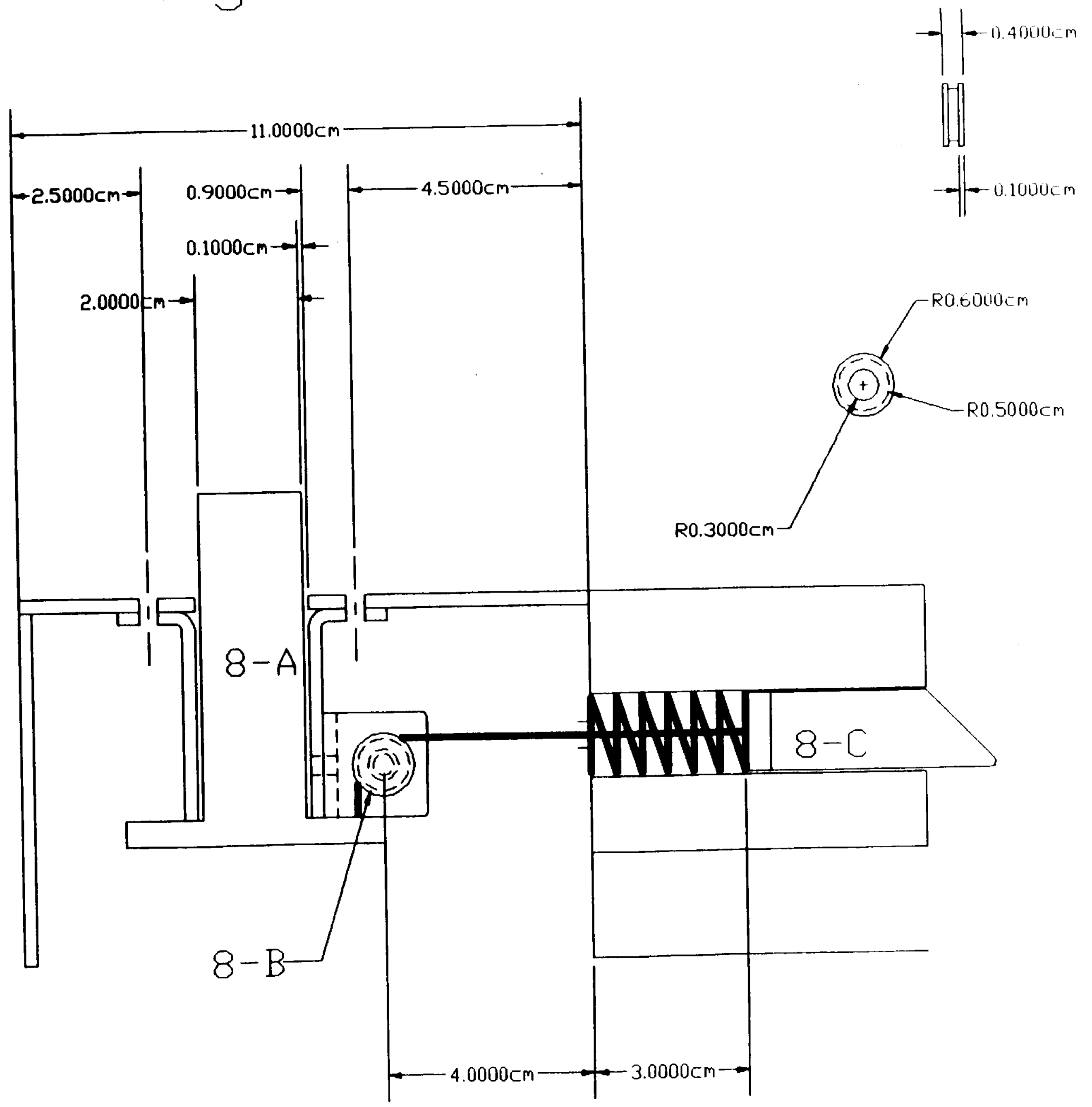


Figure 8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2.5000cm
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4.5000cm
0.1000cm
2.0000cm
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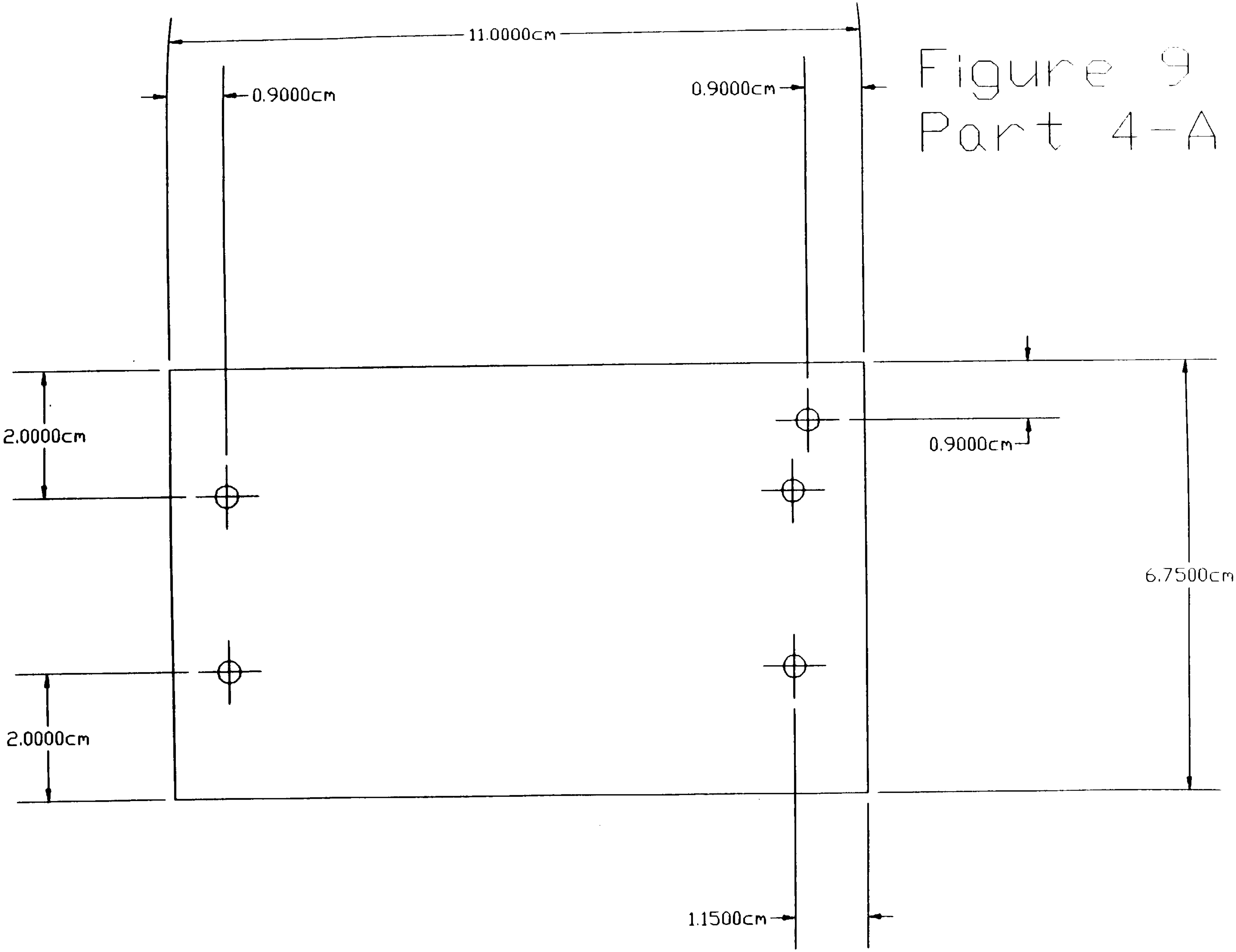
R0.3000cm
8-A
8-C
8-B
4.0000cm
3.0000cm

Figure 9
Part 4-A



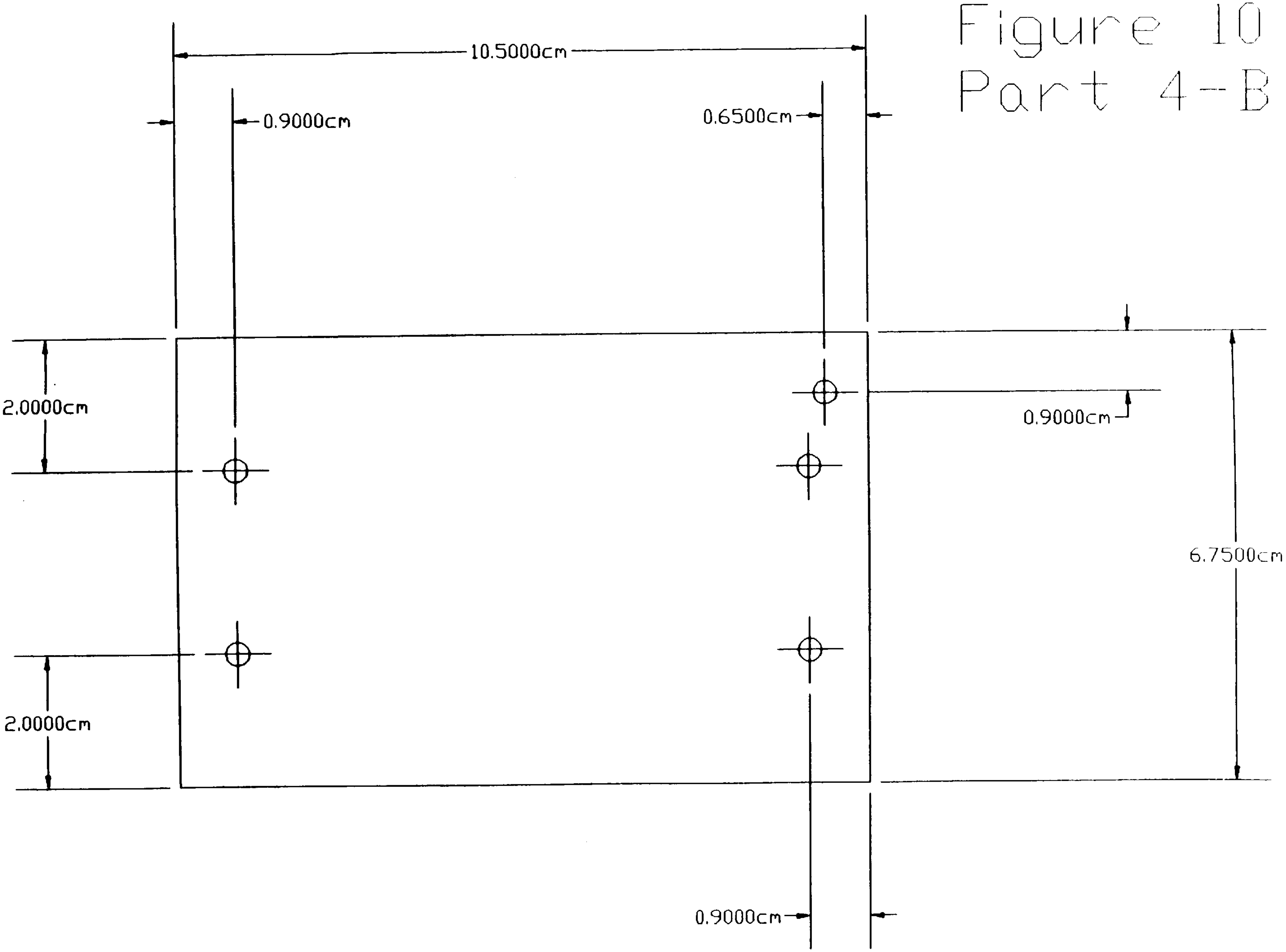


Figure 10
Part 4-B

Figure 11
Part 4-C

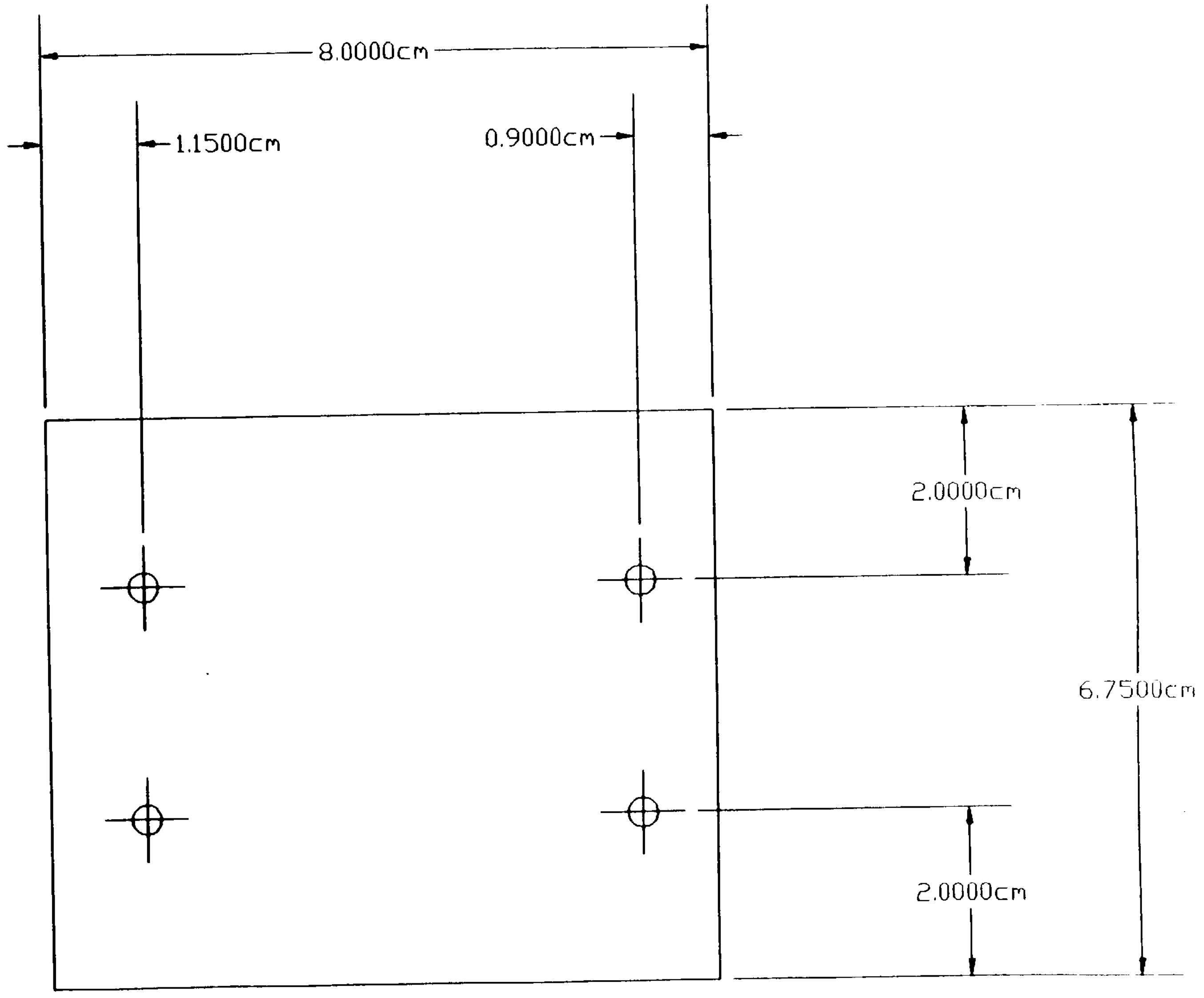


Figure 12 Part 4-D

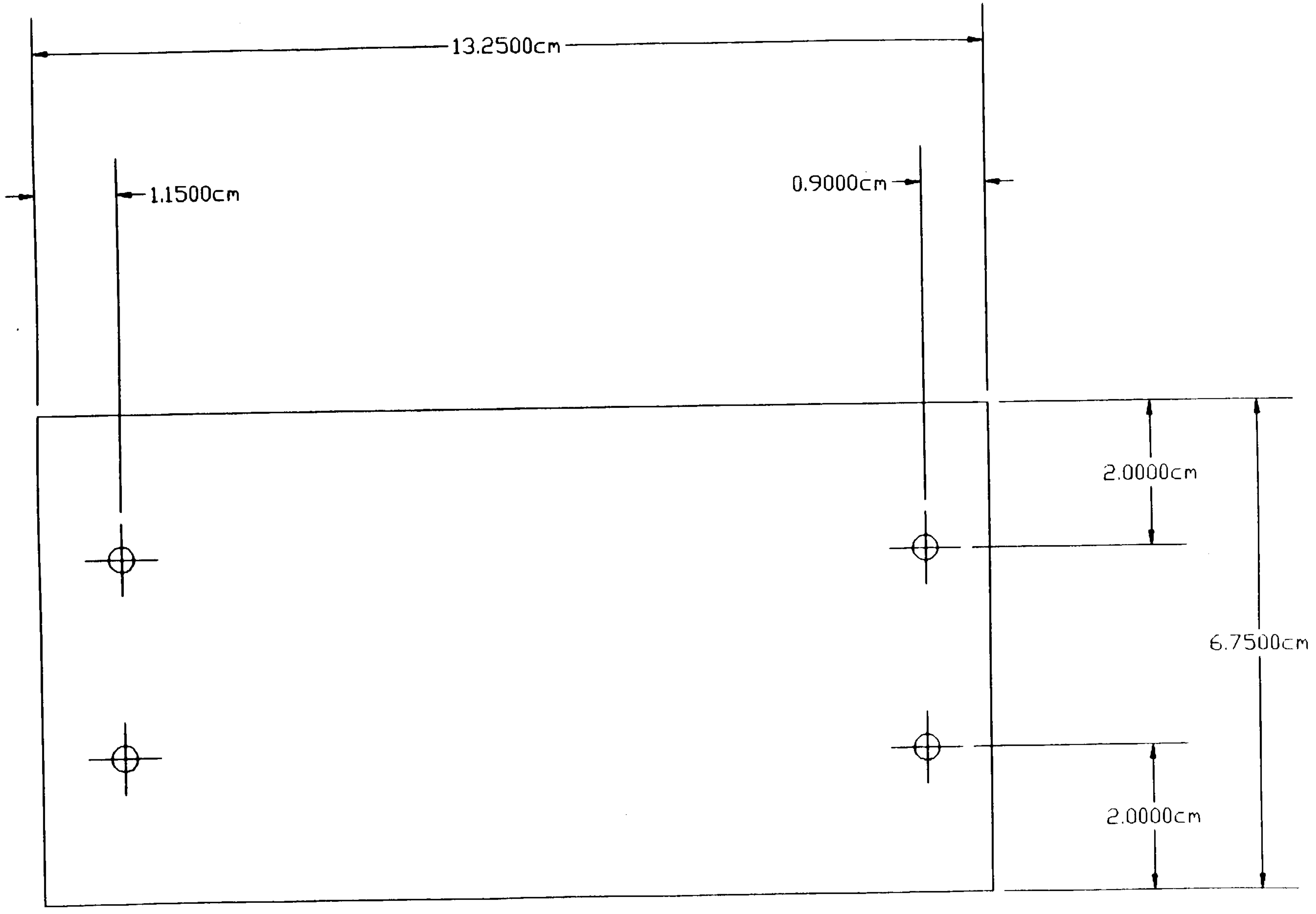
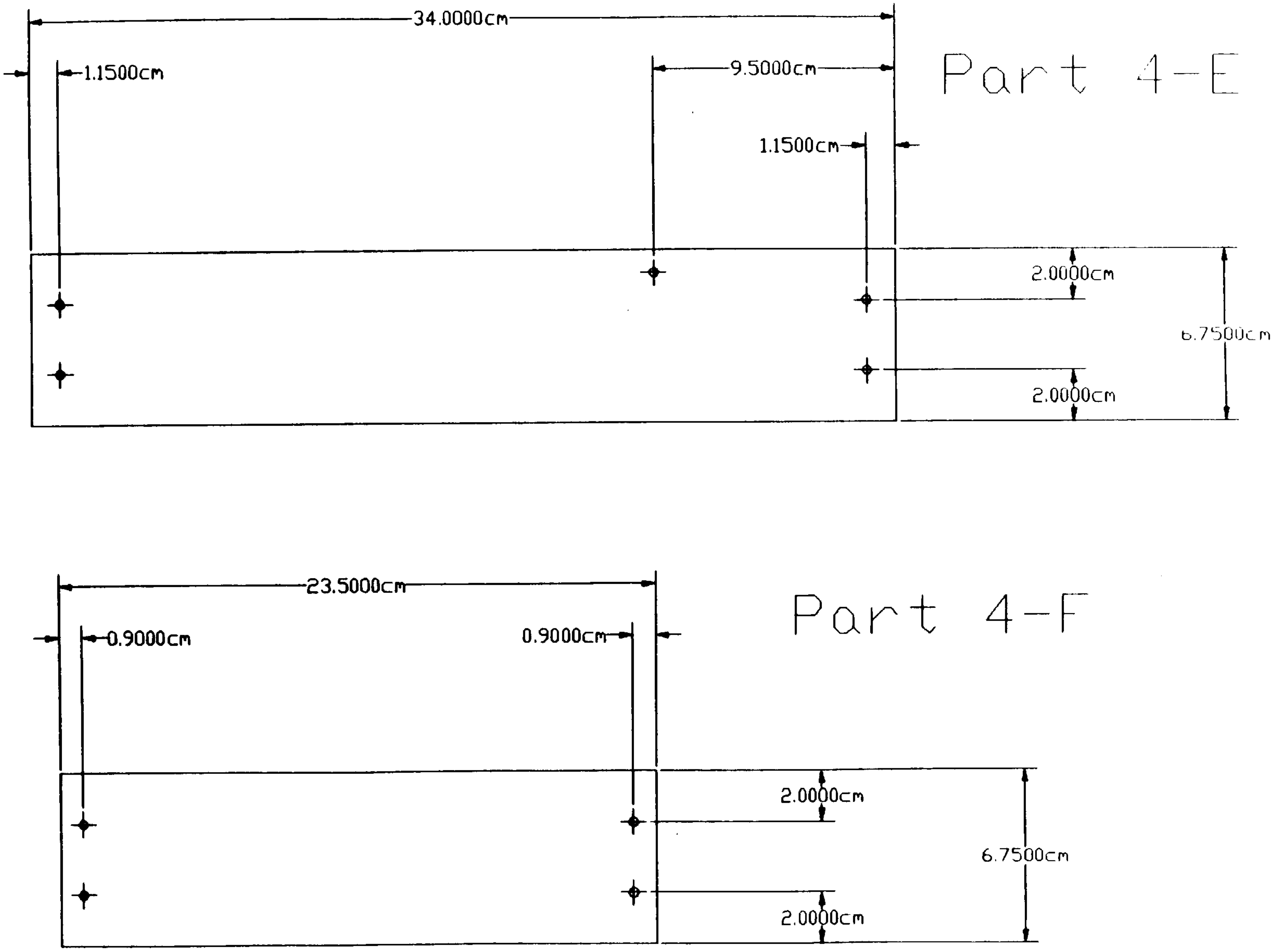


Figure 13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9.5000cm
Part 4-E
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2.0000cm
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Part 4-F
2.0000cm
6.7500cm
2.0000cm

Figure 14
Part 4-G

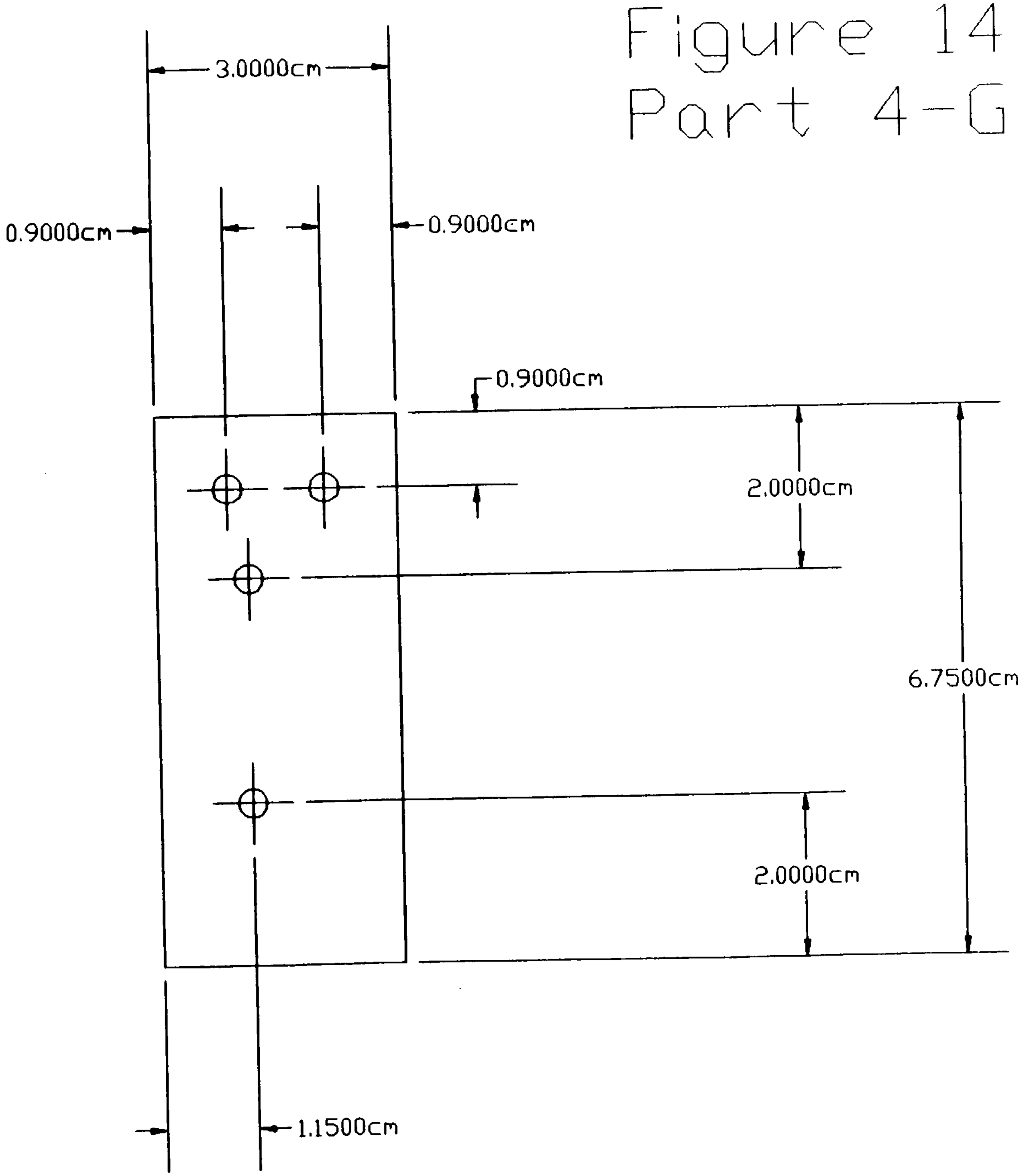


Figure 15

Wire/Pulley
System Cover

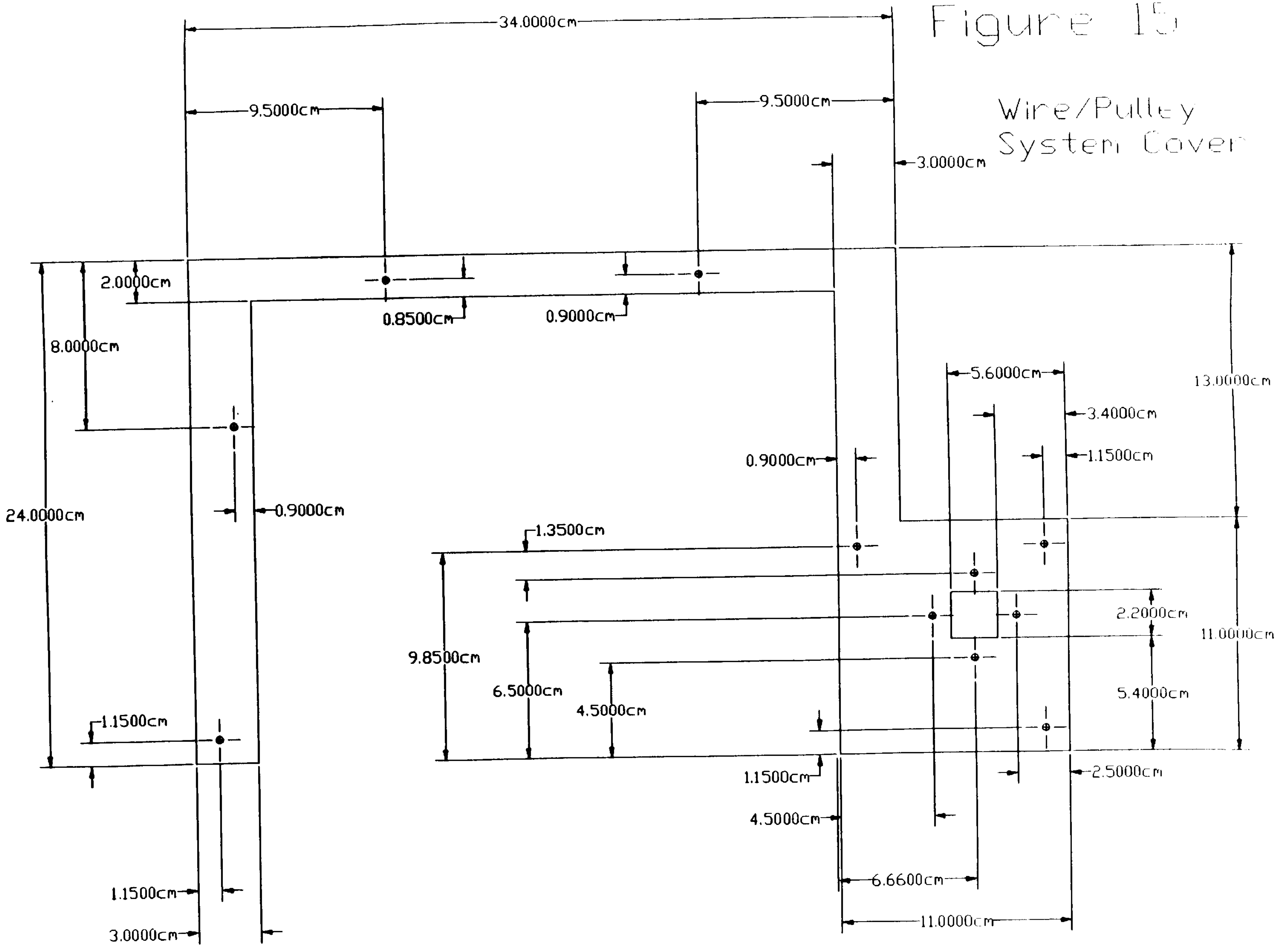
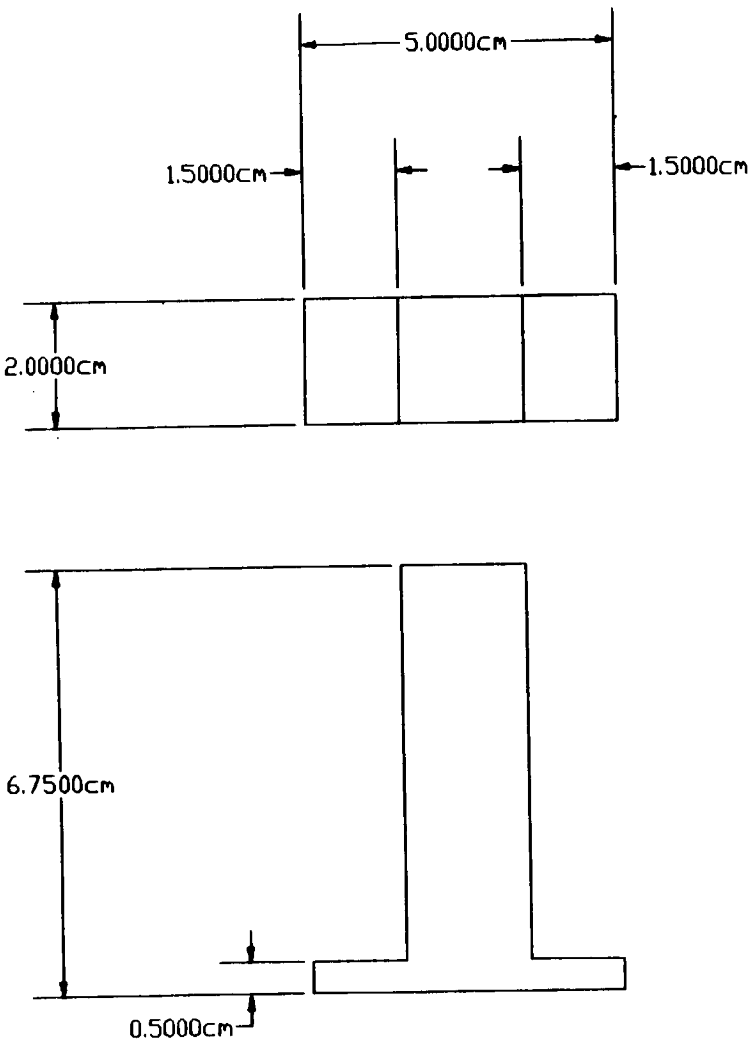
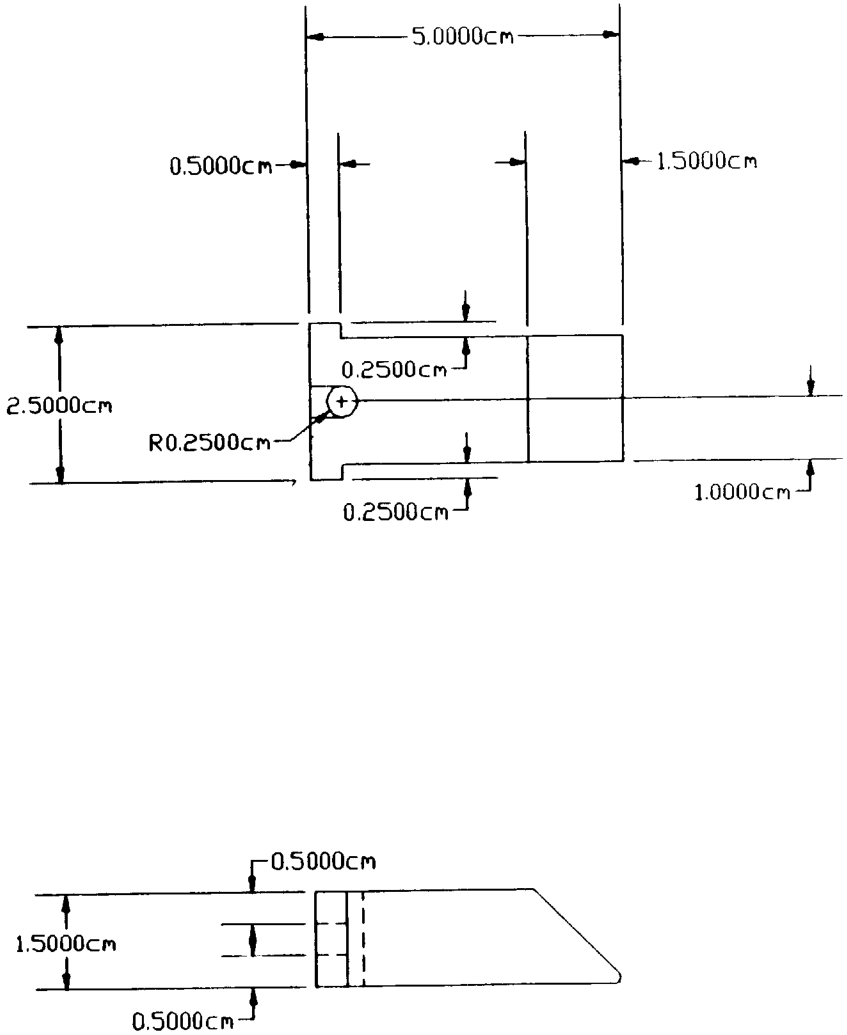


Figure 16



Release Button



Restraining Pin

Figure 17
Part 5-D

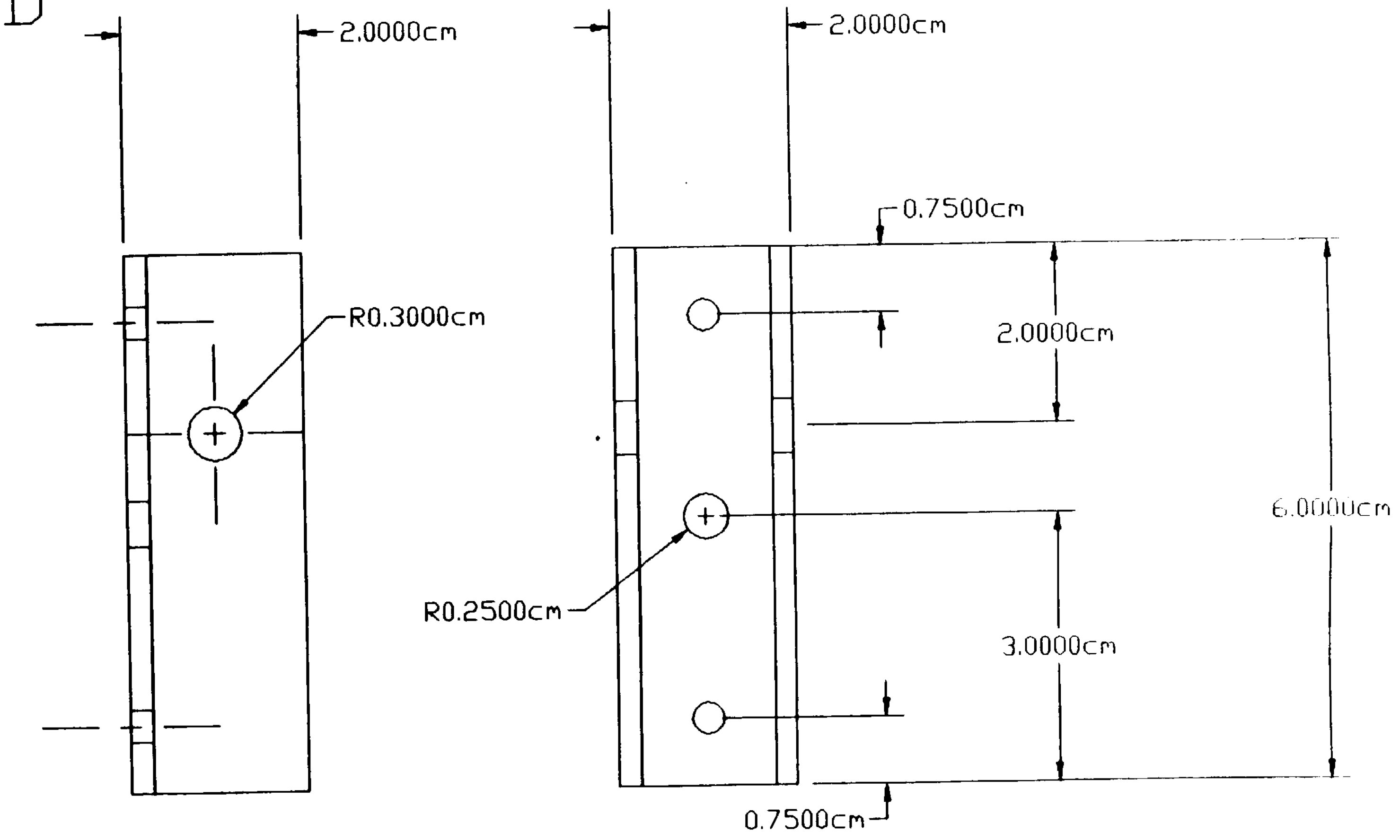


Figure 18 Part 5-E

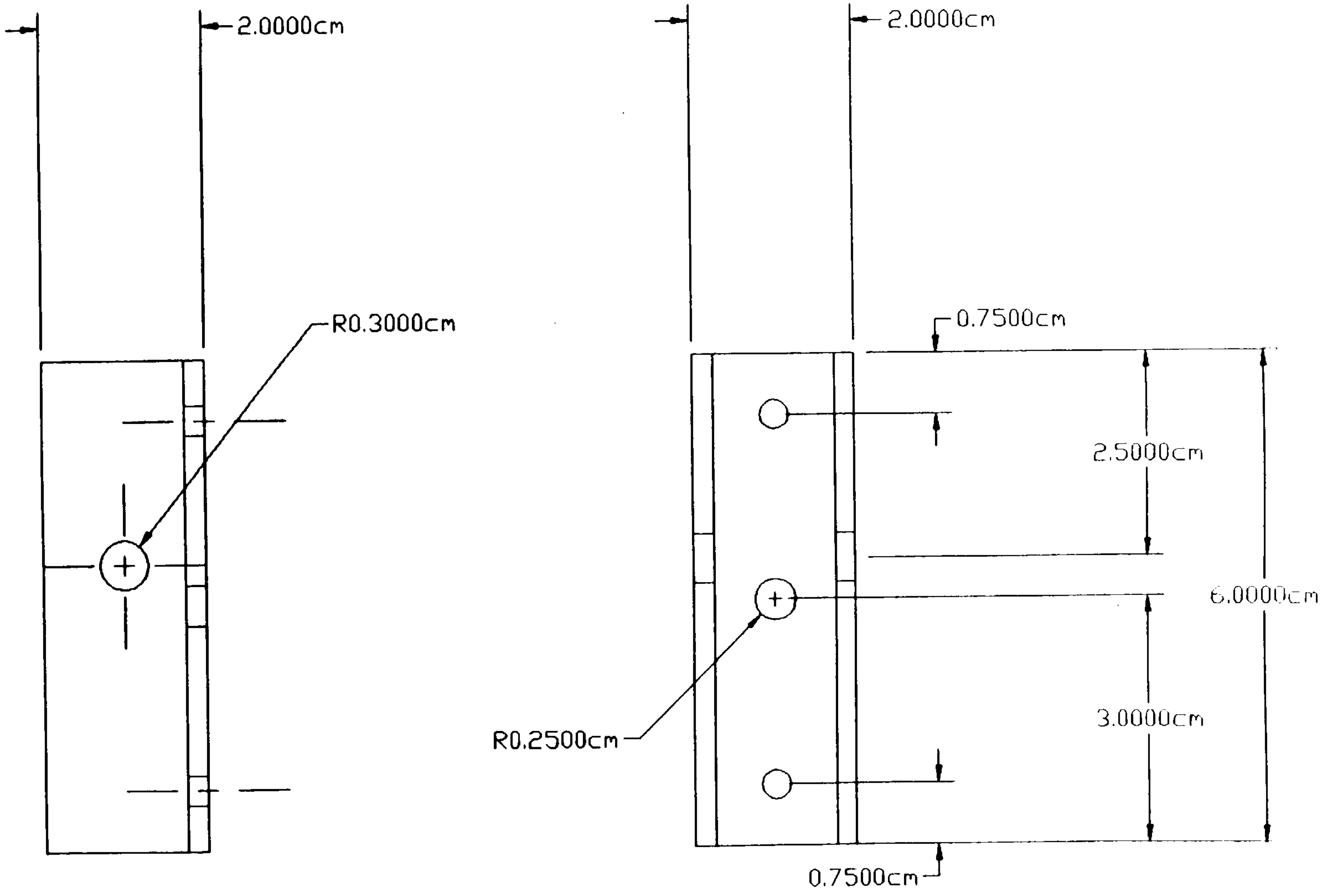


Figure 19
Part 4-H

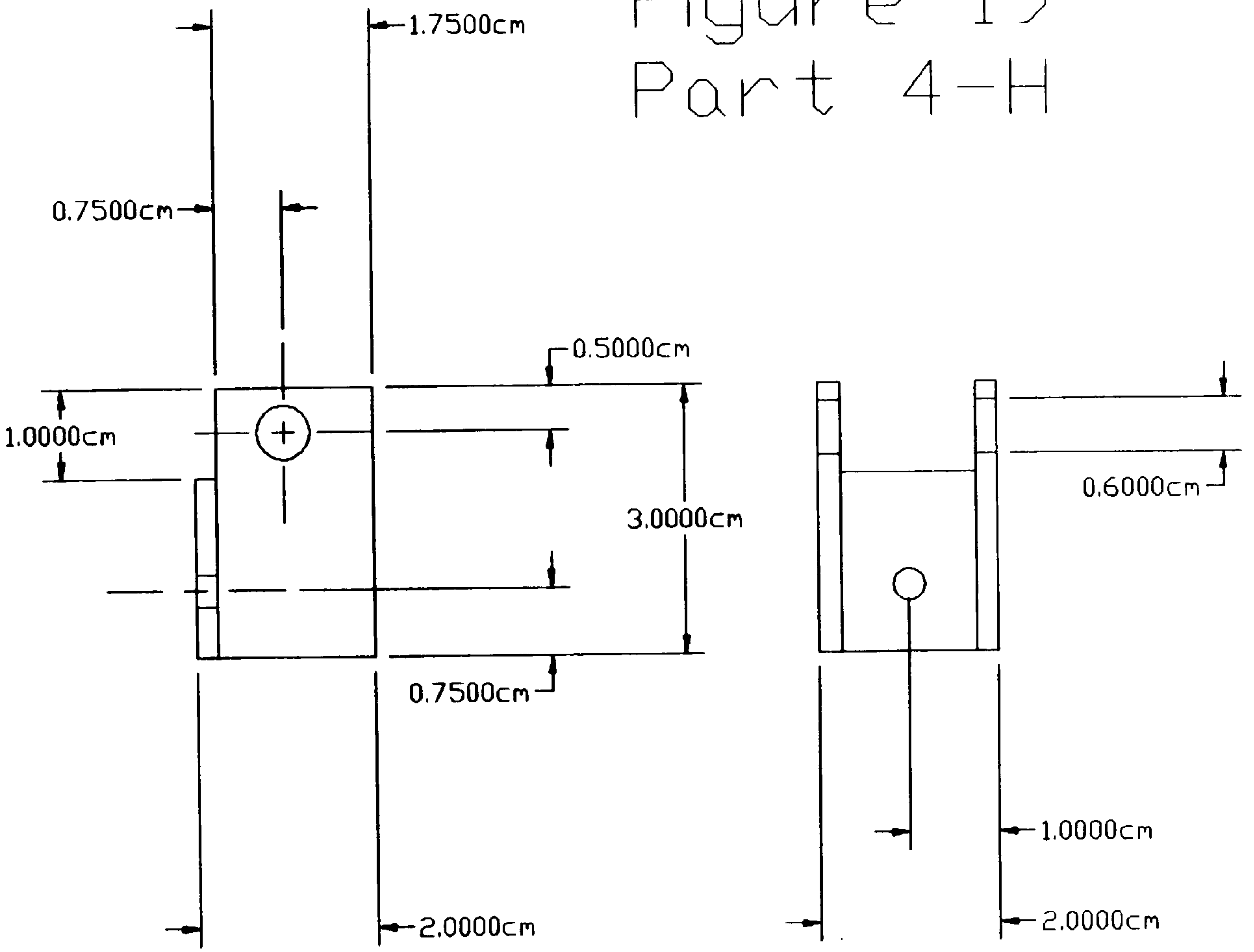
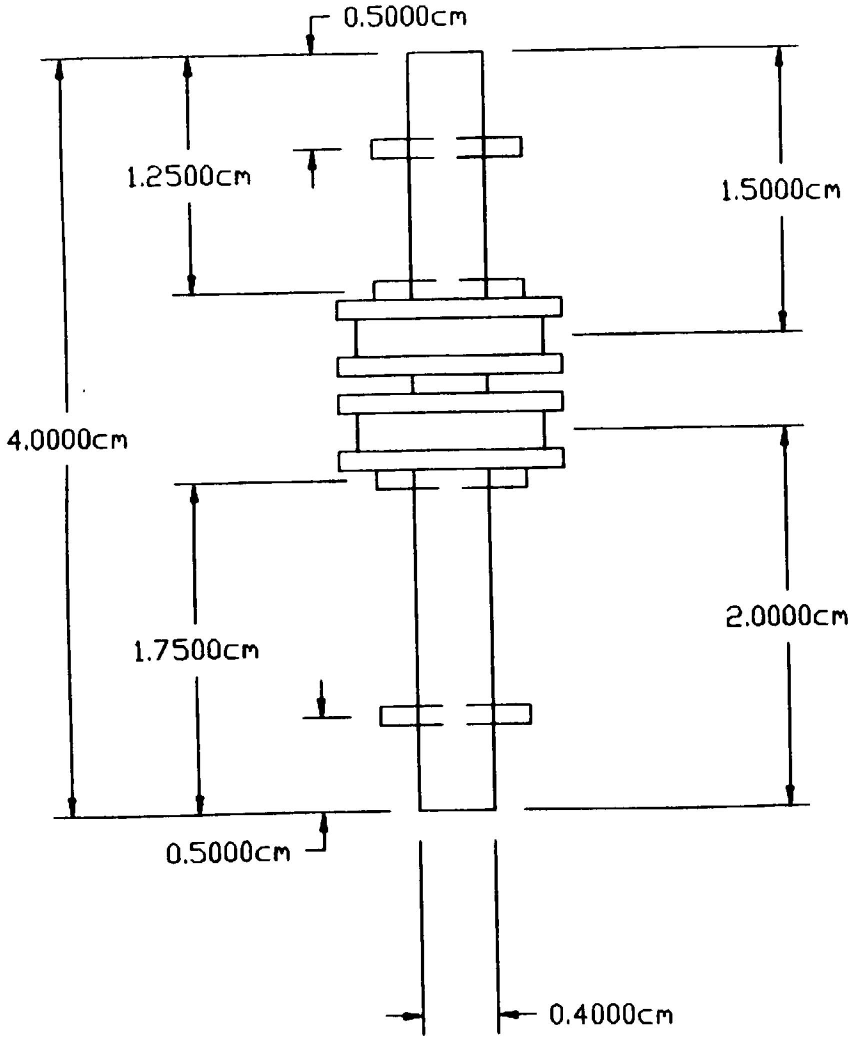


Figure 20



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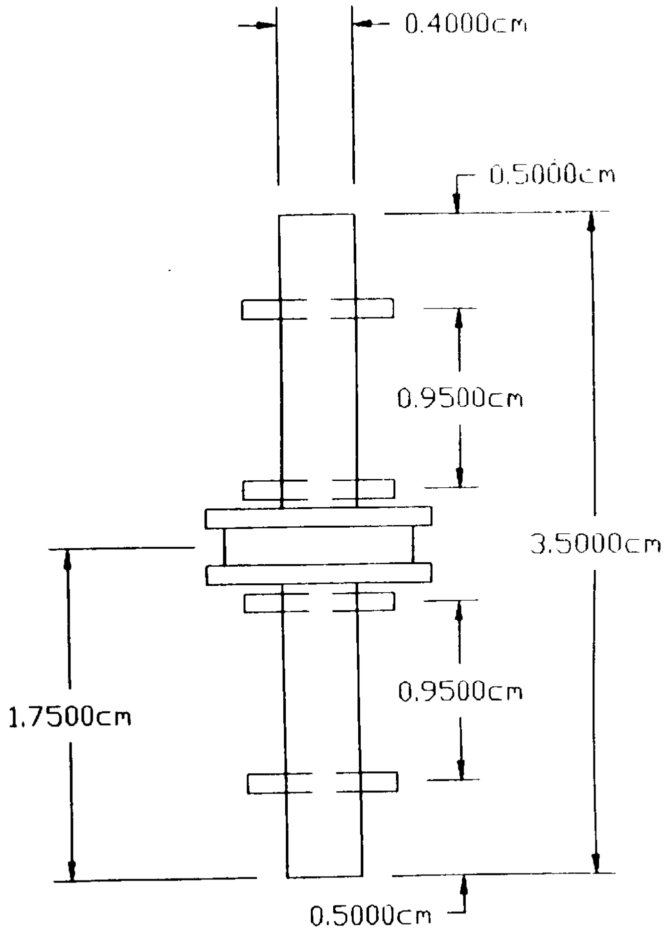

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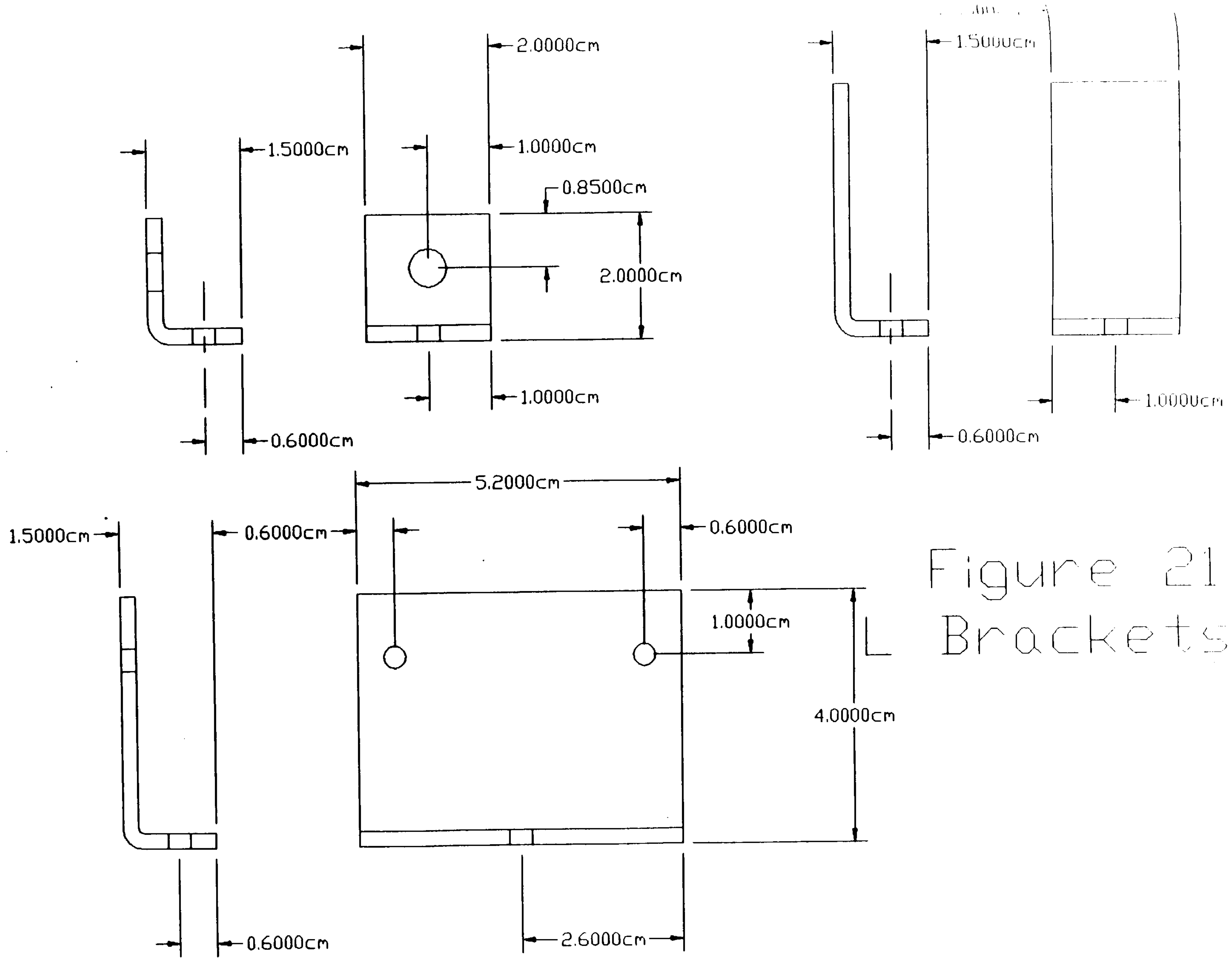


Figure 21
L Brackets

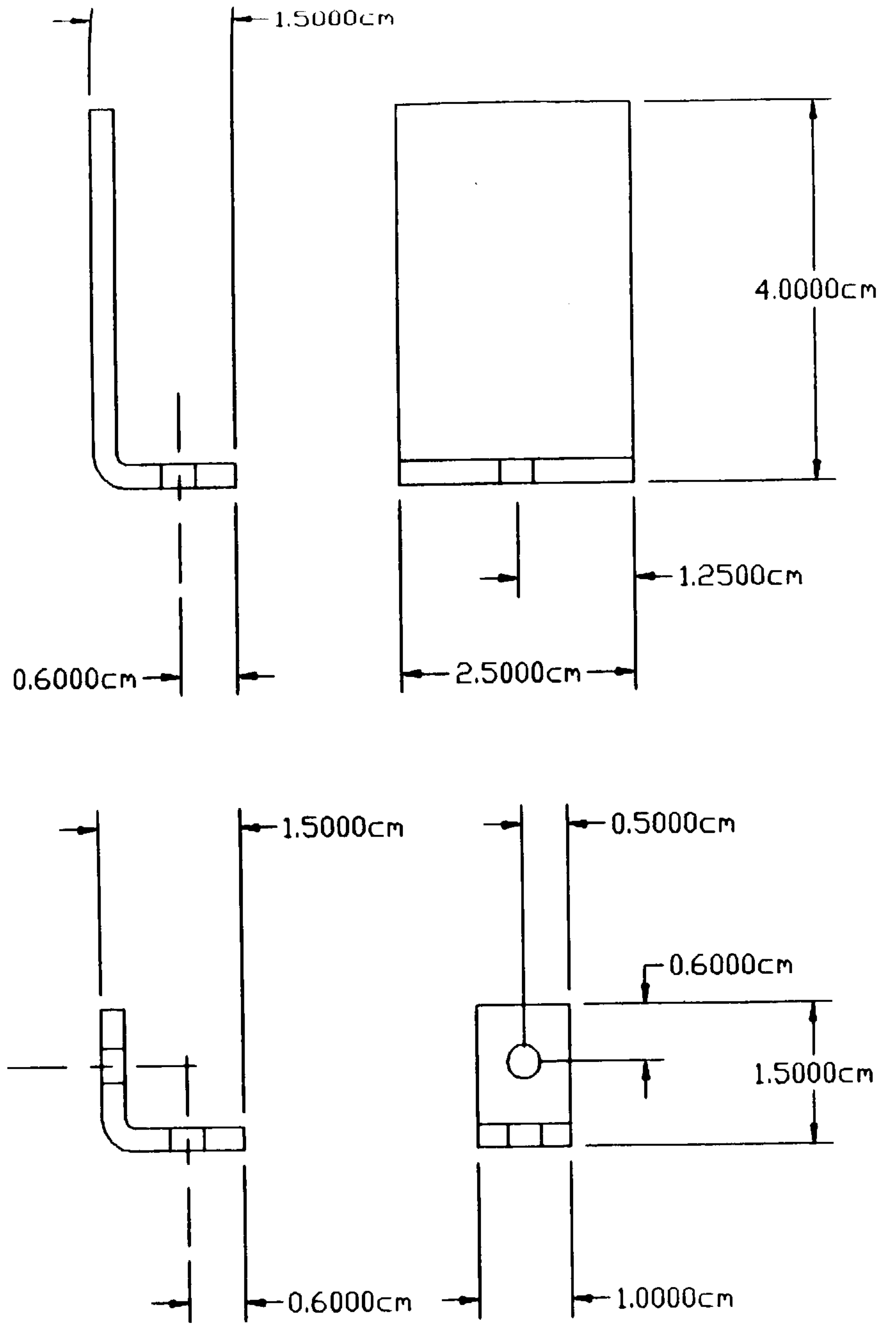


Figure 22
L Brackets

Appendix B

Calculations

Figure 23

Bolt grade 5

Up	Proof Strength
Ut	Tensile strength
Uy	Yield Strength
n	Factor of Safety
Fx	Forces in x Direction
Fy	Forces in y Direction
Fz	Forces in z Direction

At	Tensile Area
$A\tau$	Shear Area
τ	Shear Stress
σ	Compresssive Stress

$Up := 85$ kpsi $At := 0.0318$ in^2

$Ut := 120$ kpsi $A\tau := 0.0269$ in^2

$Uy := 92$ kpsi $n := 1.4$

$Fx := n \cdot 300$

$Fy := n \cdot 300$

$Fz := n \cdot 300$

$Ft := \sqrt{Fx^2 + Fy^2}$

For a grade 5 bolt the proof strength is 85 kpsi.
The shear stength is at least 42.5 kpsi.

$\sigma p := 85 \cdot 10^3$ psi

$\tau p := 0.5 \cdot \sigma p$

$\tau := \frac{Ft}{At}$ $\tau = 1.868 \cdot 10^4$ psi $\frac{\tau}{\tau p} = 0.439$

$\sigma := \frac{Fx}{At}$ $\sigma = 1.321 \cdot 10^4$ psi $\frac{\sigma}{\sigma p} = 0.155$

Figure 24

Fatigue Loading

Se	Endurance Limit
ka	Surface Factor
kb	Size Factor
kc	Load Factor
kd	Temperature Factor
ke	Miscellaneous-effect FActor

$Sel := 0.504 \cdot Ut \qquad Sel = 60.48$ kpsi $\qquad a := 2.7 \qquad b := -0.265 \qquad d := 0.25$

$ka := a \cdot Ut^{b}$

$kb := \left(\frac{d}{0.3}\right)^{-0.1133} \qquad kb = 1.021$

$kc := 0.577$

$kd := 1 \qquad r := \frac{0.25}{20} \qquad r = 0.013 \qquad d := 0.25 - 2 \cdot r \qquad \frac{r}{d} = 0.056 \qquad \frac{0.25}{d} = 1.111$

$kt := 2.6 \qquad q := 0.7$

$ke := \frac{1}{1 + q \cdot (kt - 1)} \qquad ke = 0.472$

$Se := ka \cdot kb \cdot kc \cdot kd \cdot ke \cdot Sel \qquad Se = 12.759$ kpsi

$Sa := \frac{300}{At \cdot 1000} \qquad Sm := \frac{150}{1000\,At} \qquad Syt := 92$ kpsi

$\frac{Sa}{Se} + \frac{Sm}{Syt} = 0.935$ **One Bolt would resist in fatigue loading**

Figure 25

All units are SI units

Cantilever beam end load

b Base
h Height
l Length
F Force
E Young's Modulus
I Moment of Inertia
A Area

$b := 0.02\ \text{m}$ $h := 0.015\ \text{m}$ $l := 0.015\ \text{m}$ $F := 1869\ \text{N}$ $Eal := 71 \cdot 10^{9}\ \text{Pa}$

$I := \frac{b \cdot h^{3}}{12}$

$A := b \cdot h$

$V := F$

$Mmax := -F \cdot l$ $Mmax = -28.035\ \text{Nm}$

$ymax := \frac{-F \cdot l^{3}}{3 \cdot Eal \cdot I}$ $ymax = -5.265 \cdot 10^{-6}\ \text{m}$

$\tau := \frac{3 \cdot V}{2 \cdot A}$ $\tau = 9.345 \cdot 10^{6}\ \text{Pa}$

$\tau y := \frac{296 \cdot 10^{6}}{2}\ \text{Pa}$ $\frac{\tau}{\tau y} = 0.063$

$\sigma := \frac{-Mmax \cdot \frac{h}{2}}{I}$ $\sigma = 3.738 \cdot 10^{7}\ \text{Pa}$

$\sigma y := 296 \cdot 10^{6}\ \text{Pa}$ $\frac{\sigma}{\sigma y} = 0.126$

$b := 0.02\ \text{m}$ $h := 0.006\ \text{m}$ $l := 0.015\ \text{m}$ $F := 1869\ \text{N}$ $Eal := 71 \cdot 10^{9}\ \text{Pa}$

$I := \frac{b \cdot h^{3}}{12}$

$A := b \cdot h$

$V := F$

$Mmax := -F \cdot l$ $Mmax = -28.035\ \text{Nm}$

$ymax := \frac{-F \cdot l^{3}}{3 \cdot Eal \cdot I}$ $ymax = -8.226 \cdot 10^{-5}\ \text{m}$

$\tau := \frac{3 \cdot V}{2 \cdot A}$ $\tau = 2.336 \cdot 10^{7}\ \text{Pa}$

$\tau y := \frac{296 \cdot 10^{6}}{2}\ \text{Pa}$ $\frac{\tau}{\tau y} = 0.158$

$\sigma := \frac{-Mmax \cdot \frac{h}{2}}{I}$ $\sigma = 2.336 \cdot 10^{8}\ \text{Pa}$

$\sigma y := 296 \cdot 10^{6}\ \text{Pa}$ $\frac{\sigma}{\sigma y} = 0.789$

Figure 26

Shearing of the aluminium plate

1 bolt

Shear area

$l = 0.0375$ m $h = 0.04$ m

$At = 2 \cdot l \cdot h$ $At = 0.003$ m

$F\tau = \sqrt{2 \cdot 1869}$ $\tau = \frac{F\tau}{At}$

$\tau = 2.038 \cdot 10^{4}$ Pa $\frac{\tau}{\tau y} = 1.377 \cdot 10^{-4}$

Figure 27

Calculations for the Spring.

Lo	Free length
Nt	Number of coils
Ls	Solid Length
Na	Number of active coils
D	Outside diameter
d	Wire Diameter

$G := 79.3 \cdot 10^9$ Pa $\quad Lo := 0.03$ m $\quad d := 0.001$ m

$Ls := 0.01$ m $\quad D := 0.015$ m

$Nt := \frac{Ls}{d} \qquad Nt = 10$

$Na := Nt - 2 \qquad Na = 8$

$k := \frac{d^4 \cdot G}{8 \cdot D^3 \cdot Na} \qquad k = 367.13 \ \frac{N}{m} \qquad F := k \cdot (Lo - Ls)$

$F = 7.343$ N

We will use a spring with a wire diameter of 0.001 m and outher diameter of 0.015 m

Figure 28
Shearing of the fiberglass

The area that would have to fail under shear in order for the cleat to detach is:

l	Thread grip of bolt into the fiberglass
lactive	Active shearing length
A	Shearing Area
D	Diameter of the bolt

$l := 0.17$ in $\quad D := 0.25 \quad \tau s := 60 \cdot 10^3$ psi

$lactive := 0.8751$

$A := \pi \cdot D \cdot lactive \qquad A = 0.117 \ in^2$

$n := 1.4$

$F := n \cdot 300 \qquad F = 420$ lbf

$\tau := \frac{F}{A} \qquad \tau = 3.595 \cdot 10^3$ psi

$\frac{\tau}{\tau s} = 0.06$ The fiberglass is not going to shear. The calculations were perfomed for one bolt

Figure 29

Calculations for the Wire

$\sigma s := 124 \cdot 10^3$ psi

$d := \frac{1}{16}$

$A := \frac{\pi \cdot d^2}{4}$

$F := \sigma s \cdot A$ $F = 380.427$ lbf The required force is 8 N.

$F \cdot 4.448 = 1.692 \cdot 10^3$ N

Figure 30

Mass Calculation Considering Solid Blocks of Al

$V1 := 0.605 \cdot 0.28 \cdot 0.02$ $V1 = 0.003$ m^3 piece 1a

$\rho := 2.8 \cdot 10^3$ $\frac{Kg}{m^3}$

$g := 9.8$

$F1 := V1 \cdot \rho \cdot g$ $F1 = 39.843$ N

$V2 := 0.0875 \cdot 0.028 \cdot 0.1$ piece 1b

$F2 := V2 \cdot \rho \cdot g$ $F2 = 2.881$

$V3 := 0.22 \cdot 0.28 \cdot 0.05 - 0.16 \cdot 0.15 \cdot 0.05$ piece 1c

$F3 := V3 \cdot \rho \cdot g$ $F3 = 22.109$

Cleat

$V4 := 0.425 \cdot 0.145 \cdot 0.045$

$F4 := V4 \cdot \rho \cdot g$ $F4 = 32.612$

There are two foot restraint systems

$(F1 + F2 + F3 + F4) \cdot 2 = 194.89$

Adding the four major components of the system, the weight is in the required limits.

Appendix C

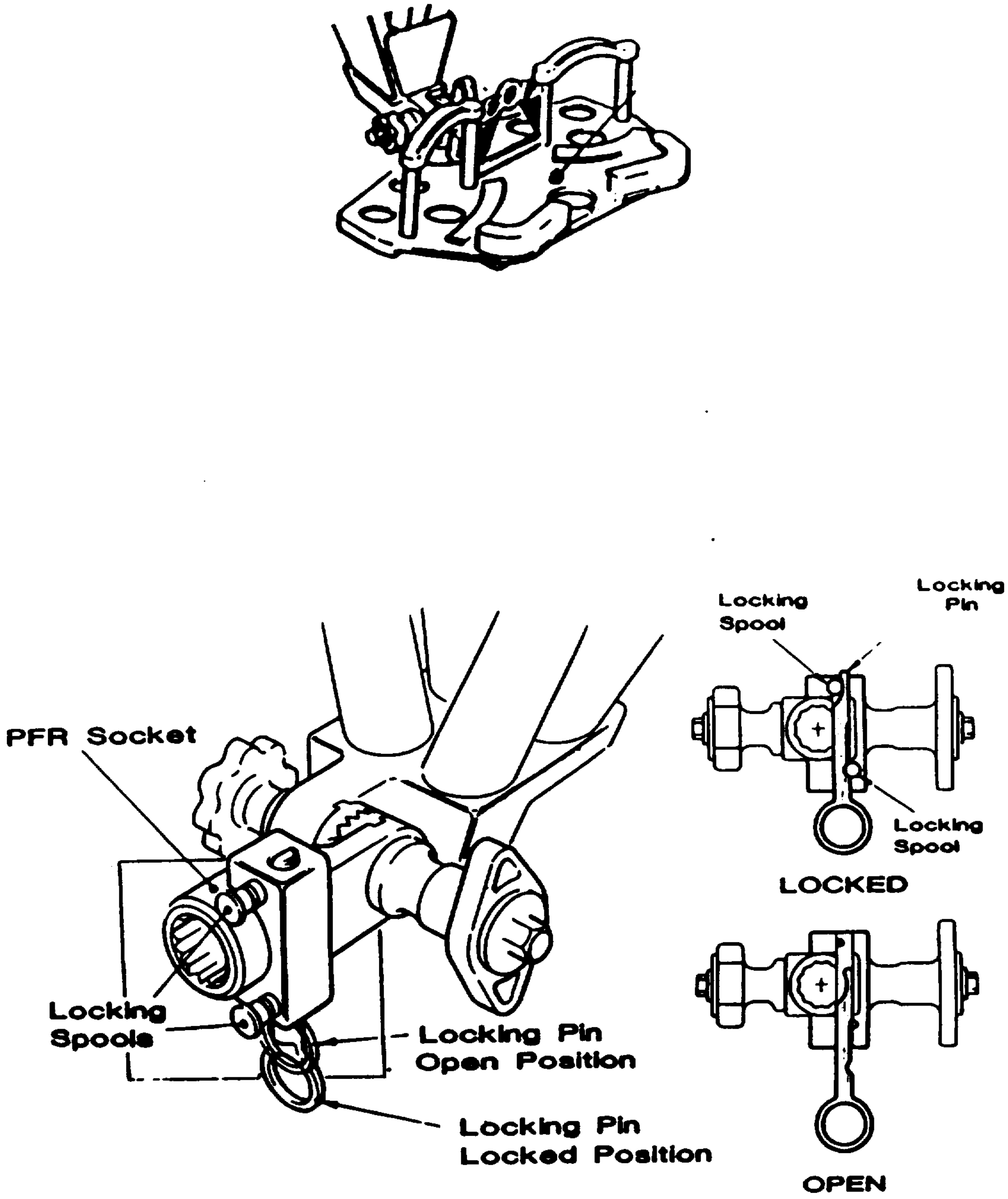
Specification List

Figure 31 - Specification List

NASA/USRA ME366J	Specification For: Portable Foot Restraint	Page 1 of 2

Changes	D/W	Requirements	Rspnsbl	Verify
		1. Function		
	D	Restrain crew member during EVA tasks.		
	D	Allow adjustment of foot position during EVA task.		
		2. Geometry		
	D	Must conform to existing EVA boot geometry (See Figure).		
	D	Maximum stowage dimensions: must fit within the shuttle middeck modular locker (see Middeck Accommodations manual in library).		
	D	Maximum usage dimensions 91.4 cm x 91.4 cm x 91.4 cm (36" x 36"x 36")		
	W	Connect to worksite with existing hex-shaped probe (See Figure 14.3.4.2-1)		
		3. Kinematics		
	D	Minimum platform pitch -75 to 105°.		
	D	Minimum platform roll -90 to 90°.		
	D	Minimum platform yaw 0 to 360°.		
	D	Constrain pitch, roll, and yaw in a desired position.		
	D	Resolution of Pitch, roll, and yaw ≤ 15°.		
		Linear boot motion associated with device:		
	D	Lateral stance width: 0.914 m (3 ft).		
	D	Ventral/Dorsal stance width: 0.914 m (3 ft).		
	D	Motion within 0.914 m (36") diameter circle.		
		4. Forces		
	D	Maximum weight of unit 222.4 N (50 lb).		
	D	Must withstand 1334.4 N (300 lb) in any direction.		
	D	Factors of safety ≥ 1.4		
		5. Energy		
	D	Positional adjustments performed by a single crew member.		
	W	Electrical energy from storage batteries available.		

Figure 32 - PFR Assembly



NASA/USRA
ME366J

Specification

For: Portable Foot Restraint

Page 2 of 2

Changes	D/W	Requirements	Rspnsbl	Verify
		6. Safety		
	D	Does not damage EMU boot.		
	D	No sharp exposed edges.		
	W	No pinch points.		
		7. Ergonomics		
	W	Minimum steps (< 3) for an astronaut in an EMU to operate.		
	W	Smooth stable movement when adjusting for different foot positions.		
		8. Production		
	D	Number of units: 8		
	W	Cost: Prototype $350k Per Unit $125k		
		9. Transportation		
	D	Withstand sustained 3g launch load		
		10. Operation		
	D	Operate within temperature range -171 to 111 degrees C (-276 to 232 degrees F).		
	W	Lifetime of 15 years		
	D	Maintenance check/procedure every mission.		
	D	Corrosion resistant.		