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THE ENABLER:
A REEVALUATION OF DESIGN CONCEPTS AND CONSTRUCTION OF A SCALED MODEL

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(NASA-CR-192061) THE ENABLER: A REEVALUATION OF DESIGN CONCEPTS AND CONSTRUCTION OF A SCALED MODEL (Georgia Inst. of Tech.) 24 p

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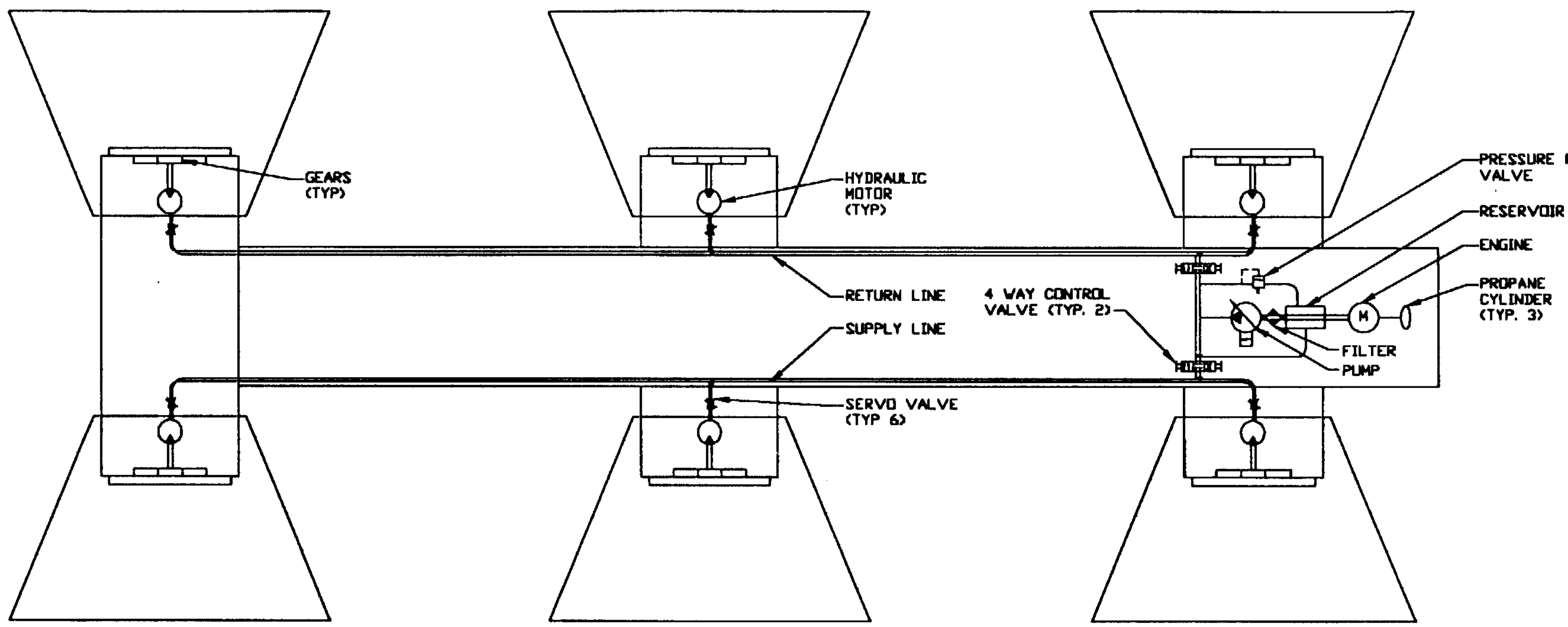

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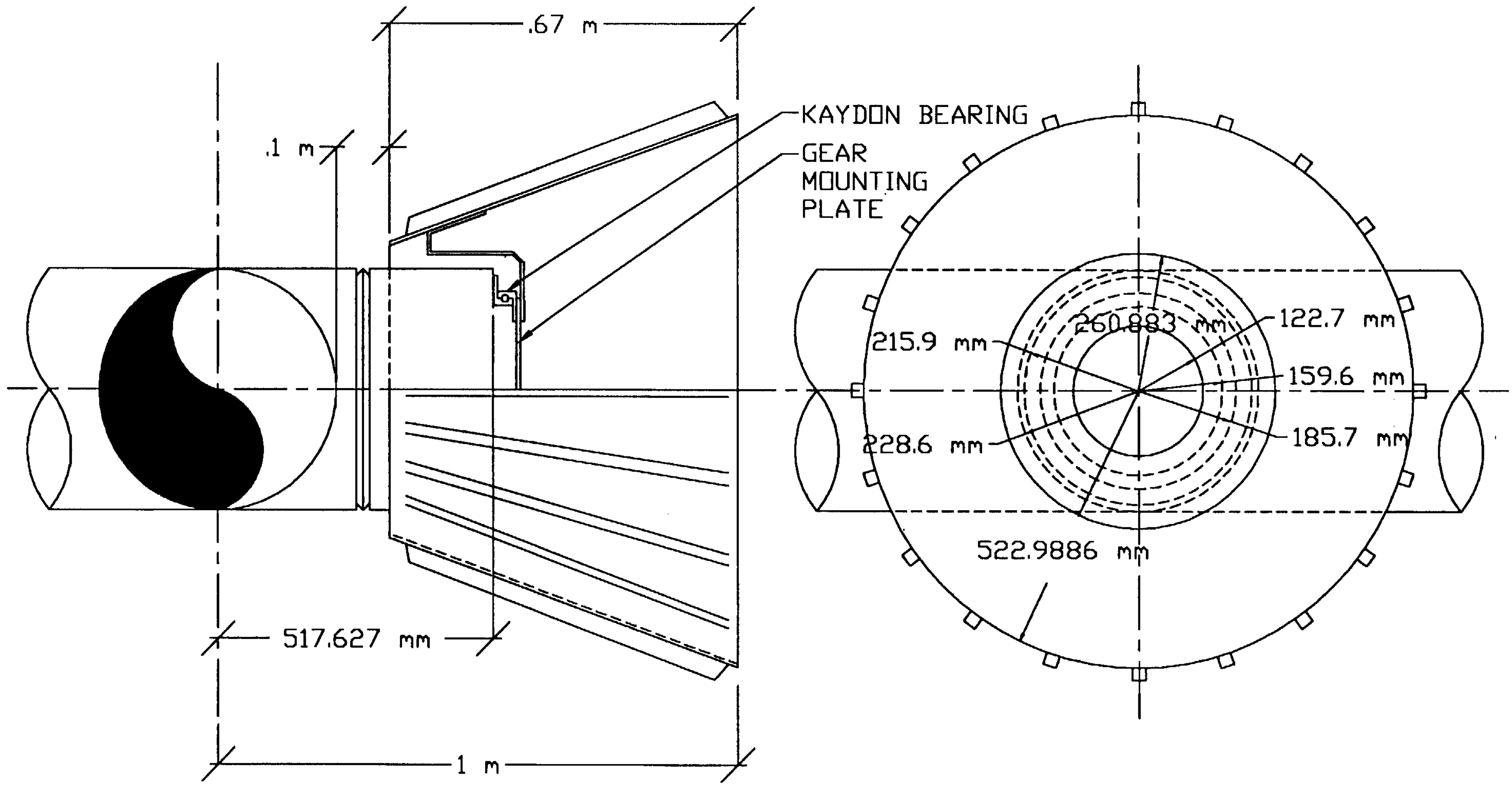

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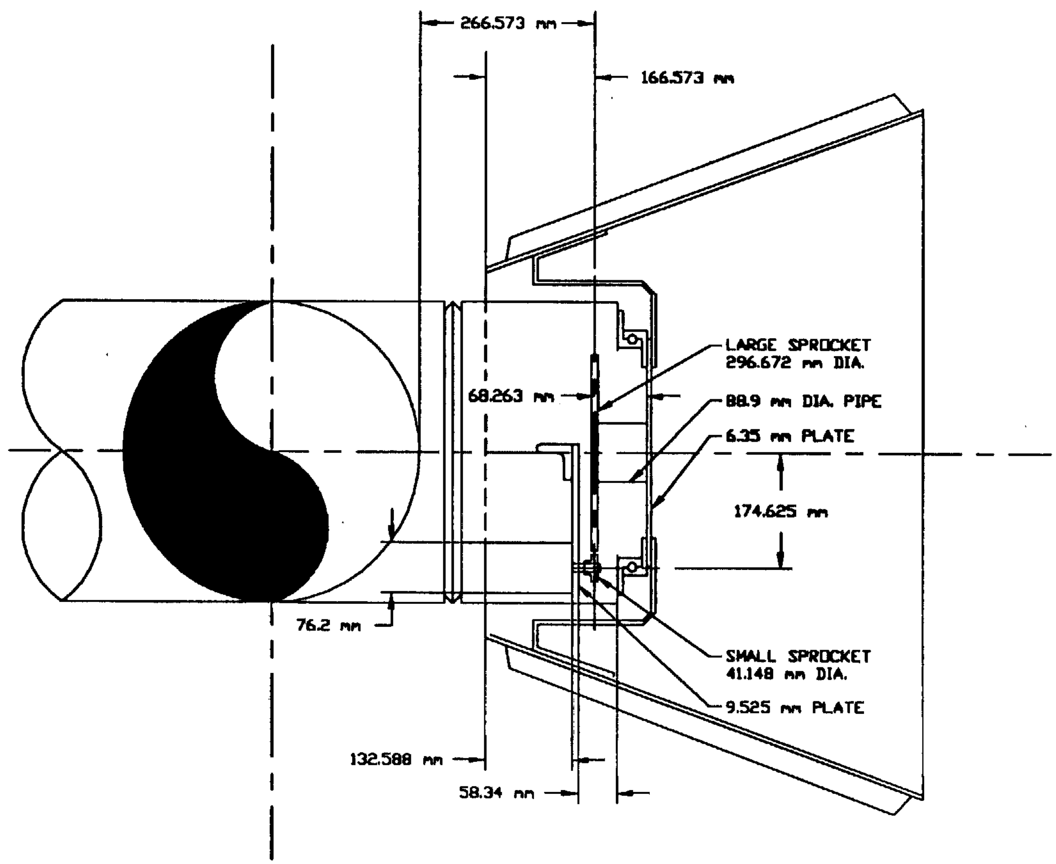

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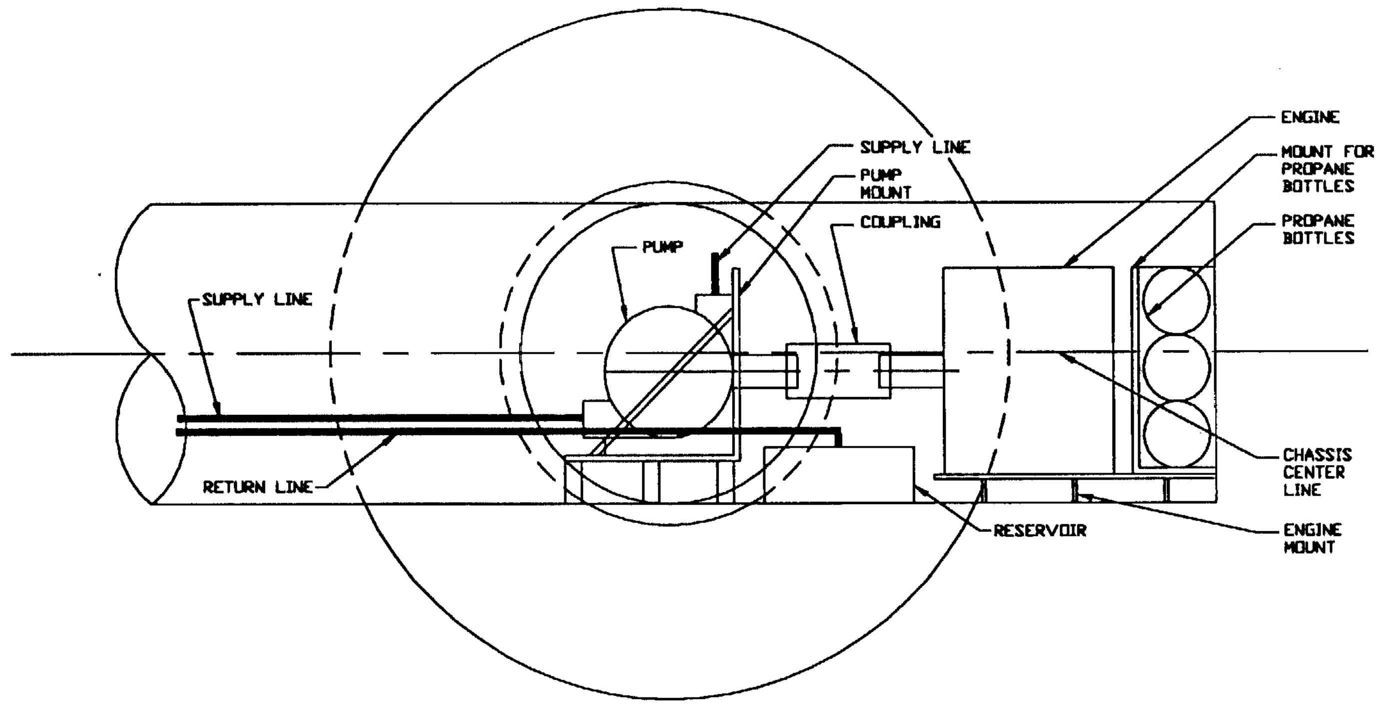

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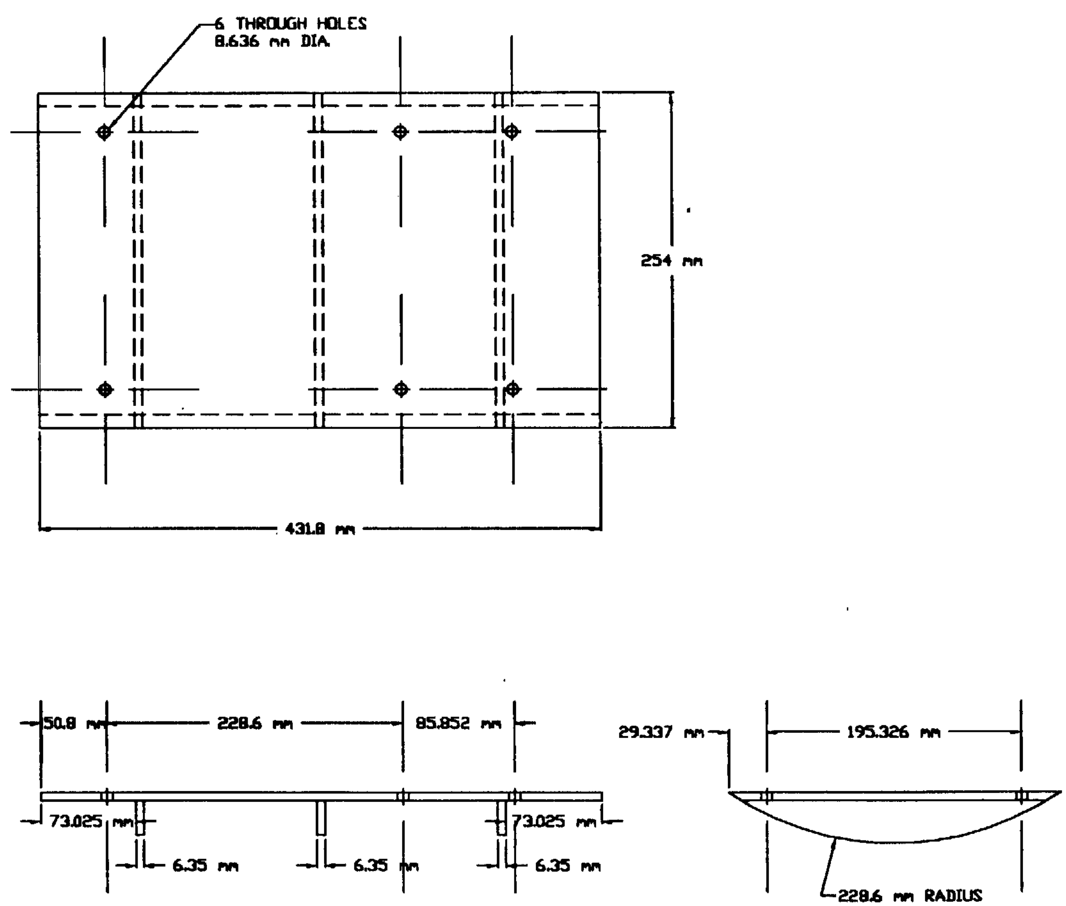

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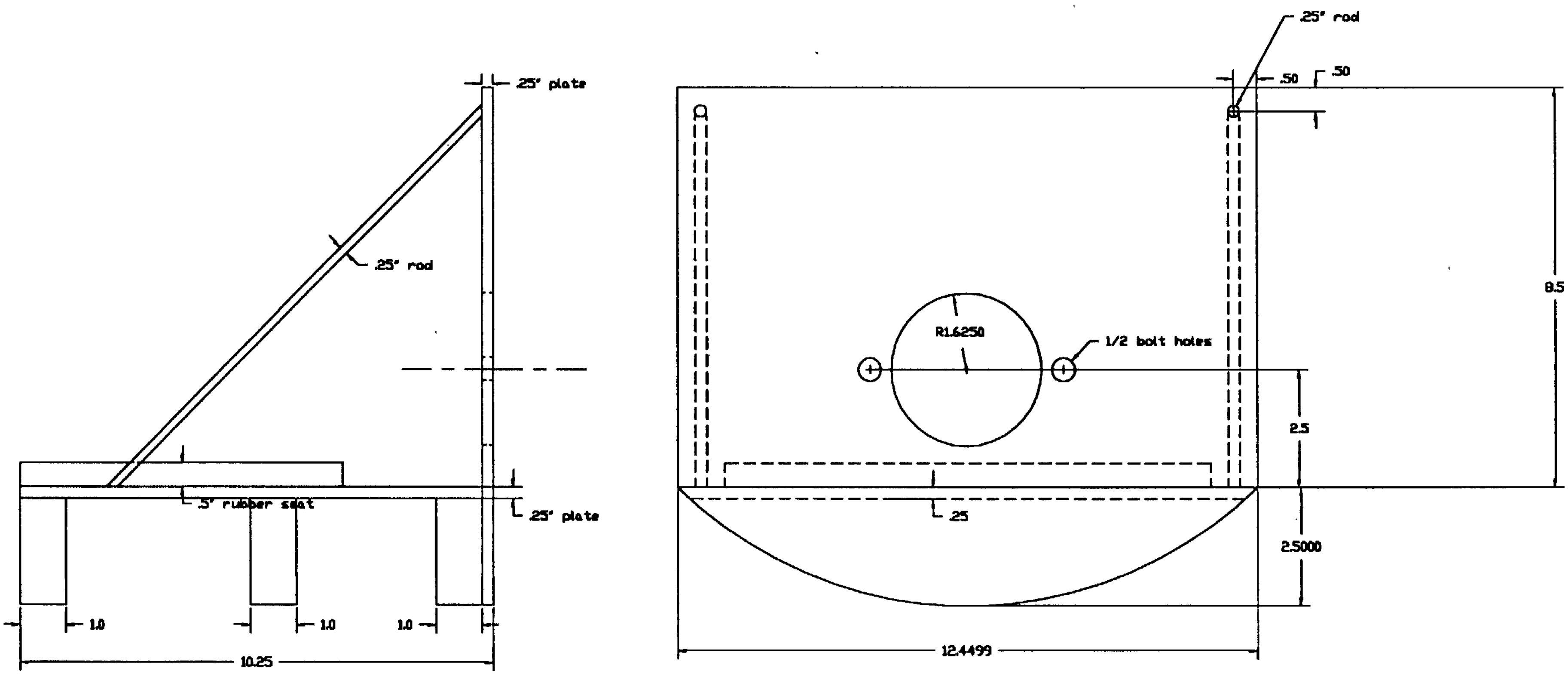

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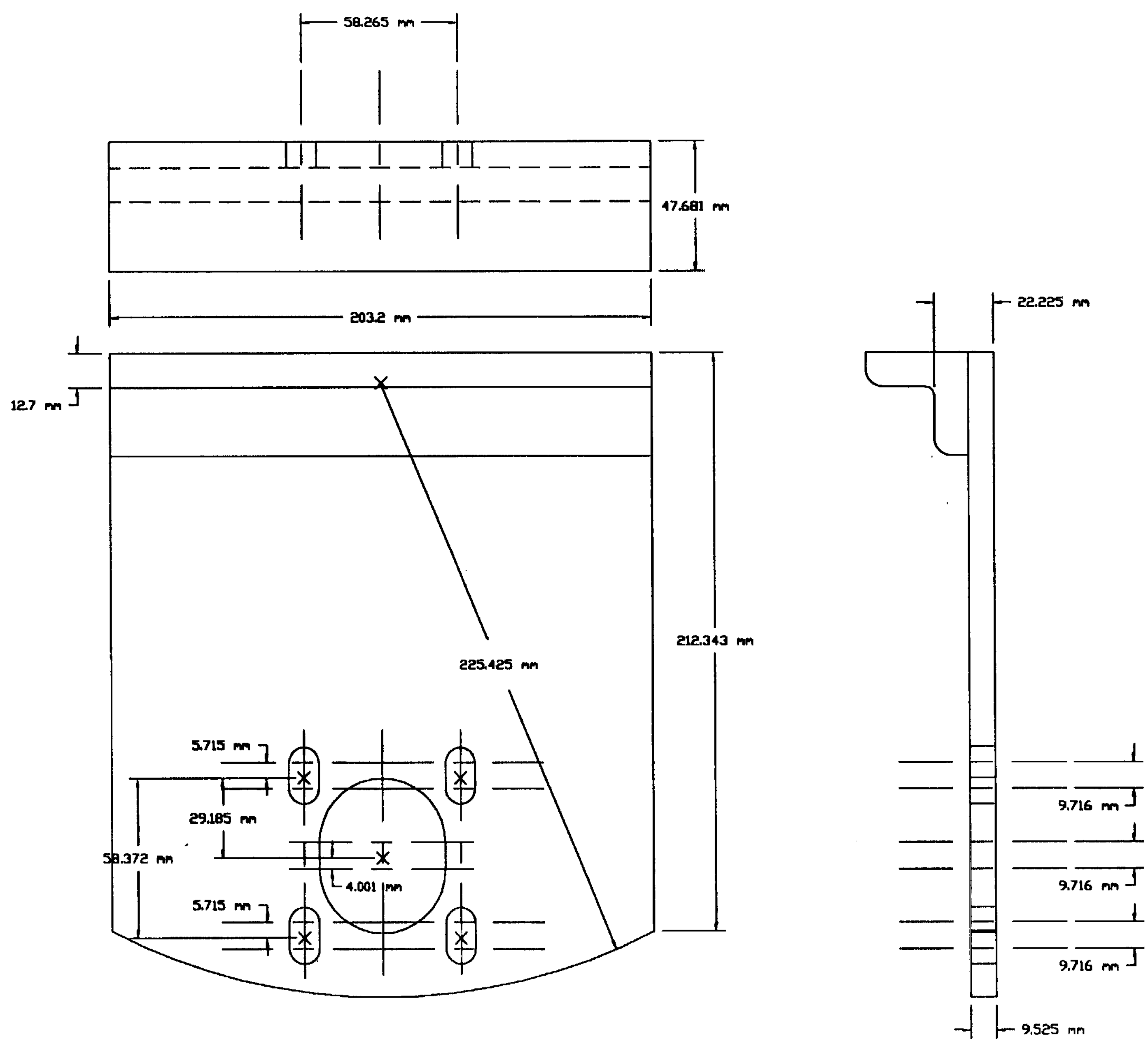

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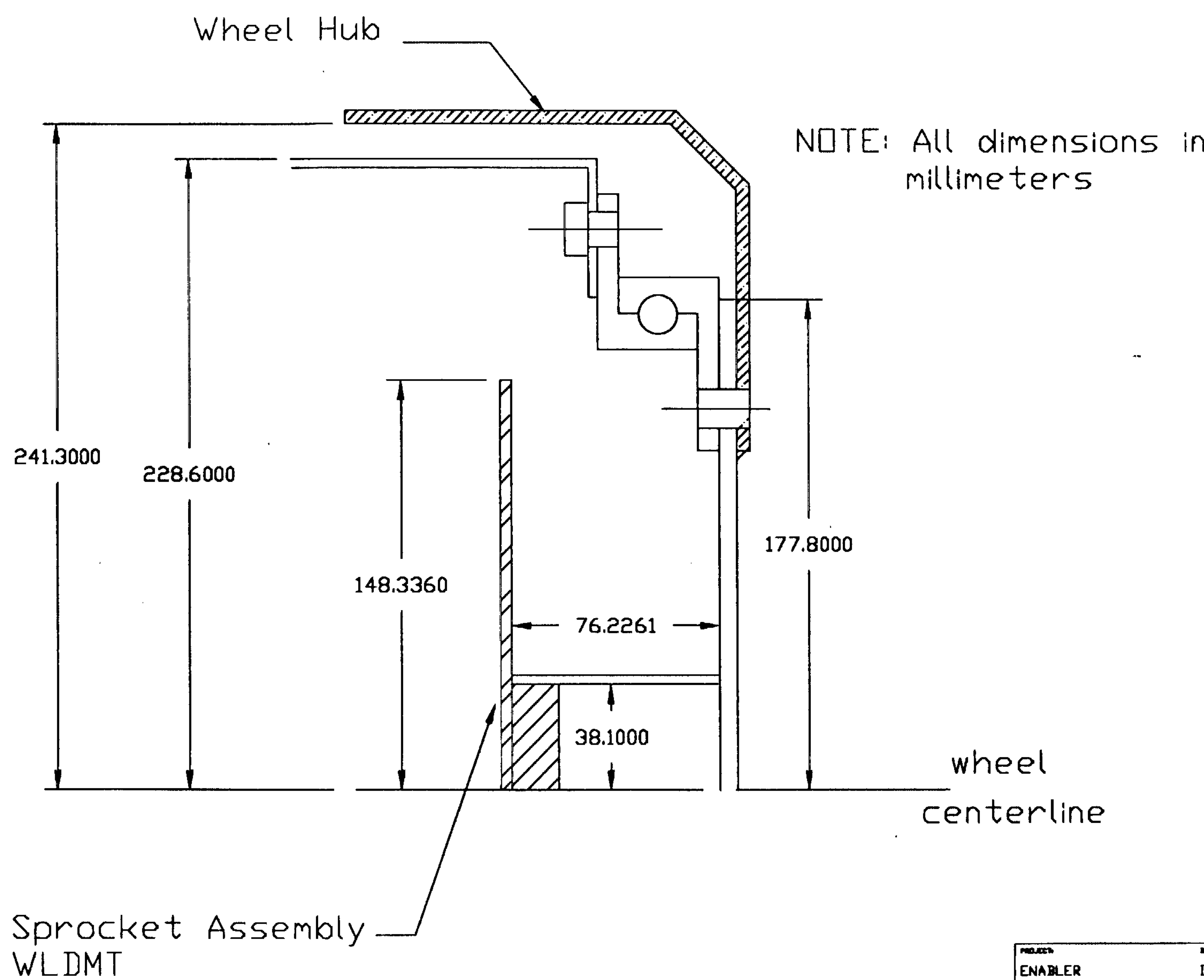

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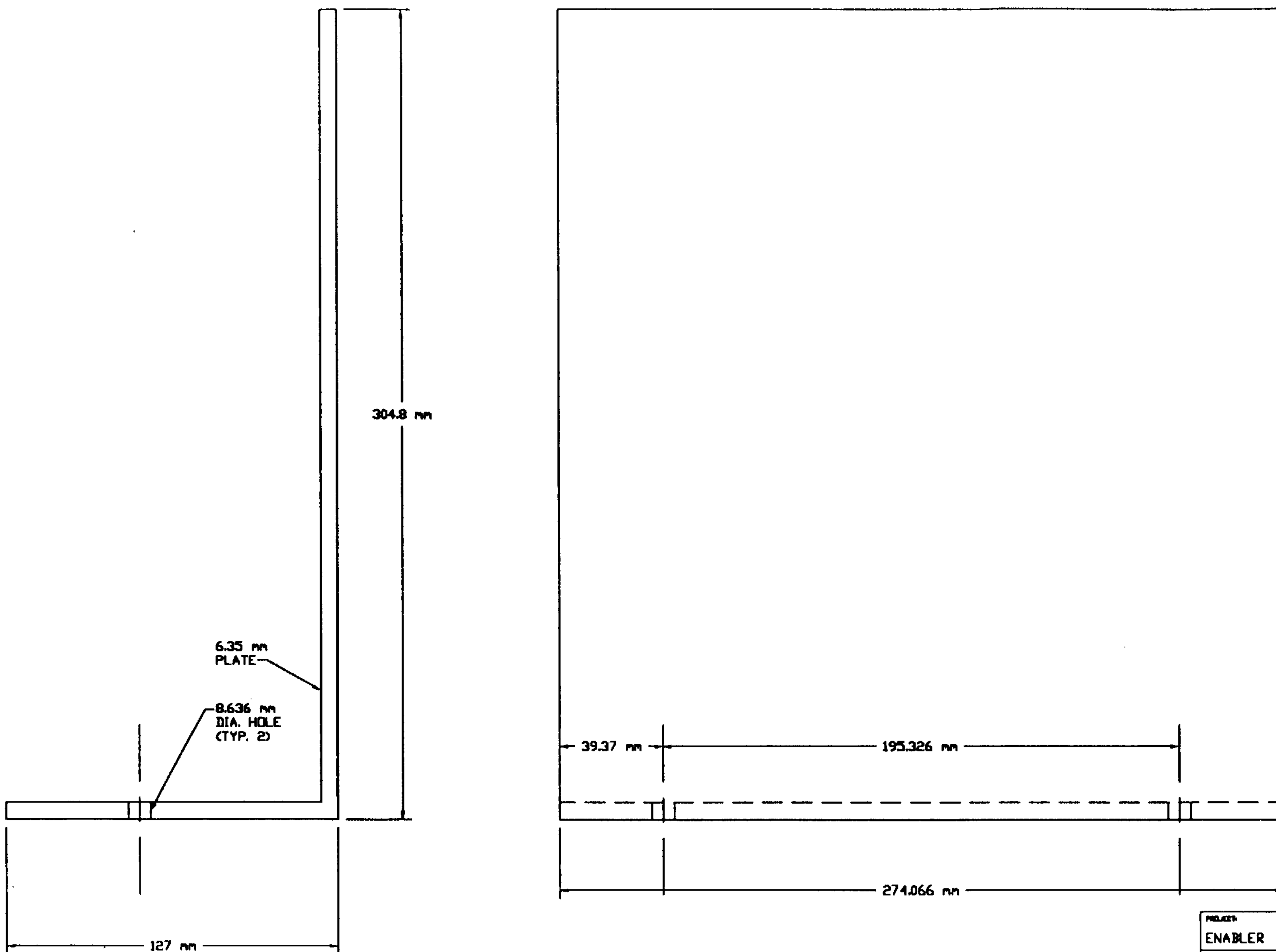

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ABSTRACT

The basic objective of our work this quarter was to make an in-depth examination of the design concepts used on the lunar vehicle "The Enabler". Several changes were made to the vehicle including a redesigned wheel, a more compact boom and a reduced articulation angle. The vehicle's final dimensions were determined through an optimization process by defining mathematical equations for several of the vehicle's defined objectives. These included the ability to scale a one meter object, traverse a one meter crevice, and maintain a wheel-to-wheel clearance of three inches while at maximum articulation. The final dimensions of the vehicle were used to construct an approximate 1/4 scale model of the chassis and wheels. The boom, however, was constructed on a 1/5 scale (from the original design). This was due to the redesign of the boom and the limitations of the constructing material and PVC fittings.

INTRODUCTION

"The Enabler" is a concept vehicle which uses several new ideas in lunar technology. It is a work vehicle which can be used for many applications in space including construction, demolition, and transportation. One of the most important features of the vehicle is that all of the subsystems that run the vehicle are self enclosed. This allows the vehicle to be operable in the harsh environments that are encountered in space. The vehicle's motion is controlled by articulation joints which provide the vehicle with the ability to steer and more importantly, to pitch. This allows the vehicle to traverse landscapes that were previously not traverseable. The wheels of the vehicle are also an important concept. They not only provide the drive force to move the vehicle, but also provide the suspension qualities for the chassis. Another important feature of the "Enabler" is the boom. The boom has been designed with the ability to withstand forces of ten pounds or less in any direction. It is also equipped with a tool interface which can grab a number of tools from a magazine and use them to perform a variety of tasks. With all of this in mind, our group set out to evaluate these design concepts in detail.

WHEEL CONCEPT REDESIGN

From last quarters wheel design, an issue was brought up about the clearance the wheel extension would have if some object with a size greater than the chassis clearance was come in contact with. The figures on the following pages show the design conceived in the previous quarter and this quarter. The previous design consisted of a flexible wheel with an initial conical section (attached to the chassis) connected to a cylindrical section. The wheel extension was long and could bottom out if the vehicle was to run over a large object. The other problem seen with this design was the possible lack of traction in loose soil or when climbing a steep hill.

To compensate, the wheel was redesigned to the shape seen on the next page. This design allows more wheel to be in contact with the surface. Also, the extending of the conical shape and the reducing of the wheel extension helped reduce the weight of the wheel assembly , i.e. there will be less "chassis" (with heavy machine parts) and more wheel (lighter than chassis material and internal parts). The new shape also allows the ribs to be extended the full length of the wheel so that more traction can be obtained. Extending the wheel to this shape relieves the problem of bottoming out as seen with the previous design. Instead the new wheel will be able to climb over the object with the wheel still acting as a suspension for the whole vehicle.

ORIGINAL WHEEL CONCEPT

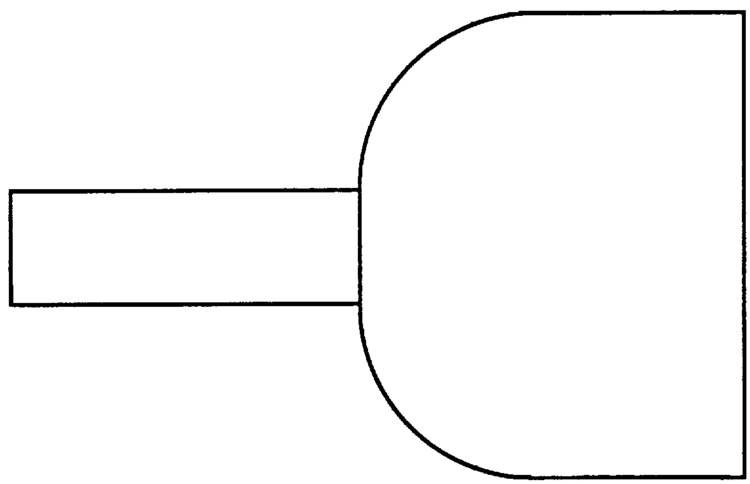


FIGURE 1:

NEW WHEEL CONCEPT

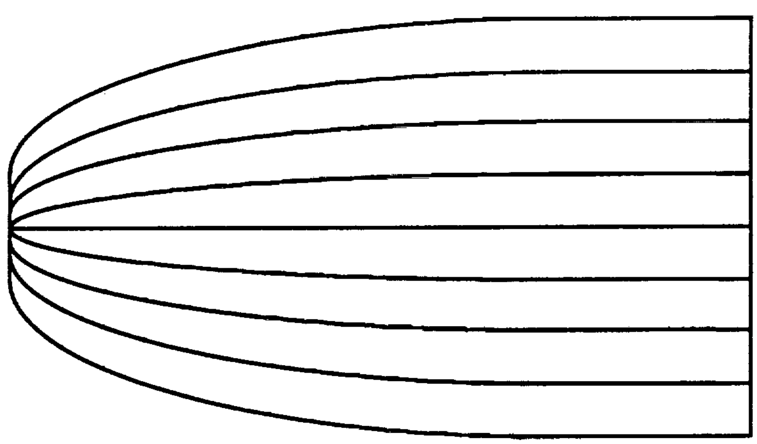


FIGURE 2:

BOOM CONCEPT REDESIGN

With the reduction in the size of the chassis and wheels, it was also necessary to reduce the size of the boom. At first, the boom was designed to be the length of the chassis and the length of the wheels on the front and back of the vehicle. To optimize the size of the boom, the length was shortened to the center axis of both the front and rear tee sections. Since the length of the chassis was shortened, the overall length of the boom was reduced by approximately 4 and 1/2 feet. With this reduction, the following parameters were affected:

1. Less weight
2. Smaller Moments
3. Less stress on chassis
4. Tipping of vehicle reduced
5. Smaller work envelope

From the optimization of the chassis and the boom, the vehicles dimensions were scaled down so a working model could be made.

OPTIMIZATION

The optimization of this design minimizes the kinematic forces created on the Enabler and maximizes its use in a lunar environment. The following constraints were used in the design:

- CLIMB AN OBSTACLE 3' IN HEIGHT
- TRAVERSE A 1' CHASSIS CLEARANCE WITHOUT ARTICULATION
- HAVE A CHASSIS CLEARANCE OF 3" IN ITS WORST CASE ARTICULATION
- MINIMIZE GAP BETWEEN TIRES TO 8"
- MINIMIZE AXLE TO AXLE LENGTH (W)
- MAXIMIZE ARTICULATION ANGLE (A)

To perform the optimization analysis of this project, several variables were considered. As shown below, the vehicle was designed with four variables in mind. Those were:

- T VEHICLE WIDTH
- D WHEEL DIAMETER
- W AXLE TO AXLE LENGTH
- A ARTICULATION ANGLE

From the model and the governing equations, a change in one variable may be both beneficial and detrimental to the design. For example, as the articulation angle increases, the turning radius of the Enabler decreases, which is a desirable effect. However, as the articulation angle decreases, the distance from wheel to wheel decreases. This is an undesirable effect because a minimum wheel gap of eight inches is required. Similarly, as the wheel diameter increases, the climbing ability of the Enabler is increased, but the turning radius is decreased. Below are a list of the dependent variables in the constraints.

- R — TURNING RADIUS
- O1 — OBSTACLE HEIGHT 1
- O2 — OBSTACLE HEIGHT 2
- C — CLEARANCE
- G — WHEEL GAP

With four independent variables, there are an infinite number of possibilities that will satisfy the constraints. To narrow down the possible number combinations the vehicle width, T, was set equal to two meters. This number was chosen to ensure easy transport of the Enabler in a typical trailer. To further narrow down the possible number of combinations, the articulation angle was chosen to range from twenty to thirty degrees.

From this point, it was necessary to analyze the design from a mathematical standpoint. Five basic formulas were found solving for the turning radius, wheel gap, and two obstacle heights.

- TURNING RADIUS
  R = W/ 2(TAN(A/2))

- WHEEL GAP
  G = W-D-(T/2 SIN(A)) - W/2(1 - COS(A))

- CLEARANCE
  C = D/2 - W/(SIN(A/2))

- OBSTACLE HEIGHT 1
  O1 = W/2(SIN(A/2)) + .1568

- OBSTACLE HEIGHT 2
  O1 = W/2(SIN(A/2) + SIN(1.5A)) + .1568

The formulas shown are dependent on only two variables, the articulation angle, A, and the wheel diameter, D. The optimal design size of those two variables are the values that meet all the constraints. In other words, all the possible combinations of W and D needed to be applied to the formulas. The output for each dependent variable then has to be weighed against all of the other dependent variable values using other independent variable sets. This was done with a simple program written in Basic.

With the program shown below, three nested loops allowed for the articulation angle to be varied from twenty to thirty degrees, while the wheel diameter varied from 1.07 meters to 2.07 meters, and while the vehicle width varied from 1.4 meters to 2.4 meters. The program produced a list of all combinations that met all the constraints. The program in effect reduced hundreds of combinations to twenty combinations.

```
10 ************************* Define Variables ***********************
20  T=Axle Length
30  W=Wheel Base
40  D=Tire Diameter
50  A=Articulation Angle
60  R=Turning Radius
70  O1=Obstacle Height1
80  O2=Obstacle Height2
90  C=Clearance
100 G=Gap
110 *********************** Loop Parameters **********************
120 T=2
130 For W= 1.2 to 2.4
```

```
140  For D= 1.07 to 2.07
150  For A= 20 to 30
160  ********************* Number Crunching *******************
170  R = W/ 2(TAN(A/2))
180  G = W-D-(T/2 SIN(A)) - W/2(1 - COS(A))
190  C = D/2 -  W/( SIN(A/2))
200  O1 =  W/2(SIN(A/2) + SIN(1.5A)) + .1568
210  O1 =  W/2(SIN(A/2)) + .1568
220  ********************* Constraints ***************************
230  If O2>1 and C>.08 and G>.13 then Print W,D,A,R,G,C,O1,O2 else
     240
240  Next A
250 Next D
260 Next W
270 End
```

The listed program produced the following data:

Axle Length	Wheel Base	Tire Diameter	Art. Angle	Turning Radius	Obstacle Height 1	Obstacle Height 2	Clear.	Wheel Gap
2	1.8	1.07	29	3.48	0.593	1	0.3096	0.1323
2	2	1.07	26	4.33	0.595	1.01	0.31	0.39
2	2	1.07	27	4.16	0.6107	1.03	0.3015	0.367
2	2	1.07	28	4.01	0.6261	1.06	0.293	0.343
2	2	1.07	29	3.87	0.6415	1.09	0.2846	0.3198
2	2	1.07	30	3.73	0.6566	1.12	0.2762	0.296
2	2.2	1.27	25	4.51	0.6085	1.01	0.4185	0.2137
2	2.2	1.27	26	4.33	0.6243	1.04	0.41	0.1904
2	2.2	1.27	27	4.16	0.6339	1.06	0.4015	0.167
2	2.2	1.07	28	4.01	0.6554	1.09	0.393	0.1434
2	2.2	1.07	24	5.17	0.6041	1.03	0.3063	0.62381
2	2.2	1.07	25	4.96	0.6215	1.06	0.2969	0.6043
2	2.2	1.07	26	4.76	0.6388	1.09	0.2875	0.5803
2	2.2	1.07	27	4.58	0.656	1.12	0.2782	0.5561

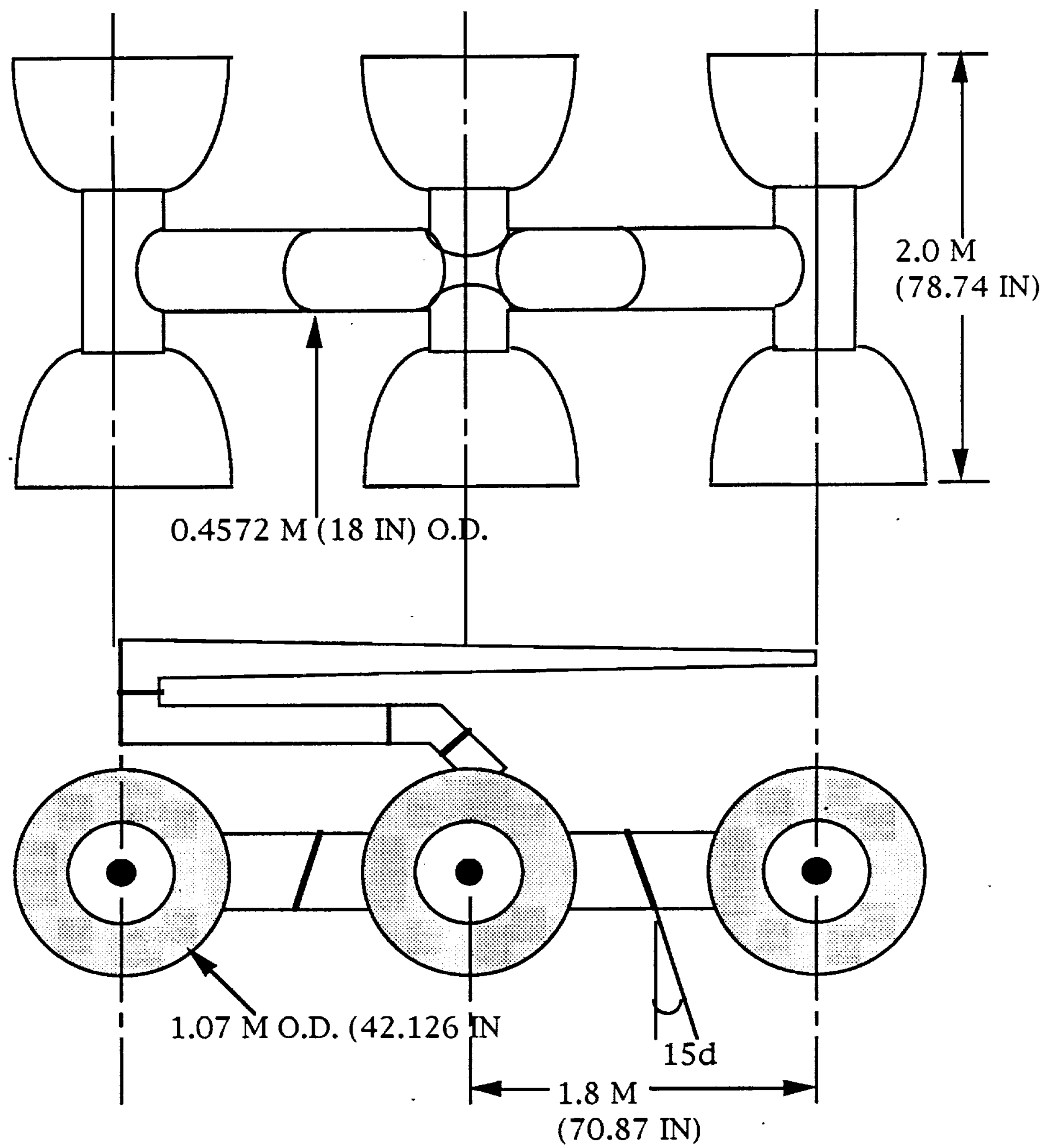
From these numbers we were able to identify an optimal sizing. The first row of numbers produced by the program were the smallest in wheel base, tire diameter and axle length. These numbers will therefore produce the smallest kinematics forces on the Enabler allowing for minimum dimensions of chassis components. This will also minimize the vehicles overall size for transport and weight.

Another method used to optimize the sizing was accomplished by using three-dimensional graphing. On the X and Y axis, the axle-to-axle length (W) and the articulation angle (α) were plotted. The five dependent variables were plotted on the Z axis. This created five three-dimensional curves with our optimal ω and α located at the lowest peak on the Z axis at the intersection of all the curves. This method produced data that was concurrent with the data listed above.

With an axle length of two meters and an articulation angle (maximum) of 29°, the resulting final dimensions (see following page) gave the Enabler a minimum turning radius of approximately 3.5 meters with all other constraints met.

FINAL DIMENSIONS

From the analysis of the parameters as described above, the final dimensions of the main chassis parameters are shown below:



TECHNICAL ACTIVITIES

The 4192 class made two trips to surrounding technical service shops this quarter to get "hands-on" experience about a few aspects of the engineering profession. Jack Seay's design consulting firm works on projects handed to them from larger corporations to implement or improve the design of a product or part. Peel's Technical Service is a machine shop which produces parts for larger corporations. Both trips were similar in that they both incorporated ideas and knowledge learned from the Mechanical Engineering field. While the Seay Group was more design oriented, the visit to Peel's showed more of the hardware involved in the creation of a product.

We would like to thank Jack Seay and William Peel Jr. for their knowledge and experience they shared with us. Each trip was very informational and an interest to all 4192 members. The information provided gave us a view of what it takes to successfully design a product and how to convey the design to the machinist so that his understanding of it is clear and complete. These activities are beneficial to students because they help provide the insight needed to make them better engineers.

ACKNOWLEDGMENTS

We would like to thank Mr. Brazell for his sponsorship of this project and our T. A. Craig Campbell for his assistance. We would also like to thank the National Aeronautics and Space Administration for providing the funds for this project.