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Integral Habitat Transport System

Group:

Bill Elliott
Scott Frazer
Joey Higgs
Jason Huff
Tigree Milam

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Introduction

In the 1993 Fall quarter, the ME 4182 design class was sponsored to study various scenarios that needed to be studied for Martian travel. The class was sponsored by NASA and there were several different design projects. The design that group three chose was an integral transport system for a Martian habitat. An integral transport system means the design had to be one that was attached to the habitat. There were several criteria that the design had to meet. Group three performed an in depth study of the Martian environment and looked at several different design ideas. The concept group three developed involved the use of kinematic linkages and the use of Martian gravity to move the habitat. The various design concepts, the criteria matrices and all other aspects that helped group three develop their design can be found in their 1993 ME 4182 design report.

Now it is Winter quarter 1994 and group three is faced with another problem. The problem is building a working prototype of their Fall design. The limitations this quarter were the parts. The group had to make the prototype work with existing manufactured parts or make the parts themselves in a machine shop. The prototype was scaled down roughly about twelve times smaller than the original design. The following report describes the actions taken by group three to build a working model.

Outline of Operations

The habitat will move by kinematic actuation of legs mounted on the end of the habitat. On each end of the habitat there are three leg linkages with each set having four legs. Each set of legs are actuated independently. There are three legs in contact with the ground at all times. The legs are located 30 degrees apart. To move the habitat, the leg located opposite to the direction of travel actuates out causing the habitat to pivot about the center leg. Once the habitat pivots passed the center of gravity the habitat rolls over by gravity onto another leg which will actuate down. To turn the habitat, the side opposite to the desired turn needs to be actuated while the other side is not. For example, to turn left the habitat needs to be actuated on the right-hand side. For a more detailed description of the operations refer to the 1993 Fall quarter ME 4182 group three design report.

Overview of Model's Parts:

Four Leg Linkages:

Material: Aluminum U-shaped beams

Lengths: Long = 25.54 inches

Short = 13.4 inches

Joints: 5/16" x 2" bolts, tapped with 8-32 screw thread

1/2" OD x 5/8" long x 3/8" ID nylon spacers

3/4" OD x 13/64" long x .385" ID nylon spacers

Rivets

Habitat:

Material: Sheet Metal

Length: 3 feet

Diameter: 16 inches

Actuator:

Rod died with 2 inches of 8-32 screw stock

Motor: Johnson Electric #3202 144233-01

Gears: Black & Decker Automatic Screwdriver

Disks:

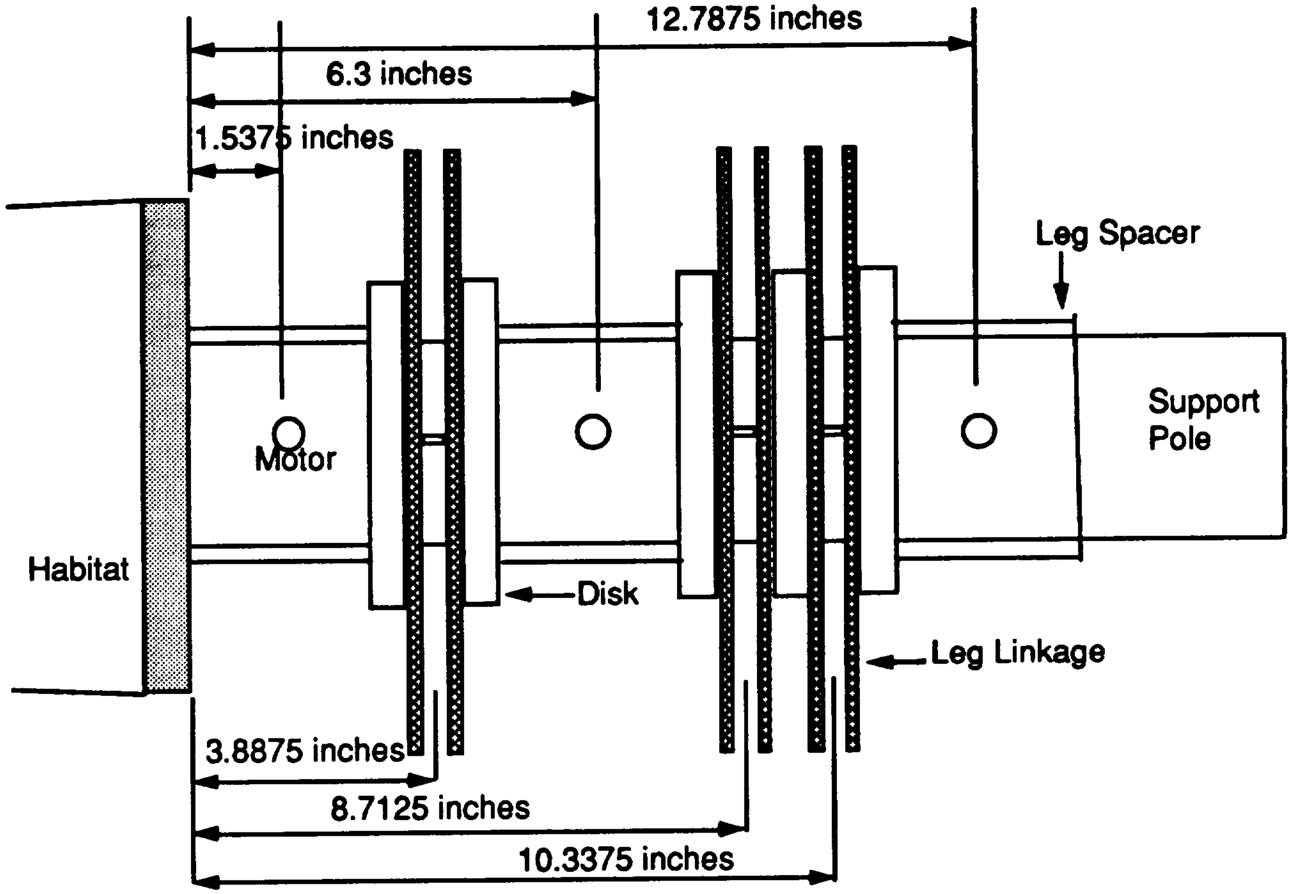
Material: Plexiglas

Outside Diameter: 10 inches

Slot Length: 1 1/2"

General Assembly

Shown below is a sketch of the assembly pattern for the integral transport system. The length shown represent the distances from the edge of the habitat to the center of the motor or the center of the actuation rod.



Habitat

The prototype is made of 16 inch sheet metal pipe. The end caps are cut out of 14 gauge sheet metal and machined to get the pipe (Material courtesy of Searcy Heating & Air Thomasville, GA). The end caps are attached by sheet metal screws.

Four Leg Linkages

The leg length were found using the proportions between the two habitat diameters. The design of the Integral Habitat Transport System (Appendix) was based on a habitat diameter of 5 meters. Using a diameter of 18 inches for the model, the leg lengths are found using the following equations.

$$\frac{L}{3.72 meters} = \frac{18 \text{ inches}}{5 meters}$$

$$L = 13.4 \text{ inches}$$

$$\frac{z}{3.5 meters} = \frac{18 \text{ inches}}{5 \text{ meters}}$$

$$z = 3.5 \text{ inches}$$

$$\frac{x}{3.2 meters} = \frac{18 inches}{5 meters}$$

$$x = 11.52 \text{ inches}$$

The long leg length = 2x + z = 26.54 inches
The short leg length = 11.52 inches

Aluminum U-shaped beams were used to build the leg linkages.
The legs were joined using rivets with a nylon spacer between each leg.
Bolts (5/16" x 2 ") and nylon spacers joined the legs at the actuation points.

Leg Spacers

Spacers were used to separate the leg linkages while allowing room for the gear sets. The length of the spacers was determined by measuring the distance from the center of the gear at the motor to the center of the actuation rod. By setting that distance equal to half the spacer length plus the width of a disk, a leg, and half of a nylon spacer, the length of the spacer is found. The length of the three spacers were as follows:

First spacer = 2.475 inches
Middle spacer = 2.7 inches
Last spacer = 2.775 inches

The leg spacers were made of a Plexiglas type tube with an inner diameter of 2 inches. The inner diameter of the spacer was the same as the outer diameter of the support pole. This provided a secure fit between the two tubes.

Support Pole

The support pole was used to house the gear sets and to place the leg linkages and disks. The pole is made of a Plexiglas type tube with an outer diameter of 2 inches and an inner diameter of 1.75 inches. The Plexiglas type tube was chosen because it had the desired inner and outer diameters, not because of its material properties. The pole had a total length of 6 feet. The pole ran through the habitat and out the end to support the leg linkages. Holes were drilled and slots were milled out to allow room for the motor and screw/actuator.

Disc System

Discs were introduced to the design to help reduce the moment on the leg linkages. The discs are 10 inches outside diameter and 2 inches inside diameter. The discs contain 1 1/2 inch slot positioned 180 degrees apart. These slots allow the leg's joints to slide up and down as they move.

Gear Assembly

Gears from the Black and Decker Automatic screwdriver were utilized to provide torque to turn the screw. In addition, two other gears were used to translate the torque to the screw/actuator position.

Forces

In order to determine the forces present in each member of the model, detailed force diagrams had to be completed. These force analysis calculations were done for the worst case scenarios to ensure proper load handling capabilities. The weight of the model was found to be 40 lbs. The first worst case scenario is found when one leg is at its minimum distance to the ground while supporting half of the weight of the entire system, with the load screw mounted parallel to the ground. The other worst case scenario occurs when the model is on a 30° slope with one leg extended to its maximum distance, while supporting the weight of half the model. To be a worst case scenario, this occurs while the load screw is mounted perpendicular to the centerline of the member. Although these two scenarios would probably never occur, the model is designed to withstand these forces as an added factor of safety.

When the load screw is mounted perpendicular to the ground and the model has to be raised from a minimum distance, the forces in the screw will always be 20 lb in compression because the screw is acting along the centerline of the model. This is not a worst case scenario, because the screw is acting along the centerline of the model. Therefore, the forces in the worst case scenarios need to be calculated, so that a torque can be determined which, when applied to the screw, will cause the model to actuate.

For the first worst case, a normal force of 20 lb acts straight up into the connection joining the two L legs together. This force is then translated into the two legs to give the force equivalents. Due to the two legs being symmetric about the normal force, the force equivalents are equal in both legs.

$$F_1 = 20\text{ lb} / [2\sin(90-\beta/2)]$$

$$F_1 = 20\text{ lb} / [2\sin(36.15)]$$

$$\mathbf{F_1 = 16.95\text{ lb}\ \ Compression}$$

Now, the forces in the two X legs can be calculated. Once again, the two angles are equivalent, therefore the two new force equivalents will also be the same.

$$F_2 = F_1 / \cos(\alpha)$$

$$F_2 = 16.95\text{ lb} / \cos(54.585°)$$

$$\mathbf{F_2 = 29.25\text{ lb}\ \ Compression}$$

At the junction of the two X legs and the two Z legs, the four legs meet symmetrically. This means that the forces present in the X legs equals those found in the Z legs. The next connection corresponds to the junction where the load screw is connected to the Z legs. Seeing as how the load screw sits symmetrically within the design at this time, the force equivalents in the screw can be easily found.

$$F_s = F_2 * \cos(\phi/2)$$

$$F_s = 29.25\text{ lb} * \cos(18.435°)$$

$$\mathbf{F_s = 27.75\text{ lb}\ \ Tension}$$

For the other worst case scenario; while on a 30° slope, a force of 20 lb acts at an angle of 30° upon the connection between the two L legs in the direction of gravity. The 20 lb force translates onto the 30° slope with a Y component and an X component, which then translate into the L legs.

$$Y = 20\text{ lb} * \sin(60°)$$

$$\mathbf{Y = 17.322\text{ lb}}$$

$$X = 20\text{ lb} * \sin(30°)$$

$$\mathbf{X = 10\text{ lb}}$$

By summing the forces in the X and Y directions, the force equivalents can be determined in the L legs. The upper leg will be designated as F_1 and the lower leg as F_2.

$$\Sigma F_y = 17.322\text{ lb} = F_2 * \sin(30 - \theta/2) + F_1 * \sin(30 + \theta/2)$$

$$\Sigma F_y = 17.322\text{ lb} = F_2 * \sin(14.389) + F_1 * \sin(45.611)$$

$$\Sigma F_x = 10\text{ lb} = F_2 * \cos(30 - \theta/2) + F_1 * \cos(30 + \theta/2)$$

$$\Sigma F_y = 10\text{ lb} = F_2 * \cos(14.389) + F_1 * \cos(45.611)$$

Solve for F_2:

$$F_2 = [10\text{ lb} - F_1 * \cos(45.611)] / \cos(14.389)$$

By substitution:

$$17.322\text{ lb} = [10\text{ lb} - F_1 * \cos(45.611)] * \tan(14.389) + F_1 * \sin(45.611)$$

$$\mathbf{F_1 = 27.575\text{ lb Compression}}$$

$$\mathbf{F_2 = 9.5903\text{ lb Tension}}$$

Now, the forces in the two X legs can be calculated. The upper X leg shall be designated as F_3 and the lower as F_4.

$$F_3 = F_1 / \cos(180 - \tau)$$

$$F_3 = 27.575 \text{ lb} / \cos(31.61)$$

$$\mathbf{F_3 = 32.38 \text{ lb} \;\; Compression}$$

$$F_4 = F_2 / \cos(180 - \tau)$$

$$F_4 = 9.5903 \text{ lb} / \cos(31.61)$$

$$\mathbf{F_4 = 11.26 \text{ lb} \;\; Tension}$$

At the junction of the two X legs and the two Z legs, the four legs meet symmetrically. This means that the forces present in the upper X leg equals those found in the lower Z leg and vice versa. The next connection corresponds to the junction where the load screw is connected to the Z legs. This connection, due to the presence of a 30° slope, will cause different forces to be applied to the load screw, depending upon whether the screw is aimed toward the ground or toward the sky. F_{s1} will be designated as the force in the screw when it is aimed toward the sky, and F_{s2} will be designated as the force in the screw when it is aimed toward the ground.

$$F_{s1} = F_4 * \cos(\gamma/2)$$

$$F_{s1} = 11.26 \text{ lb} * \cos(71.565)$$

$$\mathbf{F_{s1} = 3.5611 \text{ lb} \;\; Tension}$$

$$F_{s2} = F_3 * \cos(\gamma/2)$$

$$F_{s2} = 32.38 \text{ lb} * \cos(71.565)$$

$$\mathbf{F_{s2} = 10.24 \text{ lb} \;\; Tension}$$

It has been determined that the maximum forces found in the individual members of the model will be **32.38 lb in Compression** and **11.26 lb in Tension**. The maximum forces found in the screw will be **27.75 lb in Compression** and **10.24 lb in Tension**. Therefore, the minimum torque needed to actuate the model can be calculated using the force value of 27.75 lb. This will then help determine the gear ratio needed and the appropriate gears to be assembled in order for the model to move.

Torque

To determine the torque required to actuate the legs, a maximum force acting upon the screw is needed. This was found to be 27.75 lbs. This maximum force is then applied to the equation for determining torque when raising a load. Other factors which had to be determined were the diameter of the screw thread, the pitch of the screw, and the coefficient of friction associated with the system.

The screw thread could be any size because a steel rod was going to be threaded specifically to meet the requirements of this system. After determining to use 5/16" diameter bolts to hold the leg linkages together, a screw thread diameter of 0.164" was determined to be the optimum size due to the ease in drilling the appropriate hole in the 5/16" bolt. The bolts were drilled and tapped so as to receive an 8-32 screw thread. An 8-32 screw thread means that the diameter of the thread is 0.164", and that the pitch diameter is 1/32". The coefficient of friction of non lubricated steel on steel was found to be 0.35. Now, all of the unknowns have been determined and can now be combined to find the torque requirement of the screw.

$$T_S = 0.5 * F * dm * [(p/2 + \pi * \mu * dm)/(\pi * dm - \mu * p/2)]$$

$$T_S = 0.5 * 27.75 \text{ lbs} * 0.164 \text{ in.} * [(1/64 + \pi * 0.35 * 0.164)/(\pi * 0.164 - 0.35 * 1/64)]$$

$$\mathbf{T_S = 0.875 \text{ lb in}}$$

This torque has to be supplied by a 3.6 volt motor which has a no load stall torque of 62.28 mN m, which translates to 0.55 lb in. The motor also has a no load maximum speed of 13,030 rpm. The motor alone does not have enough torque to raise the model, therefore a gear ratio has to be determined. This gear ratio will turn the high speed, low torque output of the motor into a slow speed, high torque output. Since the stall torque was given for the motor at maximum voltage, and the model will be providing each motor with only 2 volts, a large gear ratio needs to be used. The motors were taken from hand held, rechargeable screwdrivers with a gear train between the motors and the screwdriver. This gear train consists of two sets of planetary gears which increase the torque from the motor approximately 1000 times. This is a lot higher ratio than is needed to drive the model, however, it is neatly packaged and readily accessible. After contemplating about the extra torque, it was determined that the higher torque output would result in a more constant speed, no matter what forces were applied to the system. It was therefore determined that the planetary gears would be used to enhance the effectiveness of the model. Another problem remained, however. This new problem was how to transmit the torque from the end of the screwdriver to the screw powering the model. A modified gear train was concocted which increased the torque once again by double, but which also successfully transmitted the torque to the screw. This series of three spur gears provided the best result for transmitting the torque. The final torque transmitted to the screw is approximately equal to 90 ft lbs. This guarantees that the system will not experience any serious fluctuations in speed while being actuated.