IN-18-CR

200228

71P.

A Reproduced Copy

OF

(NASA-CR-184933) PROPOSAL FOR A LUNAR LANDING POD FOR SKITTER Advanced Missions Space Design Program (Georgia Inst. of Tech.) 71 p

N90-24340

CSCL 22B

Unclas

G3/18 0200228

The George W. Woodruff
School of Mechanical Engineering

Georgia Institute
of Technology
Atlanta, Georgia 30332

GEORGIA TECH 1885-1985

DESIGNING TOMORROW TODAY

THE GEORGE W. WOODRUFF SCHOOL OF MECHANICAL ENGINEERING

ME 4182
MECHANICAL DESIGN ENGINEERING

NASA / UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

PROPOSAL FOR A LUNAR LANDING POD FOR SKITTER

AUGUST 1987

DAVID HERMAN
FRANK HUANG
MARK MORELLI
CHIMA NJAKA
MICHEAL POPE
MICHEAL RICE

Georgia Institute of Technology
Atlanta, Georgia 30332-0405

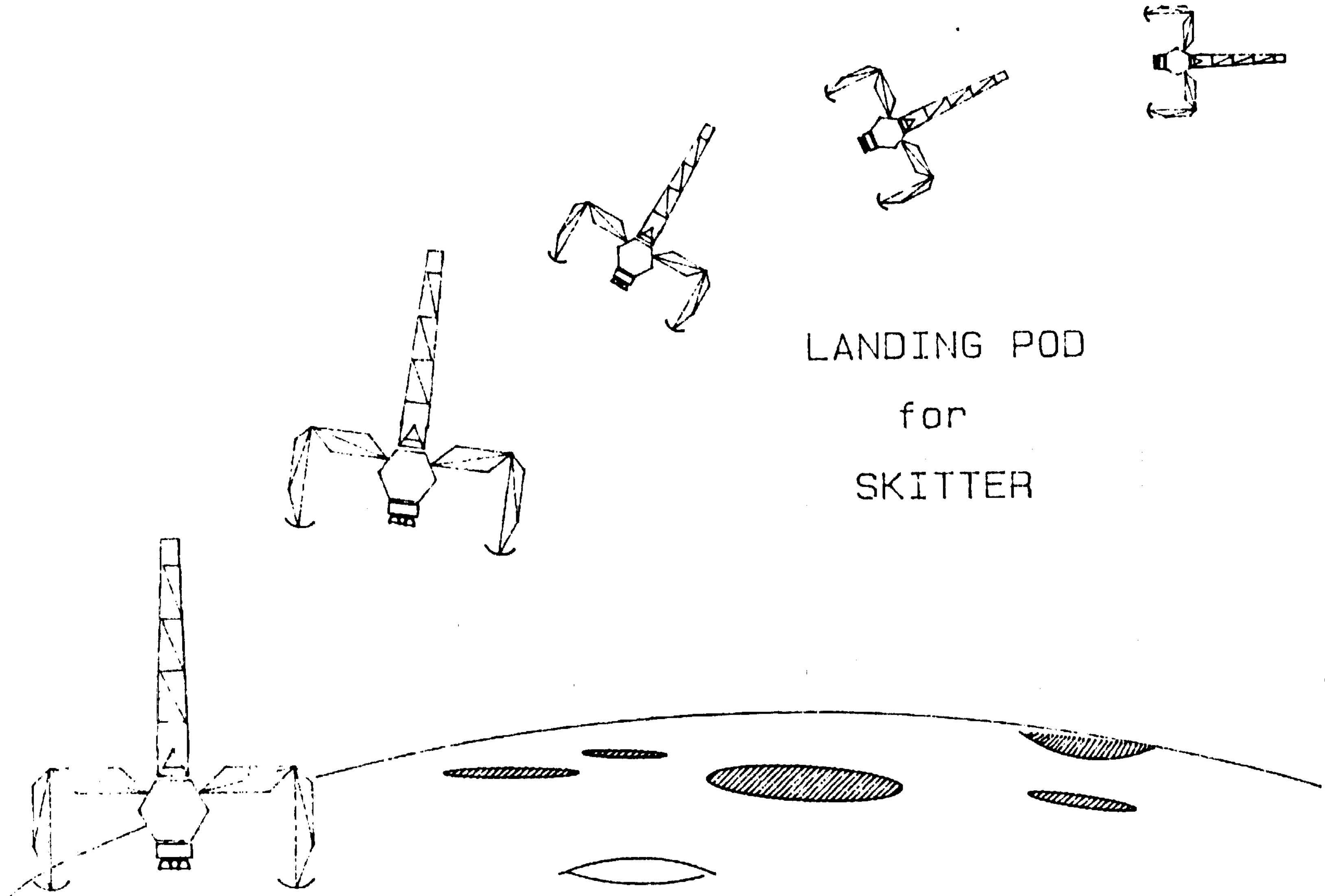

LANDING POD
for
SKITTER

TABLE OF CONTENTS

1.0 INTRODUCTION....................................1

2.0 PROPULSION SYSTEM................................2

2.1 Propellants......................................2

2.1.1 Solid Propellants..............................3

2.1.2 Liquid Propellants.............................4

2.2 Selection of Rocket Engines......................5

2.3 Minimum Fuel Requirements........................7

3.0 LANDING GEAR CONFIGURATION.......................10

3.1 Landing Shoe Configurations......................12

3.1.1 Selection of Energy Absorbtion Devices.......12

3.1.1.a Aluminum Honeycomb Material..................13

3.1.2 Selection of Landing Shoe Design.............15

3.1.3 Shear Pin/Strut Shoe Design..................21

3.1.3.a Shear Pin and Honeycomb Calculations.....21

3.1.3.b Landing Foot Pad.........................26

3.1.3.c Attachment Strut.........................27

4.0 THRUST STRUCTURE....................................29

5.0 ATTACHMENT AND RELEASE MECHANISM..................31

5.1 Guide Assembly....................................31

5.2 U Joint Brackets..................................32

5.3 Pin Release Mechanism.............................33

6.0 NAVIGATION AND CONTROL SYSTEM.....................34

7.0 POWER SYSTEM......................................35

8.0 CONCLUSIONS.......................................36

9.0 RECOMMENDATIONS...................................37

APPENDIX

FIGURES

COST ANALYSIS

OPTIMIM FUEL PROGRAM

GRAPHICAL OUTPUT

ROCKET ENGINE DATA SHEET

THRUST STRUCTURE DATA SHEET

PROJECT PROPOSAL

PROGRESS REPORTS

BIBLIOGRAPHY

ABSTRACT

The purpose of this project is to design a lunar landing module for the SKITTER vehicle. SKITTER is a three-legged mobile lunar transport and work platform. This lunar landing module must be able to bring SKITTER, with attached crane, from a lunar orbit to the surface of the moon. This propulsion system is entirely self-contained and removable after touchdown. SKITTER is unmanned and must be able to touchdown on the lunar surface and perform assigned tasks independent from other space or lunar vehicles.

The propulsion system is designed to ensure that the vehicle will make a lunar landing within the expected velocity range. A landing gear configuration is presented to safely dissipate landing forces on lunar impact and be removed from the SKITTER structure after touchdown. The overall engineering analysis was conducted to determine an economical design to land SKITTER safely on the moon.

SKITTER will perform various tasks on the surface of the moon. The completion of this project will determine the feasibility of landing SKITTER with the attached crane safely on the lunar surface.

1.0 INTRODUCTION

This report presents a preliminary design of a system which is capable of landing SKITTER, a three-legged mobile work platform, on the moon. This project is part of the NASA/University Advanced Missions Space Design Program.

The purpose of this report is to establish an initial design of a functional lunar landing system. The landing system presented here is the Bottom Mounted SKITTER Lander (BMSL). The BMSL is a primary part of the overall SKITTER project because this system transports SKITTER from a lunar orbit to the surface of the moon, and safely lands the vehicle.

This project incorporates the technology learned from previous lunar delivery systems and develops new designs tailored for the existing SKITTER vehicle. This report explores the necessary components to land the SKITTER vehicle on the moon. The main topics of this report examine the propulsion system, thrust structure and landing gear. Considerations are also given to navigation and control, and power requirements.

This report describes the selection of the propulsion system and gives an estimate of the fuel requirements. An analysis of the landing configuration resulted in a detailed design of landing shoes to absorb the touchdown forces. A thrust structure was designed to sustain all applied loads.

2.0 PROPULSION SYSTEM

2.1 Propellants

Rocket engines are divided into two main categories depending on the type of propellant they use. These are solid propellants and liquid propellants. Solid propellants include all those that are stored directly in the combustion chamber. The thrust curve is set for a given rocket and it cannot be throttled or restarted. Liquid rockets include a variety of different propellants. Many can be throttled by controlling the mass flow rate. When looking for a type of propellant to use in our design, we looked for the following desirable propellant properties:

1) Low freezing point and high boiling point : These are desired to help reduce the amount of dead space in the tanks and to prevent malfunctioning of the engines.
2) High specific gravity, specific heat, & thermal conductivity : These are desirable because the oxidizer is often used to cool the walls of the rocket engine and these quantities help increase the Nusselt number for better heat convection.
3) Good stability : Good stability is considered to be 10 years or longer. This property becomes important when choosing liquid propellants. Good chemical stability means no decomposition of the propellant during storage.

4) Low viscosity and vapor pressure : Low viscosity is desired to help reduce the dead space in the tanks and viscosity should be low to ease fuel injection.
5) Small temperature variation of thermodynamic properties : This is important for insuring accurate calibration of the flow system over a wide range of temperatures.
6) High specific impulse and density : These properties are very important for the energy characteristics of the propellant. The high specific impulse implies a high percentage of H_2 and F.
7) Throttleability and good restartability : These characteristics are important for fuel minimization for the landing of the spacecraft.
8) Price : Although price is not a primary consideration of this project, it will be considered, especially if the propellant is an extremely expensive one.

2.1.1 Solid Propellants

Solid rockets are of two entirely different types : homogeneous and composite propellants. These types can also be mixed to form Composite Double-Base (CMDB) propellants. The most important homogeneous propellant is the Double-Base (DB) propellant. It mainly consists of nitrocellulose (NC) and nitroglycerin (NG). This mixture is relatively stable and the fuel and oxidizer are contained in the same mixture.

Composite propellants usually are a mixture of an inorganic salt (oxidizer) and an organic fuel, binder, plastic, or rubber. There are a variety of chemicals that are available for use in these rockets.

Solid propellants have the advantage of simplicity because the propellant is stored directly in the combustion chamber and therefore tanks and a feed system are eliminated. Solid propellants are stored in the form of grains, which separate the fuel and the oxidizer, and come in a variety of configurations. These are used along with the type of chemicals to control the burn rate, which in turn fixes the thrust curve. Solid rockets are advantageous when high thrusts are needed for relatively short durations, such as in booster rockets. They are also much lighter than any other present type of propulsion system. Some of their disadvantages include nonthrottleability, fixed burn time, and nonrestartability.

2.1.2 Liquid Propellants

The four main types of liquid propellants that were considered were:

1) Monopropellant - Characterized by having the fuel and the oxidizer mixed together in one liquid. These are stable at ambient conditions and ignite upon contact with a catalyst bed.
2) Bipropellant - Characterized by separately stored oxidizer and fuel. They are not mixed until they reach the combustion chamber.

3) Cryogenic - These propellants are liquified gases that must be stored at extremely low temperatures, requiring special insulations and cooling systems. One example of this type of engine is the common Liquid Hydrogen (LH_2) / Liquid Oxygen (LOX) engine.

4) Storable - These are storable for 10 years or longer and include Nitric acid and gasoline fuels.

Some common liquid Oxidizers are liquid oxygen (LOX), liquid Fluorine, Hydrogen peroxide (H_2O_2), and Nitric tetroxide (N_2O_4). Some common liquid fuels are Hydrocarbons (including jet fuel, kerosene, gasoline), liquid Hydrogen (LH_2), Hydrazine (N_2H_4), Unsymmetrical Dimethylhydrazine (UDMH/N_2H_4), and Monomethylhydrazine (CH_3NHNH_2). Some common monopropellants are Nitromethane (CH_3NO_2), Hydrazine, and Hydrogen peroxide (H_2O_2).

For the purpose of this proposal both a storable propellant and a monopropellant would be desirable because more weight would be required for separate fuel tanks and cooling systems. Also, less fuel would be lost due to boil-off over the cryogenic fuels. A monopropellant called hydrazine monopropellant was found that has been stored for up to 10 years. It had good thermodynamic properties for this application and was successfully used on the Viking Mars Mission.

2.2 Selection of Rocket Engines

Several engines were considered during the design process. The original choice was the bipropellant engine used on the Apollo Lunar Descent Module (LEMDE). It used Nitrogen tetroxide as the oxidizer and unsymmetrical dimethylhydrazine as the fuel. Its thrust range was from 1000 to 9850 lbs. It was throttleable and could be restarted up to three times. This provided a good starting point, but it wasn't long before it was realized that this engine was terribly oversized for this project. The engine was large, about two and a half meters high and two meters in diameter. This would barely fit underneath SKITTER in the nominal position. The manned LEM also weighed more than five times as much as SKITTER with the attached crane.

In the process of trying to find a more reasonably sized engine engineers from Marshall Space Center were consulted. Their suggestion was the 10 lb.- 10 in. diameter engine used on the Viking Mission. It is called the MR80 and is manufactured by Rocket Research Corp. in Redmond, Washington. Although it has not been used as much as the LEMDE, it has been proven with the successful flight to Mars. However, the MR80 is limited by its relatively short burn time of 500 seconds. It has a thrust range of 60 - 600 lbs., is throttleable, and can be restarted up to eight times. It also had the added advantage of being fueled by hydrazine monopropellant, which fits the description of the fuel earlier decided upon.

This engine is unique in that each engine has 18 nozzles that were designed to minimize the amount of soil disturbed by the plume. The Viking experts were concerned that their delicate measurement devices might be damaged by these high speed abrasive particles. Although concern about this problem was not as great as that of the Viking experts, previous groups have mentioned a concern for malfunctions caused in this manner. With this added protection it is almost possible to eliminate the chance of damage to SKITTER or the instrumentation.

After calculations were done on fuel and thrust requirements, it was determined that three engines would be needed. This presented no problems because of its small size and light weight.

2.3 Minimum Fuel Requirements

This phase of the project encountered the most problems. An extensive amount of research was done to determine the proper methodology needed to determine the minimum fuel requirements for a spacecraft landing from orbit. Unfortunately, all the references that were encountered explained the calculations for a vertical take-off and hover, but would only tabulate computer generated data for the orbital fuel consumption. In order to get a rough estimate to continue with the rest of the project, some rather large simplifications were made such as assuming a constant vehicle mass throughout the flight, a constant thrust, a constant local acceleration due to gravity, and it was even found necessary to neglect the full effects of gravity. This left us with some equations that we could work with so we wrote a PASCAL computer program to generate the minimum fuel necessary to obtain a thrust level that would satisfy the criterion that the thrust-to-weight ratio must be greater than one.

The first step was to determine a relationship for the mass of the propellant. This turned out to be Tsiolkovsky's equation, which may be expressed as:

$$\text{delta } V = c \ln(M_0/M(t)) \quad \text{where,}$$

c is the effective exhaust velocity, delta V is the characteristic velocity, and M is the mass of the spacecraft. The initial mass may be written as the sum of the empty mass and the mass of the propellant. In this proposed case the empty mass must include the payload (SKITTER and its attached crane) and the landing pod. The effective exhaust velocity may be rewritten in terms of the specific impulse, which is a very important parameter in spaceflight dynamics, and the local acceleration due to gravity. The equation is now of the form:

$$\text{delta } V = I_{sp}\, g_0 \ln((M_e+M_p)/M_e)$$

at the burnout time when all fuel is expired. Now the effect of gravity is included and the following equation results:

$$\text{delta } V = I_{sp}\, g_0 \left(\ln((M_p+M_e)/M_e) - (g_0/F)(M_p) \right)$$

where F is the total thrust of engines. The program calculates the fuel required for a low thrust trajectory with a constant radial acceleration of $.45g_0$.

It was necessary to add another 100 kg of fuel for the

Vernier rocket system, which would control attitude, and an additional 2 percent for residual fuel and losses. The size of the fuel tanks were calculated from the minimum fuel requirements knowing the density of the propellant. A spherical shape to optimize volume is proposed with three tanks to provide good symmetry about the pod. The material chosen for the tanks was Titanium because the fuel needed protection from meteors and light weight was essential. Because the storage pressure of the hydrazine is relatively low, 500 PSI, the thickness of the wall should be .795 cm.

3.0 LANDING GEAR CONFIGURATION

This section of the report describes the landing gear configuration. The landing gear configuration absorbs the lunar touchdown forces in a way to protect the SKITTER structure and make the landing as soft as possible to minimize shock on equipment. The general design requirements for the landing gear are listed below.

1). Detachment requirement: The landing gear must be detachable after after landing. This is to insure that the landing gear do not impair the proper functioning of SKITTER while on the moon.

2). Landing velocity: The maximum vertical design velocity is 10 fps, which is well within the expected landing velocity.

3). Landing deceleration: The maximum deceleration of SKITTER is assumed to be 6g, which is an estimated number taken from other lunar landers with similar weight ranges and landing configurations.

4). Terrain characteristics: The lunar surface is assumed to include slopes of up to 35 degrees, and boulders of up to one foot in diameter. The soil has low density of 1.2 to 1.5 gr/cm^3, and bearing strength of 8 psi at 2 inches depth and 12 psi at 3 inches depth.

SKITTER will be deployed in the landing configuration while in lunar orbit. The legs will be extended in the nominal position and the crane will be attached and in the vertical position. In order to ensure a successful lunar landing, the landing gear system must be able to absorb landing shocks to protect SKITTER. The landing gear must also provide stability so that the structure will not overturn on impact.

In the design of the landing gear configuration, the existing SKITTER structure is used for stability with minimal impact forces being transmitted to the structure. The actual structure will remain unchanged so that the operation of SKITTER will be optimized on the moon's surface. In the nominal position, a three-legged configuration provides a stable landing platform. The nominal position is also needed to provide enough clearance for the bottom mounted engines.

Considering the design constraints a detachable landing shoe is thought to be a simple and effective way to absorb the lunar landing forces. Landing shoes will be attached to the existing SKITTER feet. SKITTER's legs will provide the stability for landing, and the shoes will protect SKITTER from landing forces. After safely landing the landing shoes will be detached from the feet and SKITTER will be free to accomplish it's lunar missions.

3.1 Landing Shoe Configurations

Several landing shoe configurations have been developed. All of the shoes are detachable and provide damping to minimize landing forces to a safe level. The different shoe configurations provide different attach and detach mechanisms, but the best energy absorption device should be used for all the landing shoe designs. With this in mind the optimum energy absorption device will be developed next.

3.1.1 Selection of Energy Absorption Devices

Several energy absorption devices were considered for the shoe design. The landing impact forces can be absorbed by:

- Foams
- Multistage crushable material
- Gaseous Systems
- spring and hydraulic dampers

Examination of the various shock absorption devices led to the selection of a multistage crushable aluminum honeycomb configuration. Some foams considered to absorb lunar landing forces were open cell foams such as Polystyrene, Polyethylene, and Ethafoam. The application of foam materials is undesirable because of the extreme temperatures caused by the lunar orbit. Gaseous systems were considered more complex, however one shoe design does use a gaseous system to dissipate landing forces. Honeycomb was selected because of it's lightweight, low cost and simplicity of design in comparison to a spring and damper system.

3.1.1.a Aluminum Honeycomb Material

Honeycomb material is used extensively in the aerospace and transportation industries to absorb energy. Other absorption devices like foams, gaseous systems and springs exhibit rebound characteristics. Aluminum honeycomb has the unique property of failing at a constant load while completely dissipating energy otherwise released in rebound. Energy absorption capability of aluminum is calculable and predictable. A properly designed energy absorber will decelerate a moving object at any desired rate, minimizing or eliminating damage.

The threshold at which compressive failure begins can be eliminated by the use of a pre-stressed or pre-crushed honeycomb core. This honeycomb has undergone slight initial compression failure to prevent shock loads from being transmitted to the SKITTER structure. Exposed to further loading, the pre-stressed core carries the load at a linear rate.

Aluminum honeycomb is manufactured in a variety of configurations. Design variables such as alloy, foil thickness, corrugation height and corrugation axis orientation in any combination allow a wide selection of crush characteristics. The honeycomb core exhibits all of the physical properties from which it is made. Aluminum honeycomb is lightweight and will readily withstand the temperatures and radiation of space.

Honeycomb can be manufactured in a variety of materials and configurations for different design applications. The shape of the honeycomb core gives the characteristics of the honeycomb. The standard and most common cellular honeycomb configuration is the hexagonal core. Other core types provide formability into compound curves and high density honeycomb.

Examination of existing honeycomb cores led to the selection of TUBE-CORE honeycomb. TUBE-CORE honeycomb is manufactured by the Hexcel Corporation and provides all the necessary characteristics needed for the shoe designs. TUBE-CORE is designed for efficient energy absorption where the space envelope requires a small diameter cylinder like the landing shoe configurations. The TUBE-CORE eliminates loss of crush strength at the edges, an inherent characteristic of conventional honeycomb which has unsupported edges when used with small diameter cylinders. This configuration of honeycomb also offers all of the energy absorption features of conventional honeycomb. Typical applications of this honeycomb are shock attenuation struts on space vehicles, tail skids for the Boeing 727 airplane, escape capsules for military aircraft and various missile protection applications.

TUBE-CORE Aluminum Honeycomb offers the following features:

- Absorbs great energy loads at a predetermined constant rate.
- Gives high performance energy absorption in cylindrical form.
- High crush strength to weight.
- Fatigue resistance.
- Ease of fabrication.
- Reliability.

TUBE-CORE is constructed of alternate sheets of flat aluminum foil and corrugated aluminum foil wound around a mandrel and adhesively bonded. Typical outside diameters vary from 0.5 inches to 30 inches and lengths from 0.5 to 62 inches. The gauge, density and the inner and outer diameters of the honeycomb can be specified for a particular design.

ALLOY USED: Al 5052

Characteristics	min.	max.
Foil Gauge	.0009 in.	.0060 in.
corrugation height	1/16 in.	3/32 in.
crush strength	2 psi	8000 psi

3.1.2 Selection of Landing Shoe Design

Several landing shoe configurations have been developed to fit over SKITTER's feet to absorb landing impact forces.

All of the shoe configurations use multistage TUBE-CORE honeycomb to absorb the landing energy. Several stages of honeycomb are sandwiched to the bottom of the landing shoe using high temperature adhesives. The crushable honeycomb forms a landing pad which deforms on lunar impact, thus absorbing the landing forces. Discontinuities in the lunar surface, such as rocks and debris also deform the landing shoe without damaging SKITTER or causing the structure to be unstable. After SKITTER has landed safely, the landing shoe must be detached from SKITTER's foot and discarded. Different attaching and detaching mechanisms were examined:

- Exploding Bolts
- Shear Pins
- Electro-mechanical Devices
- Mechanical Mechanisms

Exploring four different attach and detach systems, several designs are developed in this text. The shear pin design, electro-mechanical design, the shear pin/strut design and the the shear pin/air bag design are presented below.

1). <u>Shear Pin Design</u>: See Figure 3.1. The shear pin shoe design uses the weight of SKITTER to detach the landing shoe. When SKITTER touches the moon's surface, three shear pins per foot break under the vehicles weight. The shear pins hold the landing shoes on SKITTER's feet during lunar descent. During impact the multistage honeycomb material absorbs the landing energy. The vehicle raises one leg at a time to step out of the landing shoes. This design will not protect the SKITTER structure in the unlikely event that two of the three shear pins on a foot will break on lunar descent causing the shoe to prematurely detach. This is not likely to happen since the moon has no atmosphere to cause a rough descent.

2). Electro-mechanical Design: See Figure 3.2. This design uses two electric motors per foot to detach the landing shoe after touchdown. After SKITTER has landed safely, a command can be given to the vehicle, or internal gyros can determine when SKITTER has stopped moving and a signal can be sent to actuate six electric motors in the landing shoes. Each motor turns a worm gear which retracts the attach pins that hold the landing shoe on SKITTER's foot. The vehicle can then walk out of the landing shoes. A power source is needed to activate and run the electric motors and quick disconnect wires are used to detach the electrical wires running to the motors in the landing shoes. All six motors must work to retract the retaining pins and discard the landing shoes.

3). Shear Pin/ Strut Design: See Figure 3.3. This design uses SKITTER's weight and landing forces to detach the landing shoes. Each landing shoe is held on a foot with three movable aluminum blocks (guided catches). These guided catches are positioned above the feet in the landing configuration and are attached to the landing shoe by three sliding tracks. In the landing configuration, the guided catches are positioned to hold on SKITTER's landing shoes. During initial impact, three shear pins per foot break under the weight of SKITTER and the guided catches slide down their teflon tracks to the stopper positions. The landing impact forces are absorbed by the honeycomb in the landing shoe and extra honeycomb in the landing shoe strut.

There are three landing shoe struts which connect to the guided catches on one end, and seat against SKITTER's leg on the other end. The landing shoe struts are used primarily to move the guided catches from their landing configurations to release the landing shoe on lunar impact. The struts are also filled with higher strength honeycomb to absorb high impact forces. The struts will only be used to absorb excess landing energy if high velocity landings are attempted or if SKITTER attempts to rock off balance on touchdown.

The landing struts are fastened to the guided catches with ball joints on one end, but they merely seat against SKITTER's legs in a ball and sleeve attachment on the other end. Once the vehicle has landed on the lunar surface, and the guided catches have moved to their stopper positions, SKITTER can raise a leg and detach from the landing shoe. Even if only one guided catch per foot moves down its track to the stopper position, the landing shoe can still be removed. Acceleration forces on the landing shoe during lunar descent force the foot against the guided catches and help hold the shoes on SKITTER's feet.

4). Shear Pin/Air Bag Design: See Figure 3.4. This design uses shear pins to remove the landing shoes similar to the shear pin design. This landing shoe however, extends upward along SKITTER's legs. On lunar descent three air bags per leg are filled with gas. The air bags fill the upper regions of the shoe between the shoe and SKITTER's legs. These air bags help absorb lateral landing forces which can possibly be incurred on landing and distribute these forces along the legs. Lateral landing forces however, are expected to be small and the air bags are merely a precaution against a lateral approach and touchdown.

An elliptical dish on a large ball joint is mounted below the honeycomb and impacts with the moon's surface on touchdown. The elliptical dish aligns the vehicle with the lunar surface. After landing the air bags are deflated and SKITTER can step out of the landing shoes.

A decision matrix was created to help decide the best shoe design for the landing configuration.

LANDING SHOE DESIGN DECISION MATRIX

VARIABLE	WT.	1	2	3	4
SIMPLICITY	4	10	6	8	4
WEIGHT	3	8	2	5	3
COST	2	6	2	5	4
TRAP *	5	2	7	10	4
Total		86	69	107	53

* This is the probability that the foot will be trapped in the landing shoe after landing.

1 - Shear Pin Design

2 - Electro-mechanical Design

3 - Shear Pin/Strut Design

4 - Shear Pin/Air Bag Design

From analysis of the various shoe designs, along with the decision matrix, the shear pin/strut design was selected as the lunar landing shoe for SKITTER. This design is relatively simple and will provide a reliable and safe means to deliver SKITTER to the lunar surface. No electrical wires are needed and the shear pin/strut design will not trap SKITTER's feet inside the shoe after landing. The components for the shoe are relatively inexpensive and the shoe can be easily discarded after use.

3.1.3 Shear Pin/Strut Shoe Design

The shear pin/strut landing shoe design was selected for SKITTER and a more in depth analysis of this design is presented in this section. This design will not protect the structure if SKITTER bounces after initial lunar impact. The landing shoes will be detached after the vehicle impacts for the first time. After the initial touchdown however, most of the landing energy has been dissipated. The probability of a bounce landing is very low since modern control systems can be relied upon to bring SKITTER well within the 10 fps vertical landing speed.

The material used for the landing struts, frame of the shoe and the general structure is AL 7075-T6 with the following properties:

- Modulus of Elasticity, E = 10.5 X 10^3 ksi
- Yield Strength (compression) = 71 ksi
- Yield Strength (tension) = 64 ksi

3.1.3.a Shear Pin and Honeycomb Calculations

Symbols:

A	in^2	Impact Area
a	ft/sec^2	Acceleration or Deceleration Rate
F	lbs	Impact Force
f_{cr}	psi	Honeycomb Crush strength
g	ft/sec^2	Acceleration Due to Gravity
m	lb-mass	Mass
S	in	Stopping Distance

t_c	in	Honeycomb Core Thickness
v_i	ft/sec	Initial Velocity
v_f	ft/sec	Final Velocity
W	lbs	SKITTER's weight

Formulas

1. Dynamic Force, $F = ma$.
2. Velocity, $v_f^2 = v_i^2 + 2aS$.
3. Stopping Distance, $S = v_i^2/2a$, from equation 2 for $v_f = 0$ and $a < 0$.
4. Minimum Core Thickness, $t_c = (v_i 2/.7*2a)$. Assuming 70% of the total honeycomb thickness is available for crushing, then $S = 0.7t_c$.
5. Crush strength, $f_{cr} = F/A = ma/A = W/A$.

Calculations

1. Shear Pin (See Figure 3.5)

   W = 1000 lbs. Skitter has 3 legs, and there are 3 shear pins on each leg.

   $$F = \frac{1000}{3*3} = 111.11 \text{ lbs}$$

   Take moment about point T

   $111.11*18 - S_x*24 = 0$

   $S_x = 83.33$ lbs

   Sum of $F_x = 0$

   $S_x + T_x = 0$, $T_x = -83.33$ lbs

Use UNS alloy number A91100 which has shear modulus of 9.5 Kpsi.

Choose shear pin strength = 80 lbs.

$$\text{Cross section area of the pin } A = \frac{80}{95000} = .01 \text{ in}^2$$

The radius of the pin = .05 in.

2.Honeycomb A (See Figure 3.6)

$W = 1000$ lbs, $R = 7.87$ in, $r = 3.94$ in.

$A = \pi(R^2 - r^2) = 145.89 \text{ in}^2$.

From equation 5 and if Skitter lands on 3 legs evenly

$$f_{cr} = \frac{W}{3A} = \frac{10000}{3*145.89} = 2.28 \text{ psi.}$$

We choose 2 psi crush strength for honeycomb B to make sure the guided catch can be opened when $v_i = 0$.

3.Honeycomb B (See Figure 3.6)

$a = 6g$ for Skitter's structure limitation.

We use $a = 6g*.8 = 4.8$ g with safety factor.

$W = 6000$ lbs at $a = 1g$.

$W = 6000*4.8 = 28800$ lbs at $a = 4.8$ g.

$r = 19.69$ in $A = \pi(19.69)^2 = 1217.98 \text{ in}^2$.

Force absorbed by the shear pin and honeycomb is:

$A = 1000 + 80 = 1080$ lbs.

$$f_{cr} = \frac{28800-1080}{1217.98} = 22.76 \text{ psi}$$

We choose 22 psi for honeycomb B which can absorb the energy for a one legged landing.

From equation 4, $t_c = \dfrac{vi^2}{.7*2a}$

v_i = 10 ft/sec   a = 4.8 g

$$t_c = \frac{10^2}{.7*2*4.8*32.2} = .46 \text{ ft} = 5.55 \text{ ft.}$$

4.Honeycomb C   (See Figure 3.6)

We choose 10 psi for honeycomb C . It is an additional energy absorber for the case when SKITTER lands on a rough surface, such as rocks.

5.Honeycomb D   (See Figure 3.7)

$r = 1.75$ in, $A = \pi(1.75)^2 = 9.62$ in^2

The maximum force on the Tube-Core honeycomb

= Force of SKITTER- (force absorbed by honeycomb A

+ force absorbed by the shear pin).

F = 6000*4.8-(2*145.89+80) = 28428.22 lbs

$$f_{cr} = \frac{F}{A} = \frac{28424.89}{9.62} = 2955.12 \text{ psi}$$

We choose 2950 psi for honeycomb D.

6.Summary of Energy Absorption On One Leg Landing

	shear pin	1st stage	2nd stage
Strength(psi)	9.5k	2.00	22.0
Area(in^2)	.01	145.89	1217.9
Force(lb)	80.00	1000.00	27720.0
Stroke(in)	3.5	3.85	5.6
Energy(ft-lb)	23.23	320.83	1282.1

7.Mass Of The Shoe (See Figure 3.6)

Aluminum 7075-T6, with a density of 1.2 gr/cm^3 is used for the shoe frame. The material used for honeycomb is Al - 5052.

Density of honeycomb (gr/cm^3)

A = .0016

B = .02

C = .008

D = .32

Volume of shoe frame

$= \pi(50^2-10^2)*2+\pi(12^2-10^2)*12$

$+10*8*8*3 = 18658\ cm^3$

Mass of shoe frame = 18658*1.2 = 22390 gr = 22.39 kg.

Volume of honeycomb (cm^3)

$A = \pi(20^2-10^2)*10 = 9425$

$B = \pi(50^2-10^2)*45-\pi(20^2-10^2)*20 = 320442$

$C = \pi(42)^2*24 = 133002$

$D = \pi(4.45)^2 * 20 = 1241$

Mass of honeycomb

= 9425*.0016+320442*.02+133002*.008+1241*.32

= 7885 gr = 7.89 kg

Total mass of the shoe = mass of (honeycomb + shoe frame) = 22.39 + 7.89 = 30.28 kg.

3.1.3.b Landing Foot Pad

This section of the shoe alone can absorb the forces from a normal landing. To do this, three separate stages of honeycomb are mounted on the bottom of a SKITTER foot. The different stages of honeycomb in the foot pad are labeled A, B and C, and they can be seen in Figure 3.6.

All of the energy absorption calculations were performed assuming the landing weight of SKITTER will be 6000 lb-mass with the crane attached. The landing foot pad was designed to absorb all of the landing forces with one foot pad. This is the design criteria to insure the the vehicle will be protected in case one foot impacts the surface well before the others.

<u>Honeycomb A</u>: Two honeycomb A is 10 cm thick and will easily crush under SKITTER's weight, allowing the foot to penetrate the landing shoe approximately 9 cm. This downward motion of the foot in relation to the landing shoe will break the shear

pins. The struts will then force the guided catches along their tracks to the stopper positions, allowing the foot to be removed from the shoe has been created.

Honeycomb B: Honeycomb B is the main energy absorption material in the landing shoe. This 22 psi honeycomb can absorb all of the landing forces and 30% of the honeycomb will remain uncrushed. This material ranges from 25 to 45 cm in thickness.

Honeycomb C: Honeycomb C is 24 cm thick and rated at 10 psi. This material is not needed to absorb the landing forces. This honeycomb is used as a deformable cushion in which it can deform to take the shape of the lunar surface. This allows SKITTER to land on rocks or uneven surfaces with the ability to align itself with the lunar surface.

3.1.3.c Attachment Strut

The attachment strut is 8.9 cm in diameter and 30 cm in length. See Figure 3.7. It is made of AL 7075-T6 and has a wall thickness of .15 inches. The inside of the strut is filled with 20 cm of honeycomb D.

Honeycomb D: This is 20 cm of 2950 psi honeycomb. This section of material is not needed for normal landings. If SKITTER happens to have an unusually rough landing, energy will be dissipated with this honeycomb through the struts. This material will also absorb applied loads to the strut if the vehicle tips on impact instead of having a vertical landing.

4.0 THRUST STRUCTURE

The proposed configuration for the thrust structure is shown on Figure 4.1. The main structure is composed of a triangular lower thrust plane which serves to redistribute the locally applied loads of the three MR-80 engines to a nearly uniform compression load applied to the undercarriage of SKITTER through a triangular upper thrust plane. The basic structure also serves as the skeleton for the proposed lunar landing module (BMSL).

The structural components consist of a combination of tubular members and tension cables connecting the three engines to the lower thrust plane on the bottom and to the upper thrust plane on the top. The three engines are supported by three circular thrust plates which are welded to the vertices of the lower thrust plane. The total weight of the thrust structure is estimated to be about 831.1 Nts.

The structure was designed to withstand a maximum compressive acceleration of 2 g. Using the dry weight of SKITTER as 2636.94 kg, the test compressive force is thus computed as 5273.88 Nts. Analysis of this preliminary design showed that the structure was stable for the maximum expected vertical and horizontal loads. A summary of the design of the various members of the thrust structure is given in Table 4.1.

The choice of the structural material was made on the basis of weight, strength, stiffness, and cost. The aluminum alloy Al7075-T6 best fit these considerations for the tubular members of the structure. The steel alloy UNS-G10180-CD was chosen for the tension cables.

Separation of the thrust structure from the SKITTER undercarriage will be accomplished by pyrotechnic devices at the upper thrust plane/undercarriage interface.

5.0 ATTACHMENT AND RELEASE MECHANISM

The proposed attachment and release configuration for the landing module is shown in Figure 5.1. The basic components of the Attachment and Release Mechanism (ARM) connects to the upper thrust plane of the thrust structure and the triangular SKITTER undercarriage and serve to easily connect and release the proposed lunar landing module from the undercarriage of SKITTER. The components of the ARM were designed to enable a secure attachment for the lunar landing module to the SKITTER undercarriage given the expected loads from the landing module and thrust reactions.

The basic components of the ARM consists of a partial pyramid guide assembly, U-Joint brackets, and pyrotechnic pin release mechanisms.

5.1 Guide Assembly

The design of the partial pyramid guide assembly realized two objectives:

1) a simple method for aligning attachment components to the SKITTER undercarriage, and

2) a means of redistributing the stress of the attachment components over a greater area, thus reducing the stress.

The guide assembly is composed of two triangular based pyramids. The first uses the bottom plane of the SKITTER undercarriage as its triangular base and is formed by extending aluminum alloy tubular members from the vertices of the base up and into the SKITTER undercarriage in the shape of a three-sided pyramid.

The second pyramid fits within the first and uses the top plane of the upper thrust structure as its triangular base. The second pyramid is also formed from aluminum tubular members. These tubular members extend from the vertices of their base plane out from the upper thrust plane of the BMSL to form a three-sided pyramid which fits within the first pyramid. The action of bringing the upper thrust plane of the BMSL into contact with the SKITTER undercarriage thus forces the fit of the second pyramid within the first and aligns the corners of the upper thrust plane with the corners of the SKITTER undercarriage where the joints for attachment are located.

The two pyramids are actually partial pyramids because the tops of each pyramid has been flattened to facilitate more room in the SKITTER undercarriage area.

5.2 U-Joint Brackets

A close-up of the proposed U-Joint brackets is shown in Figure 5.2. The brackets are located at the three corners of the upper thrust plane of the BMSL and the SKITTER undercarriage. The male component of the bracket is attached to SKITTER and the female component is attached to the landing module. A hole is drilled through the male and female components to facilitate the insertion of a 30mm hold pin.

5.3 Pin Release Mechanism

The proposed Pyrotechnic Pin Release Device is shown in Figure 5.3. An electrically fired explosive charge causes the hold pin to retract at all three U-Joint brackets simultaneously, releasing the load of the lunar landing module.

5.0 NAVIGATION AND CONTROL SYSTEM

The landing pod will use the telecommunication system onboard SKITTER for communication with Earth. We decided this after we could not justify putting another one on the pod, which is only to be used once. The pod could supply the necessary power to SKITTER, if necessary, via an interface. The pod will contain gyroscopes for attitude control and to release the pod from SKITTER upon landing. The attitude will be controlled by three pairs of Vernier rockets. Each pair will be mounted on a fuel tank at angles to get a full range of motion. These rockets will provide 35 N of thrust each and will be fueled off the same propellant as the main engines. Other auxiliary engines were considered such as cold gas and chemical rockets, but each of these required an auxiliary fuel system which was deemed unnecessary. Originally we wanted an engine that could be gimballed to eliminate this system all together, but our MR-80 was not capable of gimballing. This is a common method of attitude control and was used for both the Lunar Logistics Vehicle and Viking.

7.0 POWER SYSTEM

The power for the computers and all other onboard equipment will be provided by two General Electric Nickel - Cadmium batteries. These are capable of supplying 28 volts and 8 amperes for up a total of one hour. This system is based on Viking's power supply system and will supply 224 watts of power.

8.0 CONCLUSIONS

This report outlines the basic design of a system to land SKIITER on the moon from a lunar orbit. The primary areas discussed in this report are the propulsion system, thrust structure and landing gear. The engines used to land SKITTER are the moon were adopted from the viking project and were redesigned to work for SKITTER. The three engines used are attached to SKITTER with a thrust structure and they connect with a pyramid alignment system. The landing shoes were designed to absorb the landing energies and also be discarded after touchdown. Design considerations were also given to navagation and control and to the power system.

In the 21 st century, about the time SKITTER will be making its first lunar landing, the control systems will be much more advanced than the systems on SKITTER today. It is hoped that no landing shoes will be needed to dissipate landing forces. Instead, the SKITTER controls will react to the landing loads and flex its legs accordingly, much like a person jumping from an elevated height.

9.0 RECOMMENDATIONS

Due to the high number of craters and boulders on the lunar surface, the probability of a lunar landing in a hazard free area without a television guidance approach is less than 25 percent. The presence of a television guidance system increases the probability of a safe landing to over 95 percent. With a television guided approach the exact landing location can be selected and adjustments can be made as necessary. A television guidance system for SKITTER is needed so that the probability of a safe landing, even in a hazardous location, can be increased.

Since the engines used to land SKITTER were used in conjunction with parachutes in the Mars mission, they did not require as long of a burn time. It is likely that the engines would need to be upgraded to allow for longer burn times for landing SKITTER. Jim Bartron of Rocket Research estimates that this upgrade could be completed in about 2 years and would cost about 1.5 million dollars. If this is not considered to be economical then another engine should be found.

APPENDIX

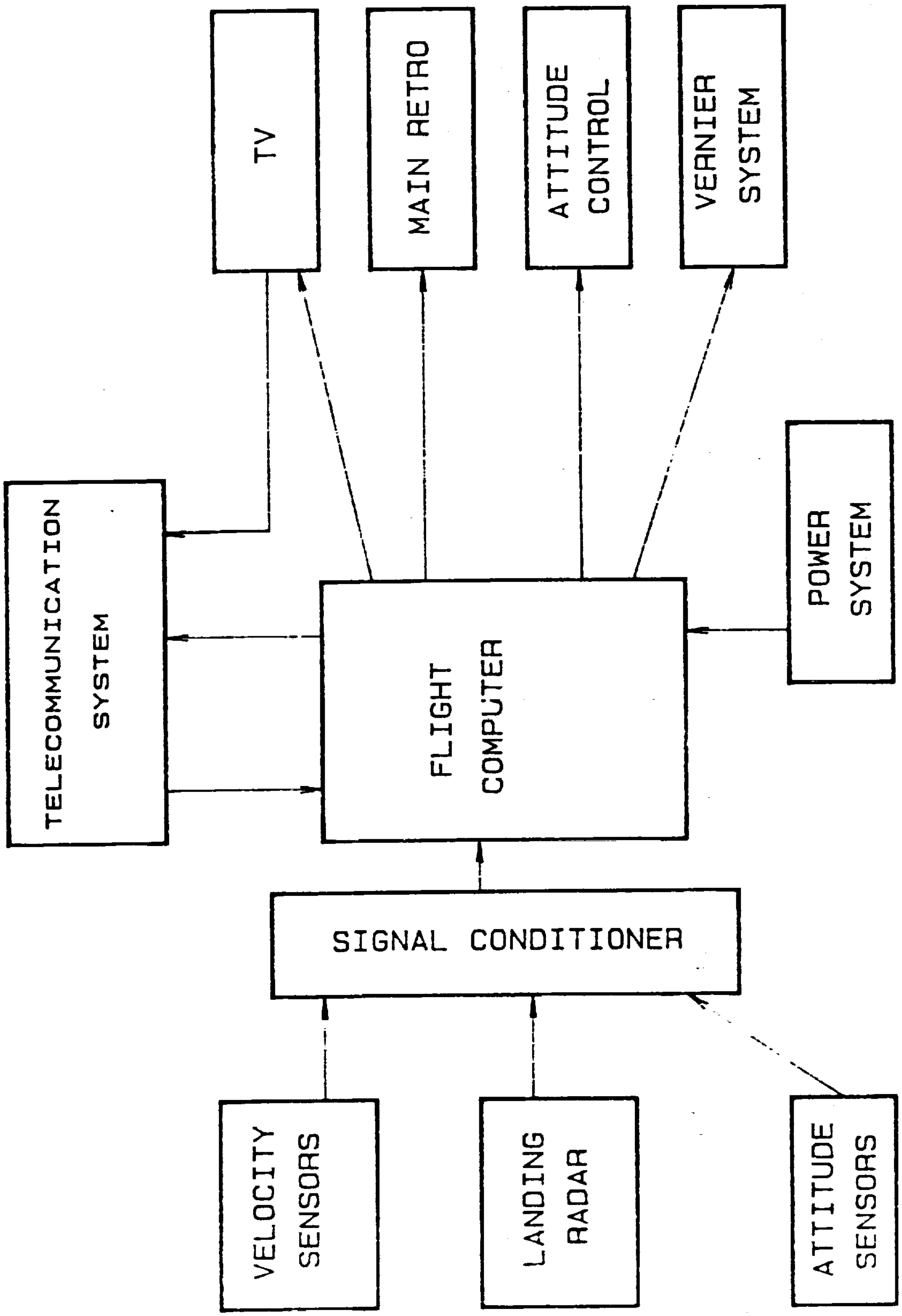

TV
MAIN RETRO
ATTITUDE CONTROL
VERNIER SYSTEM
TELECOMMUNICATION SYSTEM
FLIGHT COMPUTER
POWER SYSTEM
SIGNAL CONDITIONER
VELOCITY SENSORS
LANDING RADAR
ATTITUDE SENSORS

Figure 2.1

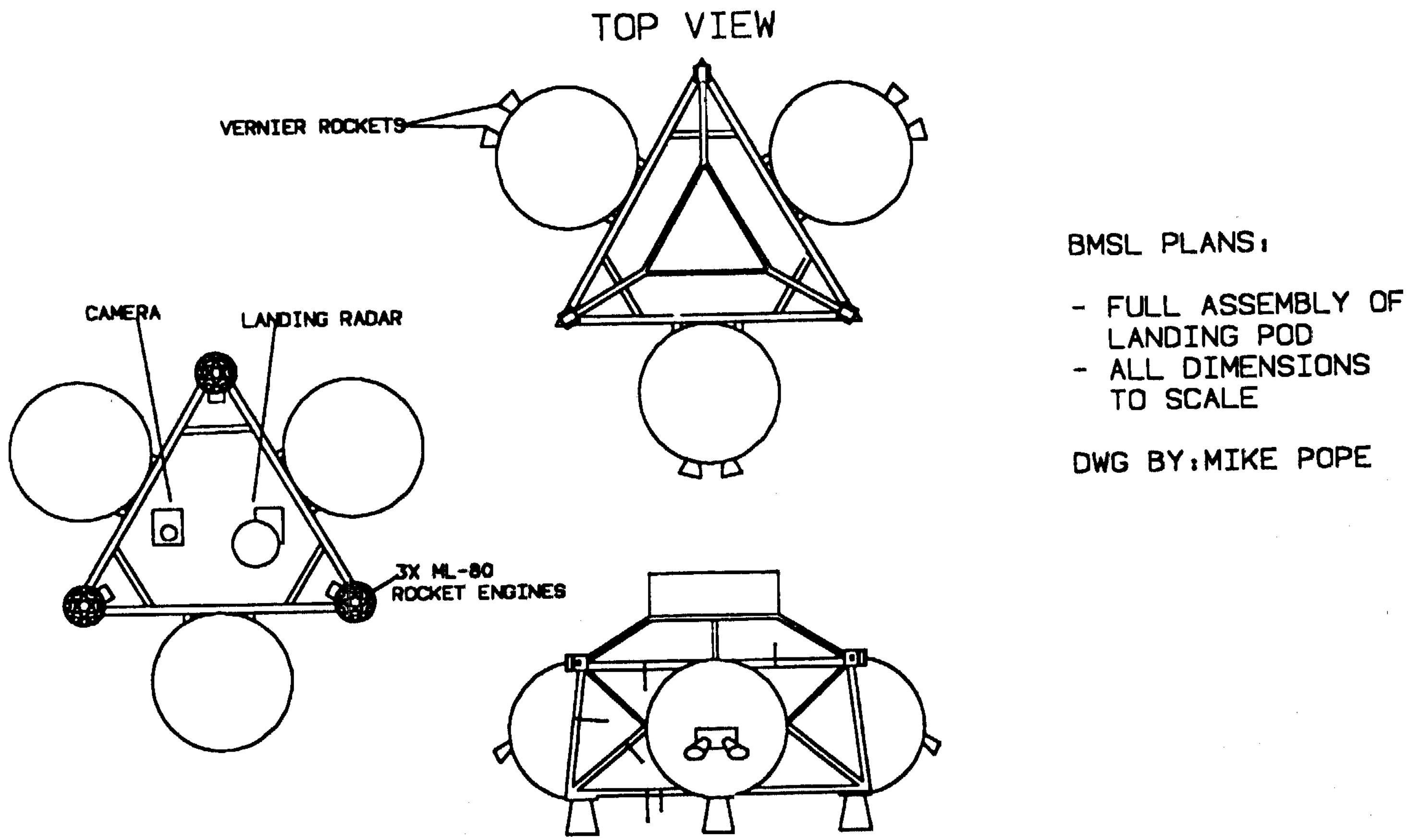

TOP VIEW
VERNIER ROCKETS
CAMERA
LANDING RADAR
3X ML-80
ROCKET ENGINES
BMSL PLANS:
- FULL ASSEMBLY OF
LANDING POD
- ALL DIMENSIONS
TO SCALE
DWG BY: MIKE POPE

Figure 2.2

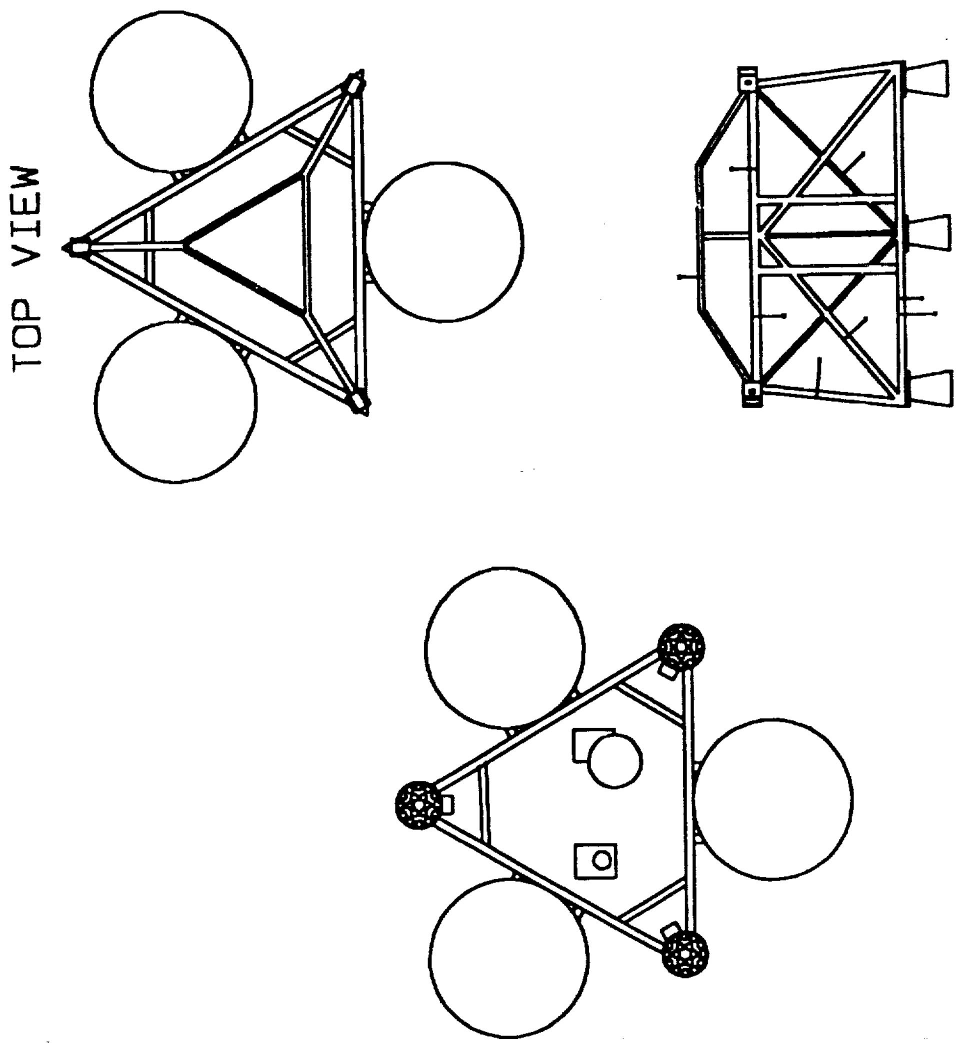
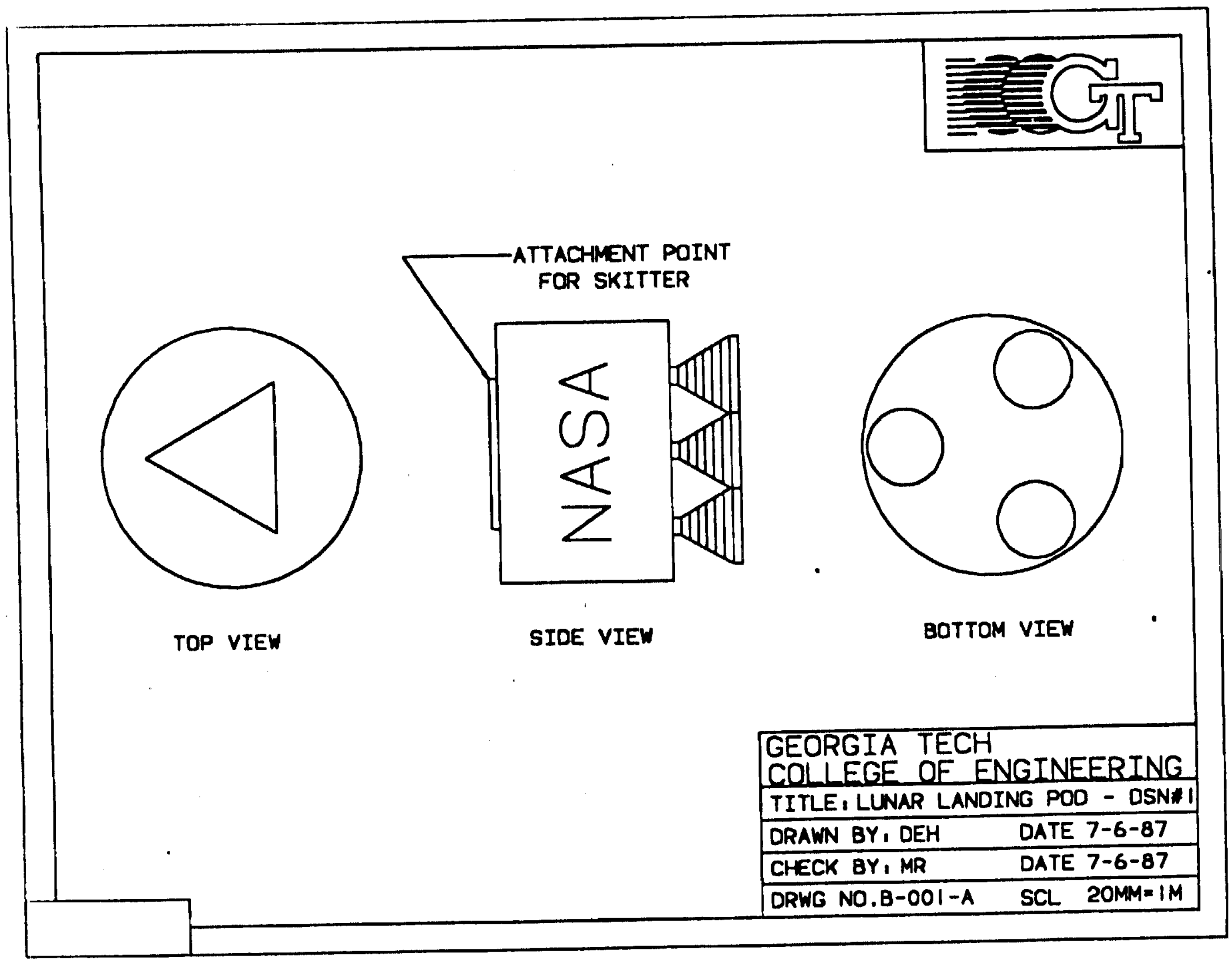


Figure 2.3


ATTACHMENT POINT
FOR SKITTER
NASA
TOP VIEW
SIDE VIEW
BOTTOM VIEW
GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: LUNAR LANDING POD - DSN#1
DRAWN BY: DEH DATE 7-6-87
CHECK BY: MR DATE 7-6-87
DRWG NO.B-001-A SCL 20MM=1M

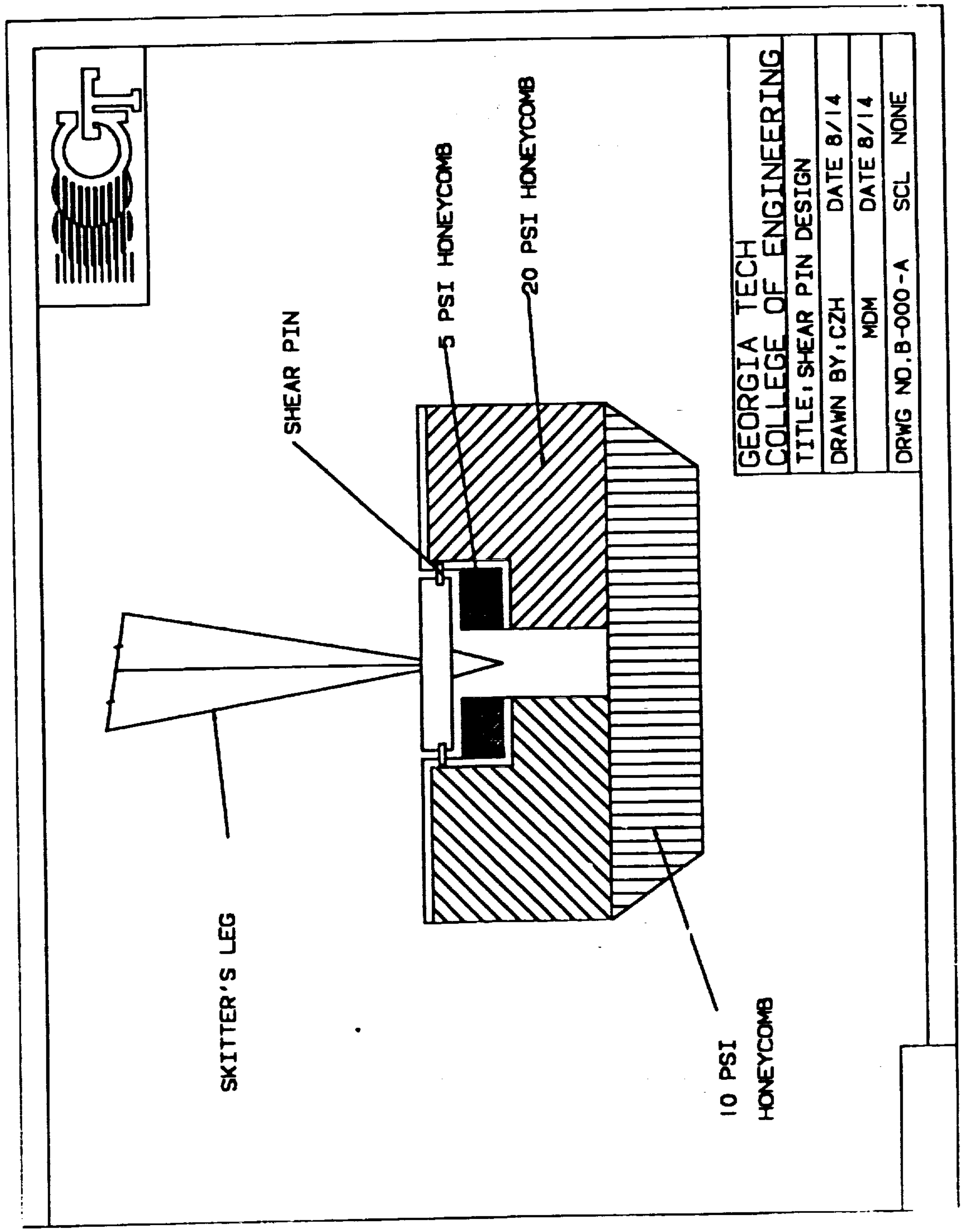

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: SHEAR PIN DESIGN
DRAWN BY: CZH DATE 8/14
MDM DATE 8/14
DRWG NO. B-000-A SCL NONE
SHEAR PIN
5 PSI HONEYCOMB
20 PSI HONEYCOMB
SKITTER'S LEG
10 PSI
HONEYCOMB

Figure 3.1

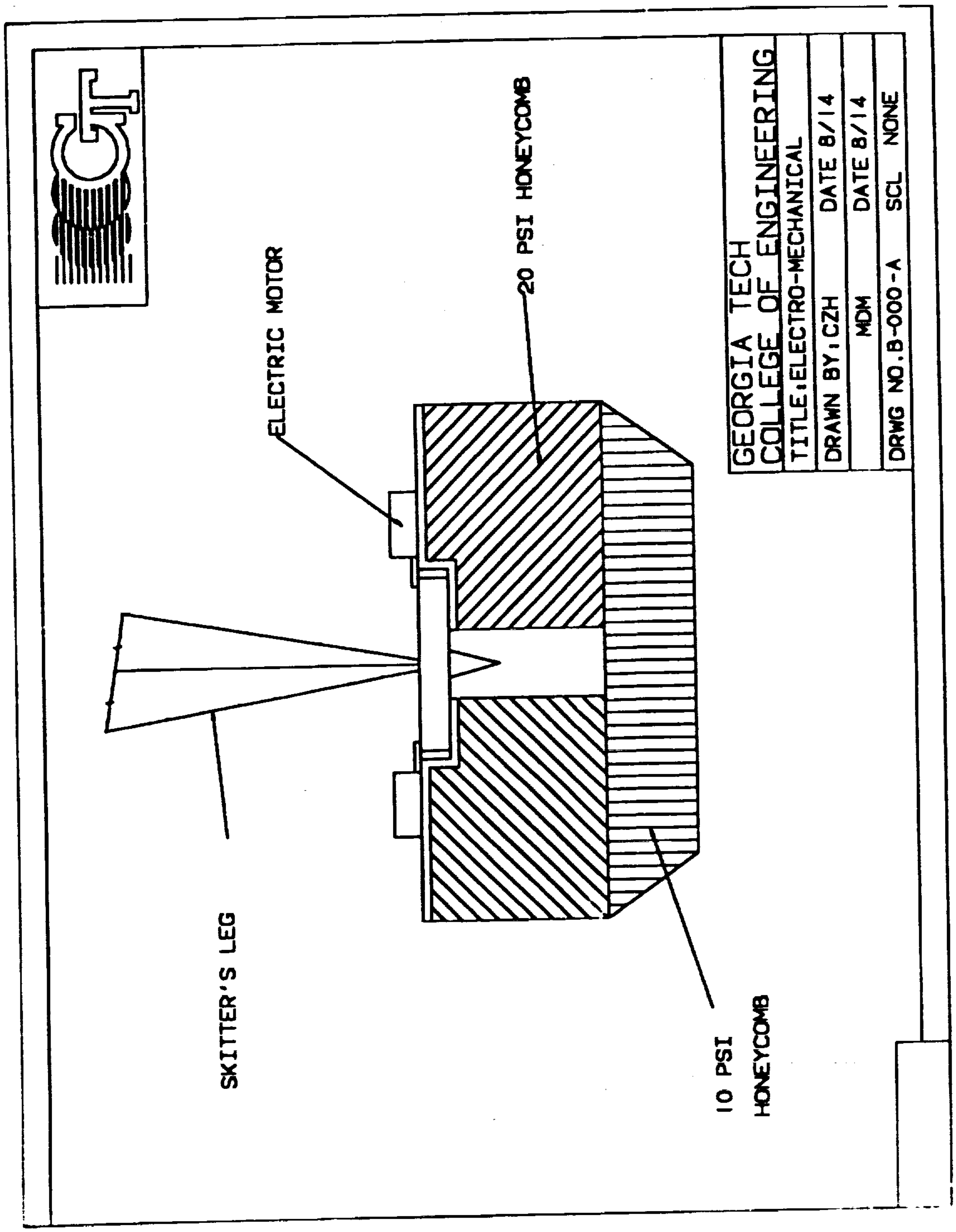

ELECTRIC MOTOR
20 PSI HONEYCOMB
SKITTER'S LEG
10 PSI HONEYCOMB
GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: ELECTRO-MECHANICAL
DRAWN BY: CZH DATE 8/14
MDM DATE 8/14
DRWG NO. B-000-A SCL NONE

Figure 3.2

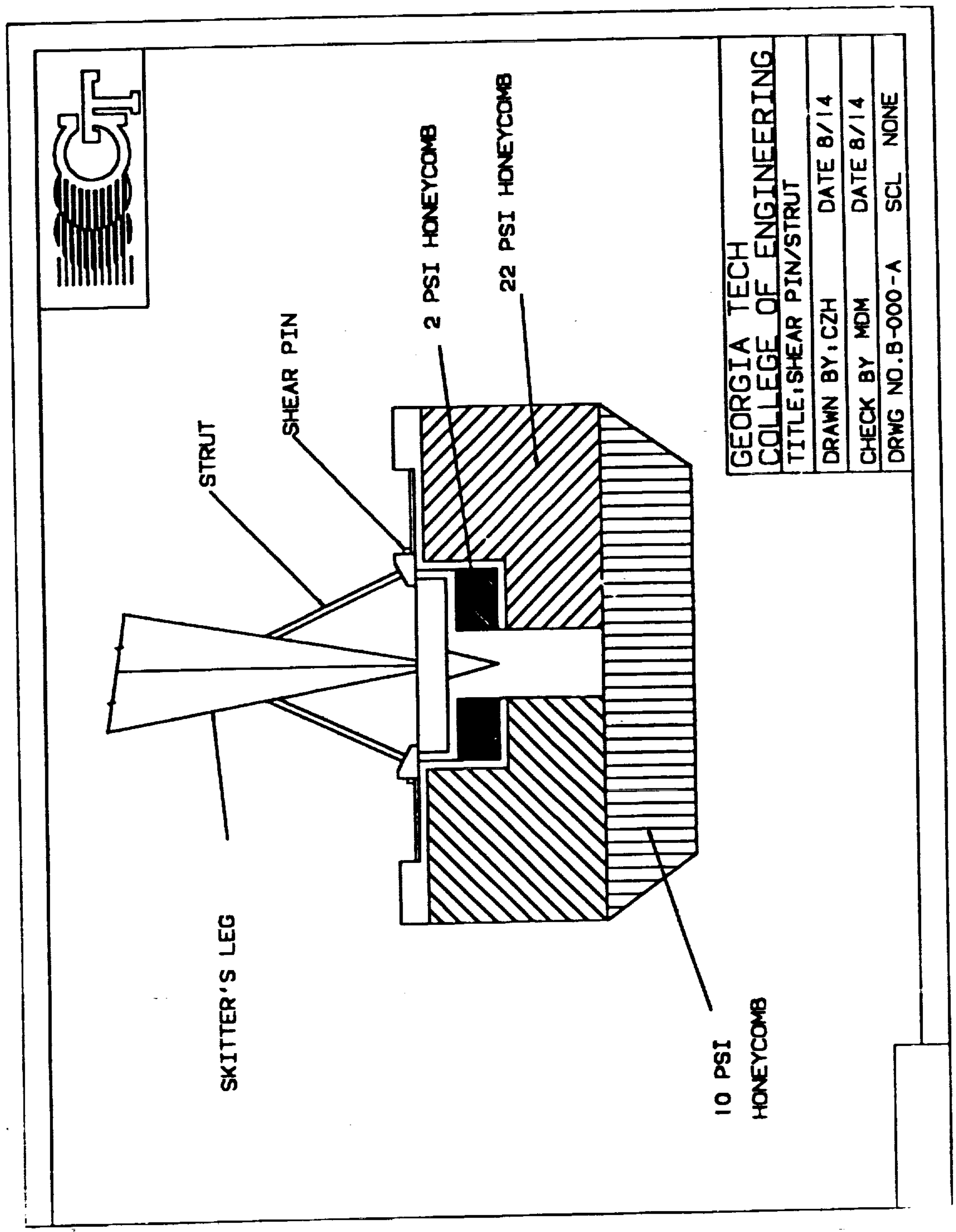

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE:SHEAR PIN/STRUT
DRAWN BY:CZH
DATE 8/14
CHECK BY MDM
DATE 8/14
DRWG NO.B-000-A
SCL NONE
STRUT
SHEAR PIN
2 PSI HONEYCOMB
22 PSI HONEYCOMB
SKITTER'S LEG
10 PSI
HONEYCOMB

Figure 3.3

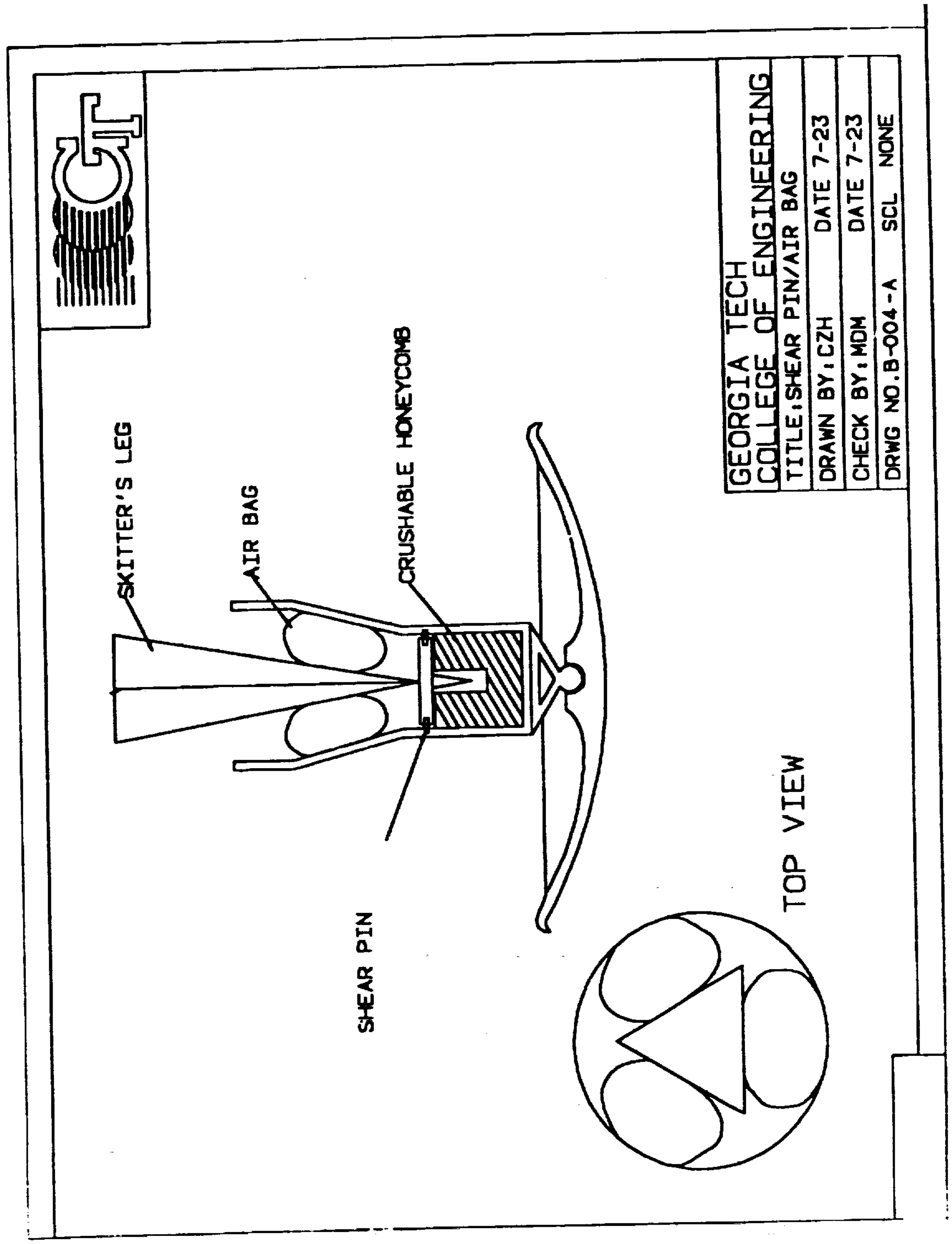

SKITTER'S LEG
AIR BAG
CRUSHABLE HONEYCOMB
SHEAR PIN
TOP VIEW
GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE:SHEAR PIN/AIR BAG
DRAWN BY:CZH DATE 7-23
CHECK BY:MDM DATE 7-23
DRWG NO.B-004-A SCL NONE

Figure 3.4

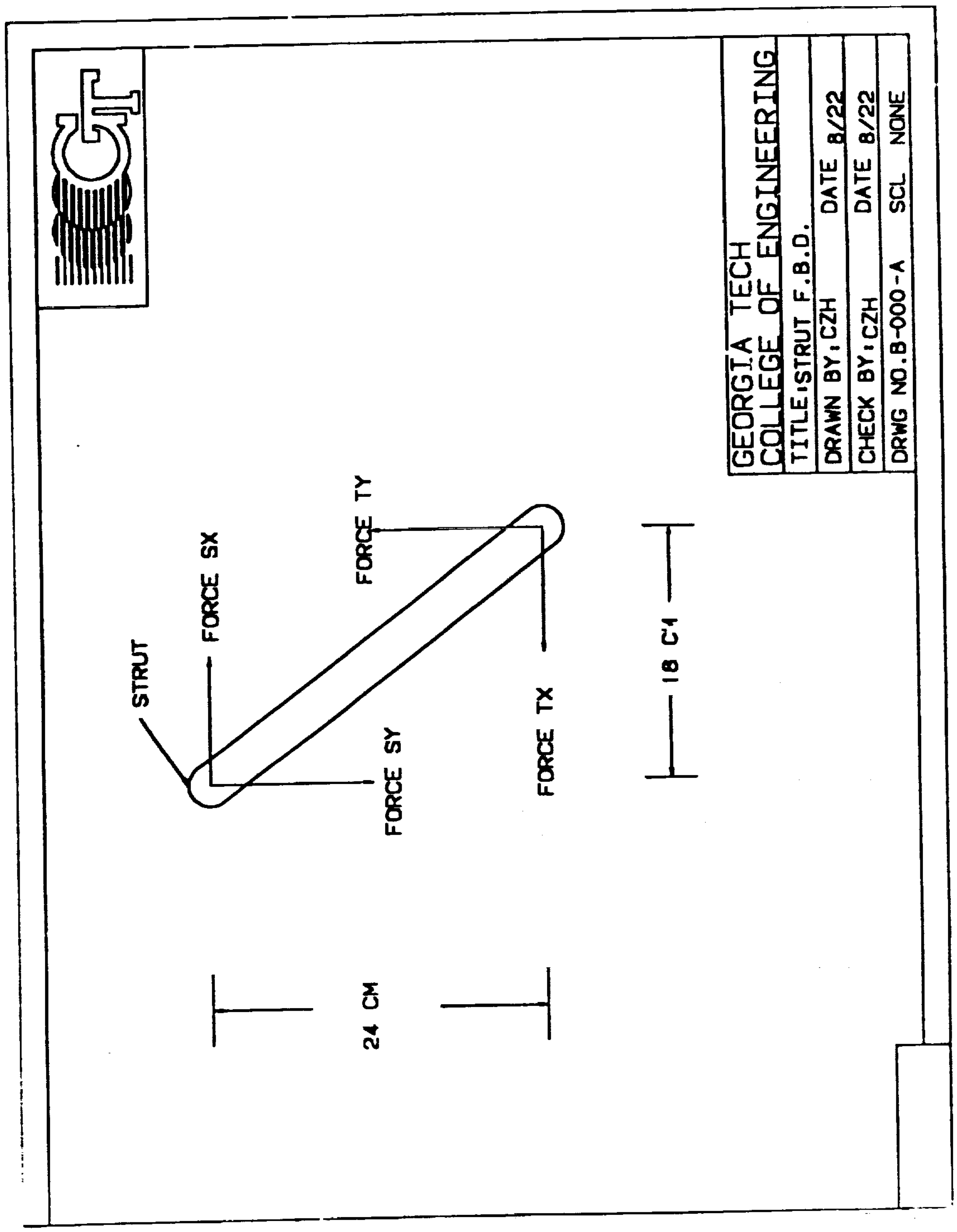
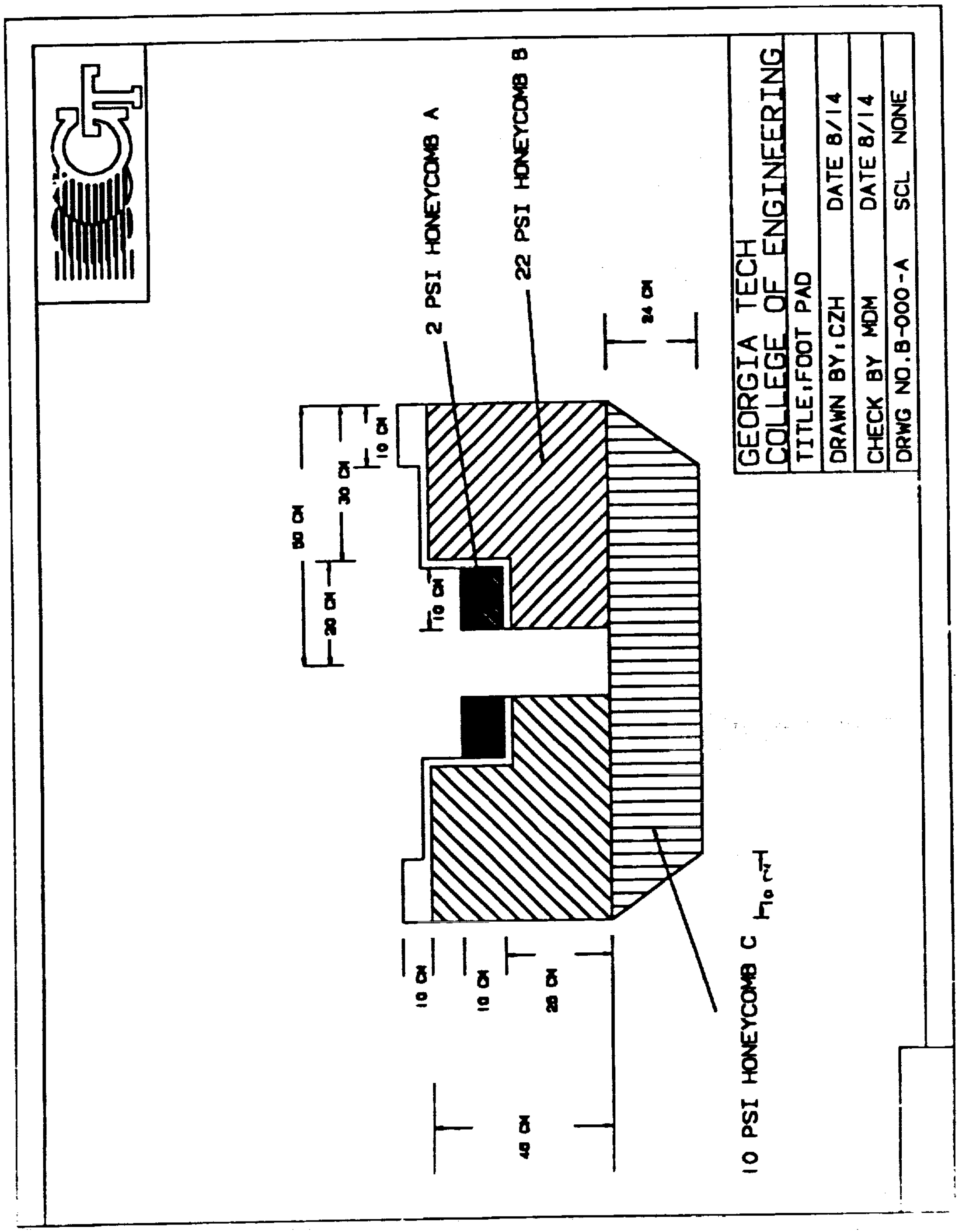

GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE:STRUT F.B.D.
DRAWN BY:CZH DATE 8/22
CHECK BY:CZH DATE 8/22
DRWG NO.B-000-A SCL NONE
STRUT
FORCE SX
FORCE SY
FORCE TY
FORCE TX
24 CM

Figure 3.5



2 PSI HONEYCOMB A
22 PSI HONEYCOMB B
10 PSI HONEYCOMB C
50 CM
30 CM
10 CM
20 CM
10 CM
24 CM
10 CM
10 CM
25 CM
40 CM
GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE:FOOT PAD
DRAWN BY: CZH DATE 8/14
CHECK BY MDM DATE 8/14
DRWG NO. B-000-A SCL NONE

Figure 3.6

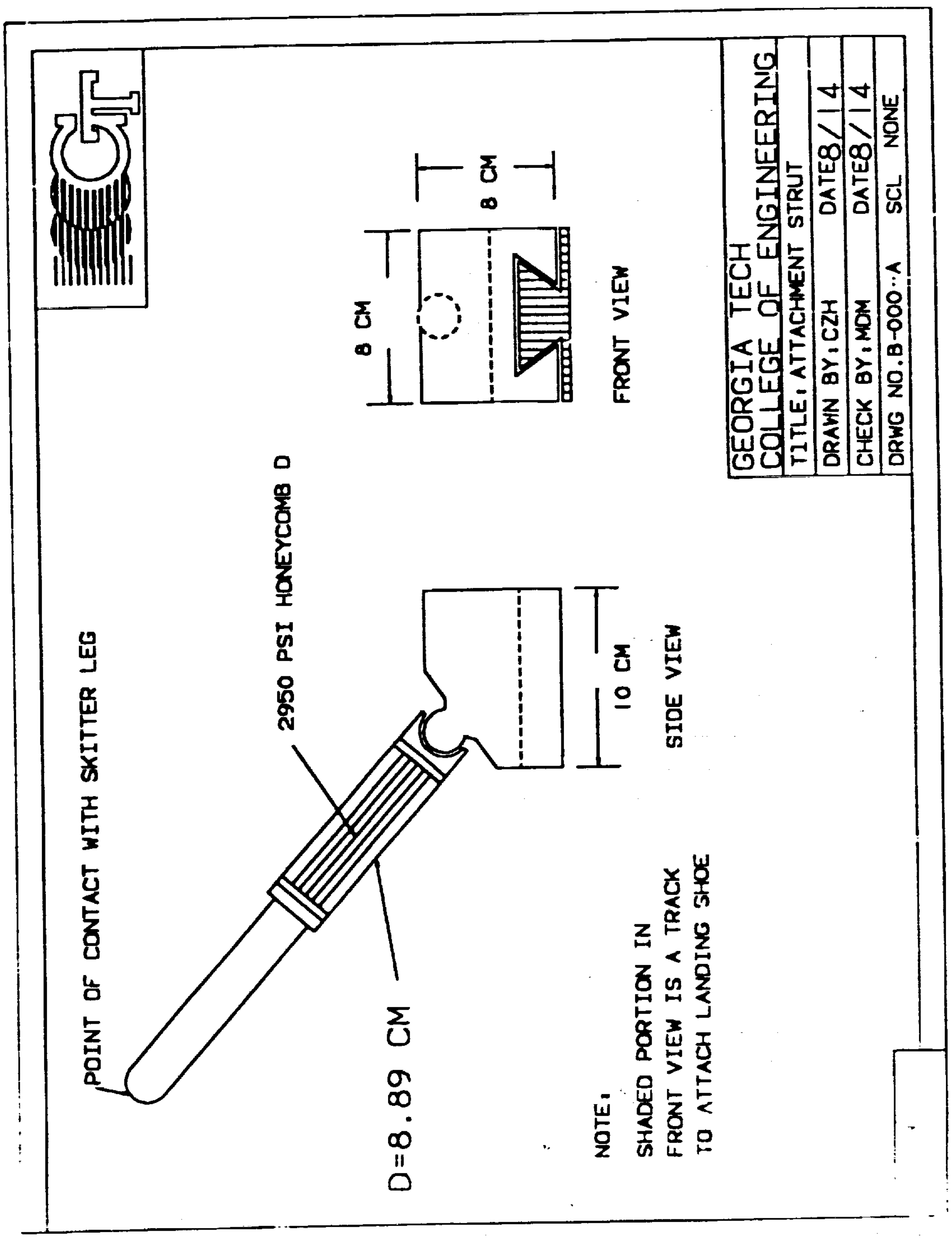

POINT OF CONTACT WITH SKITTER LEG
2950 PSI HONEYCOMB D
D=8.89 CM
10 CM
SIDE VIEW
8 CM
8 CM
FRONT VIEW
NOTE:
SHADED PORTION IN
FRONT VIEW IS A TRACK
TO ATTACH LANDING SHOE
GEORGIA TECH
COLLEGE OF ENGINEERING
TITLE: ATTACHMENT STRUT
DRAWN BY: CZH
DATE 8/14
CHECK BY: MDM
DATE 8/14
DRWG NO. B-000-A
SCL NONE

Figure 3.7

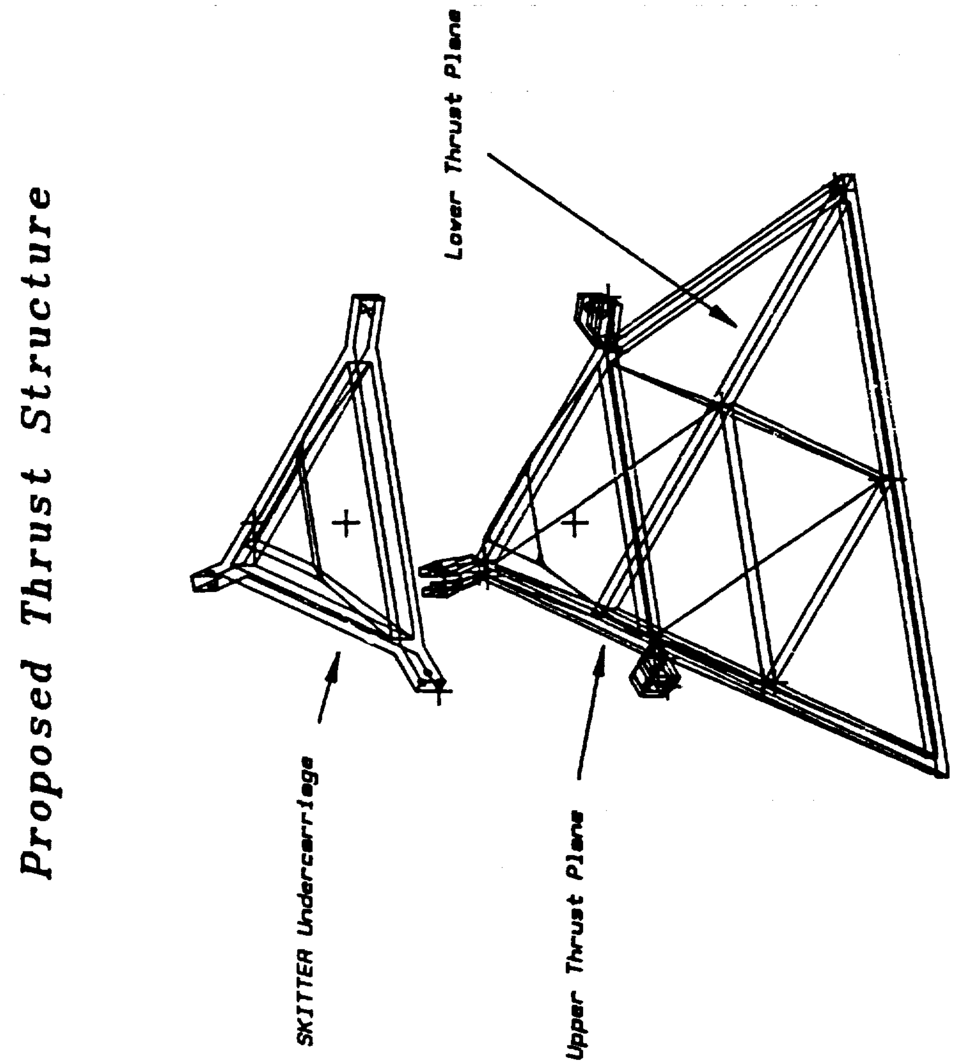

Proposed Thrust Structure
Lower Thrust Plane
SKITTER Undercarriage
Upper Thrust Plane

Figure 4.1

Proposed Attachment Assembly

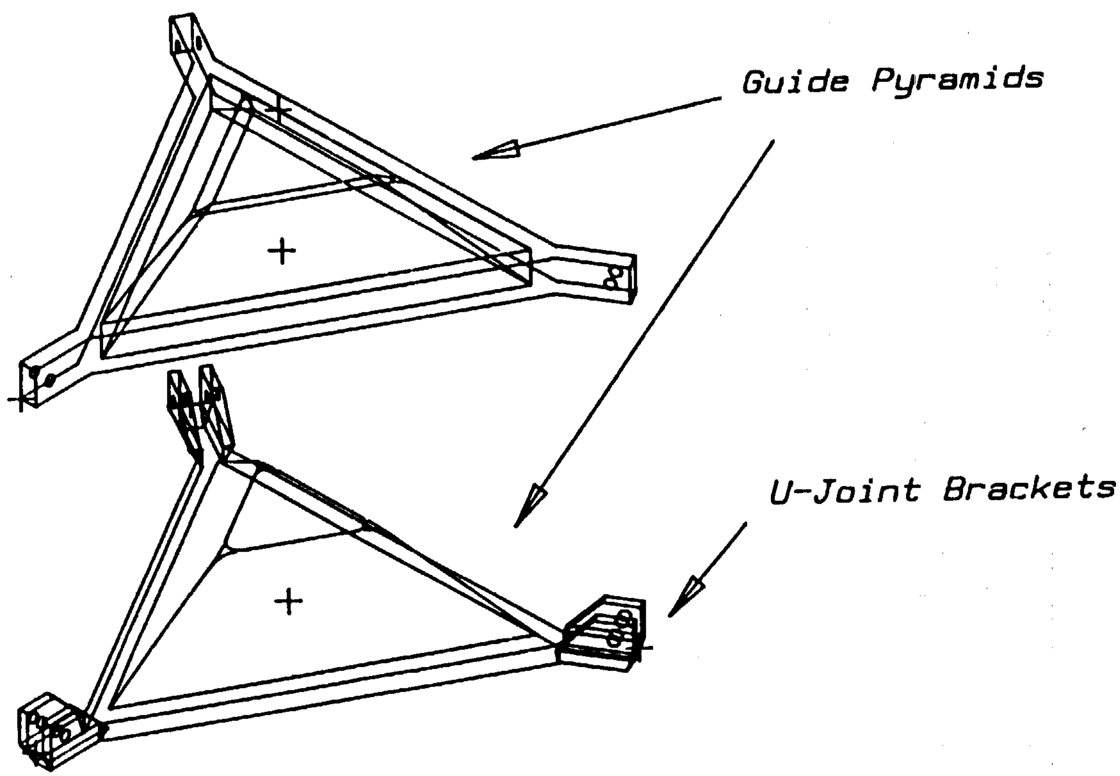


Figure 5.1

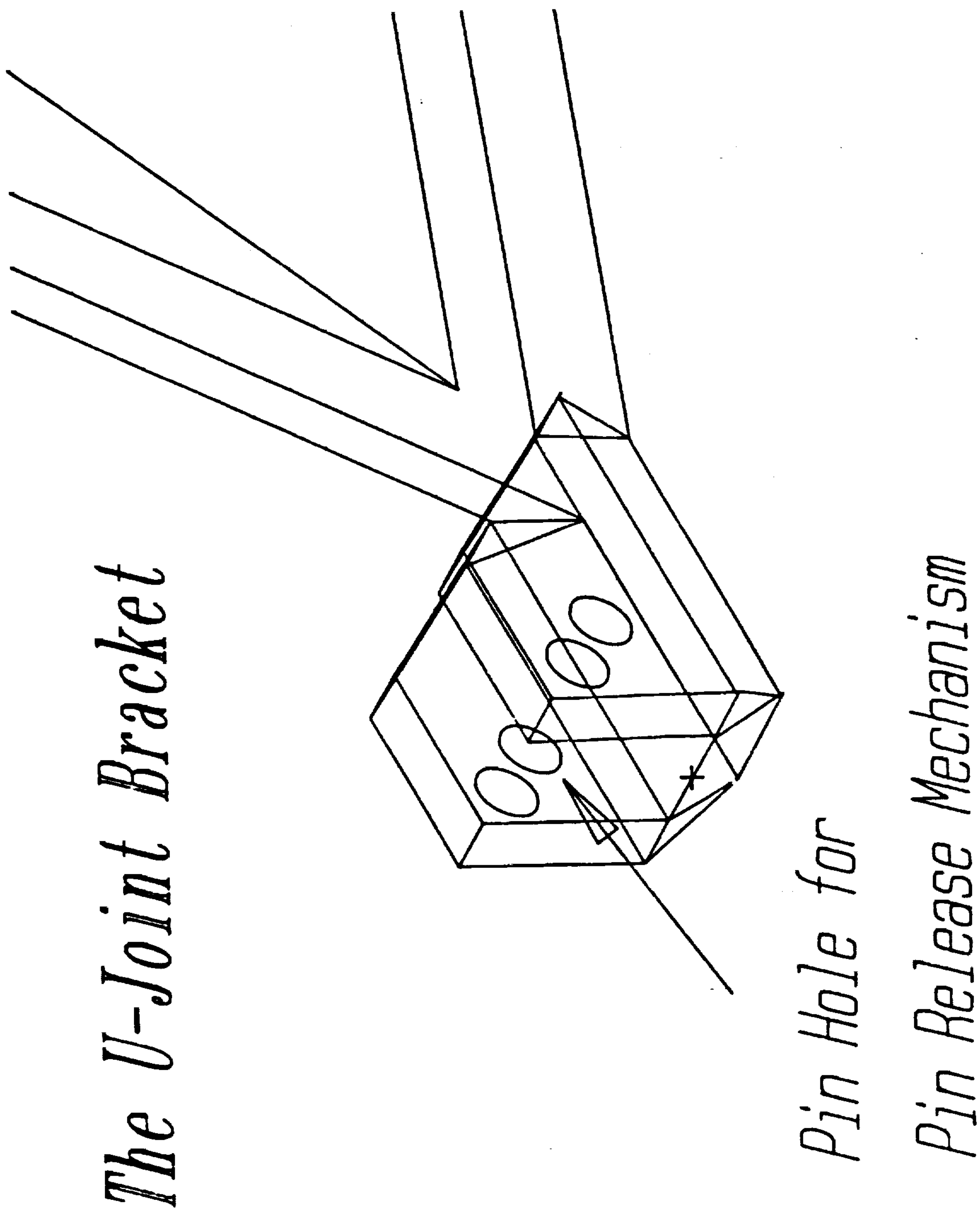
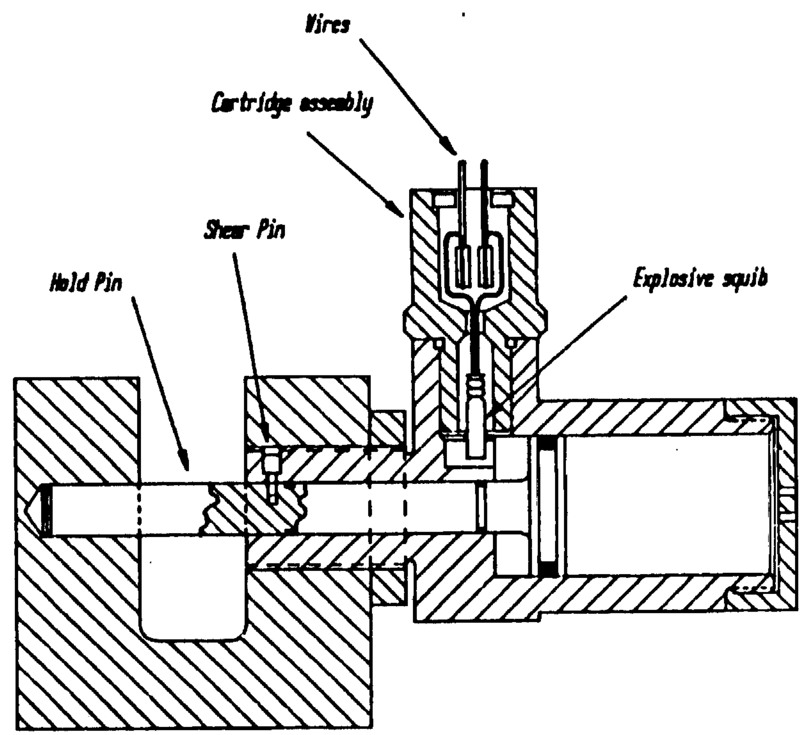


Figure 5.2

Pyrotechnic Pin Release Device



Pin retracts to release load

Figure 5.3

LANDING SHOE COST ANALYSIS

Al 7075-T6 cost: 2.50$/lb

Shoe frame: 22.4 Kg x 2.2lb/Kg x 2.5$/lb = $123.15

Labor:

5 hrs teflon track X 3 = 15 hrs
5 hrs Guided Catch X 3 = 15 hrs
20 hrs general = 20 hrs
total = 50 hrs

50 hrs X $12/hr. = $600.00

Ball Joints $30 X 3 = $90.00
Struts $50 X 3 = $150.00

Honeycomb: TUBE-CORE

psi	density (g/cm^3)	volume (cm^3)	cost
2	.0016	9,425	$1.20
22	.008	320,442	$512.72
10	.02	1,064	$85.12
2,950	.32	397	$31.80

Honeycomb total = $715.88

Total Cost for one Shoe = $123.15
\+ $600.00
\+ $ 90.00
\+ $150.00
\+ $715.88
$1579.03

cost for three shoes is $4737.09

ENGINE AND FUEL COST:

Cost to upgrade viking engine and requalify: $1.5 million

Cost per Engine: $ 250,000.00

Fuel Costs: Purified hydrazine monopropellant
$50.00 per lb mass

$1,500,000
\+ $ 750,000
\+ $170,300

$2,420,300.00

```
program FUEL_ESTIMATES (input, output);
  { This program calculates a rough estimate for the minimum  }
  { fuel requirements needed to land SKITTER on the Moon with }
  { an attached crane.                                        }

const
  MIN_SP_IMPULSE        =    179; { seconds }
  MAX_SP_IMPULSE        =    210;
  MIN_THRUST_PER_ENGINE =  275.79; { Newtons }        {     62 lbf     }
  MAX_THRUST_PER_ENGINE = 2811.26;                    {    632 lbf     }
  GRAVITY               =   1.635; {  m/s^2 } { Moon } { 6.434 ft/s^2 }
  MAX_BURN_TIME         =   510.0; {   sec  }
  RATIO_A_G             =    0.45; { Ratio of (a/g) - Trajectory      }
  PROPELLANT_DENSITY    = 1004.36; { Monoprop. Hydrazine  62.71bm/ft^3 }
  NUMBER_OF_TANKS       =       3; { One for each side for symmetry    }

var
  SP_IMPULSE         :    real;   { Total Specific Impulse                   }
  THRUST             :    real;   { Total Thrust                             }
  DELTA_V            :    real;   { Characteristic Velocity                  }
  EMPTY_MASS         :    real;   { Dry Mass of Landing Pod & Payload        }
  MASS_PROPELLANT    :    real;   { Mass of the Propellant                   }
  TOTAL_MASS         :    real;   { Total Mass : Fuel, Pod, Payload          }
  THR_TO_WT_RATIO    :    real;   { Thrust-to-Weight Ratio                   }
  PERCENT_THRUST     : integer;   { Percent of Maximum Thrust                }
  NUMBER_OF_ENGINES  : integer;   { Number of Engines Required to Land       }
  TANK_VOLUME        :    real;   { Volume of a single tank                  }
  TOTAL_TANK_VOLUME  :    real;   { Volume of all of the tanks               }
  MASS_PER_TANK      :    real;   { Mass of propellant per tank              }
  OKAY_THR_TO_WT     : boolean;   { Flag that Assures TTW > 1                }

function DRY_MASS : real;
const
  MASS_SKITTER     =  907.19; { kg }                {   2000 lbm }
  MASS_CRANE       = 1638.39;                       {   3612 lbm }
  MASS_THR_STRUCT  =   84.95;                       {  184.7 lbm }
  MASS_POWER_SYS   =  113.47;                       {    250 lbm }
  MASS_GUID_NAV    =   90.72;                       {    200 lbm }
  MASS_FUEL_SYS    =  226.80;                       {    500 lbm }
  MASS_SHOES       =   90.84;                       { 3 * 67 lbm }
  MASS_MISC        =   45.36;                       {    100 lbm }

begin
  DRY_MASS := MASS_SKITTER + MASS_CRANE + MASS_THR_STRUCT +
              MASS_POWER_SYS + MASS_GUID_NAV + MASS_FUEL_SYS +
              MASS_SHOES + MASS_MISC
end;

function INTERPOLATE ( PERCENT, NUMBER_OF_ENGINES : integer;
                       MIN_PER_ENGINE, MAX_PER_ENGINE : real ) : real;
begin
  INTERPOLATE := ((PERCENT / 100.0) * (MAX_PER_ENGINE -
                 MIN_PER_ENGINE) + MIN_PER_ENGINE) * NUMBER_OF_ENGINES
end;

function MILES_TO_METERS ( MILES : real ) : real;
const
  CONV_FACT = 6.2137E-4;
begin
  MILES_TO_METERS := MILES [illegible] CONV_FACT
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
end;

function PROPELLANT_MASS ( EMPTY_MASS, SP_IMPULSE, GRAVITY,
                           DELTA_V : real ) : real;

const
  VERNIER_FUEL_MASS = 100;   { kg }
  RESIDUAL_PERCENT  =   2;   { %  }

var
  PROPELLANT   : real; { Temporary variable for Propellant Mass }

begin
  PROPELLANT := EMPTY_MASS * exp ( DELTA_V / ( GRAVITY *
                      SP_IMPULSE )) - EMPTY_MASS;
  PROPELLANT := (PROPELLANT + VERNIER_FUEL_MASS) * ((100 +
                   RESIDUAL_PERCENT) / 100.0);
  PROPELLANT_MASS := PROPELLANT

end;

function CUBE ( X : real ) : real;
  { This function calulates x^3 }
begin
  CUBE := X * X * X
end;

function ORBIT_SPEED : real;
  { This uses Kepler's Third Law to calculate the required speed }
  { necessary to maintain an orbit around the Moon.              }
const
  PI          =   3.14159;
  MOON_RAD    =  1.738E+6;     {  meters   }
  UNIV_GRAV   = 6.673E-11;     { Nm^2/kg^2 }
  MASS_MOON   =   7.36E22;     {    kg     }
  ORBIT_MILES =      50.0;     {   miles   }

var
  ORBIT_RAD      :     real;     {  [meters]                           }
  K_SUB_S        :     real;     { Kepler's Constant [s^2/m^2]         }
  TOTAL_RADIUS   :     real;     { From center of Moon to satelite     }
  PERIOD         :     real;     {  [ sec.]                            }
  OMEGA          :     real;     {  [rad/s]                            }

begin
  ORBIT_RAD := MILES_TO_METERS ( ORBIT_MILES );
  K_SUB_S := 4.0 * sqr ( PI ) / (UNIV_GRAV * MASS_MOON);
  TOTAL_RADIUS := ORBIT_RAD + MOON_RAD;
  PERIOD := sqrt ( K_SUB_S * CUBE (TOTAL_RADIUS) );
  OMEGA := 2.0 * PI / PERIOD;
  ORBIT_SPEED := OMEGA * TOTAL_RADIUS

end;

begin
  THR_TO_WT_RATIO := 0.0;
  NUMBER_OF_ENGINES := 1;
  EMPTY_MASS := DRY_MASS;

  DELTA_V := GRAVITY * MAX_BURN_TIME * RATIO_A_B;
  OKAY_THR_TO_WT := false;
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
while not OKAY_THR_TO_WT do
  begin
    PERCENT_THRUST := 5;
    while (PERCENT_THRUST <= 100) and not OKAY_THR_TO_WT do
      begin
        THRUST := INTERPOLATE ( PERCENT_THRUST, NUMBER_OF_ENGINES,
                                MIN_THRUST_PER_ENGINE,
                                MAX_THRUST_PER_ENGINE );

        SP_IMPULSE := INTERPOLATE ( PERCENT_THRUST,NUMBER_OF_ENGINES,
                                MIN_SP_IMPULSE, MAX_SP_IMPULSE );

        MASS_PROPELLANT := PROPELLANT_MASS ( EMPTY_MASS, SP_IMPULSE,
                                GRAVITY, DELTA_V );

        TOTAL_MASS := MASS_PROPELLANT + EMPTY_MASS;
        THR_TO_WT_RATIO := THRUST / (TOTAL_MASS * GRAVITY);

        if THR_TO_WT_RATIO > 1.0 then
          OKAY_THR_TO_WT := true
        else
          PERCENT_THRUST := PERCENT_THRUST + 5
      end;  { while PERCENT_THRUST }
    if not OKAY_THR_TO_WT then
      NUMBER_OF_ENGINES := NUMBER_OF_ENGINES + 1
  end;  { while THR_TO_WT_RATIO }
 TOTAL_TANK_VOLUME := MASS_PROPELLANT / PROPELLANT_DENSITY;
 MASS_PER_TANK := MASS_PROPELLANT / NUMBER_OF_TANKS;
 TANK_VOLUME := TOTAL_TANK_VOLUME / NUMBER_OF_TANKS;

writeln; writeln; writeln; writeln; writeln; writeln;
writeln; writeln; writeln;
writeln ( 'MINIMUM FUEL CALCULATIONS FOR LANDING POD, SKITTER, AND CRANE');
writeln;
writeln ( 'Number of Engines Required:',NUMBER_OF_ENGINES : 2 );
writeln ( 'Total Thrust :', THRUST : 7 : 1, ' N' );
writeln ( 'Total Specific Impulse :', SP_IMPULSE : 6 : 1, ' sec' );
writeln ( 'Percent of Max. Thrust :', PERCENT_THRUST : 3,' %' );
writeln ( 'Total Empty Mass :', EMPTY_MASS : 7 : 1, ' kg' );
writeln ( 'Total Propellant Mass :',MASS_PROPELLANT : 7 : 1, ' kg' );
writeln ( 'Total Initial Mass of Spacecraft :',TOTAL_MASS :7:1,' kg' );
writeln ( 'Thrust to Weight Ratio :',THR_TO_WT_RATIO : 7: 4 );
writeln ( 'Orbit Speed :', ORBIT_SPEED : 6 : 1, ' m/s');
writeln ( 'Total Fuel Volume :', TOTAL_TANK_VOLUME : 7 : 4, ' m^3' );
writeln ( 'Individual Tank Volume :', TANK_VOLUME : 7: 4,' m^3' );
writeln ( 'Fuel Mass Per Tank : ', MASS_PER_TANK : 5: 1,' kg' );
writeln; writeln; writeln; writeln
end.  { FUEL_ESTIMATE }
```

MINIMUM FUEL CALCULATIONS FOR LANDING POD, SKITTER, AND CRANE

Number of Engines Required: 3
Total Thrust : 8053.5 N
Total Specific Impulse : 625.3 sec
Percent of Max. Thrust : 95 %
Total Empty Mass : 3197.7 kg
Total Propellant Mass : 1548.2 kg
Total Initial Mass of Spacecraft : 4745.9 kg
Thrust to Weight Ratio : 1.0379
Orbit Speed :1643.4 m/s
Total Fuel Volume : 1.5415 m^3
Individual Tank Volume : 0.5138 m^3
Fuel Mass Per Tank : 516.1 kg

>

Fuel Tank Wall Thickness Calculations:

The tank wall thickness is dependent on several factors. Three primary factors are vessel pressure and temperature and storage time.

The wall thickness is given by:

$$ts = k*P_t*r/2*o$$

Where:

- ts = vessel wall thickness
- k = factor of safety (between 1.5 and 2.0)
- P_t = vessel storage pressure
- o = tensile strength of material
- r = calculated required radius from fuel mass

$$ts = 1.5*(500psia*106.3cm)/2*(50{,}000psia)$$
$$= .313 \text{ inches} = .795 \text{ cm}$$

V_t = volume of titanium
$= 4*pi*r^3 - 4*pi*r^3$
$= 0.086\ m^3$

Technical Information on MR-80

Manufacturer :	Rocket Research Corp. Redmond, Washington
Overall Length :	10.3 in.
Maximum Diameter:	10.5 in.
Dry Mass :	16.9 lbm
Throttling Range :	60 - 600 lbf
Rated Duration :	500 sec
Propellant :	Monoprollant Hydrazine
Fuel Density :	62.7 lb/cu.ft
Specific Impulse :	179 - 210 lbf-s/lbm
Mass Flow Rate :	.35 - 3.10 lbm/sec
Nozzle :	
Type :	18 canted Bell Nozzles
Throat Diam. :	0.345 in
Exit Diam. :	1.422 in
Exhaust Temperature :	1600 F
Cooling Techinique :	Radiation
Material :	Hastelloy B
Injection :	
Type :	Radial Flow
State of Fuels :	Liquid
Combustion Chamber :	
Temperature :	1600 F
Cooling Techinique :	Radiation
Ignition System :	
Catalytic decomposition	
Qualification Date :	August, 1973

Thrust Structure Force and Weight Analysis

l= Length.
Size= Diameter of aluminum tubing times the thickness.
Ptot= Total applied load.
sf= safety factor.
Psf= Total applied load multiplied by the safety factor.
Pcr= Critical load.
Icalc= Calculated moment of intertia.
Istan= Standard moment of inertia in the table.
Wa= Weight of member per unit length.
W1tot= Total weight of member 1.
Z= Section modulus.
Sy= Yield strength.
Su= Tensil Strength.
Wtot= Total weight of structure.
E= 1.03E+07 psi
C= 1

Member 1 Upper Horizontal		Member 2 Diagonal		Member 3 Lower Horizontal			
Wtot	1895.334 lbf	w=	55.01889 lbf/in	I=	1.132 in^4		
sf=	2						
Wsf=	3790.669 lbf						
l=	96.4361 in	l=	68.8976 in	l=	180.25 in		
Fbx=	2680.372 lbf	Mmax=	3.26E+04 lbf-in	Pload=	2680.372 lbf		
Fr=	4642.592 lbf	Z=	0.906 in^3	Pcr=	3541.871 lbf		
Pcr=	4642.592 lbf	Sy=	72000 psi				
		Su=	82000 psi				
Icalc=	0.424719 in^4	Scalc=	36033.12 psi				
Istan=	1.132 in^4	sf=	2.00	sf=	1.32		
Size= 2.5 x .25		Size= 2.5 x .25		Size= 2.5 x .25			
Wa=	0.178166 lbf/in	Wa=	2.138 lbf/in	Wa=	2.138 lbf/in	Wtot=	
W1t=	17.19169 lbf	W2t=	12.27525 lbf	W3t=	32.11454 lbf		187.4 lbf

Cost Analysis

Al7075-T6 = 2.50 $/lb
Hourly Wage= 15 $/hr.

Total Weight of Structure	187.4 lbf
Material Cost	468.5 dollars
Total Labor Hours	125 hrs.
Labor Cost	1875 dollars
Total Cost	2343.5 dollars

ORIGINAL PAGE IS OF POOR QUALITY

ME 4182

THE DESIGN AND ANALYSIS OF A LUNAR LANDING MODULE FOR SKITTER

PROJECT PROPOSAL

GROUP B:

GL: MICHAEL RICE
DAVID HERMAN
MARK MORELLI
MICHAEL POPE
FRANK HUANG
CHIMA NJAKA

July 7,1987

PROBLEM STATEMENT

To design a lunar landing module for the SKITTER vehicle. SKITTER is a three legged mobile lunar transport and work platform. This lunar landing module must be able to bring SKITTER, with attached crane, from a lunar orbit to the surface of the moon. This propulsion system must be entirely self-contained and removable after touchdown. SKITTER is unmanned and must be able to touchdown on the lunar surface and perform assigned tasks independent from other space or lunar vehicles.

We must design the propulsion system and ensure that the SKITTER structure will withstand landing stresses. This includes modification of existing SKITTER structure if necessary. An engineering analysis will be conducted to determine the best and most economical design to land SKITTER safely on the moon.

JUSTIFICATION

SKITTER will perform various tasks on the surface of the moon. The completion of this project will determine the feasibility of landing SKITTER with the attached crane safely on the lunar surface.

ASSIGNED TASKS

The work to be performed is primarily in the areas of the propulsion system to transport SKITTER to the moon's surface and structural modifications so that the vehicle will be able to withstand landing impact forces. Engine design and minimum fuel requirement analysis will be done by Michael Pope and David Herman. Mounting apparatus and fuel cell design will be done by Michael Rice and Chima Njaka. The landing shoe design and the SKITTER structural modifications will be conducted by Frank Huang and Mark Morelli. Each member of the group will be responsible for completing assigned CADAM drawings.

BIBLIOGRAPHY

REFERENCES

1. Barrere et al., Rocket Propulsion, D. Van Nostrand Company, Inc., Princeton, New Jersey, 1960.

2. Brooker, P.J., G.C. Frewer amd G.K.C. Pardoe. Project Apollo, New York: American Elseveir, 1969.

3. Bryson, Arthur E. Jr. and Yu-Chi Ho. Applied Optimal Control, Hemisphere Publishing Corp., Washington, D.C., 1975.

4. Chironis, Nicholas P., Machine Devices and Instrumentation, New York: McGraw-Hill, 1966.

5. Cornelisse, J.W., Schoyer, H.R.F., Wakker, K.F., Rocket Propulsion and Spaceflight Dynamics, Fearon-Pitman Publishing, Inc., Belmont, California, 1979.

6. Davidson et al., LLV: Lunar Logistics Vehicle, (NASA CR 102078), N70-17551, Sept. 1979.

7. Flinn, Richard A., Trojan, Paul K., Engineering Materials and Their Applications. Third Edition. Boston: Houghton Mifflin Company, 1986.

8. Hallian, Richard P., et al. Apollo: Ten Years Since Tranquility Base, Washington, D.C.: National Air & Space Museum, 1979.

9. Martin-Marietta Corporation, The Viking Mission to Mars, Denver, Colorado, 1975.

10. Mission Evaluation Team, NASA Manned Spacecraft Center, Apollo 11 Mission Report, Washington, D.C.: National Aeronautics and Space Administration, 1971.

11. Mitchell, Larry D., Shigley, Joseph E., Mechanical Engineering Design, Fourth Edition, New York: McGraw-Hill, 1983.

12. Society of Automotive Engineers, Inc., Apollo - A Program Review SP-257, New York: 1964.

13. Sutton, George P., Rocket Propulsion Elements, 5th ed., John Wiley & Sons, New York, 1986.

14. Turner, Maxine T., Technical Writing: A Practical Aproach. Reston, Virginia: Reston Publishing Co., 1984.

15. Wilson, Andrew. The Eagle Has Wings: The Story of American Space Exploration. London, England: Gresham Press, 1982.