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Three Legged Walking Mobile Platform Kinematic & Dynamic Analysis and Simulation

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A THREE LEGGED WALKER

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The three legged walker is proposed as a mobile work platform for numerous tasks associated with Lunar Base site preparation and construction. It is seen as one of several forms of surface transportation, each of which will be best suited for its respective tasks.

Utilizing the principle of dynamic stability and taking advantage of the Moon's Gravity, it appears to be capable of walking in any radial direction and rotating about a point. Typical curved path walking could involve some combination of the radial and rotational movements.

Comprised mainly of a body, six actuators, and six moving parts, it is mechanically quite simple. Each leg connects to the body at a hip joint and has a femur, a knee joint, and a tibia that terminates at a foot.

Also capable of enabling or enhancing the dexterity of a series of implements, the walker concept provides a mechanically simple and weight efficient means of drilling, digging, mining, and transporting cargo, and performing other like tasks.

A proof of principle machine has demonstrated the feasibility of the walking concept.

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Introduction

The Georgia Institute of Technology has been involved in the design of machinery for the construction of the Lunar Base for several years. Because of the unique and stringent constraints imposed upon any piece of machinery that will operate in the Lunar environment, a three-legged walking robot, called SKITTER, is being designed and developed. While SKITTER has been initially designed for Lunar applications, it is not solely limited to the moon. Some terrestrial applications include hazardous environments, military reconnaissance, underwater operations, etc. The purpose of this paper is to discuss and detail some of the initial work leading to the development of the theory of a three-legged walker (gaits, modes of operation, kinematics, and dynamics) and the proof of principle model.

The task of designing automated machinery for the Lunar environment is very difficult. Besides the intense temperatures and lack of an atmosphere, the one-sixth gravity complicates the task of moving machinery and cargo. The reduced gravity, while making any payload lighter, also reduces the normal force at the ground to such a low point that it becomes extremely difficult to be able to do even the basic task of scraping soil at a construction site. Even though the weight has been reduced by one-sixth, the inertia has not been similarly reduced. Thus, it is not a sufficient solution to the problem to add more mass to the vehicle to generate the required normal force because the power requirements for acceleration and deceleration would then rise sharply. Since any construction machine must be able to traverse all terrain that it might encounter, the decision to use legged locomotion over wheeled vehicles was justified.

SKITTER is a very simple device from a mechanical point of view. It consists of only six actuators, six moving parts, and a central body (figs. 1 and 2). The legs are located radially through the centerline of the body at 120 degrees apart from the other. The upper part of the leg, or femur, connects to the body at a hip joint. Connected at the other end of the femur is the lower leg, or tibia, which terminates as a foot at its end. To move the legs, two actuators per leg are used. The first actuator rotates the femur about the hinge line formed by the union of the femur and the central body, while the second actuator rotates the tibia about the hinge line created by the union of the femur and tibia. In this way, each leg operates in its own plane. The central body serves a connect point for various implements that may be attached to the walker and as host for the electronic hardware and power supply.

This mechanical simplicity does, however, have its disadvantage in the fact that more complex controls are needed for machine stability. For stability in motion, the main difference between a three-legged walker and the other walking devices like the Odetics and Ohio State walking machines is that the Georgia Tech walker depends on dynamic stability to maintain its motion. It must, and does, operate routinely with less than three legs having contact with the ground at any particular moment. As the device pushes off from the ground with its legs, the center of mass undergoes a horizontal and vertical motion. This differs from the previously mentioned walkers dramatically in that they strive to constantly maintain a level motion of the center of mass. While it does take energy to move the center of mass vertically, that energy is recovered when the body and leg are brought back into contact with the ground with no energy expenditure. Since the walker is not statically stable at all times in this motion, the controls complexity increases dramatically. This situation is similar to the unipod and bipods being developed at Carnegie Mellon and Clemson Universities, however with two major distinctions. The first is that while the tripod is not statically stable at all times while in motion, the device can always return to a statically stable position by simply allowing the leg or legs to return to the ground provided that the center of mass of the device is still located inside of the triangle formed by the foot projections on the ground. The second major difference is related to the first one in that only very small movements of the legs are needed to generate motion of the platform. By taking small steps, the danger of tipping and energy consumption is minimized.

This motion of pushing off from the ground so that the foot actually leaves the ground is also significant from another point of view. That it is possible to establish a rocking motion of the walker such that the inertia and momentum from the restoration of the leg back to the ground, aids in the pushing off from the ground of the other legs. As will be discussed later in this paper, this type of motion is very similar to that of a man on crutches.

Motion

Mechanical simplicity is a primary design constraint for SKITTER. Although other walkers incorporate many complex linkages and bearings in their design, SKITTER utilizes only six actuators (two per leg) and six hinges (two per leg) to generate motion (fig. 1 and 2). The femur actuator changes the angular position of the femur relative to the central body, and the tibia actuator changes the angular position of the tibia relative to the femur. By coordinating the position and velocities of the actuators, a variety of platform positions and motions is achieved.

Lean

SKITTER's basic mode of operation is to reorient its central body or "lean" by reconfiguring the legs while always maintaining three fixed points of contact with the surface. To understand the lean sequence as well as the other modes of operation described later in this section, a fixed axis (X-Y-Z) is established such that the walking surface lies in the X-Z plane and the positive Y axis is normal to the surface following the right hand rule. SKITTER is oriented such that the motions of leg A are confined to the X-Y plane and the feet of leg B and leg C construct a line parallel to the Z axis known as pivot line A. A second axis (x-y-z) may be established such that the x-z plane lies in the mid-plane of the central body with the positive x axis in the direction of leg A and the positive z axis parallel to and in the same direction as the Z axis. The positive y axis is normal to the mid plane and follows the right hand rule. Finally, a third axis (x'-y'-z') may also be established on the femur at the femur A - tibia A hinge line such that the positive z' axis is parallel and in the same direction as the positive Z axis (fig 3).

One possible example of the lean mode sequence is shown in fig 4. Starting with SKITTER at a static equilibrium position known as the 90-90 configuration (the femur-tibia and tibia-surface angles are both 90 degrees), femur A slowly rotates cw about the z axis and tibia A slowly rotates ccw about the z' axis such that foot A never leaves its initial contact point with the surface. The motion of femur A and tibia A is analogus to the motion of a crank and coupler of a slider crank mechanism discussed in detail in the kinematics section of this paper. The movements of leg A cause the central body and other two legs of SKITTER to rotate about pivot line A. As femur A and tibia A reach a new desired position, the central body has rotated and translated from its initial position with respect to the X-Y-Z reference frame.

One interesting motion of the central body is its ability to translate along its local y axis at an obtainable platform configuration. This can be accomplished by actuating each leg such that all three body-femur joints have a velocity vector parallel to the y axis and of equal magnitude. Therefore, as a drill rig platform, SKITTER eliminates the need for angular positioning and vertical feed mechanisms by leaning to the correct orientation and then raising and lowering itself along the drill string path by a series of coordinated actuator movements. The operation is completed with SKITTER's feet never losing contact with the ground. Also, the platform is able to achieve a position such that the mid-plane of the central body is parallel to the plane of its feet by simply making the body-femur angle and the femur-tibia angle of all three legs equal respectively. The work volume which encloses all of the possible orientations of the central body is limited to the range of the actuators and the physical characteristics of the body and leg components.

Leap

One method for maneuvering around obstacles which might impair the movement of SKITTER such as small rocks or ditches is to "leap" over them. SKITTER simply reorients its central body such that the y axis lies in the intended direction of travel. All three legs move such that the body-femur joints of all three legs have a velocity vector of equal magnitude and parallel to the y axis and supply a sufficient downward force to make SKITTER leap. With increases in control logic and proper frame design, the magnitude of the leap increases giving SKITTER the ability to achieve larger distances, and thus imitating the "skip walk" used by the astronauts on the lunar missions. One advantage of the leap mode is that the magnitude of directions in which SKITTER could translate is limited only by the possible orientations of the central body; therefore, with proper design, true omni-directional motion can be obtained.

Crutch Walk

SKITTER's crutch walk mode for translational motion differs dramatically from most current walker designs which usually move one or more appendages while keeping at least three points of surface contact at all times. SKITTER, on the other hand, tries to capitalize off of its inertial characteristics and dynamic stability to propel itself forward. One inherent fact of a three legged platform such as SKITTER is that it will always be statically stable as long as all three feet are in contact with the surface and its center of gravity is positioned over the triangle formed by the feet. However, if one of the legs loses contact with the surface, the platform becomes statically unstable and starts rotating due to gravity about the pivot line constructed by the feet of the other two legs. By combining this fact with the lean motion, SKITTER can be made to translate over a surface similar to a person walking with crutches.

For example, starting at the 90-90 equilibrium position, the femur and tibia of leg A begin the slider crank motion described in the kinematics section of this paper (fig 5). The central body starts to rotate about pivot line A as in the lean mode; however, this time, femur A and tibia A have acquired enough angular acceleration to supply a sufficient force at the foot and consequently a sufficient torque about pivot line A to cause foot A to lose contact with the surface (i.e. foot A pushes off from the surface fig 6). The entire platform continues to rotate about pivot line A until SKITTER's potential energy equals the kinetic energy imparted by leg A as it left the surface. At this point, the entire platform rotates about pivot line A in the opposite direction due to gravity. While leg A is away from the surface, femur A and tibia A rotate into a new configuration causing foot A to swing towards the central body (fig 6). As leg A comes back into contact with the surface, the central body is in a new orientation and foot A has translated to a new location on the surface in relation to the X-Y-Z reference frame (fig 7).

The next stage has leg B and leg C moving identically in their respective planes of motion. legs B & C reconfigure as shown in figure 7 causing a rotation of the central body in the X-Y plane about foot A. During their reconfiguration, legs B & C acquire adequate angular acceleration to supply a sufficient force at foot B and foot C, and consequently adequate torque about foot A, to cause the feet to lose contact with the surface (fig 8). Again, the platform will continue to rotate in the X-Y plane about foot A until its potential energy equals the kinetic energy imparted by legs B & C as they left the surface. At that time, the platform begins to rotate in the opposite direction due to gravity. While away from the surface all three legs reconfigure to there original 90-90 starting configuration (fig 8). As foot B and foot C reestablish contact with the surface, it is seen that the feet are in a new location and that the center of gravity has translated (fig 9). It is important to point out that if the roles of leg A and legs B & C are interchanged (Reversed Crutch Walk mode) then a translation in the opposite direction occurs giving six radial directions of translation without a required rotation of the platform.

Surprisingly, it has been found by analysis that it takes little energy to have a leg push off from the surface with adequate force to give the leg time to reconfigure into a new position. Similarly, only a small rotation of the platform about the pivot line is needed to give adequate space for reconfiguration of the leg; therefore, the chances of the platform tipping over are small.

One important benefit which arises out of the Crutch Walk motion is a decrease in the energy input to the system as the platform gains momentum while it walks. With an increase in the gait of the crutch walk sequence and the proper control strategy, SKITTER is able to achieve a stable rocking motion. Just as a person who is walking quickly on crutches uses his momentum to swing himself forward, SKITTER uses its momentum to propel itself forward. Therefore, the horsepower to maintain the rocking motion is small since the energy input to the system only has to account for the losses in the system due to SKITTER contacting the surface.

Slopes can be negotiated quite easily using either the Crutch Walk or Reverse Crutch Walk mode with the requirement that the force vector due to gravity acting through the cg of SKITTER always intersect the triangle formed by the three feet. This requirement insures that SKITTER will not over turn and can always revert to a statically stable position. The grade of slope that SKITTER can effectively negotiate is primarily determined by the femur and tibia dimensions which determine the size of the triangle. A larger foot print triangle results in a larger margin of safety from over turning and therefore a larger grade of slope can be negotiated. The platform is able to walk up, down or tact a slope by assuming an optimum nominal position (i.e. taking the largest step possible without overturning) and proceeding with one of the sequences described above.

Squat

SKITTER has the ability to lower its central body by having each leg repeat the sequence of pushing off of the surface, reconfiguring so that the foot swings away from the central body and landing on the surface to reestablish static equilibrium. If the sequence is carried through enough iterations, the central body of SKITTER would come to rest on the surface with the legs extended outward (fig. 10). This particular position is extremely advantages if the platform is being used in conjunction with a lifting device such as a crane. In the squat mode, the legs form outriggers to counter the weight of the cargo being lifted and eliminate the need for counter weights or other stability mechanisms.

Pivoting

Although the platform has six radial directions for translation, there will be situations that will require for the platform to rotate about the surface Y axis. SKITTER is capable of two different pivoting modes. The foot pivoting mode allows the platform to pivot around one foot while the complex pivot mode allows SKITTER to swing one foot through an arc in the surface X-Z plane .

In the foot pivoting mode, Skitter pushes leg A off the surface, and while in the air, leg B reconfigures resulting in a torque about foot C . The platform will pivot around foot C, and as leg A contacts the surface, SKITTER will once again be statically stable. Since the hinge lines of the platform dictate a 120 degree interval between the planes of motion of the legs, the foot pivoting mode would also require that foot B either slide in a arc about foot C or be away from the surface for the rotation to occur.

In the complex pivoting mode, SKITTER pushes leg A off the surface, and while in the air, leg B increases its body-femur angle while leg C decreases its body-femur angle. The reconfiguring of the legs in this manner will cause the platform to under go rotations around the surface Y & X axis causing leg A to swing in a arc in the surface X-Z plane while both leg A and leg B remain fixed to the ground. Once leg A contacts the ground again, the platform becomes statically stable. If the motion is carried through for all three legs, SKITTER achieves a net rotation about its cg. Unlike the foot pivoting mode, the complex mode does not require foot B to slide or leave the surface for the rotation to occur.

Self Righting Mode

If, for some reason, the platform tripped or fell during one of the modes of operation, it has the capability of righting itself since the legs have a range of motion extending above and below the mid-plane of the central body (fig 11). As an extreme example, if SKITTER tripped and landed completely upside down on the surface, the platform could tuck two legs in toward the central body while the third leg pushed down on the ground to flip the platform over to the correct orientation (fig. 12). The resulting motion would simulate a person summersaulting and landing on his feet. This unique fault tolerant capability of SKITTER makes the platform a valuable remote field robot.

The movements just discussed were achieved by utilizing the inertia charateristics of SKITTER in conjunction with the coordinated actions of the six linear actuators. A direct relation between movement complexity and control complexity is apparent; however, the movements discussed be realized by current control strategies and devices.

DYNAMICS and KINEMATICS

Of the many possible combinations of motions of the femur and tibia joints, only two possible combinations of motions exist such that the feet do not slid on the ground. The first motion is a linear movement of the center of mass as in the jump mode of operation. To accomplish this, the femur and tibia joints must combine their motions to produce a linear motion at the each of the hinge lines of the femur and the body. To model this linear motion of the center of mass, each leg is modeled as an offset slider crank mechanism. If is it desired for the walker to actually leave the ground, then the device must supply enough force tnat the walker has sufficient velocity at the end of the leg movements to leave the ground, or jump. The derivation of this model is developed here and the results of that model presented later.

The second method of motion for the walker is one that produces a rotational displacement of the center of mass relative to a pivot line, or the lean motion. This lean motion is also the fundamental motion for the crutch walk discussed earlier. The only difference between the motions of the femur and tibia joints in the lean configuration and the crutch walk is that at the end of the crutch walk motion, the body has enough angular velocity to allow the foot to leave the ground and this allows the leg to reconfigure while off the ground. To model this rotational motion of the body, a four-bar linkage is constructed where the four links are the ground, the tibia, the femur, and a link that is composed of the rigid structure of the body and the other two legs. The final link is connected to the hinge of the femur and body of the leg that is moving and terminates at the pivot line formed by the two feet that do not move. Derivation of the kinematic and dynamic model is discussed in this section and the results of the computer simulation is discussed in a latter section.

JUMP MODE

The first motion to be discussed is the jump motion. This motion can be divided into to distinct phases. The first phase is the acceleration of the body in the local vertical axis to a prescribed velocity such that during phase two, the jump phase, the body is off the ground and it begins to decelerate under the force of gravity. Since linear motion is required, an offset slider crank mechanism is used to simulate the motion of the legs (Fig. 13a). As a simplification of the mathematical model, the problem was inverted such that the body of SKITTER was considered to be ground and the foot was constrained to move in the linear fashion. Thus, the femur is considered to be the crank and the foot is the slider. A derivation of that model is presented here along with a measure of the forces, torques, and angular velocities needed to produce this motion.

To conduct this analysis, several parameters must be defined by the user of the program developed to model this motion. The first parameter is the vertical distance, H, desired for SKITTER to jump (Fig. 13c). The second parameter is the vertical distance, D, that the legs are allowed to displace to accelerate the body to the desired velocity (Fig. 13b). This velocity, V_0, is obtained using the conservation of potential and kinetic energy theory where the final height is the jump distance ,H, and the initial velocity is V . This results in,

$$V_0 = (2gH)^{1/2}$$

In this equation, g represents the gravitational constant. For simplicity, constant linear acceleration, A_0, is maintained at the center of mass for the acceleration phase. Thus, the acceleration necessary to accelerate the body to the desired velocity, V_0, over the linear distance, D, is,

$$A_0 = V_0^2/2D$$

Given the initial joint angles of the leg (the angle between the local x axis and the femur centerline, θ_1, and the angle between the femur and tibia centerlines, θ_2), the other critical angle for the dynamic and kinematic analysis is the angle between the tibia and the vertical axis, ϕ (Fig. 13a). This angle is determined from the joint angles to be,

$$\theta_2 - \theta_1 - \pi/2 = \phi$$

The next step is to derive the angular velocities for the femur and tibia links. The angular velocity equations are written using the standard equations for finding the velocity of a link. The equations are written from both ends of the link (i.e. one equation relates the velocity of point B to the ground, A, and the other relates the velocity of point B to the foot, point C, where the velocity at point C is a known parameter). The two equations are,

$$\underset{\sim}{V}_b = \underset{\sim}{V}_a + \underset{\sim}{\omega}_{ab} \times \underset{\sim}{R}_{ab}$$

$$\underset{\sim}{V}_b = \underset{\sim}{V}_c + \underset{\sim}{\omega}_{bc} \times \underset{\sim}{R}_{cb}$$

When the above equations are evaluated for this particular geometry, the following equation is derived,

$$(-\omega_{ab}L\sin(\theta_1))\,\underset{\sim}{i} - (-\omega_{ab}L\cos(\theta\ ))\,\underset{\sim}{j} = (-\omega_{bc}L\cos(\phi))\,\underset{\sim}{i} - (V_0 + \omega_{bc}L\sin(\phi))\,\underset{\sim}{j}$$

By comparing the $\underset{\sim}{i}$ and $\underset{\sim}{j}$ terms of the above equations, then the magnitude of the angular velocities can be derived,

$$\omega_{ab} = V_0\cos(\phi)/L(\cos(\theta_1+\phi))$$

$$\omega_{bc} = \omega_{ab}\sin(\theta_1)/\cos(\phi)$$

Like the velocity equations presented earlier, acceleration equations can be written in a similar manner.

$$\underset{\sim}{A}_b = \underset{\sim}{A}_a + \underset{\sim}{\alpha}_{ab} \times \underset{\sim}{R}_{ab} + \underset{\sim}{\omega}_{ab} \times (\underset{\sim}{\omega}_{ab} \times \underset{\sim}{R}_{ab})$$

$$\underset{\sim}{A}_b = \underset{\sim}{A}_c + \underset{\sim}{\alpha}_{bc} \times \underset{\sim}{R}_{cb} + \underset{\sim}{\omega}_{bc} \times (\underset{\sim}{\omega}_{bc} \times \underset{\sim}{R}_{cb})$$

Evaluating the above equations for the geometry of this problem yields,

$$(-\alpha_{ab}L\sin(\theta_1) - \omega_{ab}^2 L\cos(\theta_1))\,\underset{\sim}{i} + (-\alpha_{ab}L\cos(\theta_1) + \omega_{ab}^2 L\sin(\theta_1))\,\underset{\sim}{j} =$$

$$(-\alpha_{bc}L\cos(\phi) + \omega_{bc}^2\, L\sin(\phi))\,\underset{\sim}{i} + (-A_0 - \alpha_{bc}L\sin(\phi) - \omega_{bc}^2 L\cos(\phi))\,\underset{\sim}{j}$$

Solving the above equations properly for the magnitude of the angular accelerations gives,

$$\alpha_{bc} = -A_0 L\sin(\theta_1) - \omega_{bc}^2 L^2\cos(\phi)\sin(\theta_1) - \omega_{bc}^2 L^2\sin(\phi)\cos(\theta_1) - \omega_{ab}^2 L^2 / -L^2(\cos(\phi+\theta_1))$$

$$\alpha_{ab} = (\alpha_{bc}L\cos(\phi) - \alpha_{bc}^2 L\sin(\phi) - \omega_{ab}^2 L\cos(\theta_1)) / L\sin(\theta_1)$$

For a complete force and torque analysis of the leg motion, it is necessary to obtain the linear acceleration of the center of mass for the tibia, $\ddot{\underset{\sim}{X}}_{cg}$ and $\ddot{\underset{\sim}{Y}}_{cg}$. Using the acceleration equation for the center of mass relative to the foot gives,

$$\underset{\sim}{A}_{cg} = \underset{\sim}{A}_c + \underset{\sim}{\alpha}_{bc} \times \underset{\sim}{R}_{ccg} + \underset{\sim}{\omega}_{bc} \times (\underset{\sim}{\omega}_{bc} \times \underset{\sim}{R}_{ccg})$$

Evaluating this equation for the geometry yields,

$$\underset{\sim}{A}_{cg} = (-\alpha_{bc}L\cos(\phi)/2 + \omega_{bc}^2 L\sin(\phi)/2)\ \underset{\sim}{i} + (-A_0 - \alpha_{bc}L\sin(\phi)/2 - \omega_{bc}^2 L\cos(\phi)/2)\ \underset{\sim}{j}$$

Which leads to,

$$\ddot{\underset{\sim}{X}}_{cg} = -\alpha_{bc}L\cos(\phi)/2 + \omega_{bc}^2 L\sin(\phi)/2$$

$$\ddot{\underset{\sim}{Y}}_{cg} = -A_0 - \alpha_{bc}L\sin(\phi)/2 - \omega_{bc}^2 L\cos(\phi)/2$$

Summing the forces for the tibia (note that the force P is the reaction force from the ground due to the weight of SKITTER) enables a determination of the reaction forces at point B,

$$\Sigma F_x = m_T \ddot{X}_{cg} = F_{bx}$$

$$\Sigma F_y = m_t \ddot{Y}_{cg} = P - F_{by} - m_T g$$

Solving for the reaction forces,

$$F_{bx} = m_t \ddot{X}_{cg}$$

$$F_{by} = m_t \ddot{Y}_{cg} + m_t g - P$$

The summation of the moments about points A and B are.

$$\Sigma M_b = I_t\ \alpha_{bc} = PL\sin(\phi) - m_t gL\sin(\phi)/2 - T_t$$

$$\Sigma M_a = I_f \alpha_{ab} = F_{by} L\cos(\theta_1) - F_{bx} L\sin(\theta_1) - m_f g L\cos(\theta_1)/2 - T_f$$

Thus, the torque needed about the femur and tibia are,

$$T_t = I_t \alpha_{bc} - PL\sin(\phi) + m_t g L\sin(\phi)/2$$

$$T_f = I_f \alpha_{ab} + F_{bx} L\sin(\theta_1) + m_f g L\cos(\theta_1)/2 - F_{by} L\cos(\theta_1)$$

The calculations for the mass moments of inertia are approximations based upon a rectangular cross section of the leg. The variable "a" is equal to the length of the leg and the variable "b" is equal to the width of the cross section of the leg.

$$I_x = m_{leg}(a^2 + b^2) / 12$$

From the above equations, all the variables are known except for the torques. Therefore, the torque needed at either the femur or tibia joints is known for any given position of the legs.

These equations were then implemented in a computer program to evaluate the angular velocity, torque, and horse power requirements for each joint of the leg as it attempts to make the leg jump the desired distance.

LEAN MOTION

As stated earlier, the lean motion is the foundation of the crutch walk and provides dexterity to the platform. The kinematic model for this mode of operation is a four-bar linkage where the four links are (Fig. 14a),

- Tibia
- Femur
- Rigid structure consisting of everything but links one and two
- Ground

The lean motion can also be divided into two separate phases of motion. The first is the acceleration phase where the femur and tibia move in such a fashion as to impart to the center of mass a prescribed angular velocity. This angular velocity is sufficient to allow the foot to leave the ground after the forces have ceased to be applied to the joints.

As in the jump mode analysis, it is necessary to input two parameters into the program to allow the remainder of the variables to be set. For the lean mode, it is necessary for the user to define the acceleration angle, Ψ, which is the angle that the center of mass of SKITTER is to undergo to obtain the necessary angular velocity (Fig. 14b). The other input parameter is the angular displacement, Φ, that the user wants the center of mass to undergo after the foot leaves the ground (Fig. 14b).

With these input parameters, an initial angular velocity must be calculated so that the center of mass will undergo the desired amount of rotation. This initial angular velocity, ω_0, is calculated from the conservation of potential and kinetic energy theory where the final angular velocity is zero and the final height of the center of mass is H_2, where H_2 is defined as (Fig. 14b):

$$H_2 = r\sin(\Psi+\Phi)$$

Where r is defined as the constant perpendicular distance from the center of mass of SKITTER to the pivot line formed by the stationery feet. Thus, the initial angular velocity must equal:

$$\omega_0 = (2mgH_2/ I)^{1/2}$$

For this equation, the m terms refers to the mass of SKITTER and the I term is the moment of inertia for SKITTER about the pivot line.

As with the jump motion, a constant angular acceleration, α_0, is assumed over the acceleration angle for the center of mass. This acceleration results in the desired angular velocity, ω_0, at the end of the acceleration angle, Ψ.

$$\alpha_0 = \omega_0^2/(2\Psi)$$

For this motion, there are a number of geometric parameters that must be summarized for the following analysis to be clear. First, the joint angles for the different links are designated as follows (Fig. 14a):

θ_1: angle between the tibia link and the ground

θ_2: angle between the femur link and horizontal at the femur-tibia joint

θ_3: angle between the rigid body of SKITTER and the ground.

As in the jump motion, all of these angles are measured in the right hand sense. The letters designate the various joints in this analy-is. Point A is the hip joint, point B is the knee joint, point C represents the contact point between the ground and the tibia, and point D is the contact point for the line that is perpendicular to the pivot line and contains the center of mass.

With this variable definition, the following equations can be written for the velocity of the points on the links:

$$\underset{\sim}{V}_b = \underset{\sim}{V}_c + \underset{\sim}{\omega}_{bc} \times \underset{\sim}{R}_{cb}$$

$$\underset{\sim}{V}_a = \underset{\sim}{V}_b + \underset{\sim}{\omega}_{ab} \times \underset{\sim}{R}_{ba}$$

$$\underset{\sim}{V}_a = \underset{\sim}{V}_d + \underset{\sim}{\omega}_{ad} \times \underset{\sim}{R}_{da}$$

The above equations are evaluated using the following conditions, $\underset{\sim}{V}_c = \underset{\sim}{V}_d = \underset{\sim}{0}$. With this above condition and the fact that $\underset{\sim}{\omega}_{ad}$ is the input velocity following a prescribed acceleration profile, then the remaining angular velocity terms can be calculated by solving the above equations for the scalar magnitudes of the angular velocities:

$$\omega_{ab} = R\omega_{ad}(\sin(\theta_1-\theta_3))/(L\sin(\theta_1-\theta_2))$$

$$\omega_{bc} = (\omega_{ad}R\sin(\theta_3) - \omega_{ab}L\sin(\theta_2))/L\sin(\theta_1)$$

As with the velocity equations, similar equations for the angular acceleration can be written.

$$\underset{\sim}{A}_b = \underset{\sim}{A}_c + \underset{\sim}{\alpha}_{bc} \times \underset{\sim}{R}_{cb} + \underset{\sim}{\omega}_{bc} \times (\underset{\sim}{\omega}_{bc} \times \underset{\sim}{R}_{cb})$$

$$\underset{\sim}{A}_a = \underset{\sim}{A}_b + \underset{\sim}{\alpha}_{ab} \times \underset{\sim}{R}_{ba} + \underset{\sim}{\omega}_{ab} \times (\underset{\sim}{\omega}_{ab} \times \underset{\sim}{R}_{ba})$$

$$\underset{\sim}{A}_a = \underset{\sim}{A}_d + \underset{\sim}{\alpha}_{ad} \times \underset{\sim}{R}_{da} + \underset{\sim}{\omega}_{ad} \times (\underset{\sim}{\omega}_{ad} \times \underset{\sim}{R}_{da})$$

Again applying the boundary conditions of $\underset{\sim}{A}_c = \underset{\sim}{A}_d = \underset{\sim}{0}$ and the fact that the angular acceleration, α_{ad}, is the α_0 calculated earlier, the following magnitudes for the angular accelerations may be derived.

$$\alpha_{ab} = (R\alpha_{ad}\sin(\theta_1 - \theta_3) - R\omega_{ad}^2\cos(\theta_1 - \theta_3) + L\omega_{ab}^2\cos(\theta_2 - \theta_1) + L\omega_{bc}^2)/L\sin(\theta_1 - \theta_2)$$

$$\alpha_{bc} = (\alpha_{ad}R\sin(\theta_3) + \omega_{ad}^2R\cos(\theta_3) - \omega_{bc}^2L\cos(\theta_1) - \alpha_{ab}L\sin(\theta_2) - \omega_{ab}^2L\cos(\theta_2))/L\sin(\theta_1)$$

Up to this point, the angular velocity and angular accelerations have been calculated for the various links. To complete the analysis for the forces and torques necessary to achieve the input motion, the linear acceleration of the center of mass for the femur, tibia, and rigid body must be calculated. Since all the velocities and accelerations are already known, this is very simple.

$$\ddot{X}_{T,cg} = A_{b,x}/2$$

$$\ddot{Y}_{T,cg} = A_{b,y}/2$$

$$\ddot{X}_{F,cg} = A_{bx} - (\alpha_{ab}L\sin(\theta_2) - \omega_{ab}^2L\cos(\theta_2))/2$$

$$\ddot{Y}_{F,cg} = A_{bx} + (\alpha_{ab}L\cos(\theta_2) - \omega_{ab}^2L\sin(\theta_2))/2$$

$$\ddot{X}_{BODY,cg} = A_{a,x}/2$$

$$\ddot{Y}_{BODY,cg} = A_{a,y}/2$$

Now the free body diagrams can be written for this system. Unfortunately, the system is a coupled one, which means that the input torque, T, about the femur can not be easily solved for without solving for a eight other variables at the same time. These additional variables are the reaction forces at the joints and ground. Thus, the equations can be best solved by putting the equations into matrix form and then solving them using Gaussian elimination with pivoting. The form of the equations to be solved is as follows.

$$\begin{bmatrix} 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & L\sin(\theta) & -L\cos(\theta) & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ L\sin(\theta_2) & -L\cos(\theta_2) & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ R\sin(\theta_3) & -R\cos(\theta_3) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} F_{a,x} \\ F_{a,y} \\ F_{b,x} \\ F_{b,y} \\ F_{c,x} \\ F_{c,y} \\ F_{d,x} \\ F_{d,y} \\ T \end{bmatrix} = \begin{bmatrix} m_T X_{T,cg} \\ m_T Y_{T,cg} \\ I_c \alpha_{bc} + m_t g L\cos(\theta_1)/2 \\ m_F X_{F,cg} \\ m_F Y_{F,cg} \\ I_b \alpha_{ab} + m_F g \cos(\theta_2)/2 \\ m_{Body} X_{Body,cg} \\ m_{Body} Y_{Body,cg} \\ I_d \alpha_{ad} - m_{Body} g \cos(\theta_3)/2 \end{bmatrix}$$

From the solution of this matrix for the variable T, the input torque required to have SKITTER lean and lift off from the ground can be calculated.

Dynamic Simulation of the Motion of SKITTER

To simulate the motion of SKITTER, the dynamic and kinematic equations were developed for the basic motions, the jump and the lean motion, and then implemented in a computer program. These motions do not cover the broad scope of motions possible, especially all the possible motions resulting from the non-symmetric configurations of the legs. However, these two motions do represent the basic modes of operation for the machine (the other gaits are a combination of these two motions). Also included in this analysis is an actuator sizing routines which allows the user to determine if a given actuator (rotary or linear) can supply the necessary torque and speed.

The programs developed are written in a general format to allow the user to vary the physical parameters of SKITTER as well as modify its performance parameters. These performance parameters include the distance that the walker will jump in the air, the distance that the legs accelerate through before they leave the ground, and the actuator specifications (torque and velocity limitations). The physical parameters that can be varied on the model include all of the actuator attach points, the length of the femur and tibia, the weight of the femur and tibia (and thus it's inertia), the weight of SKITTER, the gravity, and the type of actuator (rotary or linear).

From the dynamic analysis of the motion of SKITTER, a maximum torque and angular velocity about the hip and knee joints of the walker are calculated. If the type of actuator is a rotary one, then these values are compared against the input specifications for the actuator to determine if they will suffice. For a linear actuator, the moment arm about each joint must be calculated for that instant in time. The reason for this is that as the leg undergoes its motion, a linear actuator will not maintain a constant perpendicular distance from the joint. Thus, whether a specified actuator will provide the prescribed motion is a function of two variables: torque required and perpendicular distance. To determine if the actuator will work, the two worst cases must be compared the actuator specifications. If the actuator is able to provide the necessary linear force and velocity for the two cases of maximum torque and minimum perpendicular distance, then the actuator will work.

Jump Motion

The jump motion is described in detail in the another section of this paper and will not be redefined here. The dynamic model for this motion is one that provides linear motion of the hip joint (and thus the central body) as compared to the foot. Thus, the kinematic model for this motion is an off-set slider crank mechanism where the input is from the hip joint and the knee joint is a passive joint.

The solution to this kinematic problem was implemented in a computer program in order to solve for the angular velocities and accelerations of each joint. These values were very important in order that the dynamic problem could be solved completely. To accomplish this, the Newtonian Force equations were derived for the linkage so that the torque about each of the joints could be solved for as a function of its position.

Lean Motion

As with the jump motion, the lean motion is described in detail else where in this paper. For this problem, the motion is modeled as a four-bar linkage where the joints are comprised of:

1) Tibia

2) Femur

3) Rigid structure consisting of everything but links 1 and 2 (the rest of SKITTER)

4) Ground

The kinematic solution to this problem is also well known but with one small difference: the input to the system undergoes a constant acceleration. While this is not a drastic change in the problem, it does considerably complicate the solution. With this accomplished, the next task was to derive the dynamic solution to determine the input torque needed to generate the angular velocities calculated by the kinematic equations as necessary to move SKITTER. Again using Newtonian mechanics and the angular accelerations and velocities from the kinematic problem, a system matrix of rank nine was derived that had to be solved to determine the input torque. The system matrix, while not triangular, was solvable using Gaussian elimination with row pivoting to obtain a solution to the input torque needed at the hip joint to provide the desired motion.

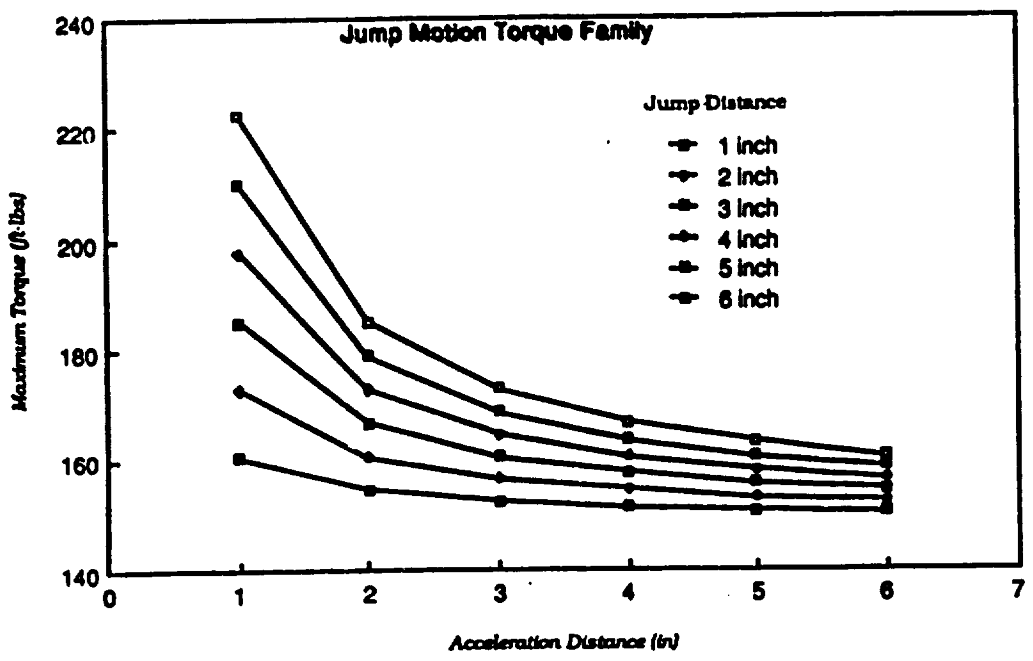
Results

Presented below are the results of the numerical calculations and simulations performed under this contract. All of the number represent the power requirements of SKITTER while operating on earth and with a weight of three hundred pounds.

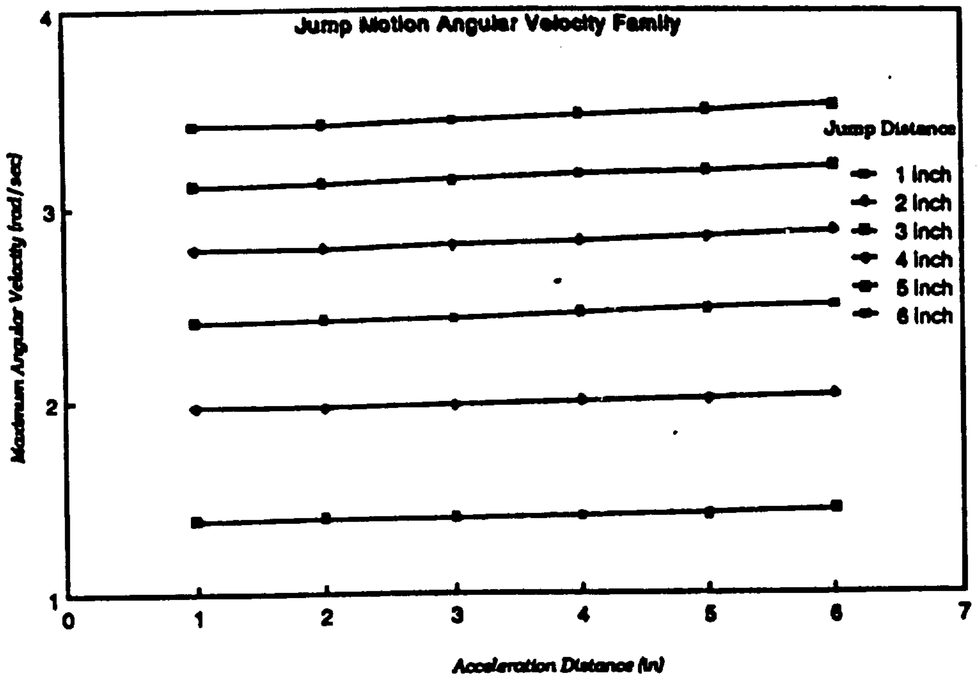
Jump Motion

Sample data presented below is from the computer simulation of the dynamics of SKITTER. The family of curves shown below is for a variety of jump heights and acceleration distances. The physical parameters for the SKITTER model were determined from the envisioned SKITTER II model. The values shown are the requirements for each leg as it attempts to jump. The total system requires three times as much torque and horse power to jump the distance desired.

The first plot shows a family of curves for the input torque at the hip joint at various jump distances and acceleration distances.



The following plot shows required maximum angular velocity at the hip joint to acclerate SKITTER to jump various heights through different acceleration distances.

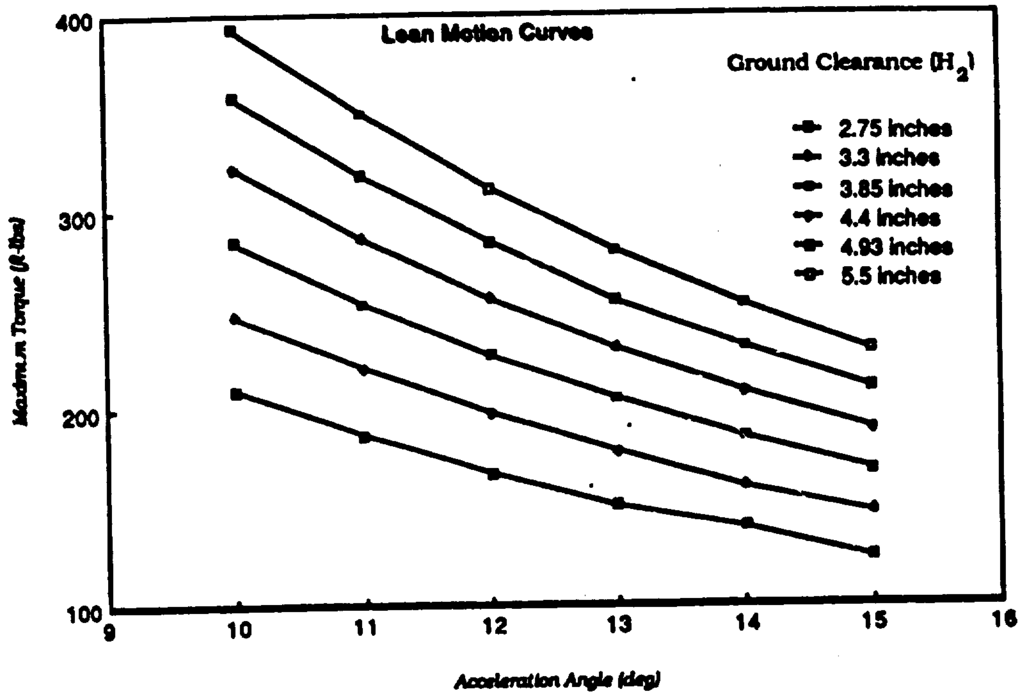


As can be seen from these plots, the requirements to jump are not as streneous as originally thought. Sizing actuators to meet these specifications is not difficult and a vendor has already been identified that can meet these requirements. The **Helac Corporation** makes a series of planetary rotary actuators that are capable of suppling 4300 inch-pounds of torque with a full 360 degrees of rotation in the joint, while weighing only 24 pounds. These actuators will be ideal choice for use on SKITTER II.

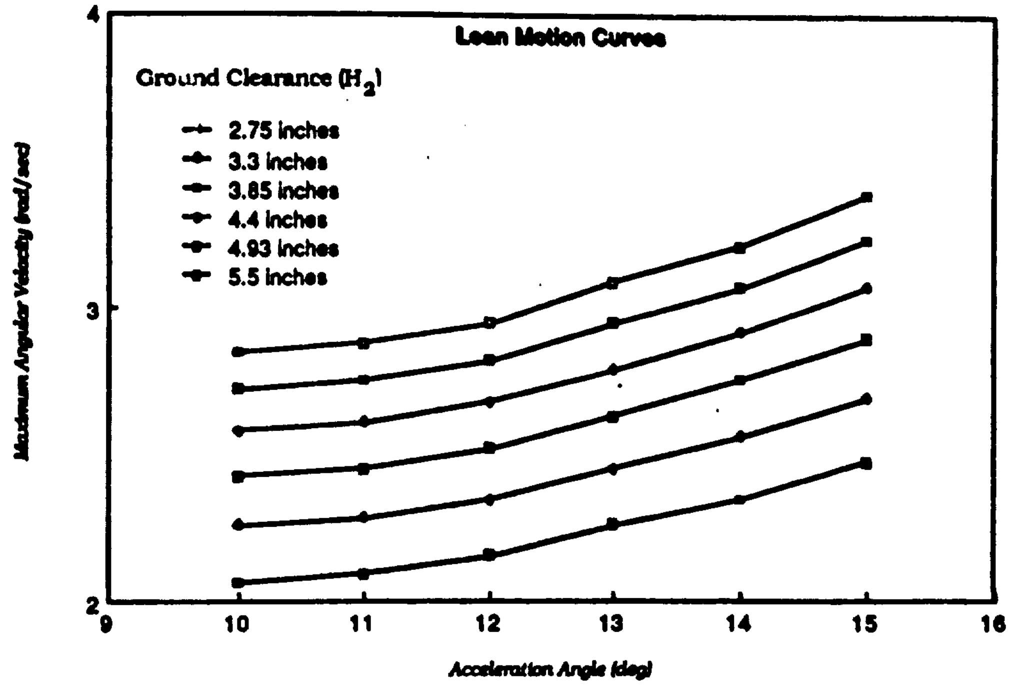
Lean Motion

For the lean motion, a family of curves was generated for various angles of acceleration (this is the angle that SKITTER accelerates through till it reaches the desired angular velocity to lift off from the ground) and ground clearances (the distance that the foot is from the ground at its maximum point). It is important to note that this simulation is for the case where one leg is providing the force to rotate SKITTER about the other two legs. In the crutch walk motion described earlier, it is also desired for the other two legs to push off from the ground and rotate about the stationary third leg during part of its motion. For this case, the angular velocity about each of the moving legs hip joint is the same whether one or two legs is pushing, but the torque can be divided between the two legs. Thus, the angular velocity requirements stay the same for this motion, but the torque requirements are divided between the two legs.

The first plot illustrates the family of curves relating the maximum input torque at the hip joint for a variety of accleration angles and ground clearances (the distance that the foot of SKITTER leaves the ground during the rotation motion).



The next plot relates the maximum angular velocity at the hip joint and a family of acceleration angles and ground clearance.



The data presented here has been checked in various manners. For the lean motion, graphical techniques were used to verify the angular velocities and accelerations generated by the computer program. Since these numbers are then used to determine the input torque, this number is believed to be correct also.

Future Work

The work completed under this contract to develop kinematic and dynamic equations for the motions of SKITTER has been completed. Actuator sizing programs have been developed so that the designer can vary the size of the structural members and optimize the power consumption for a given size actuator. The joint angles from the jump and lean motions can also be written to a file so that the graphical simulation program can display the motions of SKITTER in 3-D. The next step in this process is to improve the computer models and incorprate in the program a control algorithm and inefficiencies in the power transmission. This will give the most accurate computer simulation of what the actual SKITTER II will be like when it eventually is built. Again, by using the computer simulations, the designer is able to optimize the design before any hardware is built. This allows the best prototype to be built.

PROOF OF PRINCIPLE MODEL

To test the theory on the motion of a three-legged walker, a proof of principle working model was constructed. The walker was a one-tenth scale model of the conceptual design of the Lunar model and its purpose was only to obtain some translatory motion. This model, which weighed approximately eighty-five pounds and was completely self-contained, was demonstrated to NASA on several occasions where it fulfilled its intended goal and also demonstrated several other of the modes of operation discussed earlier.

The SKITTER proof of principle model was pneumatically actuated for cost effective reasons. A small scuba tank was attached to the underside of the model to serve as a high pressure reservoir of air. With a pneumatic actuation system, each actuator was only able to move the joint into two discrete positions, either the actuator was all the way in or all the way out (as compared to hydraulic or electromechanical actuators that can reach an infinite number of positions over its stroke length). Since the original design called for two actuators per leg, this results in four positions of the foot. To improve on this, the design for the prototype was modified such that each joint consisted of two actuators, four actuators per leg, and the actuators were connected by a free floating member. This gave each joint four possible positions that it could obtain and thus the foot could obtain sixteen different positions.

To control the actuation of the joints, a small computer was located aboard the model. Since no usable position or velocity feedback can be obtained from a pneumatic actuator, the computer was programed with a series of commands that controlled the actuators and therefore the walker could demonstrate the modes of operations discussed earlier.

There are a number of fundamental differences between the proof of principle model and the SKITTER proposed for use on the moon. The first difference is that the prototype operated outside of its intended environment on the moon where the gravity is one-sixth's of the earth's gravity. Thus, the power requirements were much higher on the prototype as compared to a comparable SKITTER on the moon. The second difference is that the prototype used a discrete actuation system that allows the feet to be in only sixteen discrete motions. Of those positions, only certain movements from these discrete positions allowed the prototype to move as designed. The final difference was that no control strategy could be implemented to provide smooth motion of the legs because of the pneumatic system's lack of useful feedback.

The fact that a successful prototype was built and demonstrated with these negative factors inhibiting its performance, shows that the idea is feasible and much easier to implement than originally thought. With the addition of servo-actuators, the motion can only be improved, but the fundamental concepts on the modes of operation of a three-legged walker have already been proved correct.

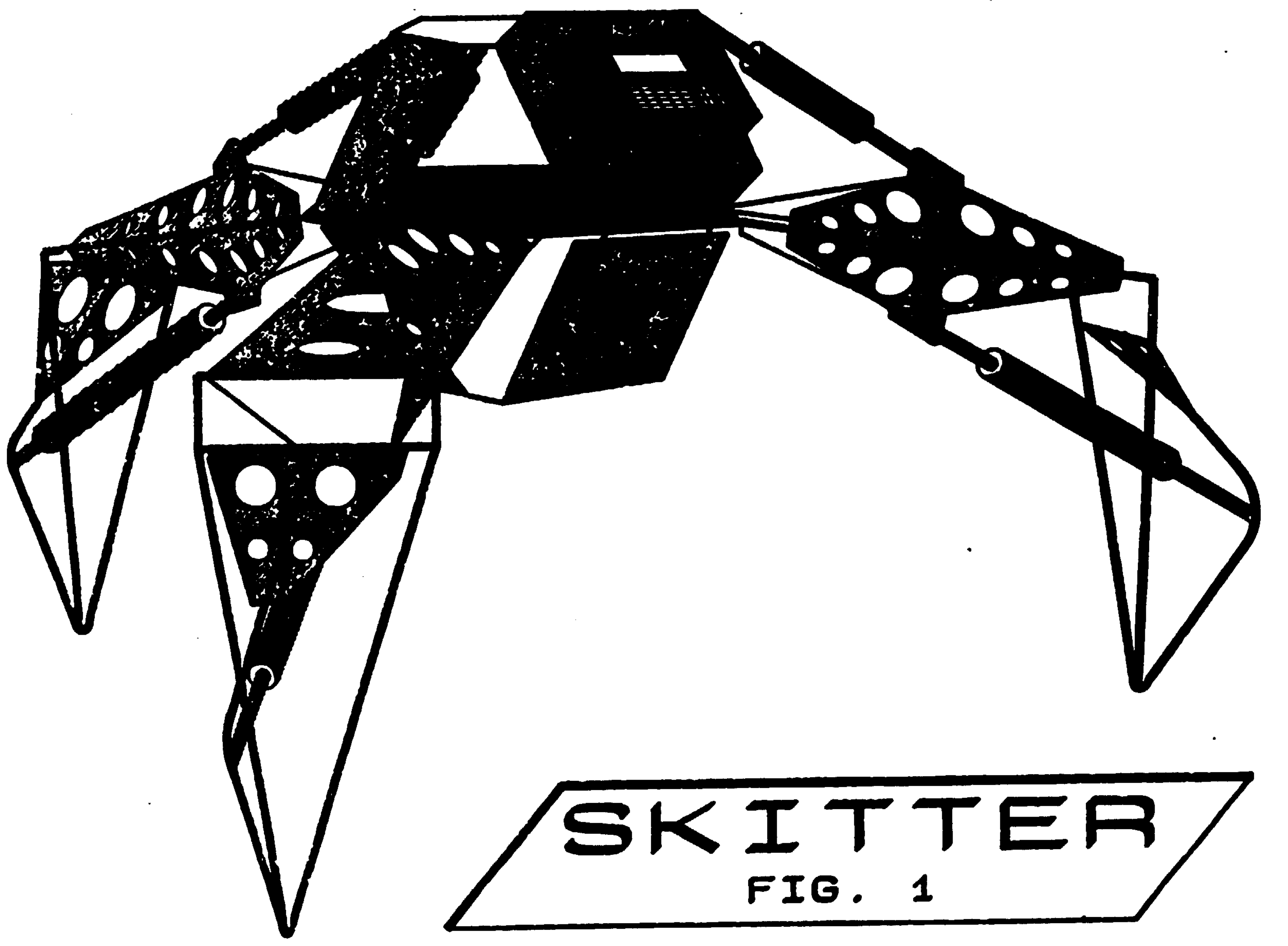
CONCLUSION

With a successful proof of principle model developed, the Georgia Institute of Technology is continuing the development of the three-legged walker, SKITTER. To further a complete understanding of the dynamics and kinematics of the walker, computer simulation is being written to incorporate the equations of motion and display graphically SKITTER as it moves. Once this work has been completed, a control strategy and hardware (actuators and sensors) will be incorporated into the computer mode! to provide a realistic simulation of the next generation prototype. This model can then be evaluated and modified by the user before any hardware is actually built.

The next version of SKITTER, or SKITTER II, will have servo-actuators at the joints to allow feedback of the position and velocity of the joint so that the motion of the legs can be accurately controlled throughout the range of their motions. This new model will be capable of all the gaits and modes of operation described previously, but it will have much greater range of motion and a much smoother motion. This next generation SKITTER model will also be compared against other walking and wheeled vehicles for overall efficiency, as well as the accuracy of the computer models.

Appendix A

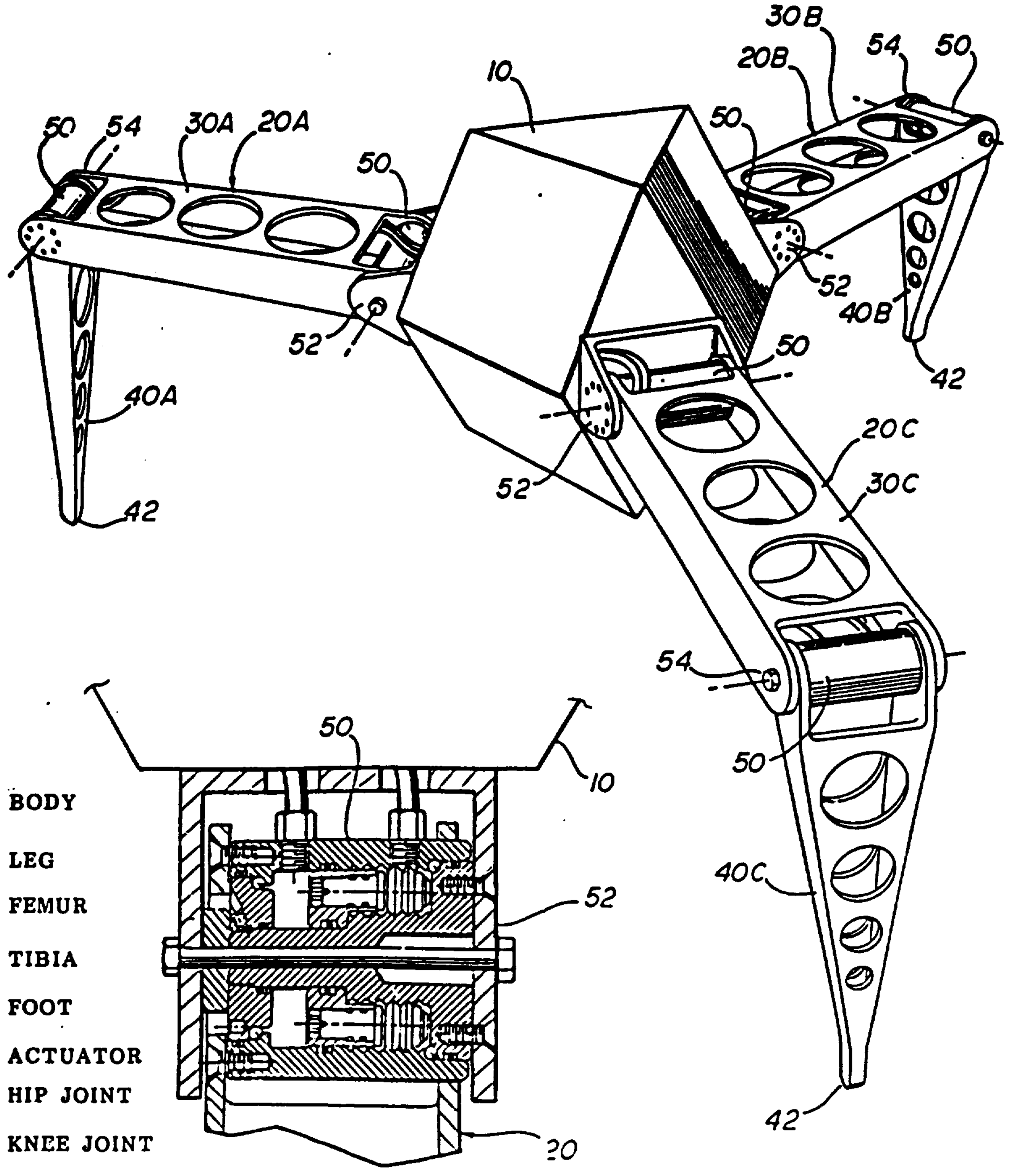
Figures



SKITTER
FIG. 1

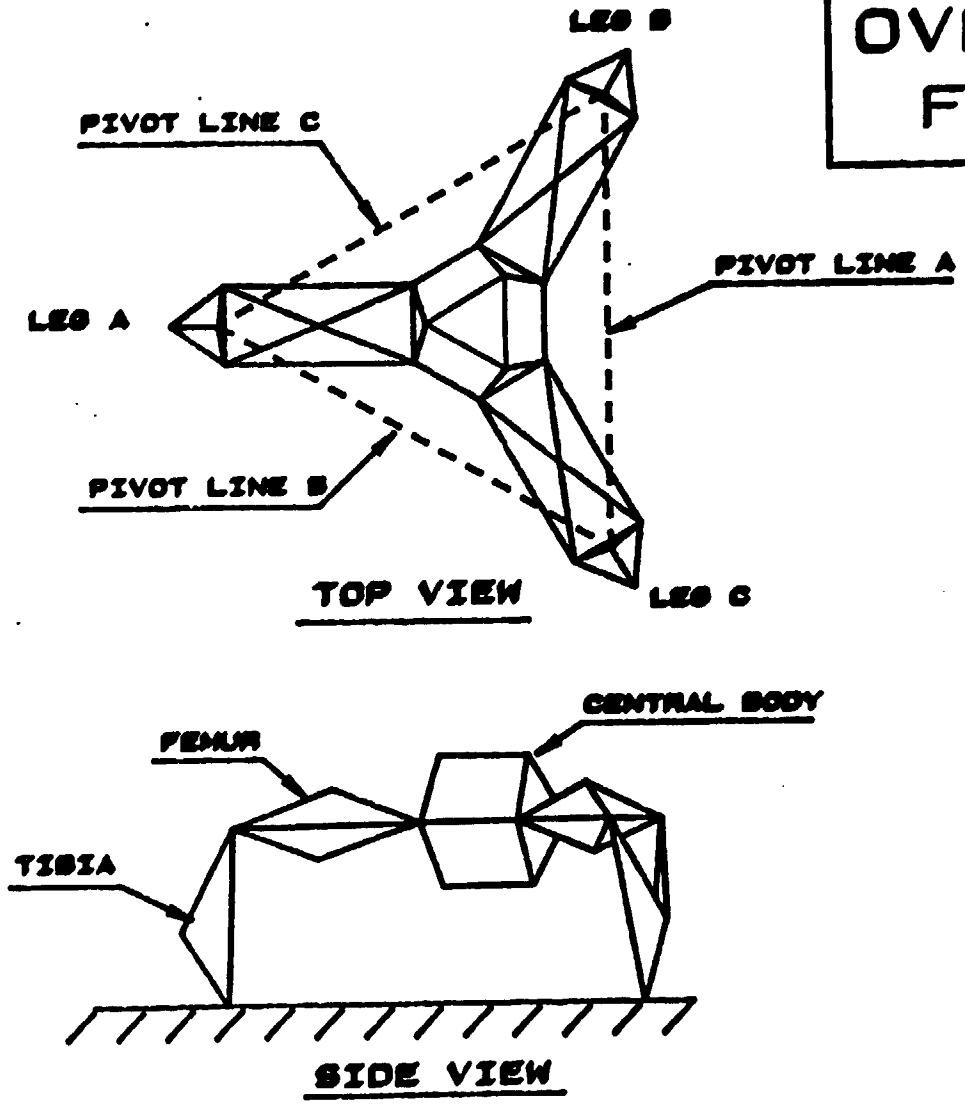
SKITTER 2

.WALKING MOBILE PLATFORM



10 -	BODY
20 -	LEG
30 -	FEMUR
40 -	TIBIA
42 -	FOOT
50 -	ACTUATOR
52 -	HIP JOINT
54 -	KNEE JOINT

SKITTER
OVERVIEW
FIG. 2



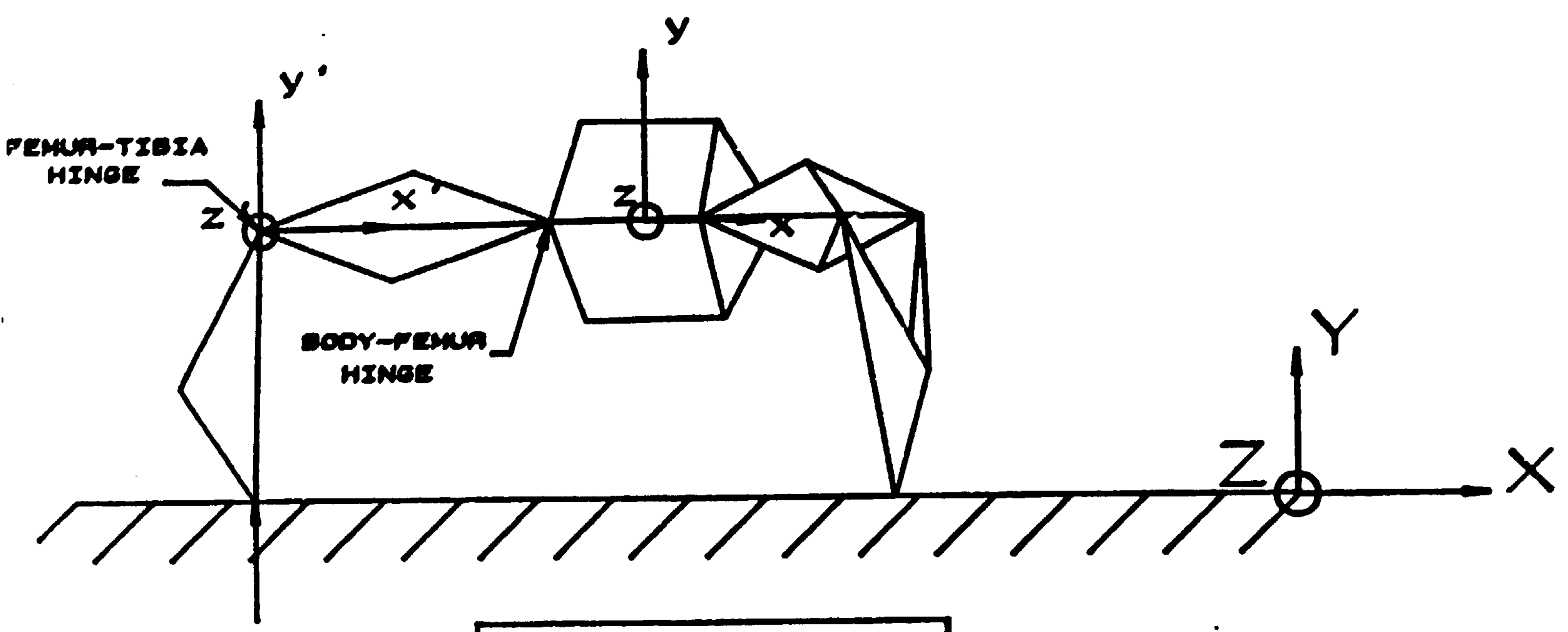
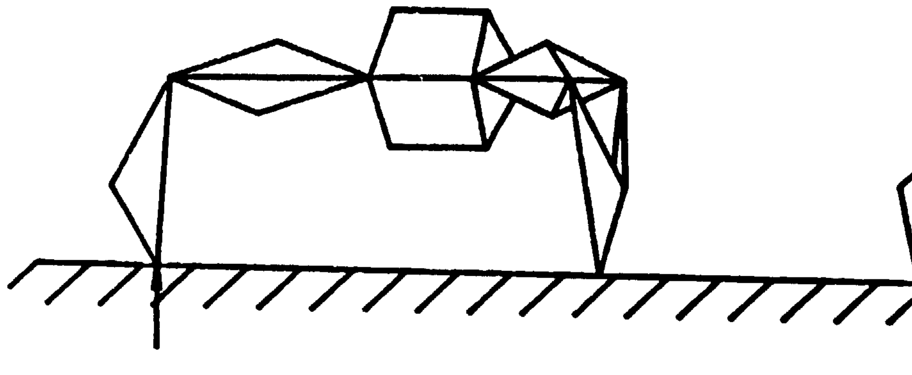
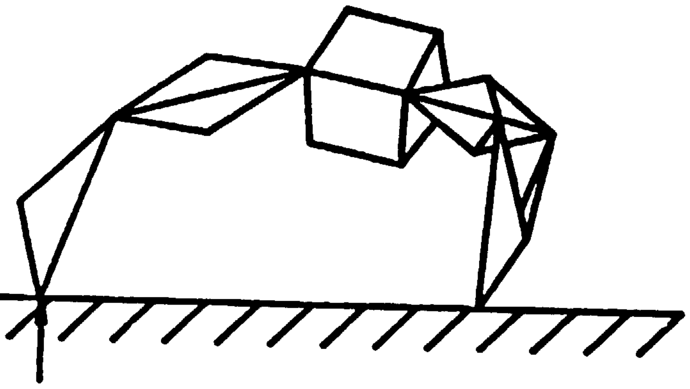


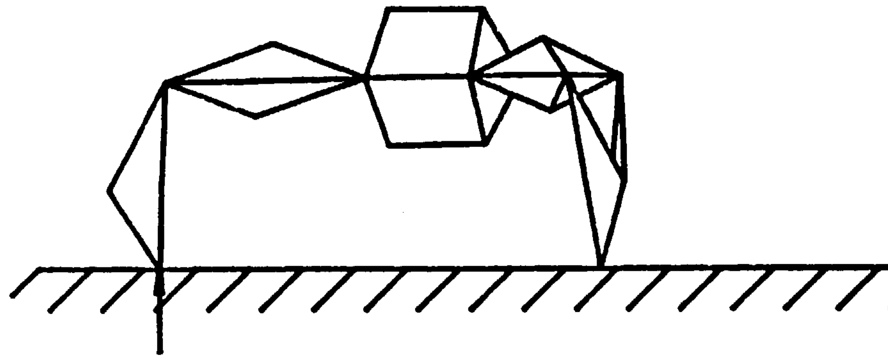
FIG. 3

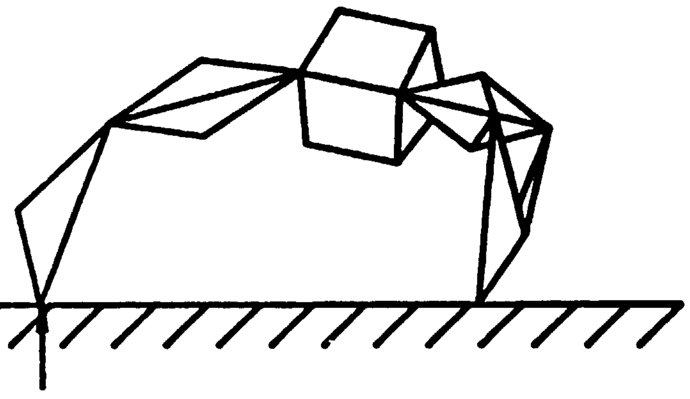
LEAN MODE

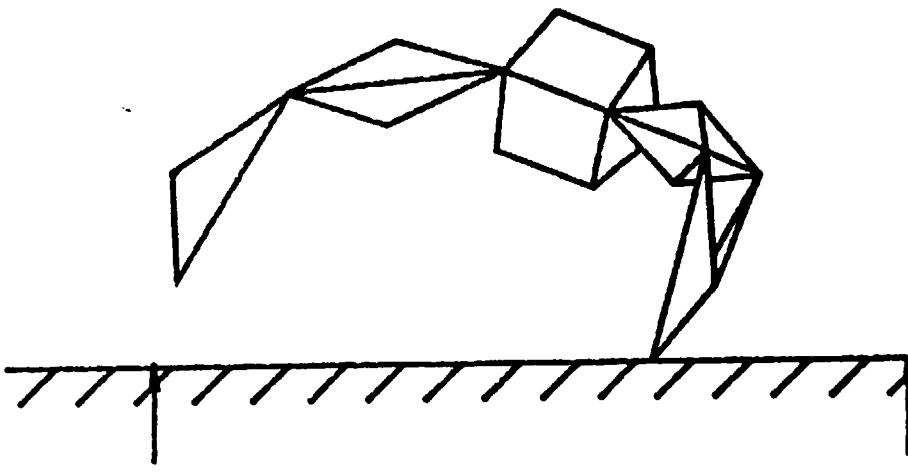

NOMINAL CONFIGURATION
FIG. 4A


LEAN
FIG. 4B

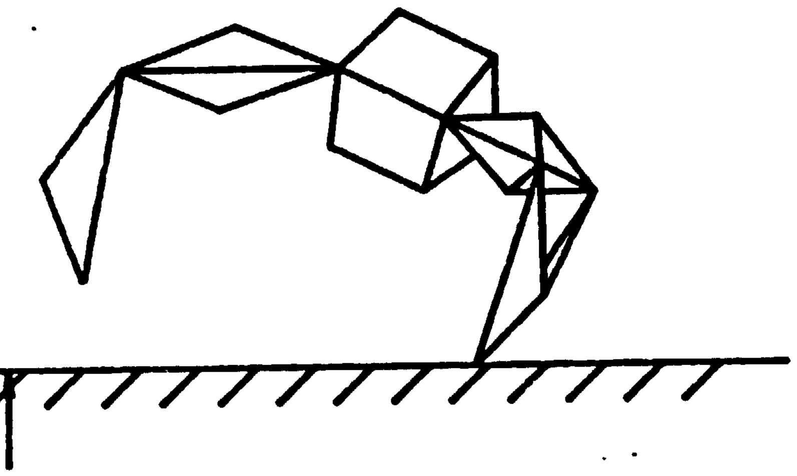
CRUTCH WALK


NOMINAL CONFIGURATION
FIG. 5A

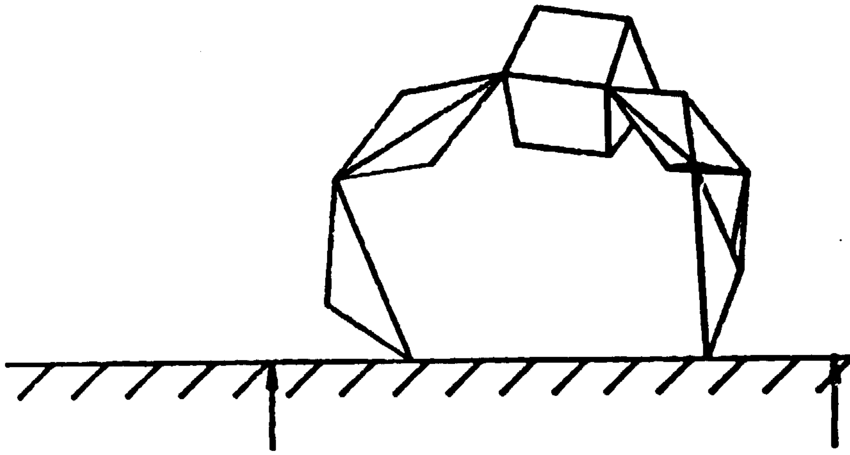

LEAN
FIG. 5B



PUSH OFF FROM
SURFACE WITH
LEG A
FIG. 6A

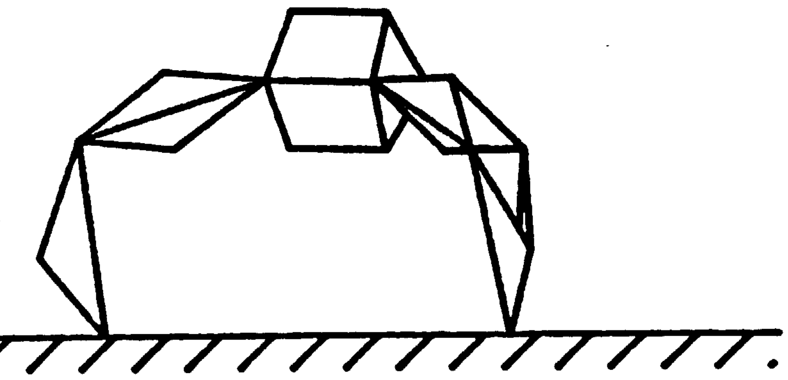


RECONFIGURE
LEG A
FIG. 6B



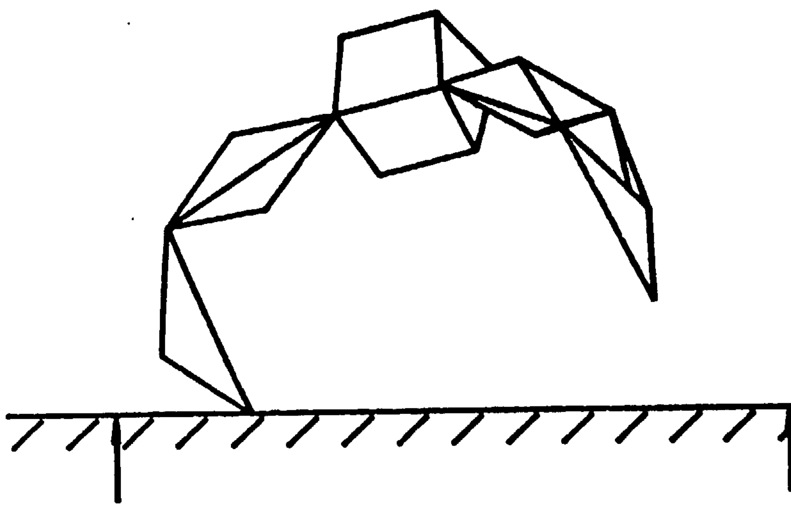
RETURN TO SURFACE

FIG. 7A

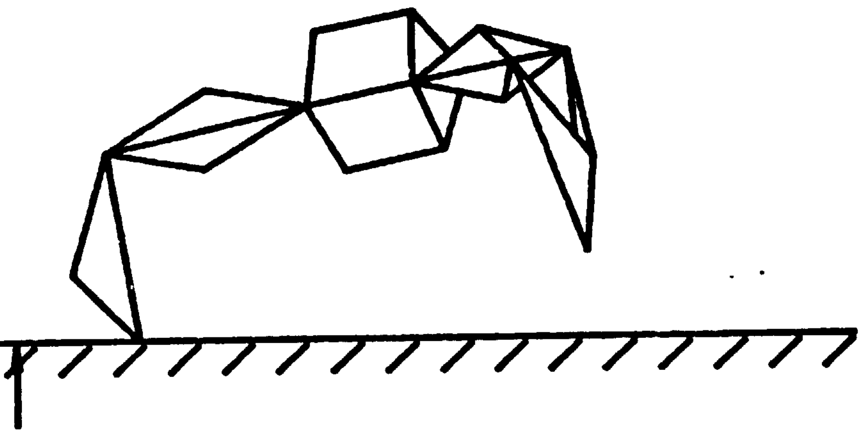


BEGIN LEAN MODE
WITH LEGS B & C

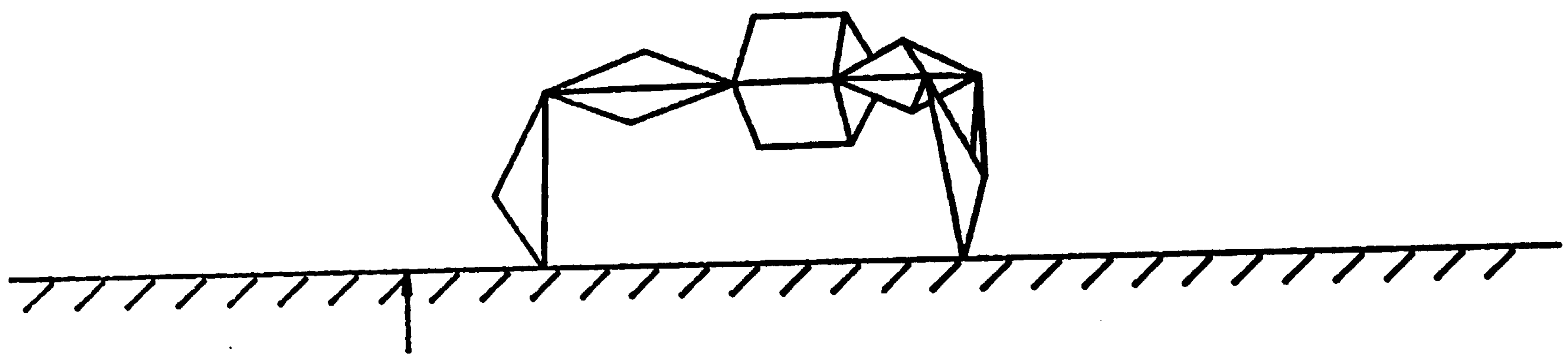
FIG. 7B



PUSH OFF FROM
SURFACE WITH
LEGS B & C
FIG. 8A

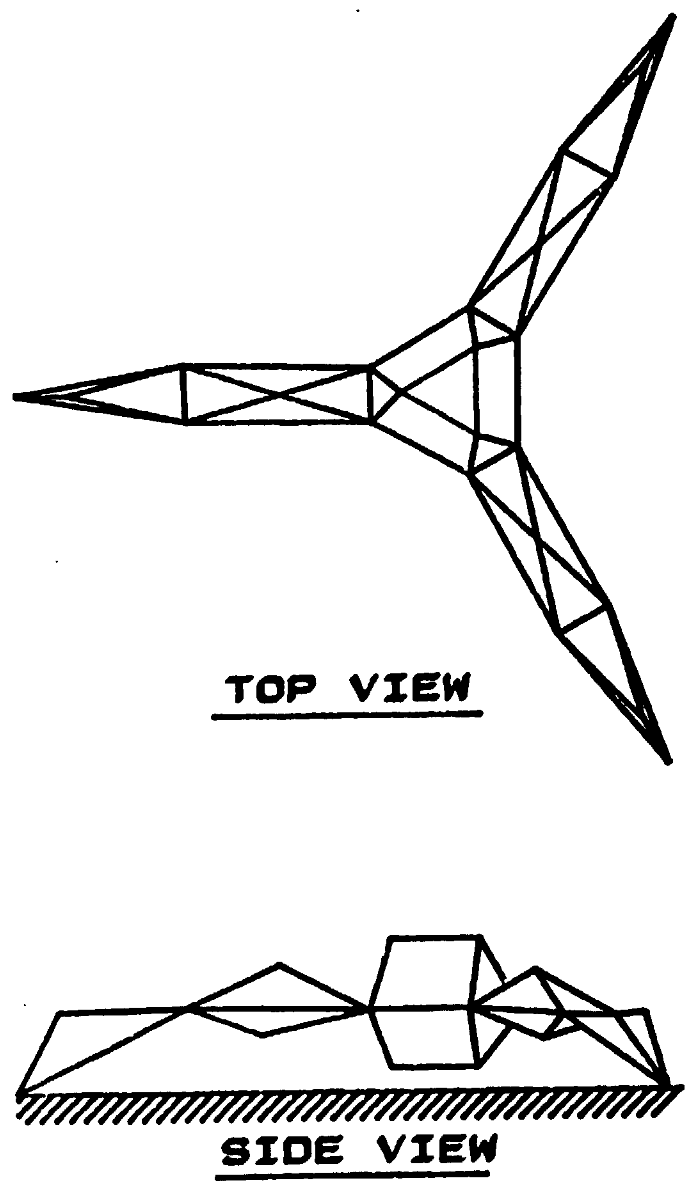


RECONFIGURE
ALL LEGS BACK
TO NOMINAL
CONFIGURATION
FIG. 8B

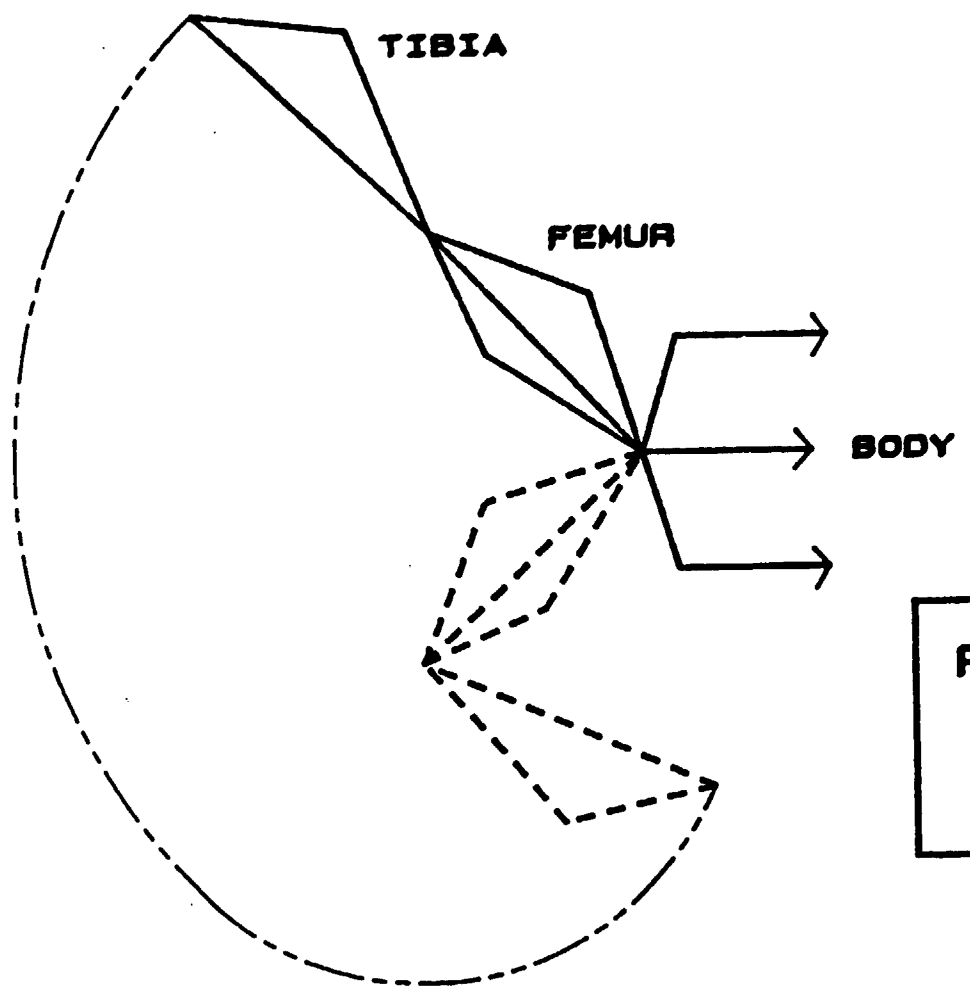


RETURN TO SURFACE

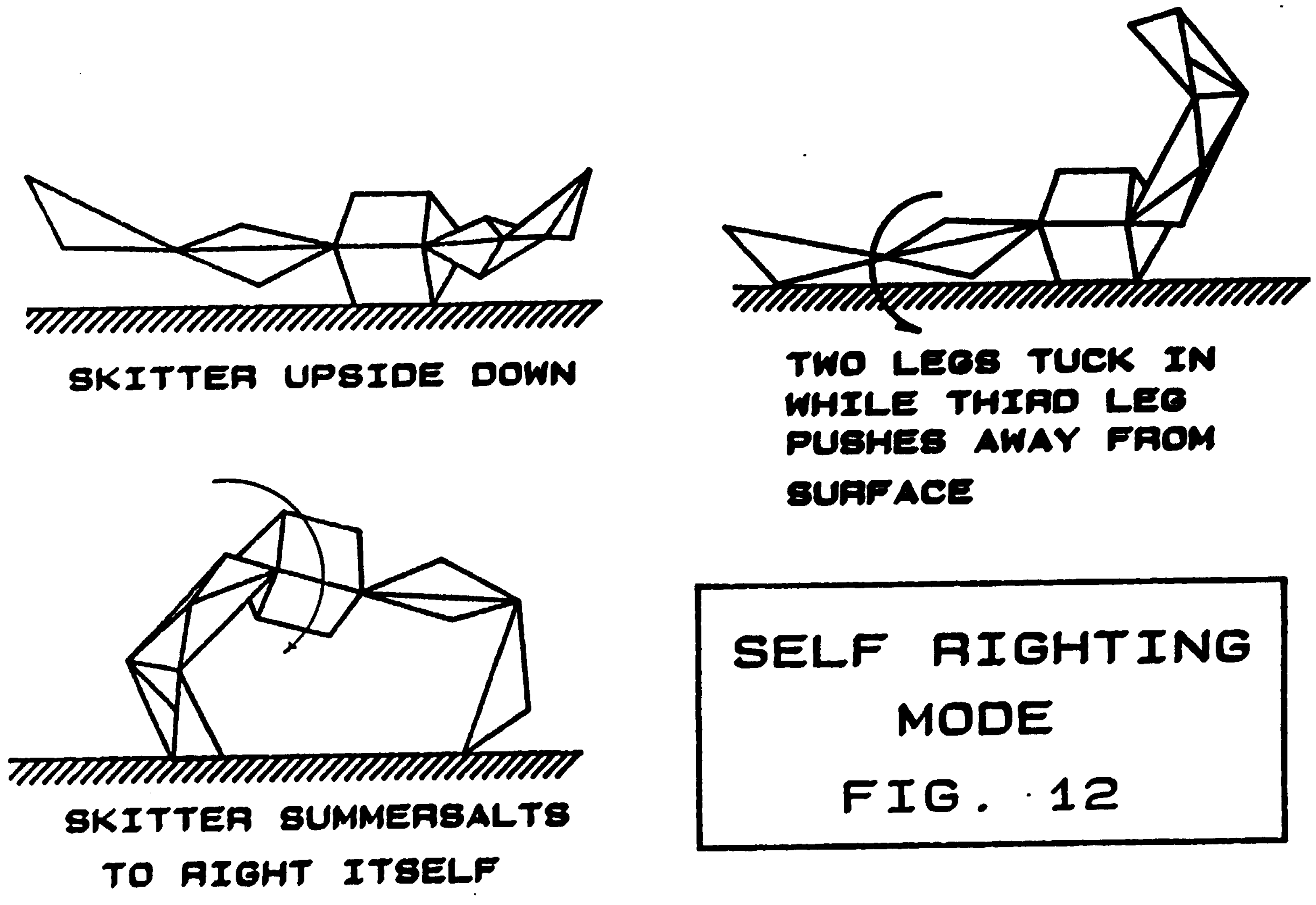
FIG. 9



SQUAT POSITION
FIG. 10

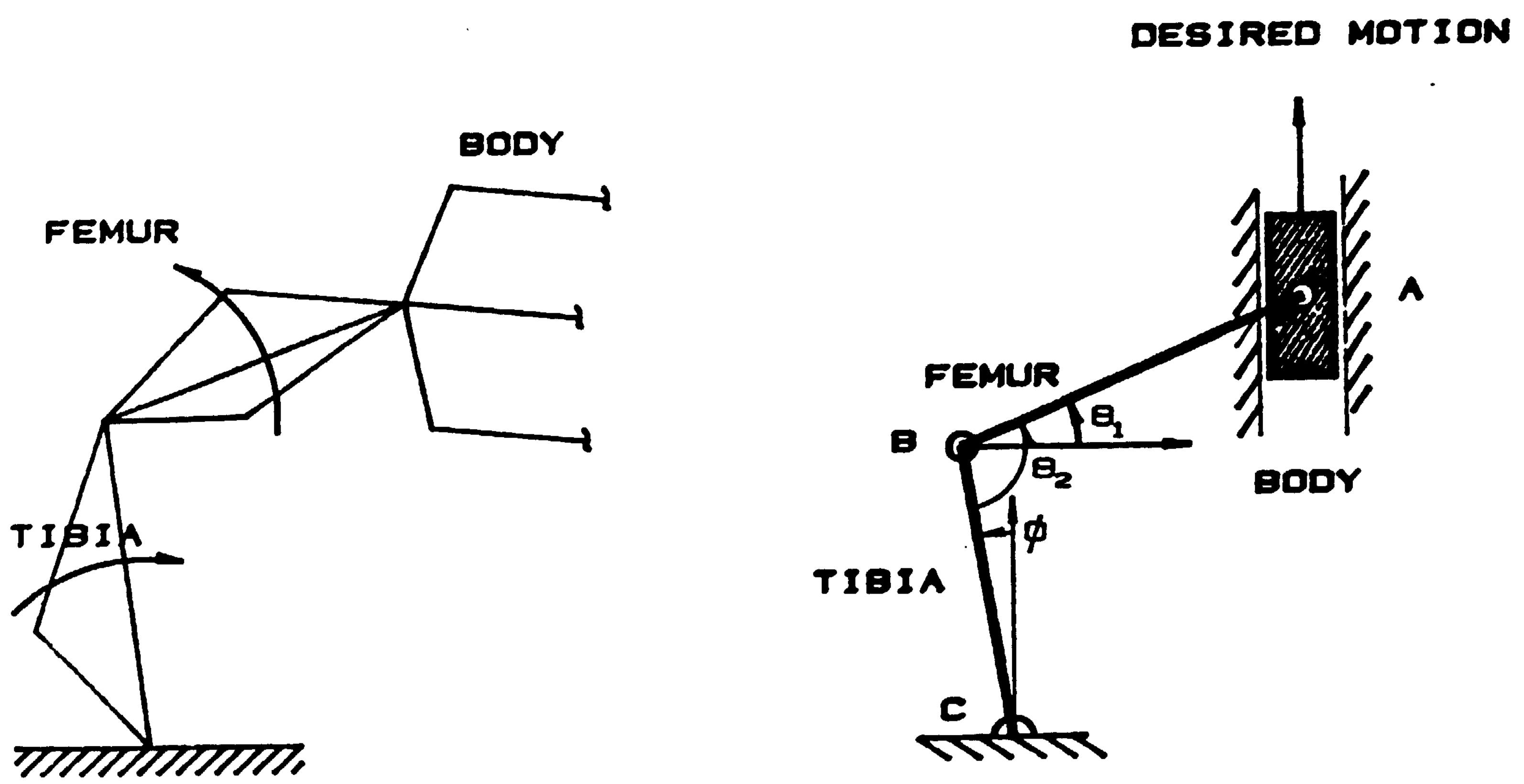


RANGE OF MOTION
FOR LEG
FIG. 11


SKITTER UPSIDE DOWN
TWO LEGS TUCK IN WHILE THIRD LEG PUSHES AWAY FROM SURFACE
SKITTER SUMMERSALTS TO RIGHT ITSELF

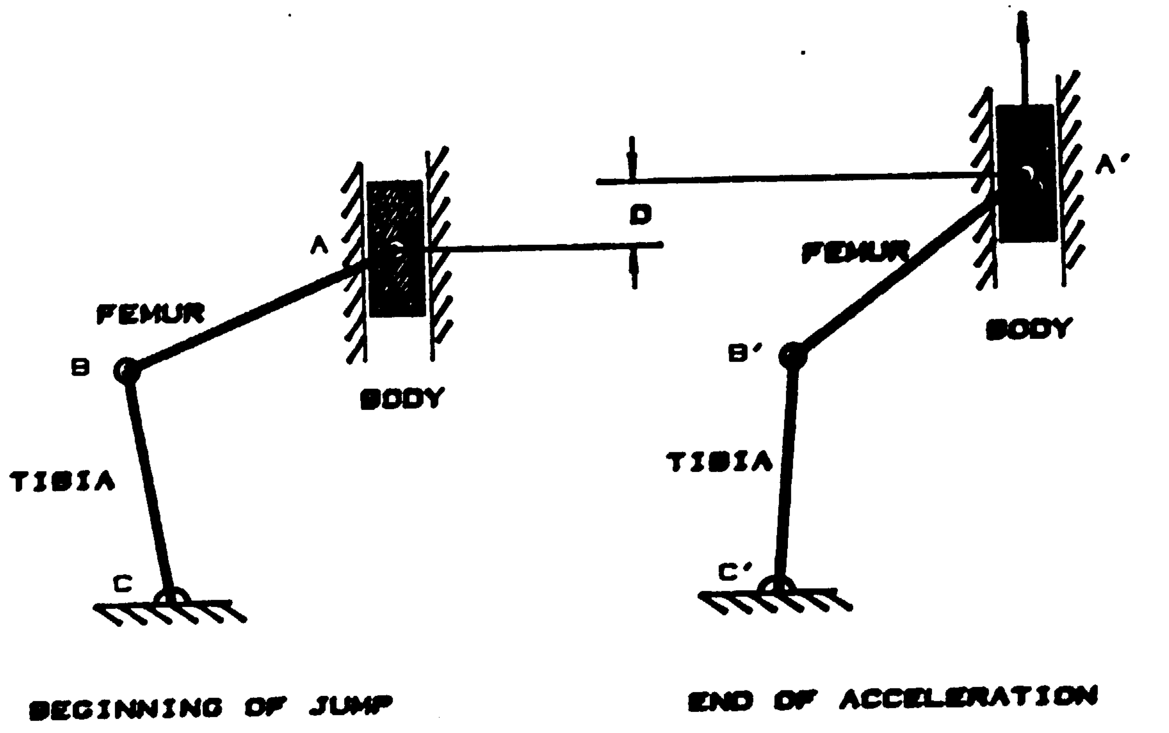
SELF RIGHTING MODE

FIG. 12

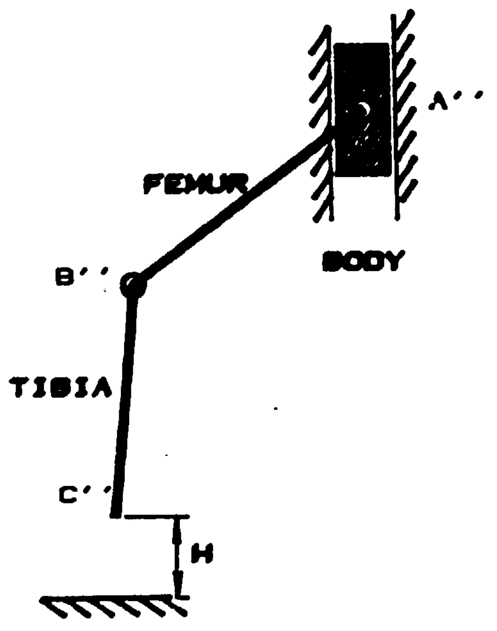


SLIDER-CRANK MECHANISM
FOR JUMP MOTION
VARIABLE DEFINITION

FIG. 13a



SLIDER-CRANK MECHANISM
FOR JUMP MOTION
VARIABLE DEFINITION
FIG. 13b



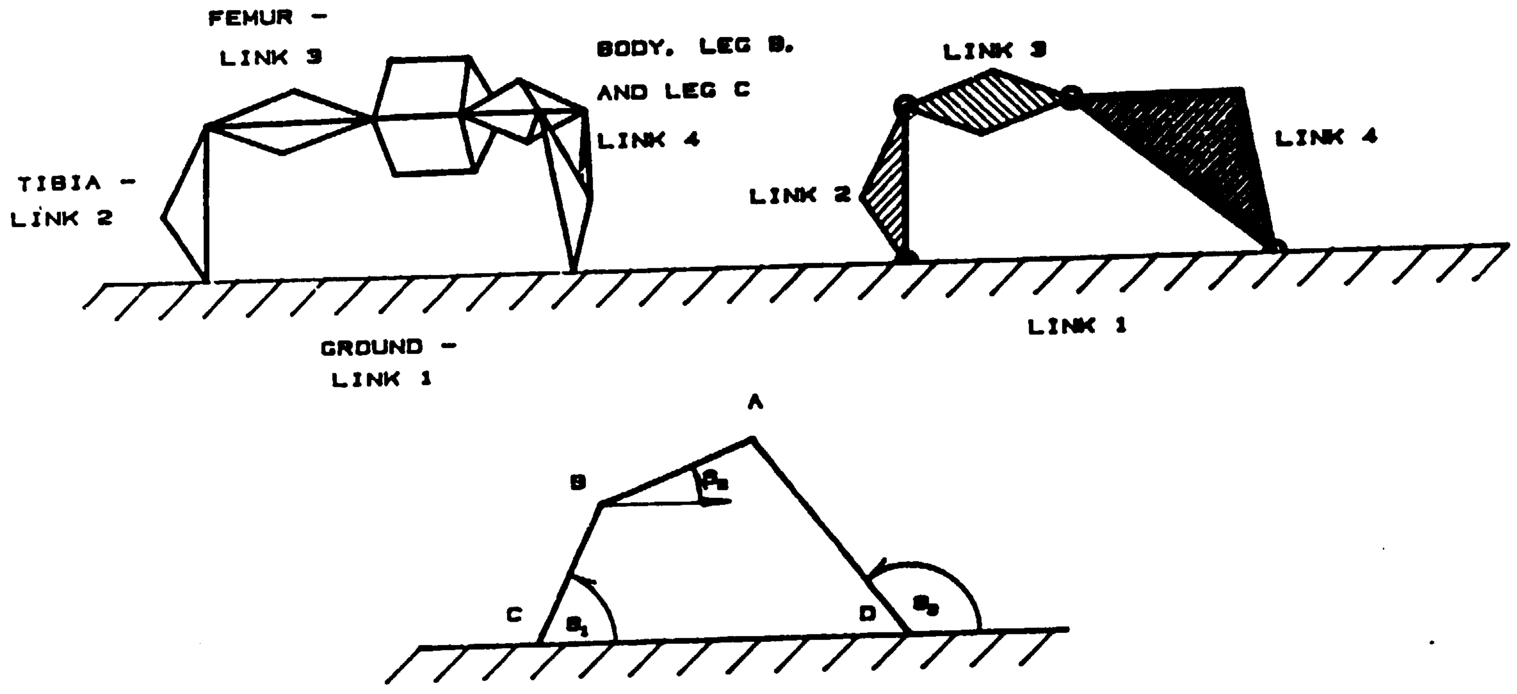
MAXIMUM HEIGHT

SLIDER-CRANK MECHANISM

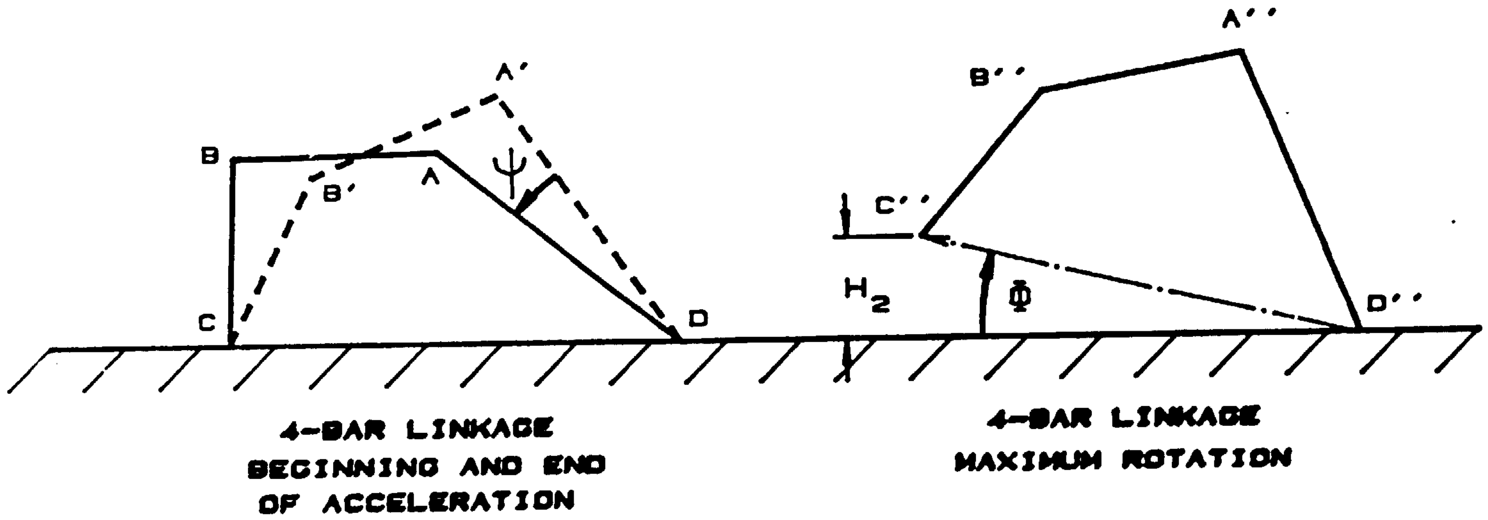
FOR JUMP MOTION

VARIABLE DEFINITION

FIG. 13c



4-BAR LINKAGE
FOR LEANING MOTION
VARIABLE DEFINITION
FIG. 14a



4-BAR LINKAGE
FOR LEANING MOTION
VARIABLE DEFINITION
FIG. 14b

Appendix B

SKIT_3D Graphic Simulation

Figures and Program Listing

SKIT_3D

Three Dimensional Graphic Simulation Program

Computer graphic simulation is an excellent engineering tool for analyzing and designing spatial mechanisms. SKIT_3D is a three dimensional graphic simulation program which allows the user to visualize SKITTER's spatial configurations by controlling system, leg segment, or actuator movements of a screen representation of the platform. User input is in the form of incremental positioning, direct positioning, or time based data files which can be used for platform animation. Output is directed to a screen, plotter, or dump device.

SYSTEM REQUIREMENTS:

Computer: Hewlett-Packard 200 or 300 series computer with input knob present on the key board.

Mass Storage: One 3.5" 720 kbyte disc drive.

Software: Hewlett-Packard Basic 4.0 or greater with the Knob_20 bin loaded.

Options: Hewlett-Packard Graphics Language (HPGL) plotter.
Hewlett-Packard LaserJet printer (or equivalent).

LOADING THE PROGRAM:

To load the program:

1) Boot the computer into the Basic System environment.
2) Make the disc drive the default mass storage device by using the Mass Storage Is command.
3) Insert the SKIT_3D disc into the disc drive.
4) Type load "SKIT_3D" <cr>.

5) Hit <RUN> key.

6) Program will begin.

USING THE PROGRAM:

The Program can be divided into two different sections depending on the type of data input. The Manual Mode of operation allows the user to input data directly or via the keyboard knob to control SKITTER's movements while the Data File Mode accepts time based data files for animating platform position sequences. All movements by the platform are relative to a local coordinate system on SKITTER. Figure 3 shows the orientation of the coordinant system (x-y-z) relative to the initial screen display.

MANUAL MODE

Main Menu:

The initial display shows a Z axis view of SKITTER with the main menu appearing at the bottom of the screen. The menu items can be accessed by pressing the corresponding function keys on the key board. Definition of the keys are as follows

SYSTEM: Allows the user to reorient the entire platform.

PIVOT LINES: Allows the user to pivot the entire platform about a line constructed by any two feet of SKITTER.

ACTUATORS: Allows the user to reorient either a leg segment or the entire platform by engaging a particular actuator.

EXIT: Allows the user to exit the program.

OUTPUT: Allows the user to output the screen display to either a plotter or dump device.

MOVIE: Allows the user to enter DATA FILE Mode.

ATTRIBUTES: Allows the user to change views, window parameters, and output devices.

WHAT: Allows the user to view screen, output device, and platform parameters.

<u>**SYSTEM :**</u>

The SYSTEM function allows the user to rotate or translate the entire platform about or along all three axis. When the key is pressed, a new menu will appear and is defined as follows:

Rotate X: Rotates the platform incrementally about the X axis when the knob is turned.

Rotate Y: Rotates the platform incrementally about the Y axis when the knob is turned.

Rotate Z: Rotates the platform incrementally about the Z axis when the knob is turned.

Rotation Angle: Rotates the platform about the last rotation axis by a user defined angle (<cr> quits).

Knob Increment: Allows the user to input a new knob increment.

Translate X: Translates the platform incrementally along the X axis when the knob is turned.

Translate Y: Translates the platform incrementally along the y axis when the knob is turned.

Translate Z: Translates the platform incrementally along the z axis when the knob is turned.

Trans Vector: Translates the platform along a user defined vector (<cr> to quit)

Main Menu: Returns the user to the main menu.

Pivot Lines:

The PIVOT LINES function allows the user to pivot the entire platform about a line constructed by two of SKITTER's feet. When the key is depressed, a new menu will appear and is defined as follows:

Leg A: Pivots the platform about the leg a pivot line constructed by the feet of legs b & c.

Leg B: Pivots the platform about the leg b pivot line constructed by the feet of legs a & c.

Leg C: Pivots the platform about the leg c pivot line constructed by the feet of legs a & b.

Main Menu: Returns the user to the main menu.

ACTUATORS:

The ACTUATORS function key allows the user to reorient a leg segment or the entire platform by engaging a particular actuator. When the key is depressed a new menu appears and is defined as follows:

Femur A: Engages the femur a actuator and will incrementally change the femur a-body angle when the knob is turned.

Femur B: Engages the femur b actuator and will incrementally change the femur b-body angle when the knob is turned.

Femur C: Engages the femur c actuator and will incrementally change the femur c-body angle when the knob is turned.

Fixed/Free: A Toggle switch which allows the user to move the platform with either its legs always in contact with the ground (fixed) or unconstrained by the ground (free).

Knob Increment: Allows the user to define a new knob increment.

Tibia A: Engages the tibia A actuator and will incrementally change the tibia-femur angle of leg a when the knob is turned.

Tibia B: Engages the tibia b actuator and will incrementally change the tibia-femur angle of leg b when the knob is turned.

Tibia C: Engages the tibia c actuator and will incrementally change the tibia-femur angle of leg c when the knob is turned.

Main Menu: Returns the user to the main menu.

OUTPUT:

The OUTPUT function key allows the user to send the screen display to a plotter or a dump device. When the key is pressed, a new menu will appear and is defined as follows:

Plotter: Outputs the screen display to the designated plotter.

Raster Dump: Outputs the screen display to the designated dump device.

Main Menu: Returns the user to the main menu.

ATTRIBUTES:

The ATTRIBUTES key allows the user to define views, window parameters, and output devices. When the key is pressed, a new menu will appear and is defined as follows:

View: Allows the user to define a new view. When this key is depressed, a new menu will appear and is defined as follows:

X Axis: Changes the users view to looking down the X axis.

Y Axis: Changes the users view to looking down the Y axis.

Z Axis: Changes the users view to looking down the Z axis.

Quit: Returns the user to the ATTRIBUTES menu.

Window: Allows the user to change window parameters. When this key is pressed, a new menu will appear and is defined as follows:

Zoom: Allows the user to zoom in and out from the current window.

Pan X: Allows the user to pan horizontally.

Pan Y: Allows the user to pan vertically.

Input Data: Allows the user to input specific window coordinants.

Quit: Returns the user to the ATTRIBUTES menu.

Disp Quantities: Displays current positions and incremental changes of the entire system or body segments as they are moved.

Dump Device: Allows the user to specify a new dump device.

Plotter Port: Allows the user to specify a new plotter port.

Main Menu: Returns the user to the main menu.

WHAT:

The WHAT function key allows the user to view the values of all parameters such as joint angles, output devices, window variables, and current view. To exit to the main menu, simply hit <cr>.

DATA FILE MODE

The MOVIE key accessible on the main menu allows the user to enter DATA FILE MODE. This mode of operation accepts time based data files created previously by the user and determines the transformation matrices for each time increment. A new file is built on the disc drive named SKITWORKS which contains the SKITTER position sequence.

After the SKITWORKS file is closed the program begins animating the position sequence on the screen.

The DATA FILE mode is extremely useful for integrating output data files from kinematic or control programs with computer graphics. The user is able to vary any particular parameter, such as mass, inertia, or gravity in his application program, create a input data file, and see graphically the effects on SKITTER as it goes through a position sequence. Once a theoretical SKITTER model is complete design of the system components can begin using the model parameters (i.e. control parameters, leg lengths, weights etc.) as design constraints.

INPUT DATA FILE STRUCTURE

The input file structure consists of values for time, free or fixed leg segment movements, and system rotations and translations. The file can be 30 lines long and each line is arranged as follows:

TIME	FREE	FEMUR A	TIBIA A	FEMUR B	TIBIA B	FEMUR C	TIBIA C	ROT X	ROT Y	ROT Z	TRAN X	TRAN Y	TRAN Z
.2	0	3.2	5	0	0	0	0	15	0	0	0	0	0

This particular example shows that the user wishes to rotate the system around the x axis 15 degrees, move femur a 3.2 degrees in fixed mode,and tibia a 5 degrees in the fixed mode at time increment .2.

TIME: Time can have any value; however the value of 999 is reserved as a pointer to tell the program that it is at the end of the input data file. On the final line of the data file the user has to make the time value equal to 999.

FREE: If the value for free equals 0, then the foot will be fixed; however, if the value for free equals 1 then the foot is free (see manual mode - actuators menu).

When the MOVIE keys is pressed, the user will be asked :

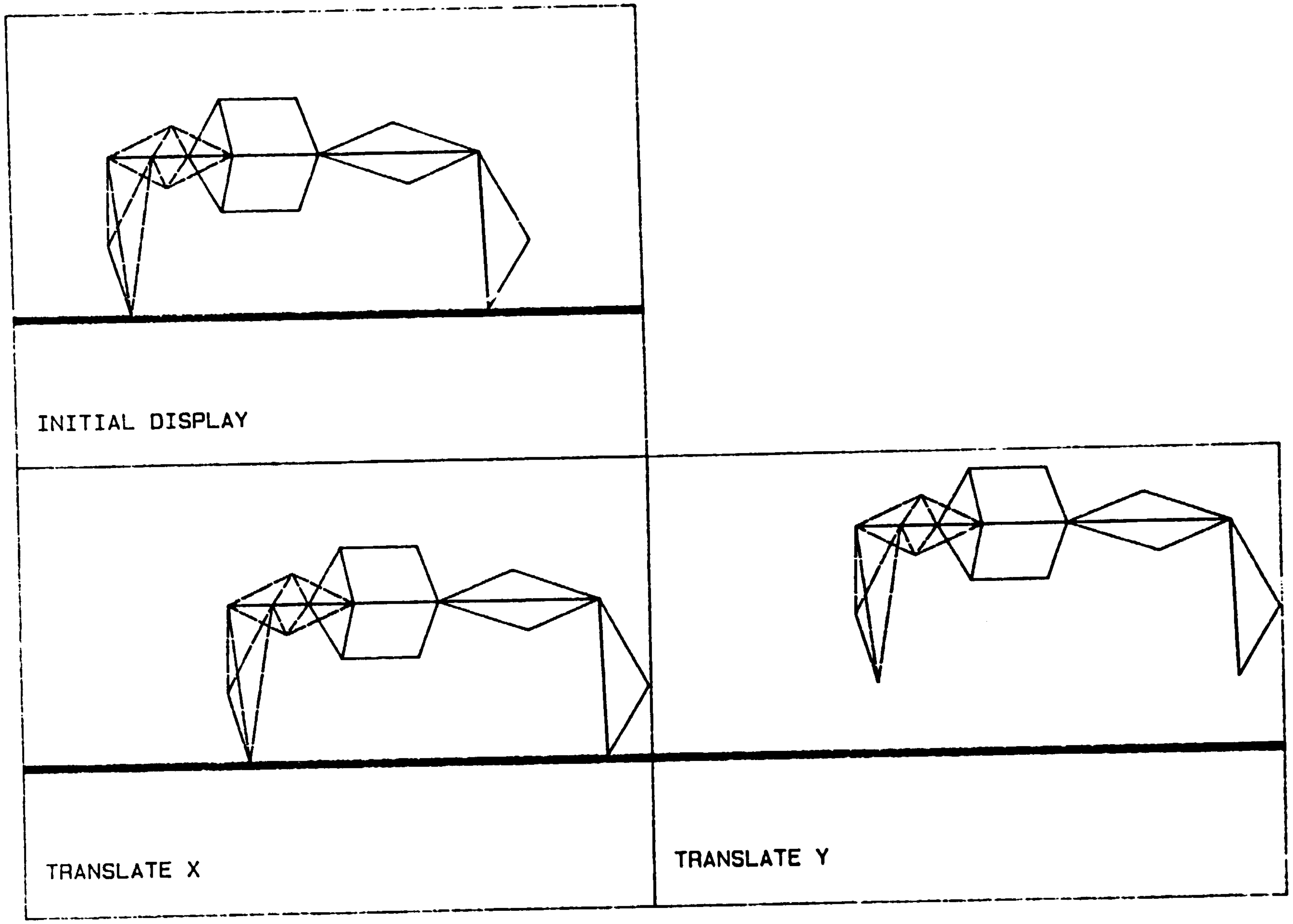
DO YOU WANT TO RUN AN ALREADY COMPUTED FILE ?   Y OR N

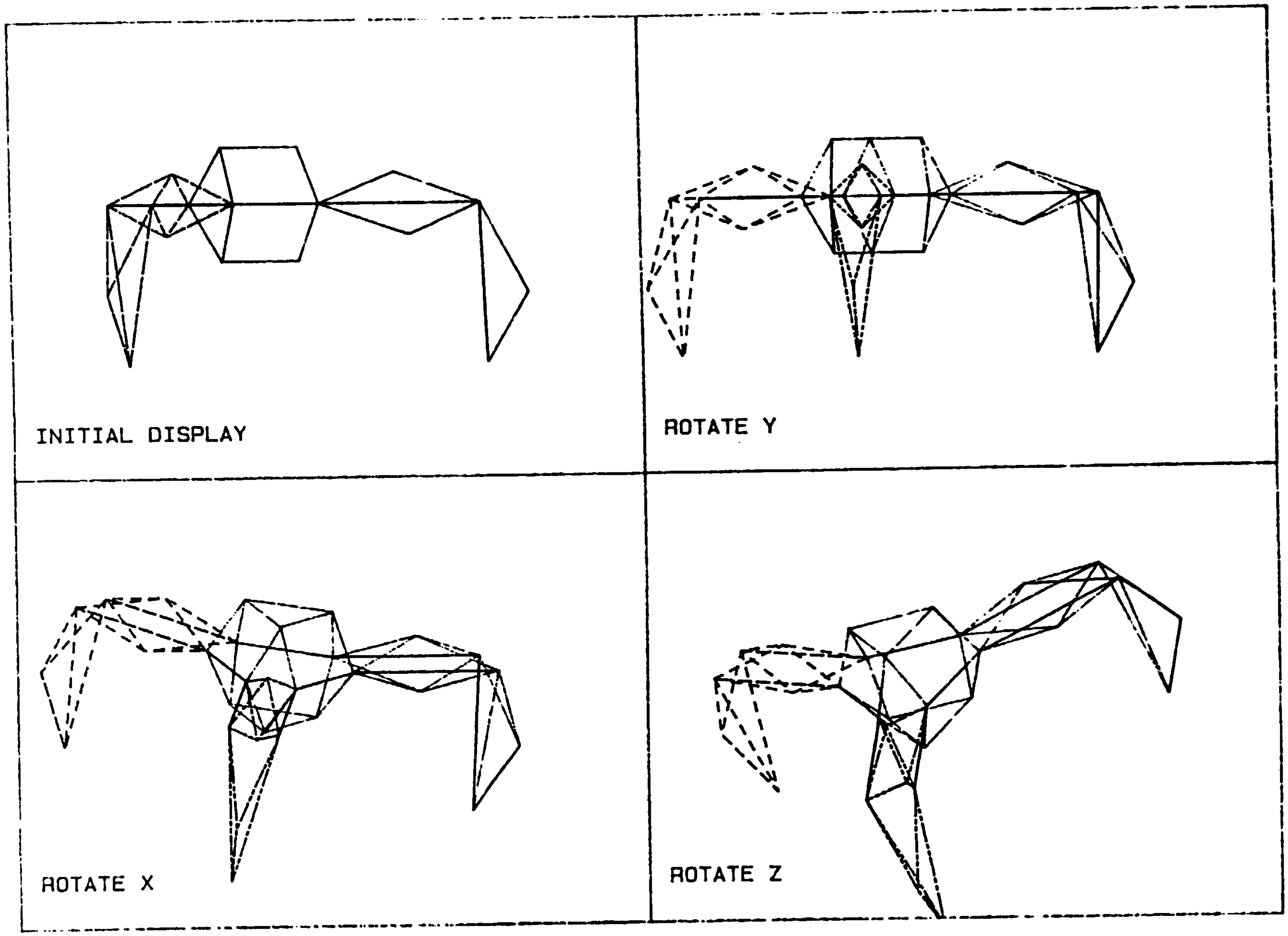
If the user has run the movie function before and as saved a SKITWORKS file, he may enter Y. However, if this is the first time through for the user or a brand new input file, he should enter N.

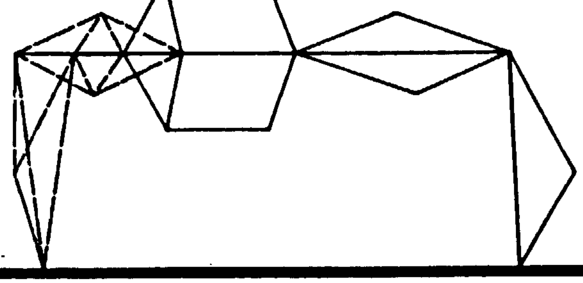
At the prompt, enter in the name of either the computed file or new input file depending on your previous answer. The program will proceed and animate the position sequence. To stop the animation sequence simply hit <cr>.

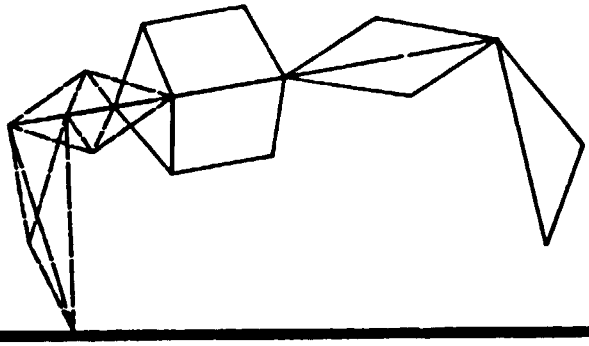
Once the animation sequence is stopped, the program will ask the user if he would like to save the SKITWORKS file as a computed file if the input data file was new. If so enter Y and enter the name of the file at the next prompt.

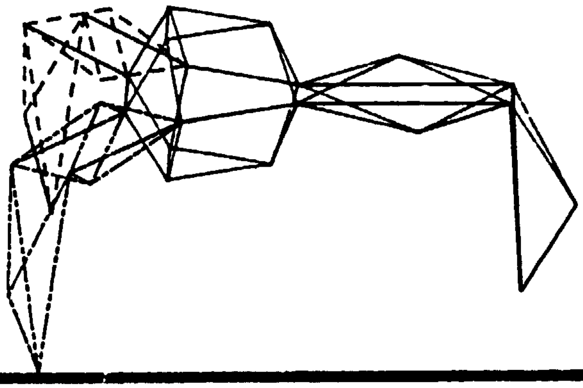
A sample input file , SHOW, and a computed file, WALK, are store on the SKIT_3D disc an can be used to demonstrate the DATA FILE mode for the user.

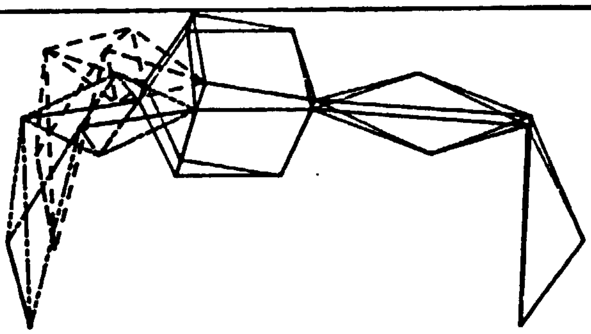

INITIAL DISPLAY
TRANSLATE X
TRANSLATE Y

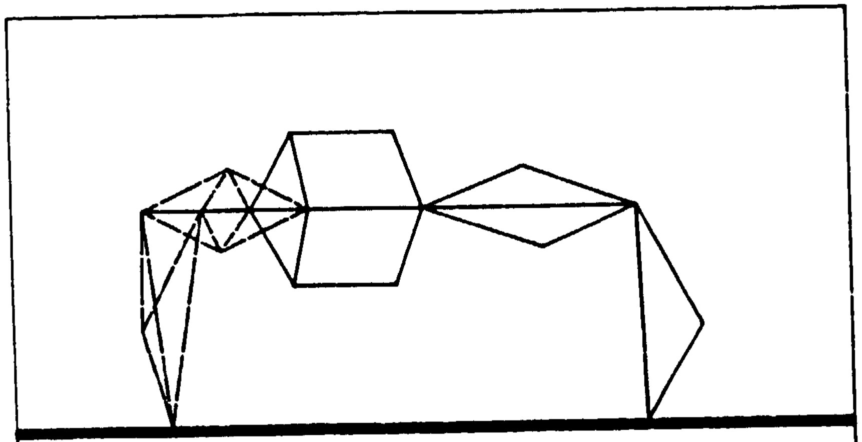

INITIAL DISPLAY
ROTATE Y
ROTATE X
ROTATE Z

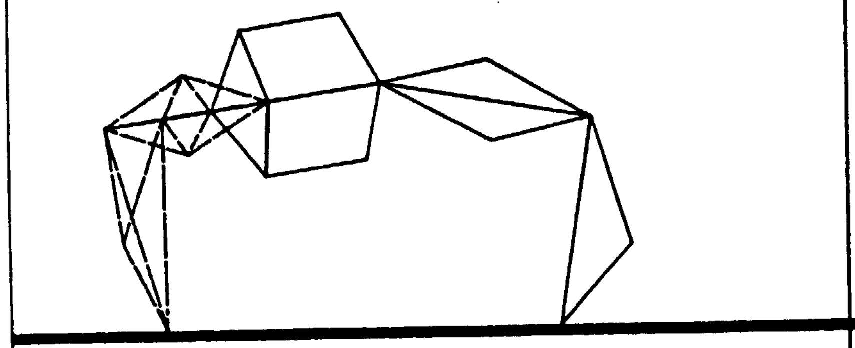

INITIAL DISPLAY

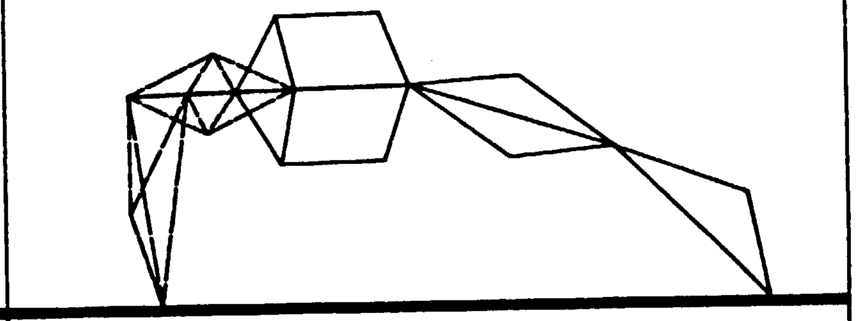

PIVOTLINES LEG A

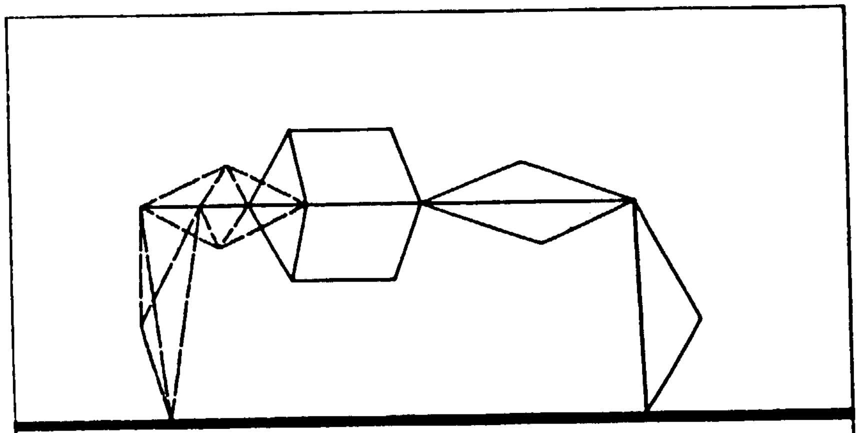

PIVOTLINES LEG B


PIVOTLINES LEG C

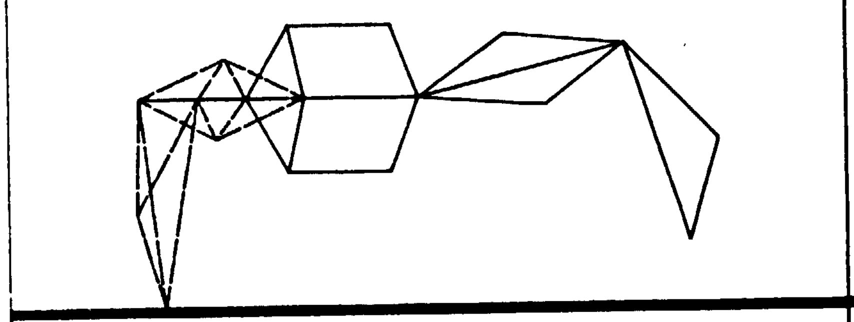

INITIAL DISPLAY


ACTUATORS FEMUR A

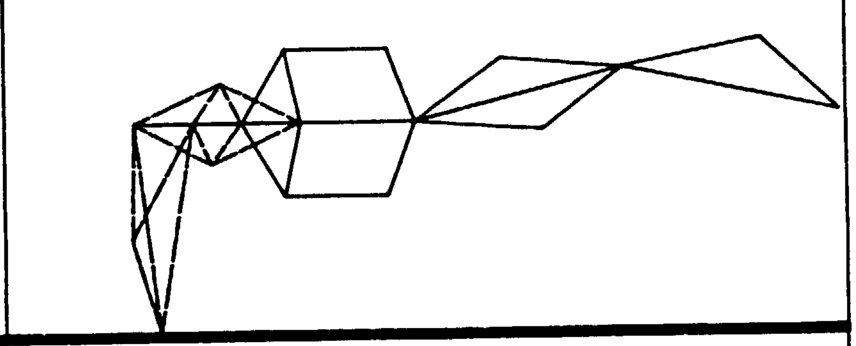

ACTUATORS TIBIA A



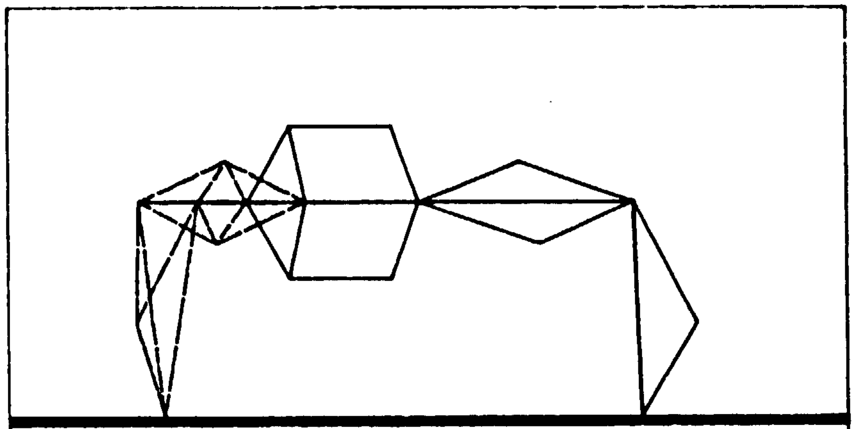
INITIAL DISPLAY



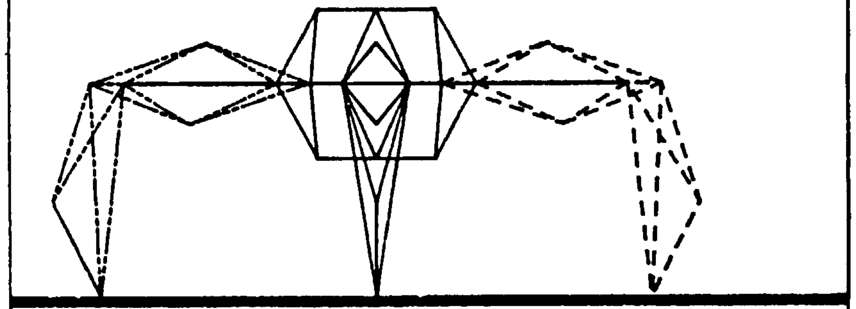
ACIUATORS FEMUR A FREE



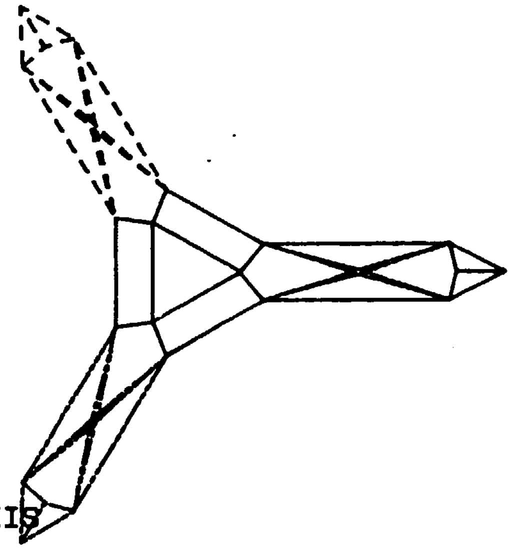
ACTUATORS TIBIA A FREE



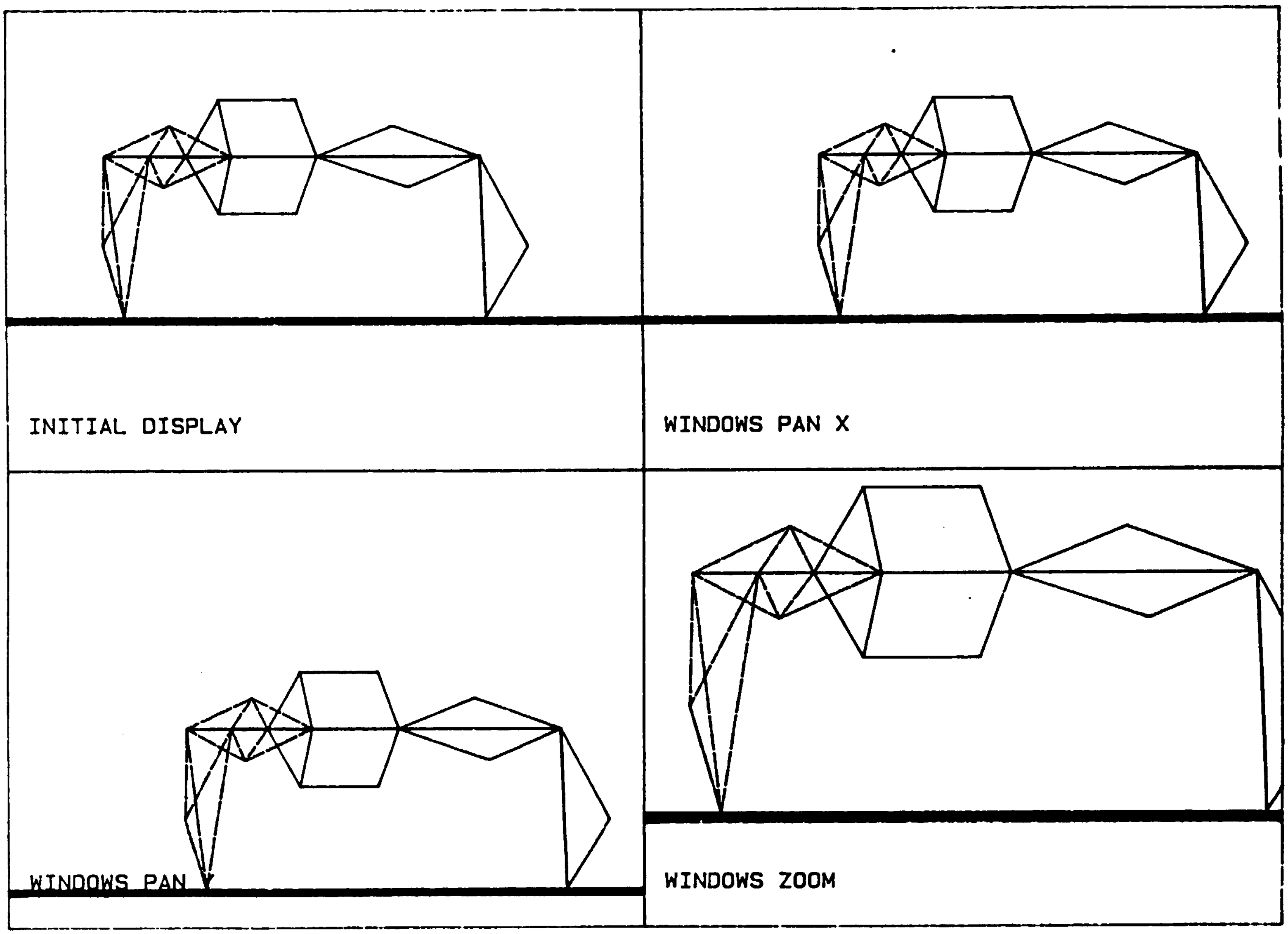
INITIAL DISPLAY Z AXIS



VIEW X AXIS



VIEW Y AXIS


INITIAL DISPLAY
WINDOWS PAN X
WINDOWS PAN
WINDOWS ZOOM

```
THESE ARE THE CURRENT PARAMETERS:

 WINDOW:         X MIN = -20         X MAX =  40
                 Y MIN = -20         Y MAX =  40

 VIEW:  LOOKING DOWN Z AXIS

PLOTTER LOACTION: 705       PRINTER LOCATION: 9

 DISPLAY VALUES IS OFF

    TRANS (in.)     ROT (deg)                  FEMUR ANGLE     TIBIA ANGLE

X       0.00          0.00               A        0.00            90.00
Y       0.00          0.00               B        0.00            90.00
Z       0.00          0.00               C        0.00            90.00

PIVOT ANG A: 0     PIVOT ANG B: 0      PIVOT ANG C: 0



   FORM FEED      |LASER PRINTER |SCREEN        |HARD DISK      |DISK DRIVE
   SCRATCH        |LOAD ""       |CATALOG DRIVE |LIST PROGRAM   |RE-STORE ""
```

TYPICAL OUTPUT FROM 'WHAT' COMMAND

```
10    REM************************************************************************
20    REM
30    REM                              SKIT_3D   V.10
40    REM               THREE DIMENSIONAL GRAPHIC SIMULATION PROGRAM
50    REM
51    REM                                         WRITTEN BY:
52    REM                                         BRICE K. MACLAREN
53    REM                                         GARY V. MCMURRAY
54    REM                                         06/23/88
55    REM
60    REM      THIS PROGRAM WILL ACCURATELY DEPICT THE SKITTER MOBILE PLATFORM
70    REM      AND THE MOTIONS THAT IT IS ABLE TO ACHIEVE BY USING EITHER
80    REM      MANUAL OR DATA FILE INPUT. USE FUNCTION KEYS AND KNOB FOR INPUT.
81    REM
90    REM          HARDWARE:  HEWLETT PACKARD 200/300 SERIES COMPUTER
.00   REM                     3.5' DISC DRIVE
.10   REM                     KEYBOARD WITH KNOB
.20   REM          SOFTWARE:  HEWLETT-PACKARD BASIC 4.0 WITH KNOB_20 BIN LOADED
.30   REM          OPTIONS:   HEWLET-PACKARD (HPGL) PLOTTER
.40   REM                     PRINTER
.41   REM
.42   REM
.50   REM       ***************************************************************
.51   REM
.52   REM
.53   REM************************************************************************
.54   REM       SKITTER DATA FILE: SEE MANUAL FOR DESCRIPTION OF BODY POINTS
.55   REM************************************************************************
.60   DATA      0,0,0,10                      !                        UPPER BODY
.70   DATA      6.5482,28.4912,0,-2           !      A
.80   DATA      9.1602,20.9817,3.2283,-1      !      H
.90   DATA      -1.7468,20.9817,9.5688,-1     !      I
:00   DATA      -3.2741,28.4912,5.6709,-1     !      B
:10   DATA      0,0,0,7
:20   !
:30   DATA      0,0,0,10
40    DATA      -3.2741,28.4912,5.6709,-2     !      B
50    DATA      -7.3759,20.9817,6.3188,-1     !      J
60    DATA      -7.3759,20.9817,-6.3188,-1    !      K
70    DATA      -3.2741,28.4912,-5.6709,-1    !      C
80    DATA      0,0,0,7
90    !
00    DATA      0,0,0,10
10    DATA      -3.2741,28.4912,-5.6709,-2     !     C
20    DATA      -1.7468,20.9817,-9.5688,-1     !     L
30    DATA      9.1602,20.9817,-3.2283,-1      !     G
40    DATA      6.5482,28.4912,0,-1            !     A
50    DATA      0,0,0,7
60    !
70    DATA      0,0,0,10                       !                       BOTTOM BODY
80    DATA      6.5482,13.4722,0,-2            !     D
90    DATA      9.1602,20.9817,3.2283,-1       !     H
00    DATA      -1.7468,20.9817,9.5688,-1      !     I
10    DATA      -3.2741,13.4722,5.6709,-1      !     E
20    DATA      0,0,0,7
30    !
40    DATA      0,0,0,10
50    DATA      -3.2741,13.4722,5.6709,-2     !      E
60    DATA      -7.3759,20.9817,6.3188,-1     !      J
70    DATA      -7.3759,20.9817,-6.3188,-1    !      K
```

```
480   DATA     -3.2741,13.4722,-5.6709,-1 !      F
490   DATA     0,0,0,7
500   !
510   DATA     0,0,0,10
520   DATA     -3.2741,13.4722,-5.6709,-2 !      F
530   DATA     -1.7468,20.9817,-9.5688,-1 !      L
540   DATA     9.1602,20.9817,-3.2283,-1  !      G
550   DATA     6.5482,13.4722,0,-1        !      D
560   DATA     0,0,0,7
570   !
580   DATA     0,0,0,4                          ! RESERVED FOR PEN
590   DATA     0,0,0,10                   !                             FEMUR ONE
600   DATA     9.1602,20.9817,-3.2283,-2  !      G
610   DATA     29.6602,20.9817,-3.2283,-1 !      M
620   DATA     18.7362,25.0731,0,-1       !      O
630   DATA     0,0,0,7
640   !
650   !
660   DATA     0,0,0,10
670   DATA     29.6602,20.9817,3.2283,-2  !      N
680   DATA     18.7362,25.0731,0,-1       !      O
690   DATA     9.1602,20.9817,3.2283,-1   !      H
700   DATA     0,0,0,7
710   !
720   DATA     0,0,0,10
730   DATA     9.1602,20.9817,-3.2283,-2   !      G
740   DATA     29.6602,20.9817,-3.2283,-1 !      M
750   DATA     20.571,16.8903,0,-1        !      P
760   DATA     0,0,0,7
770   !
780   DATA     0,0,0,10
790   DATA     29.6602,20.9817,3.2283,-2  !      N
800   DATA     20.571,16.8903,0,-1        !      P
810   DATA     9.1602,20.9817,3.2283,-1   !      H
820   DATA     0,0,0,7
830   !
840   DATA     0,0,0,10                     !                           TIBIA ONE
850   DATA     29.6602,20.9817,-3.2283,-2   ! M
860   DATA     30.4255,0,0,-1               ! A'
870   DATA     35.7901,9.2132,0,-1          ! B'
880   DATA     0,0,0,7
890   !
900   DATA     0,0,0,10
910   DATA     29.6602,20.9817,3.2283,-2      ! N
920   DATA     30.4255,0,0,-1               ! A'
930   DATA     35.7901,9.2132,0,-1          ! B'
940   DATA     0,0,0,7
950   !
960   DATA     0,0,0,4                    ! RESERVED FOR PEN
970   DATA     0,0,0,10                   !                             FEMUR TWO
980   DATA     -1.7468,20.9817,9.5688,-2  !      I
990   DATA     -9.3493,25.0731,16.2368,-1 !      S
1000  DATA     -11.9968,20.9817,27.3223,-1!      Q
1010  DATA     0,0,0,7
1020  !
1030  DATA     0,0,0,10
.040  DATA     -17.6259,20.9817,24.0723,-2!      R
.050  DATA     -9.3493,25.0731,16.2368,-1 !      S
.060  DATA     -7.3759,20.9817,6.3188,-1  !      J
.070  DATA     0,0,0,7
```

```
1080  !
1090  DATA      0,0,0,10
1100  DATA      -1.7468,20.9817,9.5688,-2  !      I
1110  DATA      -10.2667,16.8903,17.8258,-1!      T
1120  DATA      -11.9968,20.9817,27.3223,-1!      Q
1130  DATA      0,0,0,7
1140  !
1150  DATA      0,0,0,10
1160  DATA      -17.6259,20.9817,24.0723,-2!      R
1170  DATA      -10.2667,16.8903,17.8258,-1!      T
1180  DATA      -7.3759,20.9817,6.3188,-1  !      J
1190  DATA      0,0,0,7
1200  !
1210  !
1220  DATA      0,0,0,10                    !                        TIBIA TWO
1230  DATA      -11.9968,20.9817,27.3223,-2 !  Q
1240  DATA      -15.1940,0,26.3601,-1       !  C'
1250  DATA      -17.8763,9.2132,31.0059,-1  !  D'
1260  DATA      0,0,0,7
1270  !
1280  DATA      0,0,0,10
1290  DATA      -17.6259,20.9817,24.0723,-2 !  N
1300  DATA      -15.1940,0,26.3601,-1       !  C'
1310  DATA      -17.8763,9.2132,31.0059,-1   !  D'
1320  DATA      0,0,0,7
1330  !
1340  DATA      0,0,0,4                   ! RESERVED FOR PEN
1350  DATA      0,0,0,10                  !                        FEMUR THREE
1360  DATA      -7.3759,20.9817,-6.3188,-2 !      K
1370  DATA      -9.3493,25.0731,-16.2368,-1!      W
1380  DATA      -17.6259,20.9817,-24.0723,-1!     U
1390  DATA      0,0,0,7
1400  !
1410  DATA      0,0,0,10
1420  DATA      -11.9968,20.9817,-27.3223,-2 !    V
1430  DATA      -9.3493,25.0731,-16.2368,-1  !    W
1440  DATA      -1.7468,20.9817,-9.5688,-1   !    L
1450  DATA      0,0,0,7
1460  !
1470  DATA      0,0,0,10
1480  DATA      -7.3759,20.9817,-6.3188,-2   !    K
1490  DATA      -10.2667,16.8903,-17.8258,-1 !    X
1500  DATA      -17.6259,20.9817,-24.0723,-1 !    U
1510  DATA      0,0,0,7
1520  !
1530  !
1540  DATA      0,0,0,10
1550  DATA      -11.9968,20.9817,-27.3223,-2 !  V
1560  DATA      -10.2667,16.8903,-17.8258,-1!  X
1570  DATA      -1.7468,20.9817,-9.5688,-1   !  L
1580  DATA      0,0,0,7
1590  !
1600  DATA      0,0,0,10                     !                       TIBIA THREE
1610  DATA      -17.6259,20.9817,-24.0723,-2 !  U
1620  DATA      -15.1940,0,-26.3601,-1       !  E'
1630  DATA      -17.8763,9.2132,-31.0059,-1  !  F'
1640  DATA      0,0,0,7
1650  !
.660  DATA      0,0,0,10
.670  DATA      -11.9968,20.9817,-27.3223,-2 !  V
```

```
1680 DATA       -15.1940,0,-26.3601,-1        !  E'
1690 DATA       -17.8763,9.2132,-31.0059,-1   !  F'
1700 DATA       0,0,0,7
1710 REM        ****************************************************************
1720 !
1730 !
1731 REM************************************************************************
1732 REM
1733 REM              MAIN PROGRAM
1734 REM
1735 REM************************************************************************
1740      OPTION BASE 1
1750      REAL Skitter(129,4),Newskit(129,3)       ! DEFINE VAR
1760      REAL Trans(4,4),Temp(129,4),Tempa(129,4)!TRANSFORMATION MATRIX
1770      REAL Total(4,4),Skitmod(129,4)           !TOTAL TRANFORM MATRIX
1780      REAL Femur(31,4),Femurmod(31,4),Femurtemp(31,4)
1790      REAL Tibia(10,4),Tibiatemp(10,4),Tibiamod(10,4)
1800      GOSUB Init                               ! INITILIZATION ROUTINE
1810      CALL Display_skit(Skitter(*),Newskit(*),Screen_x,Screen_y)
1820                                               ! DRAW SKITTER
1821 REM************************************************************************
1822 REM
1823 REM              MENU SELECTION AND KEY DEFINITION
1824 REM
1825 REM************************************************************************
1830 Menu:                                         ! MENU SELECT
1840      SELECT Menu$
1850 !
1860           CASE "MAIN"
1870                ON KEY 0 LABEL "SYSTEM" GOTO System
1880               ON KEY 2 LABEL "ACTUATORS" GOTO Actuator
1890                ON KEY 5 LABEL "OUTPUT" GOTO Output
1900                ON KEY 7 LABEL "ATTRIBUTES" GOTO Attributes
1910                ON KEY 9 LABEL "WHAT ??" GOTO What
1920                ON KEY 4 LABEL "EXIT" GOTO Finished
1930                ON KEY 1 LABEL "PIVOT LINES" GOTO Pivotlines
1940                ON KEY 6 LABEL "MOVIE" GOTO Movie
1950                ON KEY 3 LABEL "" GOTO Main
1960                ON KEY 8 LABEL "" GOTO Main
1970                GOTO 1970
1980           CASE "PIVOTLINES"
1990                 ON KNOB .55 GOTO Knob_isr
2000                 ON KEY 0 LABEL "LEG A" GOSUB Pivotlega
2010                 ON KEY 1 LABEL "" GOTO Pivotlines
2020                 ON KEY 2 LABEL "LEG B" GOSUB Pivotlegb
2030                 ON KEY 3 LABEL "" GOTO Pivotlines
2040                 ON KEY 4 LABEL "LEG C" GOSUB Pivotlegc
2050                 ON KEY 5 LABEL "" GOTO Pivotlines
2060                 ON KEY 6 LABEL "" GOTO Pivotlines
2070                 ON KEY 7 LABEL "" GOTO Pivotlines
2080                 ON KEY 8 LABEL "" GOTO Pivotlines
2090                 ON KEY 9 LABEL "MAIN MENU" GOTO Main
2100                 GOTO 2100
2110           CASE "SYSTEM"
2120                ON KNOB .2 GOTO Knob_isr
2130                ON KEY 1 LABEL "ROTATE Y" GOSUB Rot_y
2140                ON KEY 0 LABEL "ROTATE X" GOSUB Rot_x
 150                ON KEY 2 LABEL "ROTATE Z" GOSUB Rot_z
 160                ON KEY 5 LABEL "TRANSLATE X" GOSUB Trans_x
 170                ON KEY 6 LABEL "TRANSLATE Y" GOSUB Trans_y
```

```
2180                ON KEY 7 LABEL "TRANSLATE Z" GOSUB Trans_z
2190                ON KEY 9 LABEL "MAIN MENU" GOTO Main
2200                ON KEY 8 LABEL "TRANS VECTOR" GOSUB Vector
2210                ON KEY 3 LABEL "ROTATION ANGLE" GOSUB Angle
2220                ON KEY 4 LABEL "KNB INCREMENT" GOTO Increment
2230                GOTO 2230
2240 !
2250           CASE "ATTRIBUTES"
2260                ON KEY 0 LABEL "VIEWS" GOTO Windowpane
2270                ON KEY 9 LABEL "MAIN" GOTO Main
2280                ON KEY 1 LABEL "" GOTO Attributes
2290                ON KEY 2 LABEL "WINDOW" GOTO Windows
2300                ON KEY 3 LABEL "" GOTO Attributes
2310                ON KEY 4 LABEL "DISP QUANTITY" GOTO Print_flag
2320                ON KEY 5 LABEL "DUMP DEVICE" GOTO Printer
2330                ON KEY 6 LABEL "PLOTTER PORT" GOTO Plotter
2340                ON KEY 7 LABEL "" GOTO Attributes
2350                ON KEY 8 LABEL "" GOTO Attributes
2360                GOTO 2360
2370 !
2380 !
2390           CASE "OUTPUT"
2400                ON KEY 0 LABEL "PLOT" GOTO Plot
2410                ON KEY 1 LABEL "" GOTO Output
2420                ON KEY 2 LABEL "RASTER DUMP" GOTO Dump
2430                ON KEY 3 LABEL "" GOTO Output
2440                ON KEY 4 LABEL "" GOTO Output
2450                ON KEY 5 LABEL "" GOTO Output
2460                ON KEY 6 LABEL "" GOTO Output
2470                ON KEY 7 LABEL "" GOTO Output
2480                ON KEY 8 LABEL "" GOTO Output
2490                ON KEY 9 LABEL "MAIN MENU" GOTO Main
2500                GOTO 2500
2510 !
2520           CASE "ACTUATOR"
2530               ON KNOB .21 GOTO Knob_leg_isr
2540               ON KEY 0 LABEL "FEMUR A" GOTO Femur_a
2550               ON KEY 1 LABEL "FEMUR B" GOTO Femur_b
2560               ON KEY 2 LABEL "FEMUR C" GOTO Femur_c
2570               ON KEY 5 LABEL "TIBIA A" GOTO Tibia_a
2580               ON KEY 6 LABEL "TIBIA B" GOTO Tibia_b
2590               ON KEY 7 LABEL "TIBIA C" GOTO Tibia_c
2600               ON KEY 8 LABEL "" GOTO Menu
2610               ON KEY 3 LABEL Freeleg$ GOTO Free_leg
2620               ON KEY 4 LABEL "KNB INCREMENT" GOTO Increment
2630               ON KEY 9 LABEL "MAIN MENU" GOTO Main
2640               GOTO 2640
2650        END SELECT
2660 !
2670 !
2671 REM*********************************************************************
2672 REM
2673 REM      KNOB_ISR: KNOB INTERUPT SERVICE ROUTINE.  ON KNOB ROTATION, THE
2674 REM      APPROIPRIATE FUNTION WILL BE CARRIED OUT BY THE KNOB INCREMENT
2675 REM      AMOUNT
2676 REM
2677 REM*********************************************************************
2680 Knob_isr:         !
2690                   Theta=Increment*SGN(KNOBX)
2700                   SELECT Twirl$
```

```
2701 REM*************     SYSTEM ROTATION     ************************************
2702 !
2710                      CASE "ROTATE Y"
2720                      Theta=-Theta
2730                      CALL Rotate_y(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_y,Theta,Printflag$)
2731 !
2740                      CASE "ROTATE X"
2750                      CALL Rotate_x(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_x,Theta,Printflag$)
2760 !
2770                      CASE "ROTATE Z"
2780                      CALL Rotate_z(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_z,Theta,Printflag$)
2790 !
2791 REM***************** SYSTEM TRANSLATION ************************************
2792 !
2800                      CASE "TRANSLATE"
2810                      CALL Translate_3d(Skitter(*),Skitmod(*),Total(*),Temp(*)
,Tempa(*),Trans(*),Sys_trans_x,Sys_trans_y,Sys_trans_z,Way,Theta,Printflag$)
2820 !
2821 REM***************** PIVOT LINES *******************************************
2822 !
2830                      CASE "PIVOTLINES"
2840                         Theta=-Theta
2841 !
2842 !
2850                           IF Leg_flag$="FEMUR A" THEN
2860                           Pivot_ang_a=Pivot_ang_a+Theta
2870                           DISP " MODE: ROTATE ABOUT PIVOT LINE A";Theta;" TOTA
L ANGLE:";Pivot_ang_a
2880                          Pivotx=(Skitter(96,1)+Skitter(127,1))/2
2890                          Pivoty=(Skitter(96,2)+Skitter(127,2))/2
2900                          Pivotz=(Skitter(96,3)+Skitter(127,3))/2
2910                          Dist_piv_foot=SQR((Pivotx-Skitter(65,1))^2+(Pivoty-Sk
itter(65,2))^2+(Pivotz-Skitter(65,3))^2)
2920                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
2930                          Flag=0
2940                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,-Theta,P
rintflag$,Fem_a_ang,Flag)
2950                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
2960                          MAT Skitter= Skitmod
2970                          END IF
2980 !
2981 !
2982 !
2990                          IF Leg_flag$="FEMUR B" THEN
3000                          Pivot_ang_b=Pivot_ang_b+Theta
3010                          DISP " MODE: ROTATE ABOUT PIVOT LINE B BY:";Theta;"
 TOTAL ANG:";Pivot_ang_b
3020                          Pivotx=(Skitter(65,1)+Skitter(127,1))/2
3030                          Pivoty=(Skitter(65,2)+Skitter(127,2))/2
3040                          Pivotz=(Skitter(65,3)+Skitter(127,3))/2
3050                          Dist_piv_foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
itter(96,2))^2+(Pivotz-Skitter(96,3))^2)
3060                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
3070                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
```

```
80                          Flag=0
90                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Theta,Pr
tflag$,Fem_b_ang,Flag)
00                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
10                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
,Pivotz)
20                          MAT Skitter= Skitmod
30                          END IF
40 !
41 !
42 !
50                          IF Leg_flag$="FEMUR C" THEN
60                          Pivot_ang_c=Pivot_ang_c+Theta
70                          DISP " MODE: ROTATE  ABOUT PIVOT LINE C BY:";Theta;"
OTAL ANG:";Pivot_ang_c
80                          Pivotx=(Skitter(65,1)+Skitter(96,1))/2
90                          Pivoty=(Skitter(65,2)+Skitter(96,2))/2
00                          Pivotz=(Skitter(65,3)+Skitter(96,3))/2
10                          Dist_piv_foot=SQR((Pivotx-Skitter(127,1))^2+(Pivoty-S
tter(127,2))^2+(Pivotz-Skitter(127,3))^2)
20                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
ty,-Pivotz)
30                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
40                          Flag=0
50                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Theta,Pr
tflag$,Fem_c_ang,Flag)
60                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
70                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
,Pivotz)
80                          MAT Skitter= Skitmod
90                          END IF
00 !
10                          MAT Tempa(*,1:3)= Skitter(*,1:3)
20                          MAT Temp= Tempa*Total
30                          MAT Skitmod(*,1:3)= Temp(*,1:3)
40                      END SELECT
50                      CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
60                      GOTO Menu
70 !
71 REM*******************************************************************
72 REM
73 REM      KNOB_LEG_ISR:  KNOB LEG INTERUPT SERVICE ROUTINE FOR ACTUATOR MENU
74 REM
75 REM*******************************************************************
76 !
80 Knob_leg_isr:!
90                 Theta=Increment*SGN(KNOBX)
00                  SELECT Leg$
01!
02 !
10                        CASE "FEMUR A"
20                          Theta=-Theta
30                         MAT Femur= Skitter(37:67,*)
40                         CALL Trans_fem_orig(Femur(*),Femurmod(*),-Femur(3,1),
emur(3,2),-Femur(3,3))
50                         Flag=1
60                         CALL Rotate_leg_y(Femurmod(*),Femurmod(*),180)
70                         CALL Rotate_leg_z(Femurmod(*),Femurmod(*),Leg$,Theta,
intflag$,Fem_a_ang,Flag)
80                         CALL Rotate_leg_y(Femurmod(*),Femurmod(*),180)
```

```
490                          CALL Trans_fem_orig(Femurmod(*),Femurmod(*),Femur(3,1
,Femur(3,2),Femur(3,3))
500                          MAT Skitter(37:67,*)= Femurmod
510!
520                          IF Freeleg$="FREE" THEN
530                          MAT Femurtemp(*,1:3)= Femurmod(*,1:3)
540                          MAT Femur= Femurtemp*Total
550                          MAT Skitmod(37:67,1:3)= Femur(*,1:3)
560                          GOTO End_leg
570                          END IF
580!
590                          Pivotx=(Skitter(96,1)+Skitter(127,1))/2
600                          Pivoty=(Skitter(96,2)+Skitter(127,2))/2
610                          Pivotz=(Skitter(96,3)+Skitter(127,3))/2
620                          Dist_piv_foot=SQR((Pivotx-Skitter(65,1))^2+(Pivoty-Sk
tter(65,2))^2+(Pivotz-Skitter(65,3))^2)
630                          Dist_y=Pivoty-Skitter(65,2)
640                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
650                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
oty,-Pivotz)
660                          Flag=0
670                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,-Rot_ang
Printflag$,Fem_a_ang,Flag)
680                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
690                          MAT Skitter= Skitmod
700                          MAT Tempa(*,1:3)= Skitter(*,1:3)
710                          MAT Temp= Tempa*Total
720                          MAT Skitmod(*,1:3)= Temp(*,1:3)
730 !
740 !
750 !
760                         CASE "FEMUR B"
770                          MAT Femur= Skitter(68:98,*)
780                          CALL Trans_fem_orig(Femur(*),Femurmod(*),-Femur(3,1),
Femur(3,2),-Femur(3,3))
790                          CALL Rotate_leg_y(Femurmod(*),Femurmod(*),60)
800                          Flag=1
810                          CALL Rotate_leg_z(Femurmod(*),Femurmod(*),Leg$,Theta,
rintflag$,Fem_b_ang,Flag)
820                          CALL Rotate_leg_y(Femurmod(*),Femurmod(*),-60)
830                          CALL Trans_fem_orig(Femurmod(*),Femurmod(*),Femur(3,1
,Femur(3,2),Femur(3,3))
840                          MAT Skitter(68:98,*)= Femurmod
850  !
860                          IF Freeleg$="FREE" THEN
870                          MAT Femurtemp(*,1:3)= Femurmod(*,1:3)
880                          MAT Femur= Femurtemp*Total
890                          MAT Skitmod(68:98,1:3)= Femur(*,1:3)
900                          GOTO End_leg
910                          END IF
920  !
930                          Pivotx=(Skitter(65,1)+Skitter(127,1))/2
940                          Pivoty=(Skitter(65,2)+Skitter(127,2))/2
950                          Pivotz=(Skitter(65,3)+Skitter(127,3))/2
960                          Dist_piv foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
tter(96,2))^2+(Pivotz-Skitter(96,3))^2)
970                          Dist_y=Pivoty-Skitter(96,2)
980                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
990                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
'oty,-Pivotz)
000                         CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
010                         Flag=0
020                         CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
rintflag$,Fem_b_ang,Flag)
030                         CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
040                         CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
050                         MAT Skitter= Skitmod
060                         MAT Tempa(*,1:3)= Skitter(*,1:3)
070                         MAT Temp= Tempa*Total
080                         MAT Skitmod(*,1:3)= Temp(*,1:3)
090  !
100  !
110                        CASE "FEMUR C"
120                          Theta=-Theta
130                         MAT Femur= Skitter(99:129,*)
140                         CALL Trans_fem_orig(Femur(*),Femurmod(*),-Femur(3,1),
Femur(3,2),-Femur(3,3))
150                         CALL Rotate_leg_y(Femurmod(*),Femurmod(*),-60)
160                         Flag=1
170                         CALL Rotate_leg_z(Femurmod(*),Femurmod(*),Leg$,Theta,
rintflag$,Fem_c_ang,Flag)
180                         CALL Rotate_leg_y(Femurmod(*),Femurmod(*),60)
190                         CALL Trans_fem_orig(Femurmod(*),Femurmod(*),Femur(3,1
,Femur(3,2),Femur(3,3))
200                         MAT Skitter(99:129,*)= Femurmod
210 !
220                         IF Freeleg$="FREE" THEN
230                         MAT Femurtemp(*,1:3)= Femurmod(*,1:3)
240                         MAT Femur= Femurtemp*Total
250                         MAT Skitmod(99:129,1:3)= Femur(*,1:3)
260                         GOTO End_leg
270                         END IF
280 !
290                         Pivotx=(Skitter(65,1)+Skitter(96,1))/2
300                         Pivoty=(Skitter(65,2)+Skitter(96,2))/2
310                         Pivotz=(Skitter(65,3)+Skitter(96,3))/2
320                         Dist_piv_foot=SQR((Pivotx-Skitter(127,1))^2+(Pivoty-S
itter(127,2))^2+(Pivotz-Skitter(127,3))^2)
330                         Dist_y=Pivoty-Skitter(127,2)
340                         Rot_ang=ASN(Dist_y/Dist_piv_foot)
350                         CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
oty,-Pivotz)
360                         CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
370                         Flag=0
380                         CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
rintflag$,Fem_c_ang,Flag)
390                         CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
400                         CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
410                         MAT Skitter= Skitmod
420                         MAT Tempa(*,1:3)= Skitter(*,1:3)
430                         MAT Temp= Tempa*Total
440                         MAT Skitmod(*,1:3)= Temp(*,1:3)
450 !
460 !
470 !
480                         CASE "TIBIA A"
490                         Theta=-Theta
```

```
500                     MAT Tibia= Skitter(58:67,*)
510                     CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
Tibia(2,2),-Tibia(2,3))
520                     Flag=1
530                     CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),180)
540                     CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
rintflag$,Tib_a_ang,Flag)
550                     CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),180)
560                     CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
,Tibia(2,2),Tibia(2,3))
570                     MAT Skitter(58:67,*)= Tibiamod
580 !
590                     IF Freeleg$="FREE" THEN
600                     MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
610                     MAT Tibia= Tibiatemp*Total
620                     MAT Skitmod(58:67,1:3)= Tibia(*,1:3)
630                     GOTO End_leg
640                     END IF
650 !
660                     Pivotx=(Skitter(96,1)+Skitter(127,1))/2
670                     Pivoty=(Skitter(96,2)+Skitter(127,2))/2
680                     Pivotz=(Skitter(96,3)+Skitter(127,3))/2
690                     Dist_piv_foot=SQR((Pivotx-Skitter(65,1))^2+(Pivoty-Sk
tter(65,2))^2+(Pivotz-Skitter(65,3))^2)
700                     Dist_y=Pivoty-Skitter(65,2)
710                     Rot_ang=ASN(Dist_y/Dist_piv_foot)
720                     CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
oty,-Pivotz)
730                     Flag=0
740                     CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,-Rot_ang
Printflag$,Tib_a_ang,Flag)
750                     CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
760                     MAT Skitter= Skitmod
770                     MAT Tempa(*,1:3)= Skitter(*,1:3)
780                     MAT Temp= Tempa*Total
790                     MAT Skitmod(*,1:3)= Temp(*,1:3)
300 !
310 !
320                     CASE "TIBIA B"
330                     MAT Tibia= Skitter(89:98,*)
340                     CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
Tibia(2,2),-Tibia(2,3))
350                     CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),60)
360                     Flag=1
370                     CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
rintflag$,Tib_b_ang,Flag)
380                     CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),-60)
390                     CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
.Tibia(2,2),Tibia(2,3))
00                      MAT Skitter(89:98,*)= Tibiamod
10 !
20                      IF Freeleg$="FREE" THEN
30                      MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
40                      MAT Tibia= Tibiatemp*Total
50                      MAT Skitmod(89:98,1:3)= Tibia(*,1:3)
60                      GOTO End_leg
70                      END IF
80 !
90                      Pivotx=(Skitter(65,1)+Skitter(127,1))/2
```

```
000                    Pivoty=(Skitter(65,2)+Skitter(127,2))/2
010                    Pivotz=(Skitter(65,3)+Skitter(127,3))/2
020                    Dist_piv_foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
itter(96,2))^2+(Pivotz-Skitter(96,3))^2)
030                    Dist_y=Pivoty-Skitter(96,2)
040                    Rot_ang=ASN(Dist_y/Dist_piv_foot)
050                    CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
oty,-Pivotz)
060                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
070                    Flag=0
080                    CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
rintflag$,Tib_b_ang,Flag)
090                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
100                    CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
110                    MAT Skitter= Skitmod
120                    MAT Tempa(*,1:3)= Skitter(*,1:3)
130                    MAT Temp= Tempa*Total
140                    MAT Skitmod(*,1:3)= Temp(*,1:3)
150 !
160 !
170                    CASE "TIBIA C"
180                    MAT Tibia= Skitter(120:129,*)
190                    CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
Tibia(2,2),-Tibia(2,3))
200                    CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),-60)
210                    Flag=1
220                    CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
rintflag$,Tib_c_ang,Flag)
230                    CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),60)
240                    CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
,Tibia(2,2),Tibia(2,3))
250                    MAT Skitter(120:129,*)= Tibiamod
260 !
270                    IF Freeleg$="FREE" THEN
280                    MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
290                    MAT Tibia= Tibiatemp*Total
300                    MAT Skitmod(120:129,1:3)= Tibia(*,1:3)
310                    GOTO End_leg
320                    END IF
330 !
340                    Pivotx=(Skitter(65,1)+Skitter(96,1))/2
350                    Pivoty=(Skitter(65,2)+Skitter(96,2))/2
360                    Pivotz=(Skitter(65,3)+Skitter(96,3))/2
370                    Dist_piv_foot=SQR((Pivotx-Skitter(127,1))^2+(Pivoty-S
itter(127,2))^2+(Pivotz-Skitter(127,3))^2)
380                    Dist_y=Pivoty-Skitter(127,2)
390                    Rot_ang=ASN(Dist_y/Dist_piv_foot)
400                    CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
oty,-Pivotz)
410                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
420                    Flag=0
430                    CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
rintflag$,Tib_c_ang,Flag)
440                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
450                    CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
y,Pivotz)
460                    MAT Skitter= Skitmod
470                    MAT Tempa(*,1:3)= Skitter(*,1:3)
480                    MAT Temp= Tempa*Total
```

```
5490                      MAT Skitmod(*,1:3)= Temp(*,1:3)
5500  !
5510 End_leg: !
5520           END SELECT
5530 !
5540           CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
5550           GOTO Menu
5551 REM ***********************************************************************
5552 REM
5553 REM     GOSUB ROUTINES FOR MENU AND KNOB ISR CASE SELECTION
5554 REM
5555 REM***********************************************************************
5560 Main:!
5570             Menu$="MAIN"
5580             GOTO Menu
5590 Movie:!
5600            CALL Movie
5610             RESTORE 160
5620             GOSUB Init
5630             CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
5640            GOTO Menu
5650 Pivotlines:!
5660             Menu$="PIVOTLINES"
5670             GCTO Menu
5680 !
5690 Pivotlega:!
5700            Twirl$="PIVOTLINES"
5710            Leg_flag$="FEMUR A"
5720            RETURN
5730 !
5740 Pivotlegb:!
5750            Twirl$="PIVOTLINES"
5760            Leg_flag$="FEMUR B"
5770            RETURN
5780 !
5790 Pivotlegc:!
5800            Twirl$="PIVOTLINES"
5810            Leg_flag$="FEMUR C"
5820            RETURN
5830 !
5840 System:  !
5850             Menu$="SYSTEM"
5860             GOTO Menu
5870 !
5880 Attributes:!
5890             Menu$="ATTRIBUTES"
5900             GOTO Menu
5910 !
5920 Output:!
5930             Menu$="OUTPUT"
5940             GOTO Menu
5950 !
5960 !
5970 Actuator:!
5980             Menu$="ACTUATOR"
5990             GOTO Menu
6000 !
6010 Increment:!
6020            DISP "  INPUT NEW INCREMENT  CURRENT VALUE:",Increment;
6030            LINPUT Increment$
```

```
5040              IF Increment$="" THEN
5050                 GOTO 6090
5060              ELSE
5070                Increment=VAL(Increment$)
5080              END IF
5090              GOTO Menu
5100 Free_leg:!
5110               IF Freeleg$="FIXED" THEN
5120               DISP " LEG IS NOW FREE TO ROTATE"
5130               Freeleg$="FREE"
5140               ELSE
5150               DISP " LEG IS NOW FIXED "
5160               Freeleg$="FIXED"
5170               END IF
5180               GOTO Menu
5190 Femur_a:!
5200               Leg$="FEMUR A"
5210               DISP " MODE: FEMUR A"
5220               GOTO Menu
5230 !
5240 Femur_b:!
5250               Leg$="FEMUR B"
5260               DISP " MODE: FEMUR B"
5270               GOTO Menu
5280 !
5290 Femur_c:!
5300               Leg$="FEMUR C"
5310               DISP " MODE: FEMUR C"
5320               GOTO Menu
5330 !
5340 Tibia_a:!
5350               Leg$="TIBIA A"
5360               DISP " MODE: TIBIA A"
5370               GOTO Menu
5380 !
5390 Tibia_b:!
5400               Leg$="TIBIA B"
5410               DISP " MODE: TIBIA B"
5420               GOTO Menu
5430 !
5440 Tibia_c:!
5450               Leg$="TIBIA C"
5460               DISP " MODE: TIBIA C"
5470               GOTO Menu
5480 !
5490 Windows:!
5500               CALL Zoom_pan(Window$,Screenx_win_min,Screenx_win_max,Screeny_wi
 _min,Screeny_win_max,Skitmod(*),Newskit(*),Screen_x,Screen_y)
510               GOTO Menu
520 What:!
530 !
540              Ap=Screenx_win_min
550              Bp=Screenx_win_max
560              Cp=Screeny_win_min
570              Dp=Screeny_win_max
580              Ep=Sys_trans_x
590              Fp=Sys_trans_y
600              Gp=Sys_trans_z
610              Hp=Sys_rot_x
620              Ip=Sys_rot_y
```

```
6630            Kp=Sys_rot_z
6640            Lp=Fem_a_ang
6650            Mp=Fem_b_ang
6660            Np=Fem_c_ang
6670            Op=Tib_a_ang
6680            Qp=Tib_b_ang
6690            Pp=Tib_c_ang
6700            Rp=Increment
6710            Sp=Pivot_ang_a
6720            Tp=Pivot_ang_b
6730            Up=Pivot_ang_c
6740 CALL What(Ep,Fp,Gp,Hp,Ip,Kp,Ap,Bp,Cp,Dp,Printflag$,Screen_x,Screen_y,Plot_d
evice,Dump_device,Lp,Mp,Np,Op,Qp,Pp,Rp,Sp,Tp,Up)
6750            GOTO Menu
6760 !
6770 Windowpane:!
6780             CALL Windows(Skitmod(*),Newskit(*),Screen_x,Screen_y)
6790             GOTO Menu
6800 !
6810 Window_limits:!
6820                CALL Window_limits(Skitmod(*),Newskit(*),Screen_x,Screen_y,Sc
reenx_win_min,Screenx_win_max,Screeny_win_min,Screeny_win_max)
6830                GOTO Menu
6840 !
6850 Print_flag:!
6860             IF Printflag$="OFF" THEN
6870             DISP "  DISPLAY QUANTITIES IS ";CHR$(129);" ON ";CHR$(128)
6880             Printflag$="ON"
6890             ELSE
6900             DISP "  DISPLAY QUANTITIES IS OFF"
6910             Printflag$="OFF"
6920             END IF
6930             GOTO Menu
6940 Rot_y:!
6950             Twirl$="ROTATE Y"
6960             DISP " MODE:";Twirl$
6970             RETURN
6980 !
6990 Rot_x:!
7000             Twirl$="ROTATE X"
7010             DISP " MODE:";Twirl$
7020             RETURN
7030 !
7040 Rot_z:!
7050             Twirl$="ROTATE Z"
7060             DISP " MODE:";Twirl$
7070             RETURN
7080 !
7090 Trans_x:!
7100             Twirl$="TRANSLATE"
7110             DISP " MODE: TRANSLATE X"
7120             Way=1
7130             RETURN
7140 !
7150 Trans_y:!
7160             Twirl$="TRANSLATE"
7170             DISP " MODE: TRANSLATE Y"
7180             Way=2
7190             RETURN
7200 !
```

```
7210 Trans_z:!
7220            Twirl$="TRANSLATE"
7230            DISP " MODE: TRANSLATE Z"
7240            Way=3
7250            RETURN
7260 !
7270 Vector:!
7280            DISP " MODE: VECTOR TRANSLATION"
7290            CALL Vector(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Tran
s(*),Sys_trans_x,Sys_trans_y,Sys_tran_z,Newskit(*),Screen_x,Screen_y,Printflag$)
7300            RETURN
7310 !
7320 Angle:!
7330            DISP " MODE:INPUT ANGLE ROTATION"
7340        CALL Angle(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Trans(*),S
ys_rot_x,Sys_rot_y,Sys_rot_z,Newskit(*),Screen_x,Screen_y,Printflag$,Twirl$)
7350            RETURN
7360 !
7370 !
7380 Plot:!
7381       CALL Plot_it(Plot_device)
7382       PLOTTER IS Plot_device,"HPGL"
7383       DISP "PLOT BEING GENERATED"
7384       CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
7385       PLOTTER IS CRT,"INTERNAL"
7386       PRINT "IN;ROO;IP;UP;SPO;"
7387       PRINTER IS CRT
7390       BEEP 1464.84,.5
7400       DISP " PLOT FINISHED"
7410       GOTO Menu
7420 !
7430 Dump:!
7431       DISP "GRAPHICS DUMP BEING GENERATED"
7433       DUMP DEVICE IS Dump_device
7434       DUMP GRAPHICS
7435       PRINTER IS Dump_device
7436       PRINT CHR$(12)
7437       PRINTER IS CRT
7440       BEEP 1464.84,.5
7450       DISP " GRAPHICS DUMP FINISHED"
7460       GOTO Menu
7470 !
7480 Printer:!
7490          DISP "WHERE IS THE LOCATION OF THE EXTERNAL PRINTER";
7500          LINPUT Temp$
7510          IF Temp$="" THEN GOTO 7540
7520          Dump_device=VAL(Temp$)
7530          DISP "  PRINTER IS AT ";CHR$(129);Dump_device;CHR$(128)
7540          GOTO Menu
7550 !
7560 Plotter:!
7570          DISP "  WHERE IS THE LOCATION OF THE PLOTTER";
7580          LINPUT Temp$
7590          IF Temp$="" THEN GOTO 7620
7600          Plot_device=VAL(Temp$)
7610          DISP "  PLOTTER IS AT ";CHR$(129);Plot_device;CHR$(128)
7620          GOTO Menu
7630 !**************************************************************************
7640 !
7641 !     INITIALIZATION OF PARAMETERS
```

```
7642 !
7643 !**********************************************************************
7650 Init:                                             !  INITIALIZE SCREEN,SKITTER
7660 !
7670        DEG                                       ! SET TO DEGREES
7680        GINIT                                     ! INITIATE GRAPHICS
7690        GRAPHICS ON                               ! TURN G-PLANE ON
7700        PLOTTER IS CRT,"INTERNAL"                 ! INIT PLOTTER
7710 !
7720        Dump_device=9
7730 !
7740        Plot_device=705
7750 !
7760        READ Skitter(*)                           ! READ SKITTER DATA
7770 !
7780        MAT Skitmod= Skitter
7790 !
7800        MAT Femurtemp= (1)
7810 !
7820        MAT Tibiatemp= (1)
7830        MAT Trans= IDN                            ! INIT TRANS MATRIX TO IDN
7840 !
7850        MAT Tempa= (1)
7860 !
7870        MAT Total= IDN
7880 !
7890        Menu$="MAIN"                              ! INIT MAIN MENU
7900 !
7910        Twirl$="ROTATE Y"
7920 !
7930        Freeleg$="FIXED"
7940 !
7950        Way=1                                     ! AXIS OF TRANS X=1,Y=2,Z=3
7960 !
7970        Printflag$="OFF"
7980 !
7990        Increment=5                          ! TRANS INC.
8000 !
8010        Rot_increment=3
8020 !
8030        Screen_x=1                                ! INIT VIEW PLANE
8040        Screen_y=2                                ! X=1,Y=2,Z=3
8050 !
8060        Sys_trans_x=0                             ! INIT POSITONS OF SYSTEM
8070        Sys_trans_y=0
8080        Sys_trans_z=0
8090        Sys_rot_x_=0
8100        Sys_rot_y=0
8110        Sys_rot_z=0
8120 !
8130        Fem_a_ang=0                               ! INIT LEG ANGLES
8140        Fem_b_ang=0
8150        Fem_c_ang=0
8160        Tib_a_ang=90
8170        Tib_b_ang=90
8180        Tib_c_ang=90
8190 !
8200        Pivot_ang_a=0
8210        Pivot_ang_b=0
8220        Pivot_ang_c=0
```

```
8230 !
8240        Screenx_win_max=40                           ! SET WINDOW
8250        Screenx_win_min=-20
8260        Screeny_win_max=40
8270        Screeny_win_min=-20
8280        SHOW Screenx_win_min,Screenx_win_max,Screeny_win_min,Screeny_win_max
8290 !
8300        RETURN
8310 !*********************************************************************
8320 !
8330 !
8340 !*********************************************************************
8350 !
8351 !       EXIT ROUTINE TO CLEAR SCREEN AND ENTER BASIC ENVIROMENT
8352 !
8353 !*********************************************************************
8360 Finished:                                          ! DONE WITH PROGRAM
8370        GCLEAR
8380        GRAPHICS OFF
8390        CLEAR SCREEN
8400        END
8410 !
8411 !
8412 !
8413 !
8414 !
8415 !
8416 !
8417 !
8420 !
8430 !*********************************************************************
8440 !
8441 !   SUBROUTINE ROTATE:  ROTATES SYTEM ABOUT LOCAL Y AXIS
8442 !
8443 !*********************************************************************
8444 !
8450 SUB Rotate_y(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sys_r
ot_y,Theta,Printflag$)
8460 !
8470 DIM Bogus(4,4)
8480 !
8490       Sys_rot_y=Sys_rot_y+Theta
8500       IF Printflag$="ON" THEN
8510          DISP " MODE: ROTATE Y BY ANGLE OF ",Theta,"  TOTAL ANGLE=",Sys_rot_
y
8520       END IF
8530 MAT Tempa(*,1:3)= Skitter(*,1:3)
8540 !
8550 ! SET UP ROTATION MATRIX
8560 !
8570        MAT Trans= IDN
8580        Sine=SIN(Theta)
8590        Cosine=COS(Theta)
8600        Trans(1,1)=Cosine
8610        Trans(1,3)=Sine
8620        Trans(3,1)=-Sine
8630        Trans(3,3)=Cosine
8640 !
8650 !INCREMENT Y ROTATION VARIABLE
8660 !
```

```
8670 !
8680        MAT Bogus= Trans*Total
8690        MAT Total= Bogus
8700        MAT Temp= Tempa*Total
8710        MAT Skitmod(*,1:3)= Temp(*,1:3)
8720 !
8730        SUBEND
8740 !
8750 !***************************************************************************
8760 !
8761 !   SUBROUTINE ROTATE X:  ROTATES SYSTEM ABOUT LOCAL X AXIS
8762 !
8763 !***************************************************************************
8764 !
8770 SUB Rotate_x(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sys_r
ot_x,Theta,Printflag$)
8780 OPTION BASE 1
8790 DIM Bogus(4,4)
8800 !
8810        Sys_rot_x=Sys_rot_x+Theta
8820       IF Printflag$="ON" THEN
8830          DISP " MODE: ROTATE X BY ANGLE OF ",Theta,"  TOTAL ANGLE=",Sys_rot_
x
8840       END IF
8850 MAT Tempa(*,1:3)= Skitter(*,1:3)
8860 ! SET UP ROTATION MATRIX
8870 !
8880        MAT Trans= IDN
8890        Sine=SIN(Theta)
8900        Cosine=COS(Theta)
8910        Trans(2,2)=Cosine
8920        Trans(3,3)=Cosine
8930        Trans(2,3)=-Sine
8940        Trans(3,2)=Sine
8950 !
8960 ! INCREMENT ROATATION VARIABLE
8970 !
8980        MAT Bogus= Trans*Total
8990        MAT Total= Bogus
9000        MAT Temp= Tempa*Total
9010        MAT Skitmod(*,1:3)= Temp(*,1:3)
9020 !
9030        SUBEND
9040 !
9050 !***************************************************************************
9060 !
9061 !   SUBROUTINE ROTATE Z:  ROTATES SYSTEM ABOUT LOCAL Z AXIS
9062 !
9063 !***************************************************************************
9064 !
9070 SUB Rotate_z(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sys_r
ot_z,Theta,Printflag$)
9080 OPTION BASE 1
9090 DIM Bogus(4,4)
9100        Sys_rot_z=Sys_rot_z+Theta
9110       IF Printflag$="ON" THEN
9120          DISP " MODE: ROTATE Z BY ANGLE OF ",Theta,"  TOTAL ANGLE=",Sys_rot_
z
9130       END IF
9140 MAT Tempa(*,1:3)= Skitter(*,1:3)
```

```
150 !
160 ! SET UP ROTATION MATRIX
170 !
180      MAT Trans= IDN
190      Sine=SIN(Theta)
200      Cosine=COS(Theta)
210      Trans(1,1)=Cosine
220      Trans(1,2)=-Sine
230      Trans(2,1)=Sine
240      Trans(2,2)=Cosine
250 !
260 ! INCREMENT COUNTER;  FIND NEW SKITTER MATRIX
270       MAT Bogus= Trans*Total
280       MAT Total= Bogus
290       MAT Temp= Tempa*Total
300      MAT Skitmod(*,1:3)= Temp(*,1:3)
310      SUBEND
320 !
330 !************************************************************************
340 !
341 !  SUBROUTINE TRANSLATE 3D: TRANSLATES SYSTEM ALONG A LOCAL X-Y-Z AXIS
342 !
343 !************************************************************************
344 !
350 SUB Translate_3d(Skitter(*),Skitmod(*),Total(*),Temp(*),Tempa(*),Trans(*),S
s_trans_x,Sys_trans_y,Sys_trans_z,Way,Theta,Printflag$)
360 OPTION BASE 1
370 DIM Laurie(4,4)
380 !
390 ! SET UP TEMP ARRAY SO AS NOT TO LOOSE PENS --SKITTER(*,4)
400 !
410      MAT Tempa(*,1:3)= Skitter(*,1:3)
420 !
430 !  DETERMINE DIRECTION OF TRANSLATION AND SET UP TRANS MATRIX
440 !
450      IF Way=1 THEN
460      Sys_trans_x=Sys_trans_x+Theta
470      Tx=Theta
480      Ty=0
490      Tz=0
500      IF Printflag$="ON" THEN
510         DISP " MODE: TRANSLATE X BY ",Theta,"IN.  TOTAL TRANSLATION=",Sys_t
ans_x
520      END IF
530      END IF
540      IF Way=2 THEN
550             Sys_trans_y=Sys_trans_y+Theta
560             Tx=0
570             Ty=Theta
580             Tz=0
590      IF Printflag$="ON" THEN
600         DISP " MODE: TRANSLATE Y BY ",Theta,"IN.  TOTAL TRANSLATION=",Sys_t
ans_y
610      END IF
620       END IF
630       IF Way=3 THEN
640             Sys_trans_z=Sys_trans_z+Theta
650             Tx=0
660             Ty=0
670             Tz=Theta
```

```
680       IF Printflag$="ON" THEN
690          DISP " MODE: TRANSLATE Z BY ";Theta,"IN.  TOTAL TRNASLATION=";Sys_t
rans_z
700       END IF
710         END IF
720       MAT Trans= IDN
730       Trans(4,1)=Tx
740       Trans(4,2)=Ty
750       Trans(4,3)=Tz
760 !
770 ! FIND NEW SKITTER MATRIX WITH CORRECT PENS
780 !
790      MAT Laurie= Trans*Total
800      MAT Total= Laurie
810       MAT Temp= Tempa*Total
820       MAT Skitmod(*,1:3)= Temp(*,1:3)
830       SUBEND
840 !
850 !*********************************************************************
860 !
870 SUB Scaling_3d(Sx,Sy,Sz,Array(*))
880       MAT Array= IDN
890       Array(1,1)=Sx
900       Array(2,2)=Sy
910       Array(3,3)=Sz
920       SUBEND
930 !
940 !*********************************************************************
950 !
951 !     SUBROUTINE DISPLAY_SKIT:  PLOTS SKITTER TO LOCAL PLOTTING DEVICE
952 !                               OR SCREEN
953 !
954 !*********************************************************************
955 !
960 SUB Display_skit(Skitter(*),Newskit(*),Screen_x,Screen_y)
970     OPTION BASE 1
980       DATA 1,1,4            ! PEN1
990       DATA 4,4,4            ! PEN 2
0000      DATA 8,8,4            ! PEN 3
0010      DIM Pen1(1,3),Pen2(1,3),Pen3(1,3),Temp(1,3)
0020      READ Pen1(*),Pen2(*),Pen3(*)
0030      IF Screen_x<>1 AND Screen_y<>2 THEN
0040      MAT Temp= Pen2
0050      MAT Pen2= Pen3
0060      MAT Pen3= Temp
0070      END IF
0080      MAT Newskit(*,1)= Skitter(*,Screen_x)
0090      MAT Newskit(*,2)= Skitter(*,Screen_y)
0100      MAT Newskit(*,3)= Skitter(*,4)
0110      MAT Newskit(37:37,*)= Pen1
0120      MAT Newskit(68:68,*)= Pen2
0130      MAT Newskit(99:99,*)= Pen3
0140      CLEAR SCREEN
0150      GCLEAR
0160      FRAME
0170      IF Screen_x<>3 AND Screen_y<>2 THEN GOTO 10300
0180      MOVE -100,-.9
0190      RECTANGLE 200,.15
0200      MOVE -100,-.75
0210      RECTANGLE 200,.15
```

```
10220     MOVE -100,-.6
10230     RECTANGLE 200,.15
10240     MOVE -100,-.45
10250     RECTANGLE 200,.15
10260     MOVE -100,-.3
10270     RECTANGLE 200,.15
10280     MOVE -100,-.15
10290     RECTANGLE 200,.15
10300     PLOT Newskit(*)
10310     LINE TYPE 1
10320     SUBEND
10330!
10340!
10350!***********************************************************************
10360!
10370         SUB Printmat(Array(*))
10380         OPTION BASE 1
10390         FOR Row=BASE(Array,1) TO SIZE(Array,1)+BASE(Array,1)-1
10400           FOR Column=BASE(Array,2) TO SIZE(Array,2)+BASE(Array,2)-1
10410             PRINT USING "DDDD.DD,XX,#";Array(Row,Column)
10420           NEXT Column
10430           PRINT
10440         NEXT Row
10450         SUBEND
10460 !
10470 !**********************************************************************
10480 !
10481 !   SUBROUTINE TRANS_TO_VECTOR: TRANSLATES SYSTEM TO A GIVEN POINT
10482 !
10483 !**********************************************************************
10490 SUB Trans_to_vector(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Trans(
*),Sys_trans_x,Sys_trans_y,Sys_trans_z)
10500 !
10510 OPTION BASE 1
10520 DIM Bogus(4,4)
10530 ! SET UP STORAGE ARRAY TO KEEP SKITTER PENS CORRECT  SKITTER(*,4)
10540 !
10550     MAT Tempa(*,1:3)= Skitter(*,1:3)
10560     MAT Trans= IDN
10570 !
10580 ! SET UP TRANS MATRIX
10590 !
10600     Trans(4,1)=Sys_trans_x
10610     Trans(4,2)=Sys_trans_y
10620     Trans(4,3)=Sys_trans_z
10630 !
10640 !  FIND NEW MATRIX
10650 !
10660     MAT Bogus= Trans*Total
10670     MAT Total= Bogus
10680     MAT Temp= Tempa*Total
10690     MAT Skitmod(*,1:3)= Temp(*,1:3)
10700     SUBEND
10710 !
10720 !
10730 !***********************************************************************
10740 !
10741 ! SUBROUTINE VECTOR: TRANSLATES SYSTEM TO INPUT POINT
10742 !
10743 !***********************************************************************
```

```
10744 !
10750 SUB Vector(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Trans(*),Sys_tr
ans_x,Sys_trans_y,Sys_trans_z,Newskit(*),Screen_x,Screen_y,Prinflag$)
10760 !
10770 ! ASK FOR INPUT <CR> MEANS LEAVE
10780 !
10790 Ask:!
10800 DISP " X COORDINANT RELATIVE TO ",Sys_trans_x;
10810 LINPUT Temp$
10820 IF Temp$="" THEN
10830    GOTO Leave
10840 ELSE
10850    X=VAL(Temp$)
10860 END IF
10870 DISP " Y COORDINANT RELATIVE TO ",Sys_trans_y;
10880 LINPUT Temp$
10890 IF Temp$="" THEN
10900    GOTO Leave
10910 ELSE
10920    Y=VAL(Temp$)
10930 END IF
10940 DISP " Z COORDINANT RELATIVE TO ",Sys_trans_z;
10950 LINPUT Temp$
10960 IF Temp$="" THEN
10970    GOTO Leave
10980 ELSE
10990    Z=VAL(Temp$)
11000 END IF
11010!
11020!  UPDATE TRANSLATION COUNTERS
11030!
11040 Sys_trans_x=Sys_trans_x+X
11050 Sys_trans_y=Sys_trans_y+Y
11060 Sys_trans_z=Sys_trans_z+Z
11070!
11080! FIND NEW SKITTER MATRIX
11090!
11100 CALL Trans_to_vector(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Trans
(*),X,Y,Z)
11110!
11120! DISPLAY SKITTER
11130 CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
11140 GOTO Ask
11150 Leave:!
11160 SUBEND
11170 !
11180 !
11190 !*********************************************************************
11200 !
11201 !   SUBROUTINE WINDOWS: ALLOWS USER TO CHANGE VIEWING AXIS
11202 !
11203 !*********************************************************************
11204 !
11210 SUB Windows(Skitmod(*),Newskit(*),Screen_x,Screen_y)
11220             IF Screen_x=1 AND Screen_y=2 THEN
11230                DISP "  CURRENT WINDOW = X-Y PLANE"
11240             END IF
11250             IF Screen_x=1 AND Screen_y=3 THEN
11260                DISP "  CURRENT WINDOW = X-Z PLANE"
11270             END IF
```

```
.1280              IF Screen_x=3 AND Screen_y=2 THEN
.1290                 DISP "  CURRENT WINDOW = Z-Y PLANE"
.1300              END IF
.1310 Menu:            !
.1320              ON KEY 0 LABEL "X AXIS" GOTO Zy_plane
.1330              ON KEY 2 LABEL "Y AXIS" GOTO Xz_plane
.1340              ON KEY 4 LABEL "Z AXIS" GOTO Xy_plane
.1350              ON KEY 9 LABEL "QUIT" GOTO Leave
.1360              GOTO 11360
.1370              !
.1380 Zy_plane:             !
.1390                       Screen_x=3
.1400                       Screen_y=2
.1410                       DISP "  NEW WINDOW = LOOKING DOWN X AXIS"
.1420                       CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y

.1430                       GOTO Menu
.1440             !
.1450 Xz_plane:             !
1460                        Screen_x=1
1470                        Screen_y=3
1480                        DISP "  NEW WINDOW = LOOKING DOWN Y AXIS"
1490                        CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y

1500                        GOTO Menu
1510                        !
1520 Xy_plane:                      !
1530                        Screen_x=1
1540                        Screen_y=2
1550                        DISP "  NEW WINDOW = LOOKING DOWN Z AXIS"
1560                        CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y

1570                        GOTO Menu
1580 Leave:                     !
1590                       SUBEND
1600!
1610!
1620!
1630!************************************************************************
1640!
1641 ! SUBROUTINE WINDOW_LIMITS: ALLOWS THE USER TO INPUT NEW VIEWING WINDOW
1642 !
1643 !***********************************************************************
1644 !
1650 SUB Window_limits(Skitmod(*),Newskit(*),Screen_x,Screen_y,Screenx_win_min,
creenx_win_max,Screeny_win_min,Screeny_win_max)
1660!
1670!
1680!
1690 DISP " INPUT XMIN --- CURRENT VALUE IS",Screenx_win_min," <CR> TO EXIT";
1700 LINPUT Temp$
1710 IF Temp$="" THEN GOTO Leave
1720 DISP " INPUT XMAX --- CURRENT VALUE IS",Screenx_win_max,"  <CR> TO EXIT";
1730 LINPUT Temp1$
1740 IF Temp1$="" THEN GOTO Leave
1750 IF VAL(Temp$)>VAL(Temp1$) THEN
1760   BEEP 1464.84,.5
1770   DISP " XMIN HAS TO BE LESS THAN XMAX"
1780   WAIT 3
1790   GOTO 11690
```

```
1800 ELSE
1810   Screenx_win_min=VAL(Temp$)
1820   Screenx_win_max=VAL(Temp1$)
1830 END IF
1840!
1850!
1860!
1870 DISP " INPUT YMIN ---- CURRENT VALUE IS",Screeny_win_min," <CR> TO EXIT";
1880 LINPUT Temp$
1890 IF Temp$="" THEN GOTO Leave
1900 DISP " INPUT YMAX ---- CURRENT VALUE IS",Screeny_win_max," <CR> TO EXIT";
1910 LINPUT Temp1$
1920 IF Temp1$="" THEN GOTO Leave
1930 IF VAL(Temp$)>VAL(Temp1$) THEN
1940      BEEP 1464.84,.5
1950      DISP " Y MIN MUST BE LESS THAN Y MAX"
1960      WAIT 3
1970      GOTO 11870
1980 ELSE
1990      Screeny_win_min=VAL(Temp$)
2000      Screeny_win_max=VAL(Temp1$)
2010 END IF
2020!
2030!
2040 SHOW Screenx_win_min,Screenx_win_max,Screeny_win_min,Screeny_win_max
2050 CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
2060!
2070 Leave:!
2080      SUBEND
2090!
2100!***********************************************************************
2110!
2111 ! SUBROUTINE ANGLE: ALLOWS TE USER TO ROTATE SYSTEM BY INPUT ANGLE
2112 !                  ABOUT  LAST ROTATION AXIS
2113 !
2114 !***********************************************************************
2115 !
2120 SUB Angle(Skitter(*),Skitmod(*),Temp(*),Tempa(*),Total(*),Trans(*),Sys_rot
x,Sys_rot_y,Sys_rot_z,Newskit(*),Screen_x,Screen_y,Printflag$,Twirl$)
2130!
2140! FIND MODE AND ROTATE ABOUT CORRECT AXIS
2150!
2160 IF Twirl$="ROTATE X" THEN
2170  DISP " INPUT ANGLE TO ROTATE ABOUT X AXIS -- CURRENT ANG=",Sys_rot_x;
2180  LINPUT Temp$
2190  IF Temp$="" THEN GOTO Leave
2200  Theta=VAL(Temp$)
2210  CALL Rotate_x(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sy
 rot_x,Theta,Printflag$)
2220 END IF
2230!
2240!
2250 IF Twirl$="ROTATE Y" THEN
2260  DISP " INPUT ANGLE TO ROTATE ABOUT Y AXIS -- CURRENT ANG=",Sys_rot_y;
2270  LINPUT Temp$
2280  IF Temp$="" THEN GOTO Leave
2290  Theta=VAL(Temp$)
2300  CALL Rotate_y(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sy
 rot_y,Theta,Printflag$)
2310 END IF
```

CONTINUED

```
12320!
12330!
12340 IF Twirl$="ROTATE Z" THEN
12350  DISP " INPUT ANGLE TO ROTATE ABOUT Z AXIS -- CURRENT ANG=",Sys_rot_z;
12360 LINPUT Temp$
12370 IF Temp$="" THEN GOTO Leave
12380 Theta=VAL(Temp$)
12390 CALL Rotate_z(Skitter(*),Skitmod(*),Total(*),Trans(*),Temp(*),Tempa(*),Sys
_rot_z,Theta,Printflag$)
12400 END IF
12410 !
12420 ! OUTPUT NEW PICTURE
12430 !
12440 CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
12450 GOTO 12150
12460 !
12470 !
12480 Leave:!
12490        SUBEND
12500 !
12510 !********************************************************************
12511 !
12512 !   SUBROUTINE WHAT: OUTPUTS PROGRAM VARIABLES TO SCREEN
12513 !
12514 !********************************************************************
12520 !
12530 SUB What(Sys_trans_x,Sys_trans_y,Sys_trans_z,Sys_rot_x,Sys_rot_y,Sys_rot_z
,A,B,C,D,Printflag$,Screenx,Screeny,Plotd,Dumpd,Fa,Fb,Fc,Ta,Tb,Tc,Inc,Sp,Tp,Up)
12540 !
12550 GRAPHICS OFF
12560 CLEAR SCREEN
12570 PRINT CHR$(132);"THESE ARE THE CURRENT PARAMETERS:";CHR$(128)
12580 PRINT
12590 PRINT CHR$(129);" WINDOW: ";CHR$(128);"       X MIN = ";A;"       X MAX =
";B
12600 PRINT "                   Y MIN = ";C;"       Y MAX = ";D
12610 PRINT
12620 IF Screenx=1 AND Screeny=2 THEN PRINT CHR$(129);" VIEW: ";CHR$(128);" LOOK
ING DOWN Z AXIS"
12630 IF Screenx=3 AND Screeny=2 THEN PRINT CHR$(129);" VIEW: ";CHR$(128);" LOOK
ING DOWN X AXIS"
12640 IF Screenx=1 AND Screeny=3 THEN PRINT CHR$(129);" VIEW: ";CHR$(128);" LOOK
ING DOWN Y AXIS"
12650 PRINT
12660 PRINT "PLOTTER LOACTION:";CHR$(129);Plotd;CHR$(128);"      PRINTER LOCATIO
N:";CHR$(129);Dumpd;CHR$(128)
12670 PRINT
12680 IF Printflag$="ON" THEN
12690    PRINT " DISPLAY VALUES IS ";CHR$(129);" ON ";CHR$(128)
12700 ELSE
12710    PRINT " DISPLAY VALUES IS OFF"
12720 END IF
12730 PRINT
12740 PRINT TAB(5);CHR$(132);"TRANS (in.)    ROT (deg)";CHR$(128);"
      ";CHR$(132);" FEMUR ANGLE    TIBIA ANGLE";CHR$(128)
12750 PRINT
12760 Brice:  IMAGE AA,2X,4D.2D,6X,4D.2D,18X,A,6X,4D.2D,8X,4D.2D
12770 PRINT USING Brice;"X ";Sys_trans_x;Sys_rot_x;"A";Fa;Ta
12780 PRINT USING Brice;"Y ";Sys_trans_y;Sys_rot_y;"B";Fb;Tb
12790 PRINT USING Brice;"Z ";Sys_trans_z;Sys_rot_z;"C";Fc;Tc
```

```
12800 PRINT
12810 PRINT "PIVOT ANG A:";Sp;"   PIVOT ANG B:";Tp;"    PIVOT ANG C:";Up
12820 INPUT "HIT <CR> TO CONTINUE",Temp$
12830 CLEAR SCREEN
12840 ALPHA OFF
12850 GRAPHICS ON
12860 SUBEND
12870 !
12880 !*******************************************************************
12890 !
12891 ! SUBROUTINE ROTATE LEG Z:  ROTATES ENTIRE LEG ABOUT Z AXIS
12892 !
12893 !*******************************************************************
12894 !
12900 SUB Rotate_leg_z(Femur(*),Femurmod(*),Leg$,Theta,Printflag$,OPTIONAL Femur
a_rot,Way)
12910 OPTION BASE 1
12920 DIM Bogus(4,4),Temp(196,4),Tempa(196,4),Trans(4,4)
12930      N=SIZE(Femur,1)
12940      REDIM Tempa(N,4),Temp(N,4)
12950!
12960  IF Way=1 THEN
12970      Femura_rot=Femura_rot+Theta
12980!
12990      IF Printflag$="ON" THEN
13000         DISP " MODE: ";Leg$;"   THROUGH ANGLE OF ";Theta;"  TOTAL ANGLE=",F
emura_rot
13010      END IF
13020      END IF
13030!
13040      MAT Tempa= (1)
13050      MAT Tempa(*,1:3)= Femur(*,1:3)
13060!
13070! SET UP ROTATION MATRIX
13080!
13090      MAT Trans= IDN
13100      Sine=SIN(Theta)
13110      Cosine=COS(Theta)
13120      Trans(1,1)=Cosine
13130      Trans(1,2)=-Sine
13140      Trans(2,1)=Sine
13150      Trans(2,2)=Cosine
13160!
13170!    FIND NEW SKITTER MATRIX
13180!
13190       MAT Temp= Tempa*Trans
13200      MAT Femurmod(*,1:3)= Temp(*,1:3)
13210      SUBEND
13220!
13230!*******************************************************************
13240!
13241 !  SUBROUTINE TRANS FEM ORIG: TRANSLATES LEG TO ORIGIN
13242 !
13243 !*******************************************************************
13244 !
13250 SUB Trans_fem_orig(Femur(*),Femurmod(*),X,Y,Z)
13260 !
13270 OPTION BASE 1
13280 DIM Bogus(4,4),Tempa(196,4),Temp(196,4),Trans(4,4)
13290 N=SIZE(Femur,1)
```

```
13300 REDIM Tempa(N,4),Temp(N,4)
13310 !
13320 ! SET UP STORAGE ARRAY TO KEEP SKITTER PENS CORRECT  SKITTER(*,4)
13330 !
13340       MAT Tempa= (1)
13350       MAT Tempa(*,1:3)= Femur(*,1:3)
13360       MAT Trans= IDN
13370 !
13380 ! SET UP TRANS MATRIX
13390 !
13400       Trans(4,1)=X
13410       Trans(4,2)=Y
13420       Trans(4,3)=Z
13430 !
13440 !  FIND NEW MATRIX
13450 !
13460       MAT Temp= Tempa*Trans
13470       MAT Femurmod(*,1:3)= Temp(*,1:3)
13480 SUBEND
13490 !
13500 !*********************************************************************
13510 !
13511 ! SUBROUTINE ROTATE LEG Y: ROTATES LEG ABOUT Y AXIS
13512 !
13513 !*********************************************************************
13514 !
13520  SUB Rotate_leg_y(Femur(*),Femurmod(*),Theta)
13530!
13540     OPTION BASE 1
13550     DIM Bogus(4,4),Temp(196,4),Tempa(196,4),Trans(4,4)
13560     N=SIZE(Femur,1)
13570     REDIM Tempa(N,4),Temp(N,4)
13580!
13590      MAT Tempa= (1)
13600      MAT Tempa(*,1:3)= Femur(*,1:3)
13610!
13620! SET UP ROTATION MATRIX
13630!
13640      MAT Trans= IDN
13650      Sine=SIN(Theta)
13660      Cosine=COS(Theta)
13670      Trans(1,1)=Cosine
13680      Trans(1,3)=Sine
13690      Trans(3,1)=-Sine
13700      Trans(3,3)=Cosine
13710!
13720!    FIND NEW SKITTER MATRIX
13730!
13740       MAT Temp= Tempa*Trans
13750      MAT Femurmod(*,1:3)= Temp(*,1:3)
13760      SUBEND
13770!
13780!
13790!*********************************************************************
13800!
13801 ! SUBROUTINE ZOOM PAN: ALOOWS USER TO PAN OR ZOOM WINDOW
13802 !
13803 !*********************************************************************
13804 !
13810 SUB Zoom_pan(Window$,Xmin,Xmax,Ymin,Ymax,Skitmod(*),Newskit(*),Screen_x,Sc
:een_y)
13820      ON ERROR GOTO Brice
13830!
13840      DISP "  YOUR CURRENT WINDOW VALUES ARE XMIN:";Xmin;" XMAX:";Xmax;" YM
[N:";Ymin;" YMAX:";Ymax
13850 Menu:     !
:3860      ON KNOB .15 GOTO Knob_isr
:3870      ON KEY 9 LABEL "QUIT" GOTO Leave
.3880      ON KEY 0 LABEL "ZOOM" GOTO Zoom
.3890      ON KEY 1 LABEL "" GOTO 13970
.3900      ON KEY 2 LABEL "PAN X" GOTO Pan_x
.3910      ON KEY 3 LABEL "" GOTO 13970
.3920      ON KEY 4 LABEL "PAN Y" GOTO Pan_y
.3930      ON KEY 5 LABEL "" GOTO 13970
.3940      ON KEY 6 LABEL "INPUT DATA " GOTO Input_data
.3950      ON KEY 7 LABEL "" GOTO 13970
.3960      ON KEY 8 LABEL "" GOTO 13970
.3970      GOTO 13970
.3980      !
.3990 Pan_x:!
.4000      Window$="PAN X"
.4010       GOTO Menu
.4020 Pan_y:!
.4030      Window$="PAN Y"
.4040      GOTO Menu
.4050 Zoom:!
.4060     Window$="ZOOM"
.4070     GOTO Menu
.4080 Knob_isr:!
.4090!
.4100       Theta=KNOBX
.4110      IF Window$="ZOOM" AND Theta>0 THEN
.4120         Xmin=Xmin-5
.4130         Xmax=Xmax+5
.4140         Ymin=Ymin-5
.4150         Ymax=Ymax+5
4160          SHOW Xmin,Xmax,Ymin,Ymax
4170       END IF
4180!
4190!
4200       IF Window$="ZOOM" AND Theta<0 THEN
4210          Xmin=Xmin+5
4220          Xmax=Xmax-5
4230          Ymin=Ymin+5
4240          Ymax=Ymax-5
4250          SHOW Xmin,Xmax,Ymin,Ymax
4260        END IF
4270!
4280!
4290        IF Window$="PAN X" AND Theta<0 THEN
4300           Xmin=Xmin+5
4310           Xmax=Xmax+5
4320           SHOW Xmin,Xmax,Ymin,Ymax
4330        END IF
4340!
4350!
4360        IF Window$="PAN X" AND Theta>0 THEN
4370           Xmin=Xmin-5
4380           Xmax=Xmax-5
4390           SHOW Xmin,Xmax,Ymin,Ymax
```

```
14400        END IF
14410!
14420!
14430        IF Window$="PAN Y" AND Theta>0 THEN
14440           Ymin=Ymin+5
14450           Ymax=Ymax+5
14460           SHOW Xmin,Xmax,Ymin,Ymax
14470        END IF
14480!
14490!
14500        IF Window$="PAN Y" AND Theta<0 THEN
14510           Ymin=Ymin-5
14520           Ymax=Ymax-5
14530           SHOW Xmin,Xmax,Ymin,Ymax
14540        END IF
14550!
14560        CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
14570        GOTO 13840
14580 !
14590 !
14600 Input_data:!
14610       DISP " INPUT XMIN --- CURRENT VALUE IS",Xmin," <CR> TO EXIT";
14620       LINPUT Temp$
14630       IF Temp$="" THEN GOTO Leave
14640       DISP " INPUT XMAX --- CURRENT VALUE IS",Xmax,"  <CR> TO EXIT";
14650       LINPUT Temp1$
14660       IF Temp1$="" THEN GOTO Leave
14670       IF VAL(Temp$)>VAL(Temp1$) THEN
14680       BEEP 1464.84,.5
14690       DISP " XMIN HAS TO BE LESS THAN XMAX"
14700       WAIT 3
14710       GOTO 14610
14720       ELSE
14730       Xmin=VAL(Temp$)
14740       Xmax=VAL(Temp1$)
14750       END IF
14760!
14770!
14780!
14790       DISP " INPUT YMIN ---- CURRENT VALUE IS",Ymin," <CR> TO EXIT";
14800       LINPUT Temp$
14810       IF Temp$="" THEN GOTO Leave
14820       DISP " INPUT YMAX ---- CURRENT VALUE IS",Ymax," <CR> TO EXIT";
14830       LINPUT Temp1$
14840       IF Temp1$="" THEN GOTO Leave
14850       IF VAL(Temp$)>VAL(Temp1$) THEN
14860       BEEP 1464.84,.5
14870       DISP " Y MIN MUST BE LESS THAN Y MAX"
.4880       WAIT 3
.4890       GOTO 14790
.4900       ELSE
.4910       Ymin=VAL(Temp$)
.4920       Ymax=VAL(Temp1$)
.4930       END IF
.4940!
.4950!
.4960       SHOW Xmin,Xmax,Ymin,Ymax
4970        CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
4980        GOTO Menu
4990        !
```

```
15000 Brice:!
15010       IF ERRN=31 THEN
15020          BEEP 1464,.5
15030       DISP " THIS IS AS FAR AS YOU CAN GO  !!!!!!!!!!!!!!!!!!"
15040          WAIT 2
15050          Xmin=Xmin-5
15060          Xmax=Xam+5
15070          Ymin=Ymin-5
15080          Ymax=Ymax+5
15090          SHOW Xmin,Xmax,Ymin,Ymax
15100       CALL Display_skit(Skitmod(*),Newskit(*),Screen_x,Screen_y)
15110          GOTO 13840
15120        END IF
15130 Leave:!
15140      SUBEND
15150 !**********************************************************************
15160 !
15161 ! SUBROUTINE PLOT IT:  SETS UP PLOTTER PARAMETERS FOR HARD COPY
15162 !
15163 !**********************************************************************
15164 !
15170 SUB Plot_it(Plot_device)
15180 DIM L$[32]
15190 DISP "  HOW MANY QUADRANTS 1,2 OR 4   DEFAULT=1";
15200 LINPUT Quad$
15210 IF Quad$="" THEN
15220   Quad=1
15230 ELSE
15240    Quad=VAL(Quad$)
15250 END IF
15260 IF Quad=1 THEN GOTO Label
15270  IF Quad<>1 AND Quad<>2 AND Quad<>4 THEN
15280  BEEP 1464,.5
15290  GOTO 15190
15300  END IF
15310  DISP "  WHICH SQUARE   DEFAULT=1";
15320  LINPUT What$
15330  IF What$="" THEN
15340     What=1
15350  ELSE
15360      What=VAL(What$)
15370  END IF
15380  IF What<>1 AND What<>2 AND What<>3 AND What<>4 THEN
15390      BEEP 1464,.5
15400      GOTO 15310
15410  END IF
15420  !
15430  !
15440 Label: !
15450  DISP "  INPUT ANY LABELS  DEFAULT= NONE";
15460  LINPUT L$
15470  IF L$="" THEN GOTO P1
15480 P1: !
15490  PRINTER IS Plot_device
15500  IF Quad=1 THEN
15510        PRINT "IN;IP;SP1;SI .5,.5;PA 425,1000,LB";L$;CHR$(3);";SP0;"
15520  END IF
15530  IF Quad=4 THEN
15540      IF What=1 THEN
15550        PRINT "IN;IP250,596,5250,4196;SP1;SI;PA 425,900,LB";L$;CHR$(3);";S
```

```
P0;"
15560          END IF
15570       IF What=2 THEN
15580          PRINT "IN;IP5250,596,10250,4196;SP1;SI;PA 5425,900,LB";L$;CHR$(3);
";SP0;"
15590       END IF
15600       IF What=3 THEN
15610          PRINT "IN;IP250,4196,5250,7796;SP1;SI;PA 425 4500,LB";L$;CHR$(3);"
;SP0;"
15620       END IF
15630       IF What=4 THEN
15640         PRINT "IN;IP5250,4196,10250,7796;SP1,SI,PA 5425, 4500,LB";L$;CHR$(3
);";SP0;"
15650       END IF
15660       END IF
15670    IF Quad=2 THEN
15680         IF What=2 THEN
15690            PRINT "IN;RO90;IP;IW;IP154,244,7354,5122;SP1;SI .35,.35;PA 600,6
00;LB";L$;CHR$(3);";SP0;"
15700         ELSE
15710            PRINT "IN;RO90;IP;IW;IP154,5122,7354,10244;SP1;SI .35,.35;PA 600
,5478;LB";L$;CHR$(3);";SP0;"
15720         END IF
15730    END IF
15740 Leave:  !
15750       SUBEND
15751 !
15752 !
15753 !
15754 !
15755 !*************************************************************************
15756 !
15757 !  SUBROUTINE MOVIE:  ALLOWS USER TO INPUT DATA FILES FOR ANIMATION
15758 !                     OF POSITION SEQUENCES
15759 !
15760 !*************************************************************************
15761 !
15763 SUB Movie
15770 REM        ****************************************************************
15780 DATA       0,0,0,10                     !                        UPPER BODY
15790 DATA       6.5482,28.4912,0,-2          !      A
15800 DATA       9.1602,20.9817,3.2283,-1     !      H
15810 DATA       -1.7468,20.9817,9.5688,-1    !      I
15820 DATA       -3.2741,28.4912,5.6709,-1    !      B
15830 DATA       0,0,0,7
15840 !
15850 DATA       0,0,0,10
15860 DATA       -3.2741,28.4912,5.6709,-2    !      B
15870 DATA       -7.3759,20.9817,6.3188,-1    !      J
15880 DATA       -7.3759,20.9817,-6.3188,-1   !      K
15890 DATA       -3.2741,28.4912,-5.6709,-1   !      C
15900 DATA       0,0,0,7
15910 !
15920 DATA       0,0,0,10
15930 DATA       -3.2741,28.4912,-5.6709,-2    !     C
15940 DATA       -1.7468,20.9817,-9.5688,-1    !     L
15950 DATA       9.1602,20.9817,-3.2283,-1     !     G
15960 DATA       6.5482,28.4912,0,-1           !     A
15970 DATA       0,0,0,7
15980 !
```

```
15990 DATA      0,0,0,10                       !                              BOTTOM BODY
16000 DATA      6.5482,13.4722,0,-2            !    D
16010 DATA      9.1602,20.9817,3.2283,-1       !    H
16020 DATA      -1.7468,20.9817,9.5688,-1      !    I
16030 DATA      -3.2741,13.4722,5.6709,-1      !    E
16040 DATA      0,0,0,7
16050 !
16060 DATA      0,0,0,10
16070 DATA      -3.2741,13.4722,5.6709,-2    !      E
16080 DATA      -7.3759,20.9817,6.3188,-1    !      J
16090 DATA      -7.3759,20.9817,-6.3188,-1 !        K
16100 DATA      -3.2741,13.4722,-5.6709,-1 !        F
16110 DATA      0,0,0,7
16120 !
16130 DATA      0,0,0,10
16140 DATA      -3.2741,13.4722,-5.6709,-2 !        F
16150 DATA      -1.7468,20.9817,-9.5688,-1 !        L
16160 DATA      9.1602,20.9817,-3.2283,-1    !      G
16170 DATA      6.5482,13.4722,0,-1          !      D
16180 DATA      0,0,0,7
16190 !
16200 DATA      0,0,0,4                            ! RESERVED FOR PEN
16210 DATA      0,0,0,10                     !                                  FEMUR ONE
16220 DATA      9.1602,20.9817,-3.2283,-2    !      G
16230 DATA      29.6602,20.9817,-3.2283,-1 !        M
16240 DATA      18.7362,25.0731,0,-1         !      O
16250 DATA      0,0,0,7
16260 !
16270 !
16280 DATA      0,0,0,10
16290 DATA      29.6602,20.9817,3.2283,-2    !      N
16300 DATA      18.7362,25.0731,0,-1         !      O
16310 DATA      9.1602,20.9817,3.2283,-1     !      H
16320 DATA      0,0,0,7
16330 !
16340 DATA      0,0,0,10
16350 DATA      9.1602,20.9817,-3.2283,-2     !      G
16360 DATA      29.6602,20.9817,-3.2283,-1 !        M
16370 DATA      20.571,16.8903,0,-1          !      P
16380 DATA      0,0,0,7
16390 !
16400 DATA      0,0,0,10
16410 DATA      29.6602,20.9817,3.2283,-2    !      N
16420 DATA      20.571,16.8903,0,-1          !      P
16430 DATA      9.1602,20.9817,3.2283,-1     !      H
16440 DATA      0,0,0,7
16450 !
16460 DATA      0,0,0,10                       !                                TIBIA ONE
16470 DATA      29.6602,20.9817,-3.2283,-2     !  M
16480 DATA      30.4255,0,0,-1                 !  A'
16490 DATA      35.7901,9.2132,0,-1            !  B'
16500 DATA      0,0,0,7
16510 !
16520 DATA      0,0,0,10
16530 DATA      29.6602,20.9817,3.2283,-2       !  N
16540 DATA      30.4255,0,0,-1                 !  A'
16550 DATA      35.7901,9.2132,0,-1            !  B'
16560 DATA      0,0,0,7
16570 !
16580 DATA      0,0,0,4                      ! RESERVED FOR PEN
```

```
16590 DATA        0,0,0,10                       !                           FEMUR TWO
16600 DATA        -1.7468,20.9817,9.5688,-2  !     I
16610 DATA        -9.3493,25.0731,16.2368,-1 !     S
16620 DATA        -11.9968,20.9817,27.3223,-1!     Q
16630 DATA        0,0,0,7
16640 !
16650 DATA        0,0,0,10
16660 DATA        -17.6259,20.9817,24.0723,-2!     R
16670 DATA        -9.3493,25.0731,16.2368,-1 !     S
16680 DATA        -7.3759,20.9817,6.3188,-1  !     J
16690 DATA        0,0,0,7
16700 !
16710 DATA        0,0,0,10
16720 DATA        -1.7468,20.9817,9.5688,-2  !     I
16730 DATA        -10.2667,16.8903,17.8258,-1!     T
16740 DATA        -11.9968,20.9817,27.3223,-1!     Q
16750 DATA        0,0,0,7
16760 !
16770 DATA        0,0,0,10
16780 DATA        -17.6259,20.9817,24.0723,-2!     R
16790 DATA        -10.2667,16.8903,17.8258,-1!     T
16800 DATA        -7.3759,20.9817,6.3188,-1  !     J
16810 DATA        0,0,0,7
16820 !
16830 !
16840 DATA        0,0,0,10                   !                               TIBIA TWO
16850 DATA        -11.9968,20.9817,27.3223,-2  !  Q
16860 DATA        -15.1940,0,26.3601,-1        !  C'
16870 DATA        -17.8763,9.2132,31.0059,-1   !  D'
16880 DATA        0,0,0,7
16890 !
16900 DATA        0,0,0,10
16910 DATA        -17.6259,20.9817,24.0723,-2  !  N
16920 DATA        -15.1940,0,26.3601,-1        !  C'
16930 DATA        -17.8763,9.2132,31.0059,-1    !  D'
16940 DATA        0,0,0,7
16950 !
16960 DATA        0,0,0,4                    ! RESERVED FOR PEN
16970 DATA        0,0,0,10                   !                             FEMUR THREE
16980 DATA        -7.3759,20.9817,-6.3188,-2 !     K
16990 DATA        -9.3493,25.0731,-16.2368,-1!     W
17000 DATA        -17.6259,20.9817,-24.0723,-1!    U
17010 DATA        0,0,0,7
17020 !
17030 DATA        0,0,0,10
17040 DATA        -11.9968,20.9817,-27.3223,-2 !   V
17050 DATA        -9.3493,25.0731,-16.2368,-1  !   W
17060 DATA        -1.7468,20.9817,-9.5688,-1   !   L
17070 DATA        0,0,0,7
17080 !
17090 DATA        0,0,0,10
17100 DATA        -7.3759,20.9817,-6.3188,-2   !   K
17110 DATA        -10.2667,16.8903,-17.8258,-1 !   X
17120 DATA        -17.6259,20.9817,-24.0723,-1 !   U
17130 DATA        0,0,0,7
17140 !
17150 !
17160 DATA        0,0,0,10
17170 DATA        -11.9968,20.9817,-27.3223,-2 !  V
17180 DATA        -10.2667,16.8903,-17.8258,-1!  X
```

```
17190 DATA      -1.7468,20.9817,-9.5688,-1   !  L
17200 DATA      0,0,0,7
17210 !                                                              TIBIA THREE
17220 DATA      0,0,0,10                     !
17230 DATA      -17.6259,20.9817,-24.0723,-2 !  U
17240 DATA      -15.1940,0,-26.3601,-1       !  E'
17250 DATA      -17.8763,9.2132,-31.0059,-1  !  F'
17260 DATA      0,0,0,7
17270 !
17280 DATA      0,0,0,10
17290 DATA      -11.9968,20.9817,-27.3223,-2 !  V
17300 DATA      -15.1940,0,-26.3601,-1       !  E'
17310 DATA      -17.8763,9.2132,-31.0059,-1  !  F'
17320 DATA      0,0,0,7
17330 REM       ****************************************************************
17340 !
17350 !
17360       OPTION BASE 1
17370       REAL Skitter(129,4),Newskit(129,3)          ! DEFINE VAR
17380       REAL Trans(4,4),Temp(129,4),Tempa(129,4)!TRANSFORMATION MATRIX
17390       REAL Total(4,4),Skitmod(129,4)          !TOTAL TRANFORM MATRIX
17400       REAL Femur(31,4),Femurmod(31,4),Femurtemp(31,4)
17410       REAL Tibia(10,4),Tibiatemp(10,4),Tibiamod(10,4)
17420       INTEGER Pen1(1,3),Pen2(1,3),Pen3(1,3)
17430       GOSUB Init                              ! INITILIZATION ROUTINE
17440       CALL Display_skit(Skitter(*),Newskit(*),Screen_x,Screen_y)
17450                                               ! DRAW SKITTER
17460!
17470 DATA 1,1,4     !PEN1
17480 DATA 4,4,4     !PEN2
17490 DATA 8,8,4     !PEN3
17500!
17510 Start:!
17520 DISP "DO YOU WANT TO RUN AN ALREADY COMPUTED FILE  Y OR N";
17530 LINPUT Ans$
17550 !
17560 !
17561 !  INPUT DATA FILE
17562 !
17570       IF Ans$="Y" THEN
17580           DISP "NAME OF COMPUTED FILE";
17590           LINPUT Name$
17600       IF Name$="" THEN
17610             GOTO 17520
17620         ELSE
17630        Skitwork$=Name$
17640        File_flag=1
17650        GOTO Movie
17660        END IF
17670        END IF
17680 !
17690 IF Ans$="N" THEN
17700 DISP "INPUT MOVIE FILE";
17710 LINPUT File$
17720 IF File$="" THEN
17730     GOTO 17700
17740 ELSE
17750 Skitwork$="SKITWORK"
17760 END IF
17770      CREATE BDAT Skitwork$,400
```

```
17780      ASSIGN @Path1 TO Skitwork$
17790      ASSIGN @Path2 TO File$
17800      END IF
17810!
17820 READ Pen1(*),Pen2(*),Pen3(*)
17830!
17840 Top:!
17850      ENTER @Path2;Tim,Free,Fadat,Tadat,Fbdat,Tbdat,Fcdat,Tcdat,Xr,Yr,Zr,Tx
,Ty,Tz
17851 !**********************************************************************
17852 !
17853 !   DETERMINE TRANFORMATION MATRICES FOR EACH TIME UNIT
17854 !
17855 !**********************************************************************
17856 !
17860      IF Tim=999 THEN GOTO Movie
17870      N=N+1
17880      IF Free=0 THEN Freeleg$="FIXED"
17890      IF Free=1 OR Free=2 THEN Freeleg$="FREE"
17900 !
17910      IF Fadat<>0 AND Fadat<>999 THEN
17920        Leg$="FEMUR A"
17930        IF Free=2 THEN
17940           Leg_flag$="FEMUR A"
17960        END IF
17970        Theta=Fadat
17980        GOSUB Leg_isr
17990      END IF
18000 !
18010      IF Fadat=999 THEN
18020        Leg_flag$="FEMUR A"
18030      END IF
18040 !
18050      IF Tadat<>0 THEN
18060         Leg$="TIBIA A"
18070         Theta=Tadat
18080         GOSUB Leg_isr
18090      END IF
18100 !
18110      IF Fbdat<>0 AND Fbdat<>999 THEN
18120         Leg$="FEMUR B"
18130         IF Free=2 THEN
18140           Leg_flag$="FEMUR B"
18150         END IF
18160         Theta=Fbdat
18170         GOSUB Leg_isr
18180      END IF
18190 !
18200      IF Fbdat=999 THEN
18210         Leg_flag$="FEMUR B"
18220      END IF
18230 !
18240      IF Tbdat<>0 THEN
18250         Leg$="TIBIA B"
18260         Theta=Tbdat
18270         GOSUB Leg_isr
18280      END IF
18290 !
18300      IF Fcdat<>0 AND Fcdat<>999 THEN
18310         Leg$="FEMUR C"
```

```
18320          IF Free=2 THEN
18330            Leg_flag$="FEMUR C"
18340          END IF
18350          Theta=Fcdat
18360          GOSUB Leg_isr
18370       END IF
18380 !
18390      IF Fcdat=999 THEN
18400         Leg_flag$="FEMUR C"
18410      END IF
18420 !
18430       IF Tcdat<>0 THEN
18440          Leg$="TIBIA C"
18450          Theta=Tcdat
18460          GOSUB Leg_isr
18470       END IF
18480 !
18490 !
18500       IF Yr<>0 THEN
18510           Twirl$="ROTATE Y"
18520           Theta=Yr
18530           GOSUB System_isr
18540       END IF
18550 !
18560       IF Xr<>0 THEN
18570           Twirl$="ROTATE X"
18580            Theta=Xr
18590           GOSUB System_isr
18600       END IF
18610 !
18620       IF Zr<>0 AND Free<>2 THEN
18630           Twirl$="ROTATE Z"
18640           Theta=Zr
18650           GOSUB System_isr
18660       END IF
18670 !
18680       IF Zr<>0 AND Free=2 THEN
18690           Twirl$="PIVOT"
18710           Theta=Zr
18720           GOSUB System_isr
18730       END IF
18740 !
18750       IF Tx<>0 THEN
18760            Way=1
18770            Theta=Tx
8780            Twirl$="TRANSLATE"
8790            CALL Printmat(Total(*))
8800            GOSUB System_isr
8810       END IF
8820       IF Ty<>0 THEN
8830           Way=2
8840           Theta=Ty
8850           Twirl$="TRANSLATE"
8860           GOSUB System_isr
8870       END IF
8880       IF Tz<>0 THEN
8890          Way=3
8900          Theta=Tz
8910          Twirl$="TRANSLATE"
8920          GOSUB System_isr
```

```
18930      END IF
18940 !
18950 !
18960 !
18970      MAT Tempa(*,1:3)= Skitter(*,1:3)
18980      MAT Temp= Tempa*Total
18990      MAT Skitmod(*,1:3)= Temp(*,1:3)
19000     MAT Newskit(*,1)= Skitmod(*,Screen_x)
19010     MAT Newskit(*,2)= Skitmod(*,Screen_y)
19020     MAT Newskit(*,3)= Skitmod(*,4)
19030     MAT Newskit(37:37,*)= Pen1
19040     MAT Newskit(68:68,*)= Pen2
19050     MAT Newskit(99:99,*)= Pen3
19060     OUTPUT @Path1;Newskit(*)
19070     GOTO Top
19080!
19090!
19100 Movie:!
19110      ASSIGN @Path1 TO *
19120      ASSIGN @Path2 TO *
19130      CALL Display_movie(N,Skitwork$)
19140      IF File_flag=1 THEN GOTO Finished
19150 !
19160 Save_file:!
19170      DISP "DO YOU WANT TO SAVE THE WORK FILE Y OR N";
19180      LINPUT Ans$
19190      IF Ans$<>"Y" AND Ans$<>"N" THEN GOTO 19170
19200      IF Ans$="N" THEN GOTO Delete
19210      IF Ans$="Y" THEN
19220       DISP "NAME OF FILE TO SAVE UNDER";
19230       LINPUT Name$
19250         Where$=Name$
19260         RENAME Skitwork$ TO Where$
19270         DISP "FILE SAVED UNDER";Where$
19280       GOTO Finished
19290       END IF
19300 Delete:!
19310      PURGE Skitwork$
19320      GOTO Finished
19330 System_isr:          !
19340                 SELECT Twirl$
19350                   CASE "ROTATE Y"
19360                   CALL Rotate_y(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_y,Theta,Printflag$)
19370                   CASE "ROTATE X"
19380                   CALL Rotate_x(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_x,Theta,Printflag$)
19390!
19400                   CASE "ROTATE Z"
19410                   Theta=-Theta
19420                   CALL Rotate_z(Skitter(*),Skitmod(*),Total(*),Trans(*),Te
mp(*),Tempa(*),Sys_rot_z,Theta,Printflag$)
19430!
19440                   CASE "TRANSLATE"
19450                   CALL Translate_3d(Skitter(*),Skitmod(*),Total(*),Temp(*)
Tempa(*),Trans(*),Sys_trans_x,Sys_trans_y,Sys_trans_z,Way,Theta,Printflag$)
19460!
19470                   CASE "PIVOT"
19480                      IF Leg_flag$="FEMUR A" THEN
19490                      Theta=-Theta
```

```
19500                    Pivotx=(Skitter(96,1)+Skitter(127,1))/2
19510                    Pivoty=(Skitter(96,2)+Skitter(127,2))/2
19520                    Pivotz=(Skitter(96,3)+Skitter(127,3))/2
19530                    Dist_piv_foot=SQR((Pivotx-Skitter(65,1))^2+(Pivoty-Sk
itter(65,2))^2+(Pivotz-Skitter(65,3))^2)
19540                    CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
19550                    Flag=0
19560                    CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Theta,Pr
intflag$,Fem_a_ang,Flag)
19570                    CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
19580                    MAT Skitter= Skitmod
19590                    END IF
19600!
19610                    IF Leg_flag$="FEMUR B" THEN
19620                    Pivotx=(Skitter(65,1)+Skitter(127,1))/2
19630                    Pivoty=(Skitter(65,2)+Skitter(127,2))/2
19640                    Pivotz=(Skitter(65,3)+Skitter(127,3))/2
19650                    Dist_piv_foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
itter(96,2))^2+(Pivotz-Skitter(96,3))^2)
19660                    CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
19670                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
19680                    Flag=0
19690                    CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Theta,Pr
intflag$,Fem_b_ang,Flag)
19700                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
19710                    CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
19720                    MAT Skitter= Skitmod
19730                    END IF
19740!
19750                    IF Leg_flag$="FEMUR C" THEN
19760                    Pivotx=(Skitter(65,1)+Skitter(96,1))/2
19770                    Pivoty=(Skitter(65,2)+Skitter(96,2))/2
19780                    Pivotz=(Skitter(65,3)+Skitter(96,3))/2
19790                    Dist_piv_foot=SQR((Pivotx-Skitter(129,1))^2+(Pivoty-S
kitter(129,2))^2+(Pivotz-Skitter(129,3))^2)
19800                    CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
19810                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
19820                    Flag=0
19830                    CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Theta,Pr
intflag$,Fem_c_ang,Flag)
19840                    CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
19850                    CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
19860                    MAT Skitter= Skitmod
19870                    END IF
19880!
19890                END SELECT
19900                RETURN
19910!
19920 Leg_isr:!
19930              SELECT Leg$
19940                   CASE "FEMUR A"
19950                    MAT Femur= Skitter(37:67,*)
19960                    CALL Trans_fem_orig(Femur(*),Femurmod(*),-Femur(3,1),
-Femur(3,2),-Femur(3,3))
```

```
20480                          Dist_piv_foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
itter(96,2))^2+(Pivotz-Skitter(96,3))^2)
20490                          Dist_y=Pivoty-Skitter(96,2)
20500                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
20510                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
20520                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
20530                          Flag=0
20540                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
Printflag$,Fem_b_ang,Flag)
20550                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
20560                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
20570                          MAT Skitter= Skitmod
20580                          MAT Tempa(*,1:3)= Skitter(*,1:3)
20590                          MAT Temp= Tempa*Total
20600                          MAT Skitmod(*,1:3)= Temp(*,1:3)
20610 !
20620 !
20630                         CASE "FEMUR C"
20640                          MAT Femur= Skitter(99:129,*)
20650                          CALL Trans_fem_orig(Femur(*),Femurmod(*),-Femur(3,1),
-Femur(3,2),-Femur(3,3))
20660                          CALL Rotate_leg_y(Femurmod(*),Femurmod(*),-60)
20670                          Flag=1
20680                          CALL Rotate_leg_z(Femurmod(*),Femurmod(*),Leg$,Theta,
Printflag$,Fem_c_ang,Flag)
20690                          CALL Rotate_leg_y(Femurmod(*),Femurmod(*),60)
20700                          CALL Trans_fem_orig(Femurmod(*),Femurmod(*),Femur(3,1
),Femur(3,2),Femur(3,3))
20710                          MAT Skitter(99:129,*)= Femurmod
20720!
20730                          IF Freeleg$="FREE" THEN
20740                          MAT Femurtemp(*,1:3)= Femurmod(*,1:3)
20750                          MAT Femur= Femurtemp*Total
20760                          MAT Skitmod(99:129,1:3)= Femur(*,1:3)
20770                          GOTO End_leg
20780                          END IF
20790!
20800                          Pivotx=(Skitter(65,1)+Skitter(96,1))/2
20810                          Pivoty=(Skitter(65,2)+Skitter(96,2))/2
20820                          Pivotz=(Skitter(65,3)+Skitter(96,3))/2
20830                          Dist_piv_foot=SQR((Pivotx-Skitter(127,1))^2+(Pivoty-S
kitter(127,2))^2+(Pivotz-Skitter(127,3))^2)
20840                          Dist_y=Pivoty-Skitter(127,2)
20850                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
20860                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
20870                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
20880                          Flag=0
20890                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
Printflag$,Fem_c_ang,Flag)
20900                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
20910                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
20920                          MAT Skitter= Skitmod
20930                          MAT Tempa(*,1:3)= Skitter(*,1:3)
20940                          MAT Temp= Tempa*Total
20950                          MAT Skitmod(*,1:3)= Temp(*,1:3)
20960!
```

```
20970!
20980!
20990                                      CASE "TIBIA A"
21000                                      MAT Tibia= Skitter(58:67,*)
21010                                      CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
-Tibia(2,2),-Tibia(2,3))
21020                                      Flag=1
21030                                      CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),180)
21040                                      CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
Printflag$,Tib_a_ang,Flag)
21050                                      CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),180)
21060                                      CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
),Tibia(2,2),Tibia(2,3))
21070                                      MAT Skitter(58:67,*)= Tibiamod
21080!
21090                                      IF Freeleg$="FREE" THEN
21100                                      MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
21110                                      MAT Tibia= Tibiatemp*Total
21120                                      MAT Skitmod(58:67,1:3)= Tibia(*,1:3)
21130                                      GOTO End_leg
21140                                      END IF
21150!
21160                                      Pivotx=(Skitter(96,1)+Skitter(127,1))/2
21170                                      Pivoty=(Skitter(96,2)+Skitter(127,2))/2
21180                                      Pivotz=(Skitter(96,3)+Skitter(127,3))/2
21190                                      Dist_piv_foot=SQR((Pivotx-Skitter(65,1))^2+(Pivoty-Sk
itter(65,2))^2+(Pivotz-Skitter(65,3))^2)
21200                                      Dist_y=Pivoty-Skitter(65,2)
21210                                      Rot_ang=ASN(Dist_y/Dist_piv_foot)
21220                                      CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
21230                                      Flag=0
21240                                      CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,-Rot_ang
,Printflag$,Tib_a_ang,Flag)
21250                                      CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
21260                                      MAT Skitter= Skitmod
21270                                      MAT Tempa(*,1:3)= Skitter(*,1:3)
21280                                      MAT Temp= Tempa*Total
21290                                      MAT Skitmod(*,1:3)= Temp(*,1:3)
21300!
21310!
21320                                      CASE "TIBIA B"
21330                                      MAT Tibia= Skitter(89:98,*)
21340                                      CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
-Tibia(2,2),-Tibia(2,3))
21350                                      CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),60)
21360                                      Flag=1
21370                                      CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
Printflag$,Tib_b_ang,Flag)
21380                                      CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),-60)
21390                                      CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
),Tibia(2,2),Tibia(2,3))
21400                                      MAT Skitter(89:98,*)= Tibiamod
21410!
21420                                      IF Freeleg$="FREE" THEN
21430                                      MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
21440                                      MAT Tibia= Tibiatemp*Total
21450                                      MAT Skitmod(89:98,1:3)= Tibia(*,1:3)
21460                                      GOTO End_leg
```

```
21470                          END IF
21480!
21490                          Pivotx=(Skitter(65,1)+Skitter(127,1))/2
21500                          Pivoty=(Skitter(65,2)+Skitter(127,2))/2
21510                          Pivotz=(Skitter(65,3)+Skitter(127,3))/2
21520                          Dist_piv_foot=SQR((Pivotx-Skitter(96,1))^2+(Pivoty-Sk
itter(96,2))^2+(Pivotz-Skitter(96,3))^2)
21530                          Dist_y=Pivoty-Skitter(96,2)
21540                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
21550                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
21560                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
21570                          Flag=0
21580                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
Printflag$,Tib_b_ang,Flag)
21590                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
21600                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
21610                          MAT Skitter= Skitmod
21620                          MAT Tempa(*,1:3)= Skitter(*,1:3)
21630                          MAT Temp= Tempa*Total
21640                          MAT Skitmod(*,1:3)= Temp(*,1:3)
21650!
21660!
21670                          CASE "TIBIA C"
21680                          MAT Tibia= Skitter(120:129,*)
21690                          CALL Trans_fem_orig(Tibia(*),Tibiamod(*),-Tibia(2,1),
-Tibia(2,2),-Tibia(2,3))
21700                          CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),-60)
21710                          Flag=1
21720                          CALL Rotate_leg_z(Tibiamod(*),Tibiamod(*),Leg$,Theta,
Printflag$,Tib_c_ang,Flag)
21730                          CALL Rotate_leg_y(Tibiamod(*),Tibiamod(*),60)
21740                          CALL Trans_fem_orig(Tibiamod(*),Tibiamod(*),Tibia(2,1
),Tibia(2,2),Tibia(2,3))
21750                          MAT Skitter(120:129,*)= Tibiamod
21760!
21770                          IF Freeleg$="FREE" THEN
21780                          MAT Tibiatemp(*,1:3)= Tibiamod(*,1:3)
21790                          MAT Tibia= Tibiatemp*Total
21800                          MAT Skitmod(120:129,1:3)= Tibia(*,1:3)
21810                          GOTO End_leg
21820                          END IF
21830!
21840                          Pivotx=(Skitter(65,1)+Skitter(96,1))/2
21850                          Pivoty=(Skitter(65,2)+Skitter(96,2))/2
21860                          Pivotz=(Skitter(65,3)+Skitter(96,3))/2
21870                          Dist_piv_foot=SQR((Pivotx-Skitter(127,1))^2+(Pivoty-S
kitter(127,2))^2+(Pivotz-Skitter(127,3))^2)
21880                          Dist_y=Pivoty-Skitter(127,2)
21890                          Rot_ang=ASN(Dist_y/Dist_piv_foot)
21900                          CALL Trans_fem_orig(Skitter(*),Skitmod(*),-Pivotx,-Pi
voty,-Pivotz)
21910                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),-60)
21920                          Flag=0
21930                          CALL Rotate_leg_z(Skitmod(*),Skitmod(*),Leg$,Rot_ang,
Printflag$,Tib_c_ang,Flag)
21940                          CALL Rotate_leg_y(Skitmod(*),Skitmod(*),60)
21950                          CALL Trans_fem_orig(Skitmod(*),Skitmod(*),Pivotx,Pivo
ty,Pivotz)
```

```
21960                         MAT Skitter= Skitmod
21970                         MAT Tempa(*,1:3)= Skitter(*,1:3)
21980                         MAT Temp= Tempa*Total
21990                         MAT Skitmod(*,1:3)= Temp(*,1:3)
22000 !
22010 End_leg:!
22020         END SELECT
22030         RETURN
22040!
22050!
22060 Windows:!
22070!          CALL Zoom_pan(Window$,Screenx_win_min,Screenx_win_max,Screeny_wi
n_min,Screeny_win_max,Skitmod(*),Newskit(*),Screen_x,Screen_y)
22080           GOTO Menu
22090!*************************************************************************
22100!
22110 Init:                                           !  INITIALIZE SCREEN,SKITTER
22120!
22130      DEG                                        ! SET TO DEGREES
22140      GINIT                                      ! INITIATE GRAPHICS
22150      GRAPHICS ON                                ! TURN G-PLANE ON
22160      PLOTTER IS CRT,"INTERNAL"                  ! INIT PLOTTER
22170!
22180      Dump_device=9
22190!
22200      Plot_device=705
22210!
22220      READ Skitter(*)                            ! READ SKITTER DATA
22230!
22240      MAT Skitmod= Skitter
22250!
22260      MAT Femurtemp= (1)
22270!
22280      MAT Tibiatemp= (1)
22290      MAT Trans= IDN                             ! INIT TRANS MATRIX TO IDN
22300!
22310      MAT Tempa= (1)
22320!
22330      MAT Total= IDN
22340!
22350      Menu$="MAIN"                               ! INIT MAIN MENU
22360!
22370      Twirl$="ROTATE Y"
22380!
22390      Freeleg$="FIXED"
22400!
22410      Way=1                                      ! AXIS OF TRANS X=1,Y=2,Z=3
22420!
22430      Printflag$="OFF"
22440!
22450      Increment=5                           ! TRANS INC.
22460!
22470      Rot_increment=3
22480!
22490      Screen_x=1                                 ! INIT VIEW PLANE
22500      Screen_y=2                                 ! X=1,Y=2,Z=3
22510!
22520      Sys_trans_x=0                              ! INIT POSITONS OF SYSTEM
22530      Sys_trans_y=0
22540      Sys_trans_z=0
```

```
22550     Sys_rot_x_=0
22560     Sys_rot_y=0
22570     Sys_rot_z=0
22580!
22590     Fem_a_ang=0                                   ! INIT LEG ANGLES
22600     Fem_b_ang=0
22610     Fem_c_ang=0
22620     Tib_a_ang=90
22630     Tib_b_ang=90
22640     Tib_c_ang=90
22650!
22660     Screenx_win_max=40                            ! SET WINDOW
22670     Screenx_win_min=-20
22680     Screeny_win_max=40
22690     Screeny_win_min=-20
22700     SHOW Screenx_win_min,Screenx_win_max,Screeny_win_min,Screeny_win_max
22710!
22720     RETURN
22730!************************************************************************
22740!
22750!
22760!************************************************************************
22770!
22780 Finished:                                         ! DONE WITH PROGRAM
22790     GCLEAR
22800     CLEAR SCREEN
22810     SUBEND
22820!
22830 SUB Display_movie(N,Skitwork$)
22840 !
22850 OPTION BASE 1
22860     DIM Newskit(129,3)
22870     ON KBD GOTO Leave
22880     DISP "HIT ANY KEY TO QUIT"
22890     ASSIGN @Path1 TO Skitwork$
22900     ON END @Path1 GOTO Start_again
22910     ENTER @Path1;Newskit(*)
22920     CLEAR SCREEN
22930     GCLEAR
22940     FRAME
22950     AREA INTENSITY 0,0,.2
22960     MOVE -100,-.5
22970     RECTANGLE 200,.5,FILL,EDGE
22980     PLOT Newskit(*)
22990     LINE TYPE 1
23000     GOTO 22910
23010 Start_again:!
23020     ASSIGN @Path1 TO *
23030     GOTO 22890
23040 Leave:!
23050     ASSIGN @Path1 TO *
23060     SUBEND
```

Appendix C

SKITTER Dynamic Simulation Program Listing

```
10    REM***************************************************************
20    REM
30    REM  THIS PROGRAM WILL ALLOW THE USER
40    REM  TO DETERMINE WHETHER OR NOT A
50    REM  PARTICULAR ACTUATOR WILL PROVIDE
60    REM  SUFFICIENT TORQUE AND ANGULAR
70    REM  VELOCITY TO HAVE SKITTER JUMP A
80    REM
90    REM  TO DOS THIS, A INVERSE SLIDER CRANK
100   REM  MECHANISM WILL BE SIMULATED.  JOINT
110   REM  ANGLES, VELOCITIES, AND ACCELERATIONS
120   REM  WILL BE CALCULATED ALONG WITH THE TORQUES.
130   REM
140   REM          PROGRAM WRITTEN BY:
150   REM          BRICE MACLAREN
160   REM          GARY MCMURRAY
170   REM
180   REM***************************************************************
190   RAD
200   OPTION BASE 1
210   REM***************************************************************
220   REM
230   DIM A(4),B(4),C(4),D(4),E(4),F(4),Rot1(4,4),Rot2(4,4),Rot3(4,4)
240   DIM Femur(4),Foot(4),Tibcon(4),Oflag(6),Trans1(4,4),Matrix(4,4)
250   DIM Trans2(4,4),Trans3(4,4),Newfem(4),Newfoot(4),Temp1(4),Dist(4)
260   DIM Newb(4),Newd(4),Newe(4),Newfem2(4),Temp2(4),Temp3(4)
270   DIM Ftorque(800),Ttorque(800),Fomega(800),Tomega(800),Fhp(800),Thp(200)
280   DIM Origb(4),Origd(4),Orige(4),Newfoot2(4)
290   DIM Temp$[8]
300   REM
310   REM***************************************************************
320   REM
330   REM        INITIALIZE VARIABLES
340   REM
350   Delstep=1
360   G=32.2
370   Jdist=6/12
380   Adist=3/12
390   Wgt=300
400   Mfemur=10/G
410   Mtibia=6/G
420   Flen=20/12
430   Tlen=20/12
440   Beta=0
450   Iota=PI/2
460   CALL Invar(Mfemur,Ifemur,Flen,Mtibia,Itibia,Tlen)
470   MAT Trans3= IDN
480   MAT Trans2= IDN
490   MAT Trans1= IDN
500   Angf=23.62
510   Angt=27.5
520   Aforce=100
530   Avel=5
540   Avel=Avel/12
550   Atorque=100
560   Aomega=2
570   REM***************************************************************
580   REM
590   REM  WHAT FOLLOWS ARE THE ORIGINAL POINT LOCATIONS FOR THE VARIOUS
```

```
600   REM  CONNECT POINTS -- THEY ARE, IN ORDER, PNT.A,B,C,D,E,& F.  PLEASE
610   REM  THE DOCUMENTATION FOR DEFINITIONS OF THESE POINTS.
620   REM
630   REM*******************************************************************
640   DATA -1.95,7.5095,0,1
650   DATA 9.576,4.09,0,1
660   DATA 0,0,0,1
670   DATA 11.411,-4.09,0,1
680   DATA 23.714,-11.7685,0,1
690   REM
700   READ A(*)
710   READ B(*)
720   READ C(*)
730   READ D(*)
740   READ E(*)
750   REM*******************************************************************
760   REM
770   REM·  THE NEXT 3 DATA STATEMENTS ARE FOR THE ORIGINAL VECTORS OF THE
780   REM   FEMUR, FOOT, AND THE CONNECTION POINT OF THE ACTUATOR TO THE
790   REM   TIBIA (THE LAST TWO ARE RELATIVE TO THE FEMUR END POINT)
800   REM
810   REM*******************************************************************
820   DATA 20,0,0,1
830   DATA -20,0,0,1
840   DATA 6.95,-11.71,0,1
850   REM
860   READ Femur(*)
870   READ Foot(*)
880   READ Tibcon(*)
890   !   CONVERT INCHES TO FEET
900   FOR I=1 TO 3
910      A(I)=A(I)/12
920      B(I)=B(I)/12
930      C(I)=C(I)/12
940      D(I)=D(I)/12
950      E(I)=E(I)/12
960      Femur(I)=Femur(I)/12
970      Foot(I)=Foot(I)/12
980      Tibcon(I)=Tibcon(I)/12
990   NEXT I
1000  Flag=0                  !  FLAG CONTROLS WHICH MENU YOU GO TO
1010  Simflag=0               !  FLAG CONTROLS IF SIMULATION FILE IS DESIRED
1020  Rflag=1                 !  FLAG CONTROLS TYPE OF RUN USER DESIRES
1030  FOR I=1 TO 6
1040     Oflag(I)=0         !  OFLAG CONROLS WHETHER DATA GOES TO CRT OR FILE
1050  NEXT I
1060 Menu:    !
1070          CLEAR SCREEN
1080          CALL Invar(Mfemur,Ifemur,Flen,Mtibia,Itibia,Tlen)
1090          IF Flag<>0 THEN
1100                CALL Printvar(Jdist,Adist,Wgt,G,Mfemur,Flen,Mtibia,Tlen,Angf,
Angt,A(*),B(*),C(*),D(*),E(*),Beta,Iota,Aforce,Avel,Actflag,Atorque,Aomega)
1110          ELSE
1120                DISP "CHOOSE TYPE OF ACTUATOR"
1130          END IF
1140  REM
1150  REM     NOW THE MENUS ARE DEFINED
1160  REM
1170  SELECT Flag
1180  CASE 0
```

```
1190      ON KEY 0 LABEL "ROTARY ACT." GOTO Ract
1200      ON KEY 1 LABEL "" GOTO Try
1210      ON KEY 2 LABEL "" GOTO Try
1220      ON KEY 3 LABEL "" GOTO Try
1230      ON KEY 4 LABEL "LINEAR ACT." GOTO Lact
1240      ON KEY 5 LABEL "" GOTO Try
1250      ON KEY 6 LABEL "" GOTO Try
1260      ON KEY 7 LABEL "STOP" GOTO St
1270      ON KEY 8 LABEL "" GOTO Try
1280      ON KEY 9 LABEL "" GOTO Try
1290   CASE 1
1300      ON KEY 0 LABEL "JUMP DISTANCE" GOTO Jd
1310      ON KEY 1 LABEL "ACCELERATION DIST" GOTO Ad
1320      ON KEY 2 LABEL "LEG PROPERTIES" GOTO Lp
1330      ON KEY 3 LABEL "JOINT LOCATIONS" GOTO Jnt
1340      ON KEY 4 LABEL "ACTUATORS" GOTO Act
1350      ON KEY 5 LABEL "CHANGE ACT" GOTO Cha
1360      ON KEY 6 LABEL "DATA FILES" GOTO Fn
1370      ON KEY 7 LABEL "STOP" GOTO St
1380      ON KEY 8 LABEL "PRINTER IS ?" GOTO Prnt
1390      ON KEY 9 LABEL "RUN DATA" GOTO Rn
1400   CASE 2
1410      ON KEY 0 LABEL "FEMUR MASS" GOTO Fm
1420      ON KEY 1 LABEL "" GOTO Try
1430      ON KEY 2 LABEL "INIT FEMUR ANGLE" GOTO Fang
1440      ON KEY 3 LABEL "" GOTO Try
1450      ON KEY 4 LABEL "LEG LENGTH" GOTO Llen
1460      ON KEY 5 LABEL "TIBIA MASS" GOTO Tm
1470      ON KEY 6 LABEL "" GOTO Try
1480      ON KEY 7 LABEL "INIT TIBIA ANGLE" GOTO Tang
1490      ON KEY 8 LABEL "MAIN MENU" GOTO Mm
1500      ON KEY 9 LABEL "RUN DATA" GOTO Rn
1510   CASE 3
1520      ON KEY 0 LABEL "POINT A" GOTO Ba1
1530      ON KEY 1 LABEL "" GOTO Try
1540      ON KEY 2 LABEL "POINT B" GOTO Ba2
1550      ON KEY 3 LABEL "" GOTO Try
1560      ON KEY 4 LABEL "POINT D" GOTO Ta1
1570      ON KEY 5 LABEL "" GOTO Try
1580      ON KEY 6 LABEL "POINT E" GOTO Ta2
1590      ON KEY 7 LABEL "" GOTO Try
1600      ON KEY 8 LABEL "MAIN MENU" GOTO Mm
1610      ON KEY 9 LABEL "RUN DATA" GOTO Rn
1620   CASE 4
1630      ON KEY 0 LABEL "FEMUR FILES" GOTO Cf
1640      ON KEY 1 LABEL "" GOTO Try
1650      ON KEY 2 LABEL "TIBIA FILES" GOTO Tibfiles
1660      ON KEY 3 LABEL "" GOTO Try
1670      ON KEY 4 LABEL "SIMULATION " GOTO Simfil
1680      ON KEY 5 LABEL "" GOTO Try
1690      ON KEY 6 LABEL "CLOSE FILES" GOTO Clf
1700      ON KEY 7 LABEL "" GOTO Try
1710      ON KEY 8 LABEL "MAIN MENU" GOTO Mm
1720      ON KEY 9 LABEL "RUN DATA" GOTO Rn
1730   CASE 5
1740      ON KEY 0 LABEL "TORQ VS JDIST" GOTO Ftj
1750      ON KEY 1 LABEL "" GOTO Try
1760      ON KEY 2 LABEL "OMEQA VS JDIST" GOTO Foj
1770      ON KEY 3 LABEL "" GOTO Try
1780      ON KEY 4 LABEL "HP VS JDIST" GOTO Fhj
```

```
1790     ON KEY 5 LABEL "" GOTO Try
1800     ON KEY 6 LABEL "" GOTO Try
1810     ON KEY 7 LABEL "" GOTO Try
1820     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
1830     ON KEY 9 LABEL "RUN DATA" GOTO Rn
1840  CASE 6
1850     ON KEY 0 LABEL "TORQ VS JDIST" GOTO Ttj
1860     ON KEY 1 LABEL "" GOTO Try
1870     ON KEY 2 LABEL "OMEQA VS JDIST" GOTO Toj
1880     ON KEY 3 LABEL "" GOTO Try
1890     ON KEY 4 LABEL "HP VS JDIST" GOTO Thj
1900     ON KEY 5 LABEL "" GOTO Try
1910     ON KEY 6 LABEL "" GOTO Try
1920     ON KEY 7 LABEL "" GOTO Try
1930     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
1940     ON KEY 9 LABEL "RUN DATA" GOTO Rn
1950  CASE 7
1960     ON KEY 0 LABEL "MAX FORCE" GOTO Actf
1970     ON KEY 1 LABEL "" GOTO Try
1980     ON KEY 2 LABEL "MAX VELOCITY" GOTO Actv
1990     ON KEY 3 LABEL "" GOTO Try
2000     ON KEY 4 LABEL "" GOTO Try
2010     ON KEY 5 LABEL "" GOTO Try
2020     ON KEY 6 LABEL "" GOTO Try
2030     ON KEY 7 LABEL "" GOTO Try
2040     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
2050     ON KEY 9 LABEL "RUN DATA" GOTO Rn
2060  CASE 8
2070     ON KEY 0 LABEL "MAX TORQUE" GOTO Actt
2080     ON KEY 1 LABEL "" GOTO Try
2090     ON KEY 2 LABEL "MAX OMEGA" GOTO Acto
2100     ON KEY 3 LABEL "" GOTO Try
2110     ON KEY 4 LABEL "" GOTO Try
2120     ON KEY 5 LABEL "" GOTO Try
2130     ON KEY 6 LABEL "" GOTO Try
2140     ON KEY 7 LABEL "" GOTO Try
2150     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
2160     ON KEY 9 LABEL "RUN DATA" GOTO Rn
2170  CASE 9
2180     ON KEY 0 LABEL "CRT" GOTO Pcrt
2190     ON KEY 1 LABEL "" GOTO Try
2200     ON KEY 2 LABEL "" GOTO Try
2210     ON KEY 3 LABEL "" GOTO Try
2220     ON KEY 4 LABEL "LASER" GOTO Las
2230     ON KEY 5 LABEL "" GOTO Try
2240     ON KEY 6 LABEL "" GOTO Try
2250     ON KEY 7 LABEL "" GOTO Try
2260     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
2270     ON KEY 9 LABEL "RUN DATA" GOTO Rn
2280  CASE 10
2290     ON KEY 0 LABEL "JUMP DISTANCE" GOTO Jd
2300     ON KEY 1 LABEL "" GOTO Try
2310     ON KEY 2 LABEL "" GOTO Try
2320     ON KEY 3 LABEL "" GOTO Try
2330     ON KEY 4 LABEL "ACCELERATION" GOTO Ad
2340     ON KEY 5 LABEL "" GOTO Try
2350     ON KEY 6 LABEL "" GOTO Try
2360     ON KEY 7 LABEL "" GOTO Try
2370     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
2380     ON KEY 9 LABEL "RUN DATA" GOTO Rn
```

```
2390  CASE 11
2400     ON KEY 0 LABEL "FIND MAX VALS" GOTO Fmv
2410     ON KEY 1 LABEL "" GOTO Try
2420     ON KEY 2 LABEL "" GOTO Try
2430     ON KEY 3 LABEL "" GOTO Try
2440     ON KEY 4 LABEL "INCREMENTAL" GOTO Inc
2450     ON KEY 5 LABEL "" GOTO Try
2460     ON KEY 6 LABEL "" GOTO Try
2470     ON KEY 7 LABEL "" GOTO Try
2480     ON KEY 8 LABEL "MAIN MENU" GOTO Mm
2490     ON KEY 9 LABEL "RUN DATA" GOTO Rn
2500  END SELECT
2510  GOTO 2510
2520  !
2530  !    BEGIN SOFTKEY DEFINATIONS
2540  !                                           ACTUATORS WILL BE ROTARY
2550 Ract:      !
2560            Actflag=1
2570            Flag=1
2580            GOTO Menu                        ACTUATORS WILL BE LINEAR
2590 Lact:      !
2600            Actflag=2
2610            Flag=1
2620            GOTO Menu                       GO TO RUN CONDITIONS MENU
2630 Rcond:     !
2640            Flag=11
2650            GOTO Menu                         INPUT A NEW JUMP DISTANCE
2660 Jd:   !
2670       DISP "DISTANCE YOU DESIRE SKITTER TO JUMP (IN INCHES)";
2680       INPUT Jdist
2690       Jdist=Jdist/12
2700       GOTO Menu                      INPUT A NEW ACCELERATION DISTANCE
2710 Ad: !
2720      DISP "ACCELERATION DISTANCE FOR FOOT (IN INCHES)";
2730      INPUT Adist
2740      Adist=Adist/12
2750      GOTO Menu                               GO TO LEG MENU
2760 Lp:    !
2770        Flag=2
2780        GOTO Menu                             GO TO JOINT MENU
2790 Jnt:   !
2800        Flag=3
2810        GOTO Menu                             GO TO ACTUATOR MENU
2820 Act:   !
2830        IF Actflag=1 THEN
2840           Flag=8
2850        ELSE
2860           Flag=7
2870        END IF
2880        GOTO Menu                          CHANGE TYPE OF ACTUATORS
2890 Cha:   !
2900        Flag=0
2910        GOTO Menu                          CHANGE PRINTER
2920 Prnt:  !
2930        Flag=9
2940        GOTO Menu                          UNDEFINED SOFTKEY CHOOSEN, TRY AGAI
2950 Try:   !
2960        DISP "BAD CHOICE -- TRY AGAIN"
2970        GOTO Menu                          GO TO DATA FILE MENU
2980 Fn:    !
```

```
990          Flag=4
000          GOTO Menu
010 St:      !                                  EXIT THE PROGRAM
020          PRINTER IS CRT
030          CLEAR SCREEN
040          DISP "PROGRAM TERMINATED"
050          WAIT 1
060          DISP "OR IS IT????"
070          STOP
080 Rn:      !                                  RUN PROGRAM WITH DATA AS IT IS
090          Flag=11
100          GOTO Menu
110 Fm:      !                                  INPUT WEIGHT OF FEMUR
120          DISP "FEMUR WEIGHT (IN POUNDS FORCE)  ";
130          INPUT Mfemur
140          Mfemur=Mfemur/G
150          GOTO Menu
160 Llen:  !                                        INPUT LENGTH OF LEGS
170           DISP "LEG LENGTH (IN INCHES)";
180           INPUT Flen
190           Flen=Flen/12
200           Tlen=Flen
210           GOTO Menu
220 Tm:       !                                    INPUT WEIGHT OF TIBIA
230          DISP "TIBIA WEIGHT (IN POUNDS FORCE)  ";
240          INPUT Mtibia
250          Mtibia=Mtibia/G
260          GOTO Menu
270 Fang:       !                                  INPUT INITIAL ANGLE OF FEMUR
280           DISP "INITIAL ANGLE BETWEEN FEMUR AND HORIZONTAL (IN DEGREES)";
290           INPUT Beta
300           Beta=Beta*PI/180
310           GOTO Menu
320 Tang:       !                                  INPUT INITIAL ANGLE BETWEEN
330             !                                  FEMUR AND TIBIA
340           DISP "INITIAL ANGLE BETWEEN FEMUR AND TIBIA (IN DEGREES)";
350           INPUT Iota
360           Iota=Iota*PI/180
370           GOTO Menu
380 Mm:        !                                   GO BACK TO MAIN MENU
390            Flag=1
400            GOTO Menu
410 Bal:      !                                    CHANGE PNT. A
420           DISP "POINT A - X COORDINATE (DEFAULT = ",A(1)*12,"IN.)";
430           LINPUT Temp$
440           IF Temp$="" THEN
450           ELSE
460              A(1)=VAL(Temp$)
470              A(1)=A(1)/12
480           END IF
490           DISP "POINT A - Y COORDINATE (DEFAULT = ",A(2)*12,"IN.)";
500           LINPUT Temp$
510           IF Temp$="" THEN
520           ELSE
530              A(2)=VAL(Temp$)
540              A(2)=A(2)/12
550           END IF
560           DISP "POINT A - Z COORDINATE (DEFAULT = ",A(3)*12,"IN.)";
570           LINPUT Temp$
580           IF Temp$="" THEN
```

```
1590         ELSE
1600            A(3)=VAL(Temp$)
1610            A(3)=A(3)/12
1620         END IF
1630         GOTO Menu
1640 Ba2:    !                                   CHANGE PNT. B
1650         DISP "POINT B - X COORDINATE (DEFAULT = ",B(1)*12,"IN.)";
1660         LINPUT Temp$
1670         IF Temp$="" THEN
1680         ELSE
1690            B(1)=VAL(Temp$)
1700            B(1)=B(1)/12
1710         END IF
1720         DISP "POINT B - Y COORDINATE (DEFAULT = ",B(2)*12,"IN.)";
1730         LINPUT Temp$
1740         IF Temp$="" THEN
1750         ELSE
1760            B(2)=VAL(Temp$)
1770            B(2)=B(2)/12
1780         END IF
1790         DISP "POINT B - Z COORDINATE (DEFAULT = ",B(3)*12,"IN.)";
1800         LINPUT Temp$
1810         IF Temp$="" THEN
1820         ELSE
1830            B(3)=VAL(Temp$)
1840            B(3)=B(3)/12
1850         END IF
1860         GOTO Menu
1870 Ta1:    !                                   CHANGE PNT. D
1880         DISP "POINT D - X COORDINATE (DEFAULT = ",D(1)*12,"IN.)";
1890         LINPUT Temp$
1900         IF Temp$="" THEN
1910         ELSE
 920            D(1)=VAL(Temp$)
 930            D(1)=D(1)/12
 940         END IF
 950         DISP "POINT D - Y COORDINATE (DEFAULT = ",D(2)*12,"IN.)";
 960         LINPUT Temp$
 970         IF Temp$="" THEN
 980         ELSE
 990            D(2)=VAL(Temp$)
 000            D(2)=D(2)/12
 010         END IF
 020         DISP "POINT D - Z COORDINATE (DEFAULT = ",D(3)*12,"IN.)";
 030         LINPUT Temp$
 040         IF Temp$="" THEN
 050         ELSE
 060            D(3)=VAL(Temp$)
 070            D(3)=D(3)/12
 080         END IF
 090         GOTO Menu
 100 Ta2:    !                                   CHANGE PNT. E
 110         DISP "POINT E - X COORDINATE (DEFAULT = ",E(1)*12,"IN.)";
 120         LINPUT Temp$
 130         IF Temp$="" THEN
 140         ELSE
 150            E(1)=VAL(Temp$)
 160            E(1)=E(1)/12
 170         END IF
 180         DISP "POINT E - Y COORDINATE (DEFAULT = ",E(2)*12,"IN.)";
```

```
4190        LINPUT Temp$
4200        IF Temp$="" THEN
4210        ELSE
4220           E(2)=VAL(Temp$)
4230           E(2)=E(2)/12
4240        END IF
4250        DISP "POINT E - Z COORDINATE (DEFAULT = ",E(3)*12,"IN.)";
4260        LINPUT Temp$
4270        IF Temp$="" THEN
4280        ELSE
4290           E(3)=VAL(Temp$)
4300           E(3)=E(3)/12
4310        END IF
4320        GOTO Menu
4330 Cf:    !                               CREATE DATA FILES FOR FEMUR
4340        Flag=5
4350        GOTO Menu
4360 Tibfiles:   !                          CREATE DATA FILES FOR TIBIA
4370             Flag=6
4380             GOTO Menu
4390 Clf:   !                               CLOSE ALL DATA FILES
4400        ASSIGN @Path1 TO *
4410        ASSIGN @Path2 TO *
4420        ASSIGN @Path3 TO *
4430        ASSIGN @Path4 TO *
4440        ASSIGN @Path5 TO *
4450        ASSIGN @Path6 TO *
4460        ASSIGN @Pathsim TO *
4470        FOR I=1 TO 6
4480           Oflag(I)=0
4490        NEXT I
4500        GOTO Menu
4510 Simfil:     !                 THIS CREATES A BDAT FILE THE OUTPUT OF THE
4520             !                 ANGLES FOR THE SIMULATION OF SKITTER
4530             DISP "FILE NAME FOR THE SIMULATION FILE ";
4540             LINPUT Sim$
4550             CREATE BDAT Sim$,200
4560             ASSIGN @Pathsim TO Sim$
4570             Simflag=1
4580             GOTO Menu
4590 Ftj:    !                     CREATE TORQUE vs JUMP DISTANCE FILE FOR FEMUR
4600        DISP "FILE NAME FOR TORQUE VS JUMP DISTANCE ";
4610        LINPUT Tvj$
4620        CREATE ASCII Tvj$,25
4630        ASSIGN @Path1 TO Tvj$
4640        Oflag(1)=1
4650        GOTO Menu
4660 Foj:    !                     CREATE OMEGA vs JUMP DISTANCE FILE FOR FEMUR
4670        DISP "FILE NAME FOR OMEGA VS JUMP DISTANCE ";
4680        LINPUT Ovj$
4690        CREATE ASCII Ovj$,25
4700        ASSIGN @Path2 TO Ovj$
4710        Oflag(2)=1
4720        GOTO Menu
4730 Fhj:    !                     CREATE HP vs JUMP DISTANCE FILE FOR FEMUR
4740        DISP "FILE NAME FOR HORSE POWER VS JUMP DISTANCE ";
4750        LINPUT Hvj$
4760        CREATE ASCII Hvj$,25
4770        ASSIGN @Path3 TO Hvj$
4780        Oflag(3)=1
```

```
4790         GOTO Menu
4800 Ttj:     !                     CREATE TORQUE vs JUMP DISTANCE FILE FOR TIBIA
4810         DISP "FILE NAME FOR TORQUE VS JUMP DISTANCE ";
4820         LINPUT Tvj$
4830         CREATE ASCII Tvj$,25
4840         ASSIGN @Path4 TO Tvj$
4850         Oflag(4)=1
4860         GOTO Menu
4870 Toj:     !                     CREATE OMEGA vs JUMP DISTANCE FILE FOR TIBIA
4880         DISP "FILE NAME FOR OMEGA VS JUMP DISTANCE ";
4890         LINPUT Ovj$
4900         CREATE ASCII Ovj$,25
4910         ASSIGN @Path5 TO Ovj$
4920         Oflag(5)=1
4930         GOTO Menu
4940 Thj:     !                     CREATE HP vs JUMP DISTANCE FILE FOR TIBIA
4950         DISP "FILE NAME FOR HORSE POWER VS JUMP DISTANCE ";
4960         LINPUT Hvj$
4970         CREATE ASCII Hvj$,25
4980         ASSIGN @Path6 TO Hvj$
4990         Oflag(6)=1
5000         GOTO Menu
5010 Actf:      !                       INPUT MAXIMUM FORCE ACTUATOR CAN EXERT
5020            DISP "MAXIMUM FORCE ACTUATOR CAN EXERT (IN POUNDS FORCE) ";
5030            INPUT Aforce
5040            GOTO Menu
5050 Actv:      !                    INPUT MAXIMUM VELOCITY ACTUATOR CAN ACHIEVE
5060            DISP "MAXIMUM ACTUATOR VELOCITY ACHIEVE (IN IN/SEC) ";
5070            INPUT Avel
5080            Avel=Avel/12
5090            GOTO Menu
5100 Actt:      !                       INPUT MAXIMUM TORQUE ACTUATOR CAN EXERT
5110            DISP "MAXIMUM TORQUE ACTUATOR CAN EXERT (IN FT-LBS) ";
5120            INPUT Atorque
5130            GOTO Menu
5140 Acto:      !                    INPUT MAXIMUM VELOCITY ACTUATOR CAN ACHIEVE
5150            DISP "MAXIMUM ACTUATOR OMEGA ACHIEVE (IN RAD/SEC) ";
5160            INPUT Aomega
5170            GOTO Menu
5180 Pcrt:      !                      MAKE PRINTER CRT
5190            PRINTER IS CRT
5200            Flag=1
5210            GOTO Menu
5220 Las:      !                      MAKE PRINTER THE LASER JET
5230           PRINTER IS 9
5240           Flag=1
5250           GOTO Menu
5260 Fmv:      !                     RUNS THE PROGRAM TO FIND MAX TORQUE & OMEGA
5270           DISP "NUMBER OF STEPS PER INCH OF ACCELERATION ";
5280           INPUT Delstep
5290           Delstep=1/Delstep
5300           Rflag=2
5310           Flag=1
5320           GOTO Rest
5330 Inc:      !                     RUNS THE PROGRAM ON AN INCREMENTAL SETTING
5340           Rflag=1
5350           Flag=1
5360           GOTO Rest
5370 Rest:      !                      RUN THE PROGRAM WITH THE VALUES AS SET
5380            Flag=1
```

```
5390          CLEAR SCREEN
5400   !
5410   !   IF NO FILE ASSIGNMENTS HAVE BEEN MADE, THEN OUTPUT IS TO THE CRT
5420   !
5430   IF Oflag(1)=0 THEN
5440      ASSIGN @Path1 TO CRT
5450   END IF
5460   IF Oflag(2)=0 THEN
5470      ASSIGN @Path2 TO CRT
5480   END IF
5490   IF Oflag(3)=0 THEN
5500      ASSIGN @Path3 TO CRT
5510   END IF
5520   IF Oflag(4)=0 THEN
5530      ASSIGN @Path4 TO CRT
5540   END IF
5550   IF Oflag(5)=0 THEN
5560      ASSIGN @Path5 TO CRT
5570   END IF
5580   IF Oflag(6)=0 THEN
5590      ASSIGN @Path6 TO CRT
5600   END IF
5610   !*********************************************************************
5620   !
5630   !         START THE PROGRAM
5640   !
5650   !*********************************************************************
5660   !
5670   !
5680   !   DEFINE YOUR END CONDITIONS
5690   !
5700   Maxvel=SQR(2*G*Jdist)
5710   Totaltime=ABS(2*Adist/Maxvel)
5720   Accel=Maxvel/Totaltime
5730   !
5740   !   DETERMINE ANGLES FOR THIS POSITION OF THE FOOT
5750   !
5760   CALL Findfoot(-1*Beta,Iota,Femur(*),Foot(*),Newfoot(*),Newfem(*))
5770   !
5780   !
5790   !        DEFINE ORIGINAL LOCATION OF ACTUATOR CONNECT POINTS FOR THIS
5800   !        CONFIGURATION OF THE LEGS
5810   !
5820   CALL Rot(-1*Beta,Trans1(*))
5830   MAT Origb= Trans1*B
5840   MAT Origd= Trans1*D
5850   MAT Temp2= E-Femur
 860   Temp2(4)=1
 870   MAT Temp1= Trans3*Temp2
 880   Xnew=Newfoot(1)
 890   Ynew=Newfoot(2)
 900   Lac=SQR(Xnew^2+(Ynew)^2)
 910   CALL Sss(Tlen,Lac,Flen,A3)
 920   A3=A3-PI/2
 930   CALL Rot(A3,Trans2(*))
 940   CALL Trans(Newfem(*),Trans2(*))
 950   MAT Orige= Trans2*Temp1
 960   !
 970   !   SET END POINTS FOR LOOPING OVER SLIDER CRANK
 980   !
```

```
5990 I=1    !         COUNTER
6000 IF Rflag=1 THEN
6010    Delstep=1
6020    Y0=Delstep
6030 ELSE
6040    Y0=Delstep
6050 END IF
6060 Endpnt=Adist*12
6070 Theta2=-1*Beta
6080 Iota2=Iota
6090 !
6100 !                 BEGIN LOOP OVER ACCELERATION DISTANCE
6110 !
6120 FOR Y=Y0 TO Endpnt STEP Delstep
6130     Y1=Y/12
6140     T=ABS(SQR(2*Y1/Accel))
6150     V=Accel*T
6160 !
6170 !                 DETERMINE JOINT ANGLES
6180 !
6190     Xnew=Newfoot(1)
6200     Ynew=Newfoot(2)
6210     Lac=SQR(Xnew^2+(Ynew-(Y1))^2)
6220     Psi=ATN((Ynew-(Y1))/Xnew)
6230     CALL Sss(Flen,Tlen,Lac,A3)
6240     IF Psi<0. THEN A3=-1*A3
6250     Theta=Psi-A3
6260     IF Psi>0. THEN
6270        Gamma=PI/2-Psi
6280     ELSE
6290        Gamma=Psi+PI/2
6300     END IF
6310     CALL Sss(Lac,Flen,Tlen,A3)
6320     IF Gamma>0. THEN
6330        Phi=Gamma-A3
6340     ELSE
6350        Phi=A3-Gamma
6360     END IF
6370     !
6380     !        NOW OUTPUT ANGLES FOR SIMULATION IF SIMFLAG=1
6390     !
6400     IF Simflag=1 THEN
6410        CALL Sss(Tlen,Lac,Flen,Iota1)
6420        Theta1=Theta
6430        Angle1=(Theta1-Theta2)*180/PI
6440        Angle2=(Iota1-Iota2)*180/PI
6450        Free=2.0
6460        OUTPUT @Pathsim;T
6470        OUTPUT @Pathsim;Free
6480        OUTPUT @Pathsim;Angle1
6490        OUTPUT @Pathsim;Angle2
6500        Theta2=Theta1
6510        Iota2=Iota1
6520     END IF
6530     !
6540     !     NOW CALCULATE THE PHYSICAL PARAMETERS
6550     !
6560     Fomega(I)=ABS((V*COS(Phi))/(Flen*(COS(Theta)*COS(Phi)-SIN(Theta)*SIN(P
hi))))
6570     Tomega(I)=ABS((Fomega(I)*SIN(Theta))/COS(Phi))
```

```
6580      Numbbc=-1*Accel*Tlen*SIN(Theta)-Tomega(I)^2*Tlen^2*(COS(Phi)*SIN(Theta
)+SIN(Phi)*COS(Theta))+Fomega(I)^2*Flen^2*(COS(Theta)^2-SIN(Theta)^2)
6590      Talpha=Numbbc/(-1*Tlen^2*(COS(Phi)*COS(Theta)+SIN(Phi)*SIN(Theta)))
6600      Falpha=(Talpha*Tlen*COS(Phi)/2-Tomega(I)^2*Tlen*SIN(Phi)+Fomega(I)^2*F
len*COS(Theta))/(Tlen*SIN(Theta))
6610      Axtibia=-1*Talpha*Tlen*COS(Phi)/2+Tomega(I)^2*Tlen*SIN(Phi)/2
6620      Aytibia=-1*Accel-Talpha*SIN(Phi)*Tlen/2-Tomega(I)^2*Tlen*COS(Phi)/2
6630      Fbx=Mtibia*Axtibia
6640      Fby=Wgt/3-Mtibia*Aytibia-Mtibia*G
6650      Ftorque(I)=ABS(Ifemur*Falpha+Fbx*Flen*SIN(Theta)+Mfemur*G*Flen*COS(The
ta)/2-Fby*Flen*COS(Theta))
6660      Ttorque(I)=ABS(-1*Itibia*Talpha-Mtibia*G*Tlen*SIN(Phi)/2+Wgt*Tlen*SIN(
Phi)/2)
6670      Fhp(I)=ABS(Ftorque(I)*Fomega(I)/550)
6680      Thp(I)=ABS(Ttorque(I)*Tomega(I)/550)
6690   !
6700   !     IF ACTUATOR IS A LINEAR ONE, THEN CALCULATE THE MOMENT ARM
6710   !     IF IT IS A ROTARY ONE, THEN COMPARE TORQUE'S AND OMEGA'S NEEDED
6720   !     WITH THE ONES YOU CAN SUPPLY
6730   !
6740   Cnt=0   !CNT COUNTS THE NUMBER OF LINES PRINTED ON THE SCREEN SO THAT
6750   !        SCROLLING OF THE SCREEN CAN BE PREVENTED
6760      IF Actflag=2 THEN
6770   !
6780   !   NOW, CALCULATE THE MOMENT ARM FOR THE LINEAR ACTUATOR
6790   !
6800      MAT Trans3= IDN
6810      MAT Trans2= IDN
6820      CALL Rot(Theta,Trans3(*))
6830      MAT Newfem= Trans3*Femur
6840      MAT Newb= Trans3*B
6850      MAT Newd= Trans3*D
6860      MAT Temp2= E-Femur
6870      Temp2(4)=1
6880      MAT Temp1= Trans3*Temp2
6890      CALL Sss(Tlen,Lac,Flen,A3)
6900      A3=A3-PI/2
6910      CALL Rot(A3,Trans2(*))
6920      CALL Trans(Newfem(*),Trans2(*))
6930      MAT Newe= Trans2*Temp1
6940      CALL Eqline(A(*),Newb(*),C(*),Farm)
6950      CALL Eqline(Newd(*),Newe(*),Newfem(*),Tarm)
6960      A3=A3+PI/2
6970      CALL Rot(A3,Trans2(*))
6980      MAT Temp1= Trans3*Foot
6990      MAT Newfoot2= Trans2*Temp1
7000   !
7010   !    CAN GIVEN ACTUATOR SUPPLY POWER?
7020   !
7030      Test=ABS(Ftorque(I)/Farm)
7040      Test2=ABS(Fomega(I)*Farm)
7050      Testf=ABS(Ttorque(I)/Tarm)
7060      Testv=ABS(Tomega(I)*Tarm)
7070      IF Test>Aforce THEN
7080         IF Rflag=1 THEN
7090         PRINT CHR$(129)
7100         PRINT "FEMUR ACTUATOR IS NOT GOOD ENOUGH - FORCE NOT ENOUGH!!!"
7110         PRINT CHR$(128)
7120         Minarm=Ftorque(I)/Aforce
7130         PRINT USING "29A,DDDDD.DD";"MINIMUM MOMENT ARM NEEDED IS ";Minarm*1
```

```
2;" IN."
7140          PRINT USING "29A,DDD.DD";"PRESENTLY, HAVE MOMENT ARM = ";Farm*12;"
IN."
7150          PRINT USING "30A,DDDDDD.DD,17A,DDDDD.DD";"OR INCREASE ACTUATOR FORC
E TO ";Test;" LBF. INSTEAD OF ";Aforce;" LBF"
7160          PRINT
7170          Cnt=Cnt+7
7180          ELSE
7190          Femfflag=2
7200          END IF
7210        END IF
7220        IF Test2>Avel THEN
7230          IF Rflag=1 THEN
7240          PRINT CHR$(129)
7250          PRINT "FEMUR ACTUATOR IS NOT GOOD ENOUGH - VELOCITY NOT ENOUGH!!!"
7260          PRINT CHR$(128)
7270          Maxarm=Avel/Fomega(I)
7280          PRINT USING "49A,DDD.DD";"MAXIMUM MOMENT ARM POSSIBLE FOR THIS ACTU
ATOR IS ";Maxarm*12;" IN."
7290          PRINT USING "29A,DDD.DD";"PRESENTLY, HAVE MOMENT ARM = ";Farm*12;"
IN."
7300          PRINT USING "33A,DDD.DD,19A,DDD.DD";"OR INCREASE ACTUATOR VELOCITY
TO ";Test2*12;" IN/SEC INSTEAD OF ";Avel*12;" IN/SEC"
7310          PRINT
7320          Cnt=Cnt+7
7330          ELSE
7340          Femvflag=2
7350          END IF
7360        END IF
7370        IF Cnt>9 THEN
7380         DISP "HIT ANY KEY TO CONTINUE";
7390         ON KBD GOTO 7410
7400         GOTO 7400
7410         Cnt=0
7420         CLEAR SCREEN
7430        END IF
7440        IF Testf>Aforce THEN
7450          IF Rflag=1 THEN
7460          PRINT CHR$(129)
7470          PRINT "TIBIA ACTUATOR IS NOT GOOD ENOUGH - FORCE NOT ENOUGH!!!"
7480          PRINT CHR$(128)
7490          Minarm=Ttorque(I)/Aforce
7500          PRINT USING "29A,DDD.DD";"MINIMUM MOMENT ARM NEEDED IS ";Minarm*12;
" IN."
7510          PRINT USING "29A,DDD.DD";"PRESENTLY, HAVE MOMENT ARM = ";Tarm*12;"
IN."
7520          PRINT USING "30A,DDDDDD.DD,17A,DDD.DD";"OR INCREASE ACTUATOR FORCE
TO ";Testf;" LBF. INSTEAD OF ";Aforce;" LBF"
7530          PRINT
7540          Cnt=Cnt+7
7550          ELSE
7560          Tibfflag=2
7570          END IF
7580        END IF
7590        IF Cnt>9 THEN
7600         DISP "HIT ANY KEY TO CONTINUE";
7610         ON KBD GOTO 7630
7620         GOTO 7620
7630         Cnt=0
7640         CLEAR SCREEN
```

```
650       END IF
660       IF Testv>Avel THEN
670          IF Rflag=1 THEN
680          PRINT CHR$(129)
590          PRINT "TIBIA ACTUATOR IS NOT GOOD ENOUGH - VELOCITY NOT ENOUGH!!!"
700          PRINT CHR$(128)
710          Maxarm=Avel/Tomega(I)
720          PRINT USING "49A,DDD.DD";"MAXIMUM MOMENT ARM POSSIBLE FOR THIS ACTU
TOR IS ";Maxarm*12;" IN."
730          PRINT USING "29A,DDD.DD";"PRESENTLY, HAVE MOMENT ARM = ";Tarm*12;"
N."
740          PRINT USING "33A,DDD.DD,19A,DDD.DD";"OR INCREASE ACTUATOR VELOCITY
) ";Testv*12;" IN/SEC INSTEAD OF ";Avel*12;" IN/SEC"
750          PRINT
760          Cnt=Cnt+7
770          ELSE
780          Tibvflag=2
790          END IF
300       END IF
310    !
320    !     NOW, FOR A ROTARY ACTUATOR
330    !
340    ELSE
350       IF Ftorque(I)>Atorque THEN
360          IF Rflag=1 THEN
370          PRINT CHR$(129)
380          PRINT "FEMUR ACTUATOR IS NOT GOOD ENOUGH - TORQUE NOT ENOUGH"
390          PRINT CHR$(128)
)00          PRINT USING "15A,DDD.DD,35A,DDD.DD";"NEED TORQUE OF ";Ftorque(I);"
-LBS,BUT ACTUATOR ONLY SUPPLIES ";Atorque
)10          PRINT
)20          Cnt=Cnt+5
)30          ELSE
)40          Femfflag=2
)50          END IF
)60       END IF
)70       IF Fomega(I)>Aomega THEN
)80          IF Rflag=1 THEN
)90          PRINT CHR$(129)
)00          PRINT "FEMUR ACTUATOR IS NOT GOOD ENOUGH - OMEGA NOT ENOUGH"
)10          PRINT CHR$(128)
)20          PRINT USING "14A,DDD.DD,36A,DDD.DD";"NEED OMEGA OF ";Fomega(I);" RA
'SEC,BUT ACTUATOR ONLY SUPPLIES ";Aomega
)30          PRINT
)40          Cnt=Cnt+5
)50          ELSE
)60          Femtflag=2
)70          END IF
)80       END IF
)90       IF Ttorque(I)>Atorque THEN
.00          IF Rflag=1 THEN
.10          PRINT CHR$(129)
 20          PRINT "TIBIA ACTUATOR IS NOT GOOD ENOUGH - TORQUE NOT ENOUGH"
 30          PRINT CHR$(128)
 40          PRINT USING "15A,DDD.DD,35A,DDD.DD";"NEED TORQUE OF ";Ttorque(I);"
-LBS,BUT ACTUATOR ONLY SUPPLIES ";Atorque
 50          PRINT
 60          Cnt=Cnt+5
 70          ELSE
 80             Tibfflag=2
```

```
8190          END IF
8200        END IF
8210        IF Cnt>11 THEN
8220          DISP "HIT ANY KEY TO CONTINUE";
8230          ON KBD GOTO 8250
8240          GOTO 8240
8250          Cnt=0
8260          CLEAR SCREEN
8270        END IF
8280        IF Tomega(I)>Aomega THEN
8290           IF Rflag=1 THEN
8300           PRINT CHR$(129)
8310           PRINT "TIBIA ACTUATOR IS NOT GOOD ENOUGH - OMEGA NOT ENOUGH"
8320           PRINT CHR$(128)
8330           PRINT USING "14A,DDD.DD,36A,DDD.DD";"NEED OMEGA OF ";Tomega(I);" RA
D/SEC,BUT ACTUATOR ONLY SUPPLIES ";Aomega
8340           PRINT
8350           Cnt=Cnt+5
8360           ELSE
8370              Tibvflag=2
8380           END IF
8390        END IF
8400    END IF
8410    !
8420    !                  LOOP BACK FOR ACCELERATION DISTANCE
8430    !
8440        IF Rflag=1 THEN
8450        CALL Outdata(Jdist,Adist,Ftorque(*),Ttorque(*),Fomega(*),Tomega(*),Fhp
(*),Thp(*),@Path1,@Path2,@Path3,@Path4,@Path5,@Path6,Oflag(*),Y,Cnt,I)
8460        END IF
8470        I=I+1
8480    NEXT Y
8490    !
8500    !          WRITE LINE TO END SIMULATION FILE
8510    !
8520    IF Simflag=1 THEN
8530       Endnum=999.0
8540       OUTPUT @Pathsim;Endnum
8550       OUTPUT @Pathsim;Free
8560       OUTPUT @Pathsim;Free
8570       OUTPUT @Pathsim;Free
8580    END IF
8590    !
8600    !   NOW CALCULATE THE STROKE LENGTH FOR THE ACTUATOR
8610    !
8620    Fsl=ABS(SQR((Origb(1)-A(1))^2+(Origb(2)-A(2))^2)-SQR((Newb(1)-A(1))^2+(New
b(2)-A(2))^2))
8630    Tsl=ABS(SQR((Origd(1)-Orige(1))^2+(Origd(2)-Orige(2))^2)-SQR((Newd(1)-Newe
(1))^2+(Newd(2)-Newd(2))^2))
8640    !
8650    CLEAR SCREEN
8660    !
8670    !      IF THE MAXIMUM VALUES WERE DESIRED, THEN THIS SECTION
8680    !      DETERMINES THE MAXIMUM TORQUE AND ANGULAR VELOCITY
8690    !
8700    IF Actflag=2 THEN
8710       PRINT USING "22A,DD.DD";"FEMUR STROKE LENGTH = ";Fsl*12;" IN."
8720       PRINT USING "22A,DD.DD";"TIBIA STROKE LENGTH = ";Tsl*12;" IN."
8730       PRINT
8740    END IF
```

```
8750      IF Femfflag=2 THEN
8760         PRINT "FEMUR ACTUATOR NOT GOOD ENOUGH !!  NEED MORE TORQUE ABOUT JOI
NT !!"
8770      END IF
8780      IF Femvflag=2 THEN
8790         PRINT "FEMUR ACTUATOR NOT GOOD ENOUGH !!  NEED MORE ANGULAR VELOCITY
 ABOUT JOINT !!"
8800      END IF
8810      IF Tibfflag=2 THEN
8820         PRINT "TIBIA ACTUATOR NOT GOOD ENOUGH !!  NEED MORE TORQUE ABOUT JOI
NT !!"
8830      END IF
8840      IF Tibvflag=2 THEN
8850         PRINT "TIBIA ACTUATOR NOT GOOD ENOUGH !!  NEED MORE ANGULAR VELOCITY
 ABOUT JOINT !!"
8860      END IF
8870      PRINT
8880      MAT SEARCH Ftorque,MAX;Maxft
8890      MAT SEARCH Ttorque,MAX;Maxtt
8900      MAT SEARCH Fomega,MAX;Maxfo
8910      MAT SEARCH Tomega,MAX;Maxto
8920      MAT SEARCH Fhp,MAX;Maxfhp
8930      MAT SEARCH Thp,MAX;Maxthp
8940      PRINT USING "35A,DDDD.DD";"MAXIMUM TORQUE ABOUT THE FEMUR WAS ";Maxft;"
 FT-LBS"
8950      PRINT USING "45A,DD.DDD";"MAXIMUM ANGULAR VELOCITY ABOUT THE FEMUR WAS
";Maxfo;" RAD/SEC"
8960      PRINT USING "35A,DDDD.DD";"MAXIMUM TORQUE ABOUT THE TIBIA WAS ";Maxtt;"
 FT-LBS"
8970      PRINT USING "45A,DD.DDD";"MAXIMUM ANGULAR VELOCITY ABOUT THE TIBIA WAS
";Maxto;" RAD/SEC"
8980      PRINT USING "42A,D.DDD";"MAXIMUM HORSE POWER ABOUT THE FEMUR WAS - ";Ma
xfhp;" HP"
8990      PRINT USING "42A,D.DDD";"MAXIMUM HORSE POWER ABOUT THE TIBIA WAS - ";Ma
xthp;" HP"
9000      DISP "HIT ANY KEY TO CONTINUE";
9010      ON KBD GOTO 9030
9020      GOTO 9020
9030    !
9040    !    LOOP BACK TO THE MENU
9050    !
9060    GOTO Menu
9070    !
9080    !   STOP PROGRAM
9090    !
9100    END
9110    !
9120    !
9130    !
9140    SUB Printvar(Jdist,Adist,Wgt,G,Mfemur,Flen,Mtibia,Tlen,Angf,Angt,A(*),B(*)
,C(*),D(*),E(*),Beta,Iota,Aforce,Avel,Actflag,Actt,Acto)
9150    !
9160    !  THIS SUBROUTINE SIMPLY PRINTS THE VARIABLES THAT THE USER CAN
9170    !  CHNAGE TO THE SCREEN
9180    !
9190    PRINT "HERE ARE THE PRESET PARAMETERS:"
9200    PRINT " "
9210    PRINT "INITAL ANGLE FEMUR AND HORIZONTAL = ";Beta*180/PI;"DEG"
9220    PRINT "INITAL ANGLE FEMUR AND TIBIA = ";Iota*180/PI;"DEG"
9230    PRINT "JUMP DISTANCE = ";Jdist*12;"IN."
```

```
9240  PRINT "ACCELERATION DISTANCE = ";Adist*12;"IN."
9250  PRINT "WEIGHT OF SKITTER = ";Wgt;"LBF"
9260  PRINT "FEMUR'S WEIGHT = ";Mfemur*G;"LBF"
9270  PRINT "FEMUR'S LENGTH = ",Flen*12;"IN."
9280  PRINT "TIBIA'S WEIGHT = ";Mtibia*G;"LBF"
9290  PRINT "TIBIA'S LENGTH = ";Tlen*12;"IN."
9300  IF Actflag=2 THEN
9310       PRINT USING "37A,DDD.DD,2X,DDD.DD,2X,DDD.DD";"POINT A COORDINATES ARE
(IN INCHES): ";A(1)*12,A(2)*12,A(3)*12
9320       PRINT USING "37A,DDD.DD,2X,DDD.DD,2X,DDD.DD";"POINT B COORDINATES ARE
(IN INCHES): ";B(1)*12,B(2)*12,B(3)*12
9330       PRINT USING "37A,DDD.DD,2X,DDD.DD,2X,DDD.DD";"POINT C COORDINATES ARE
(IN INCHES): ";C(1)*12,C(2)*12,C(3)*12
9340       PRINT USING "37A,DDD.DD,2X,DDD.DD,2X,DDD.DD";"POINT D COORDINATES ARE
(IN INCHES): ";D(1)*12,D(2)*12,D(3)*12
9350       PRINT USING "37A,DDD.DD,2X,DDD.DD,2X,DDD.DD";"POINT E COORDINATES ARE
(IN INCHES): ";E(1)*12,E(2)*12,E(3)*12
9360  END IF
9370     IF Actflag=2 THEN
9380        PRINT USING "17A,DDDD.DD";"ACTUATOR FORCE = ";Aforce;" LBF"
9390        PRINT USING "20A,DDD.DD";"ACTUATOR VELOCITY = ";Avel*12;" IN/SEC"
9400     ELSE
9410        PRINT USING "18A,DDDD.DD";"ACTUATOR TORQUE = ";Actt;" FT-LBS"
9420        PRINT USING "17A,DDD.DD";"ACTUATOR OMEGA = ";Acto;" RAD/SEC"
9430     END IF
9440  !
9450  !    END SUBROUTINE
9460  !
9470  SUBEND
9480  !
9490  !
9500  !
9510  SUB Invar(Mfemur,Ifemur,Flen,Mtibia,Itibia,Tlen)
9520  !
9530  !    THIS SUBROUTINE DEFINES THE VARIABLES THAT NEED BE CALCULATED
9540  !    FROM OTHER INPUT VARIABLES
9550  !
9560  Ifemur=.0252+Mfemur*(Flen/2)^2
9570  Itibia=.01495+Mtibia*(Tlen/2)^2
9580  !
9590  !    END SUBROUTINE
9600  !
9610  SUBEND
9620  !
9630  !
9640  !
9650  SUB Outdata(Jdist,Adist,Ftorque(*),Ttorque(*),Fomega(*),Tomega(*),Fhp(*),T
hp(*),@Path1,@Path2,@Path3,@Path4,@Path5,@Path6,Oflag(*),Y,Cnt,I)
9660  !
9670  !   THIS SUBROUTINE OUTPUTS THE DATA
9680  !
9690  Temp=0
9700  FOR J=1 TO 6
9710     IF Oflag(J)=0 THEN Temp=1
9720  NEXT J
9730  IF Cnt>13 THEN
9740     DISP "HIT ANY KEY TO CONTINUE";
9750     ON KBD GOTO 9770
9760     GOTO 9760
9770     Cnt=0
```

```
9780      CLEAR SCREEN
9790   END IF
9800   IF Temp=1 THEN
9810      PRINT USING "DDD.D,32A";Y/(Adist*12)*100;" % THROUGH ACCELERATION DISTA
NCE"
9820      PRINT
9830      PRINT
9840      Cnt=Cnt+3
9850   END IF
9860   IF Cnt>14 THEN
9870      DISP "HIT ANY KEY TO CONTINUE";
9880      ON KBD GOTO 9900
9890      GOTO 9890
9900      Cnt=0
9910      CLEAR SCREEN
9920   END IF
9930   IF Temp=1 THEN
9940      PRINT USING "16A,DDD.DD";"JUMP DISTANCE = ";Jdist*12;" IN."
9950      PRINT USING "24A,DDD.DD";"ACCELERATION DISTANCE = ";Adist*12;" IN"
9960      Cnt=Cnt+2
9970   END IF
9980   IF Oflag(1)=1 THEN
9990      OUTPUT @Path1;Jdist*12,Ftorque(I)
10000  ELSE
10010     IF Cnt>15 THEN
10020        DISP "HIT ANY KEY TO CONTINUE";
10030        ON KBD GOTO 10050
10040        GOTO 10040
10050        Cnt=0
10060        CLEAR SCREEN
10070     END IF
10080     PRINT USING "15A,DDDDDD.DD";"FEMUR TORQUE = ";Ftorque(I);" FT-LB"
10090     Cnt=Cnt+1
10100  END IF
10110  IF Oflag(2)=1 THEN
10120     OUTPUT @Path2;Jdist*12,Fomega(I)
10130  ELSE
10140     IF Cnt>15 THEN
10150        DISP "HIT ANY KEY TO CONTINUE";
10160        ON KBD GOTO 10180
10170        GOTO 10170
10180        Cnt=0
10190        CLEAR SCREEN
10200     END IF
10210     PRINT USING "14A,DDDD.DD";"FEMUR OMEGA = ";Fomega(I);" RAD/SEC"
10220     Cnt=Cnt+1
10230  END IF
10240  IF Oflag(3)=1 THEN
10250     OUTPUT @Path3;Jdist*12,Fhp(I)
10260  ELSE
10270     IF Cnt>15 THEN
10280        DISP "HIT ANY KEY TO CONTINUE";
10290        ON KBD GOTO 10310
10300        GOTO 10300
10310        Cnt=0
10320        CLEAR SCREEN
10330     END IF
10340     PRINT USING "11A,DDDD.DD";"FEMUR HP = ";Fhp(I);" HP"
10350     Cnt=Cnt+1
10360  END IF
```

```
10370 IF Oflag(4)=1 THEN
10380    OUTPUT @Path4;Jdist*12,Ttorque(I)
10390 ELSE
10400    IF Cnt>15 THEN
10410       DISP "HIT ANY KEY TO CONTINUE";
10420       ON KBD GOTO 10440
10430       GOTO 10430
10440       Cnt=0
10450       CLEAR SCREEN
10460    END IF
10470    PRINT USING "15A,DDDD.DDDD";"TIBIA TORQUE = ";Ttorque(I);" FT-LB"
10480    Cnt=Cnt+1
10490 END IF
10500 IF Oflag(5)=1 THEN
10510    OUTPUT @Path5;Jdist*12,Tomega(I)
10520 ELSE
10530    IF Cnt>15 THEN
10540       DISP "HIT ANY KEY TO CONTINUE";
10550       ON KBD GOTO 10570
10560       GOTO 10560
10570       Cnt=0
10580       CLEAR SCREEN
10590    END IF
10600    PRINT USING "14A,DDDD.DDDD";"TIBIA OMEGA = ";Tomega(I);" RAD/SEC"
10610    Cnt=Cnt+1
10620 END IF
10630 IF Oflag(6)=1 THEN
10640    OUTPUT @Path6;Jdist*12,Thp(I)
10650 ELSE
10660    IF Cnt>15 THEN
10670       DISP "HIT ANY KEY TO CONTINUE";
10680       ON KBD GOTO 10700
10690       GOTO 10690
10700       Cnt=0
10710       CLEAR SCREEN
10720    END IF
10730    PRINT USING "11A,DDDD.DDDD";"TIBIA HP = ";Thp(I);" HP"
10740    Cnt=Cnt+1
10750 END IF
10760 !
10770 IF Temp=1 THEN
10780    DISP "HIT ANY KEY TO CONTINUE";
10790    ON KBD GOTO 10810
10800    GOTO 10800
10810    CLEAR SCREEN
10820 END IF
10830 !
10840 !    END SUBROUTINE
10850 !
10860 SUBEND
10870 !
10880 !
10890 !
10900 SUB Rot(Angle,Matrix(*))
10910 !
10920 !   THIS SUBROUTINE FORMS THE TRANSFORMATION MATRIX FOR A ROTATION
10930 !   ABOUT THE Z-AXIS.  THE MATRIX IS A 4x4.
.0940 !
.0950 OPTION BASE 1
.0960 Matrix(1,1)=COS(Angle)
```

```
10970 Matrix(2,2)=COS(Angle)
10980 Matrix(1,2)=-1*SIN(Angle)
10990 Matrix(2,1)=SIN(Angle)
11000 FOR I=1 TO 4
11010    FOR J=1 TO 4
11020       IF ABS(Matrix(I,J))<.0000001 THEN Matrix(I,J)=0.
11030    NEXT J
11040 NEXT I
11050 !
11060 !    END SUBROUTINE
11070 !
11080 SUBEND
11090 !
11100 !
11110 !
11120 SUB Trans(Dist(*),Matrix(*))
11130 !
11140 !    THIS FORMS A TRANSLATION MATRIX THAT OFFSETS A ROTATION MATRIX
11150 !
11160 OPTION BASE 1
11170 Matrix(1,4)=Dist(1)
11180 Matrix(2,4)=Dist(2)
11190 Matrix(3,4)=Dist(3)
11200 !
11210 !    END SUBROUTINE
11220 !
11230 SUBEND
11240 SUB Findfoot(Beta,Iota,Femur(*),Foot(*),Newfoot(*),Newfem(*))
11250 !
11260 !   THIS SUBROUTINE WILL FIND THE FOOT POSITION GIVEN THE ANGLES
11270 !   BETWEEN THE FEMUR & THE HORIZONTAL & THE ANGLE BETWEEN THE FEMUR
11280 !   AND THE TIBIA
11290 !
11300 OPTION BASE 1
11310 DIM Trans1(4,4),Trans2(4,4),Templ(4)
11320 MAT Trans1= IDN
11330 MAT Trans2= IDN
11340 CALL Rot(Beta,Trans1(*))
11350 MAT Newfem= Trans1*Femur
11360 MAT Templ= Trans1*Foot
11370 CALL Rot(Iota,Trans2(*))
11380 CALL Trans(Newfem(*),Trans2(*))
11390 MAT Newfoot= Trans2*Templ
11400 !
11410 !    END SUBROUTINE
11420 !
11430 SUBEND
11440 !
11450 !
11460 !
11470 SUB Sss(S1,S2,S3,A3)
11480 !
11490 !    THIS SUBROUTINE DETERMINES ANGLE 3 FOR A TRIANGLE WHERE YOU
11500 !    KNOW THE 3 SIDES
11510 !
11520 P=(S1+S2+S3)/2
11530 Temp=SQR(P*(P-S2)/(S1*S3))
11540 IF ABS(Temp)>1.0 THEN
11550    PRINT "IMPOSSIBLE POSITION TO REACH!!!"
11560 ELSE
```

```
11570     A3=2*ACS(Temp)
11580 END IF
11590 !
11600 !   END SUBROUTINE
11610 !
1620 SUBEND
1630 !
1640 !
1650 !
1660 SUB Eqline(J(*),K(*),L(*),Marm)
1670 !
1680 !    THIS SUBROUTINE DETERMINES THE MOMENT ARM
1690 !
1700      OPTION BASE 1
1710      DIM R(4)
1720      M=(J(2)-K(2))/(J(1)-K(1))
1730      B1=J(2)-M*J(1)
1740      B2=L(2)+L(1)/M
1750      R(1)=(B2-B1)/(M+1/M)
1760      R(2)=M*R(1)+B1
1770      Marm=SQR((R(1)-L(1))^2+(R(2)-L(2))^2)
1780 !
1790 !    END SUBROUTINE
1800 !
1810 SUBEND
```

```
10    REM ****************************************************************
20    !
30    !      THIS PROGRAM WILL DETERMINE THE TORQUE NEEDED TO LEAN
40    !      SKITTER THROUGH A DESIRED NUMBER OF DEGREES
50    !
60    !      THE NECESSERY TORQUE AND ANGULAR VELOCITY AT THE HIP
70    !
80    !      PROGRAM WRITTEN BY:
90    !      BRICE MACLAREN
100   !      GARY MCMURRAY
110   !
120   REM ****************************************************************
130   OPTION BASE 1
140   RAD
150   DIM A(9,10),B(9),X(9)
160   !
170   !      THIS DATA DEFINES THE SYSTEM MATRIX THAT
180   !      MUST BE SOLVED IN THE DYNAMICS TO CALCULATE THE
190   !      INPUT TORQUE.
200   !
210   DATA 0,0,-1,0,1,0,0,0,0,0
220   DATA 0,0,0,-1,0,1,0,0,0,0
230   DATA 0,0,1,-1,0,0,0,0,0,0
240   DATA -1,0,1,0,0,0,0,0,0,0
250   DATA 0,-1,0,1,0,0,0,0,0,0
260   DATA 1,-1,0,0,0,0,0,0,1.0
270   DATA 1,0,0,0,0,0,1,0,0,0
280   DATA 0,1,0,0,0,0,0,1,0,0
290   DATA -1,-1,0,0,0,0,0,0,0,0
300   N=9
310   !
320   !      USER PROPMTED FOR VARIABLES
330   !
340   DISP "INPUT ANGLE OF ROTATION IN DEGREES";
350   INPUT Rotangle
360   Rotangle=Rotangle*PI/180
370   DISP "INPUT ACCELERATION ANGLE IN DEGREES";
380   INPUT Aangle
390   Aangle=Aangle*PI/180
400   !
410   !      DEFINE LINK LENGTHES OF 4-BAR
420   !
430   R=SQR(((9.1602+15.194)/12)^2+(20/12)^2)
440   R1=44.35
450   R2=R*12
460   R3=20
470   R4=20
480   Tlen=20/12
490   Flen=20/12
500   L=Flen
510   G=32.2
520   Mfemur=3/G
530   Mtibia=2/G
540   Wgt=100
550   Mbody=85/G
560   !
570   !      DEFINE INERTIA'S
580   !
590   CALL Invar(Mfemur,Ifemur,Flen,Mtibia,Itibia,Tlen,R,Mbody,Ibody)
```

```
600   !
610   !    CALCULATE NECESSSERY ANGULAR VELOCITES AND ACCELERATION
620   !
630   Phi=ASN(20/(R*12))
640   H=R*SIN(Rotangle+Phi+Aangle)-R*SIN(Phi+Aangle)
650   Finalomegaad=-1*SQR(2*Wgt*H/Ibody)
660   Alphaad=-1*Finalomegaad^2/(2*Aangle)
670   Totaltime=ABS(Finalomegaad/Alphaad)
680   !
690   !      DEFINE INITIAL ANGLES
700   !
710   Theta4=PI-ASN(20/(R*12))
720   PRINT "INITIAL THETA4 =";Theta4*180/PI
730   CALL Findthetas(R1,R2,R3,R4,Theta2,Theta3,Theta4)
740   Inittheta4=Theta4
750   Inittheta3=Theta3
760   Inittheta2=Theta2
770   Finalangle=Theta4-Rotangle-Aangle
780   !
790   !      BEGIN LOOPING OVER THETA4
800   !
810   Deltatheta=Aangle/10
820   FOR Temp=(Inittheta4-Deltatheta) TO (Inittheta4-Aangle) STEP -1*Deltatheta
830       Theta4=Temp
840   !
850   !      UPDATE ANGLES
860   !
870       CALL Findthetas(R1,R2,R3,R4,Theta2,Theta3,Theta4)
880   !
890   !      CALCULATE TIME
900   !
910   T=SQR(ABS((Temp-Inittheta4)*2/Alphaad))
920   !
930   !      CALCULATE ANGULAR VELOCITIES
940   !
950       Omegaad=Alphaad*T
960       Omegaab=R*Omegaad*SIN(Theta3-Theta4)/(L*SIN(Theta3-Theta2))
970       Omegabc=(Omegaad*R*SIN(Theta4)-L*Omegaab*SIN(Theta2))/(L*SIN(Theta3))
980   !
990   !      CALCULATE ANGULAR ACCELERATIONS
1000  !
1010      Num1=R*Alphaad*SIN(Theta3-Theta4)-R*(Omegaad^2)*COS(Theta4-Theta3)+L*(
Omegaab^2)*COS(Theta2-Theta3)+L*(Omegabc^2)
1020      Alphaab=Num1/(L*SIN(Theta3-Theta2))
1030      Num2=Alphaad*R*SIN(Theta4)+Omegaad^2*R*COS(Theta4)-Omegabc^2*L*COS(The
ta3)-Alphaab*L*SIN(Theta2)-Omegaab^2*L*COS(Theta2)
1040      Alphabc=Num2/(L*SIN(Theta3))
1050  !
1060  !      CALCULATE CENTER OF MASSES ACCELERATIONS
1070  !
1080      Accelbx=-1*Alphabc*L*SIN(Theta3)-Omegabc^2*L*COS(Theta3)
1090      Accelby=Alphabc*L*COS(Theta3)-Omegabc^2*L*SIN(Theta3)
1100      Accelax=-1*Alphaad*R*SIN(Theta4)-Omegaad^2*R*COS(Theta4)
1110      Accelay=Alphaad*R*COS(Theta4)-Omegaad^2*R*SIN(Theta4)
1120      Acceltibx=Accelbx/2
1130      Acceltiby=Accelby/2
1140      Accelfemx=Accelbx-Alphaab*L*SIN(Theta2)/2-Omegaab^2*L*COS(Theta2)/2
1150      Accelfemy=Accelby+Alphaab*L*COS(Theta2)/2-Omegaab^2*L*SIN(Theta2)/2
1160      Accelbodx=Accelax/2
1170      Accelbody=Accelay/2
```

```
1180 !
1190 NEXT Temp
1200 !
1210 READ A(*)
1220 A(3,3)=L*ABS(SIN(Theta3))
1230 A(3,4)=-1*L*ABS(COS(Theta3))
1240 A(6,1)=L*ABS(SIN(Theta2))
1250 A(6,2)=-1*L*AP3(COS(Theta2))
1260 A(9,1)=-1*ABS(R*SIN(Theta4))
1270 A(9,2)=-1*ABS(R*COS(Theta4))
1280 B(1)=Mtibia*Acceltibx
1290 B(2)=Mtibia*Acceltiby+Mtibia*G
1300 B(3)=Itibia*Alphabc+Mtibia*G*Tlen*COS(Theta3)/2
1310 B(4)=Mfemur*Accelfemx
1320 B(5)=Mfemur*Accelfemy+Mfemur*G
1330 B(6)=Ifemur*Alphaab+Mfemur*G*Flen*COS(Theta2)/2
1340 B(7)=Mbody*Accelbodx
1350 B(8)=Mbody*Accelbody+Mbody*G
1360 B(9)=Ibody*Alphaad-Mbody*R*COS(Theta4)/2
1370 !
1380 CALL Gauss(N,A(*),B(*),X(*))
1390 !
1400 Power=X(9)*Omegaab
1410 Hp=Power/550
1420 !
1430 !       STOP PROGRAM
1440 !
1450 END
1460 !
1470 !
1480           SUB Gauss(N,A(*),B(*),X(*))
1490 !
1500 !       THIS SUBROUTINE PERFORMS GAUSSIAN ELIMINATION
1510 !
1520 OPTION BASE 1
1530 !
1540 !       FIRST, REPLACE THE LAST COLUMN OF THE A MATRIX WITH THE
1550 !       B MATRIX
1560 !
1570 FOR I=1 TO N
1580    A(I,10)=B(I)
1590 NEXT I
1600 !
1610 FOR K=1 TO N-1
1620      Jj=K
1630      Big=ABS(A(K,K))
1640      Temp2=K+1
1650      FOR I=Temp2 TO N
1660         Ab=ABS(A(I,K))
1670         IF Big-Ab<0 THEN
1680            Big=Ab
1690            Jj=I
1700         END IF
1710      NEXT I
1720      IF Jj-K<>0 THEN
1730         FOR J=K TO N+1
1740            Temp=A(Jj,J)
1750            A(Jj,J)=A(K,J)
1760            A(K,J)=Temp
1770         NEXT J
```

```
1780      END IF
1790      FOR I=Temp2 TO N
1800          Quot=A(I,K)/A(K,K)
1810          FOR J=Temp2 TO N+1
1820              A(I,J)=A(I,J)-Quot*A(K,J)
1830          NEXT J
1840      NEXT I
1850      FOR I=Temp2 TO N
1860          A(I,K)=0.
1870      NEXT I
1880  NEXT K
1890  X(N)=A(N,N+1)/A(N,N)
1900  FOR Nn=1 TO N-1
1910      Sum1=0
1920      I=N-Nn
1930      Ip1=I+1
1940      FOR J=Ip1 TO N
1950          Sum1=Sum1+A(I,J)*X(J)
1960      NEXT J
1970      X(I)=(A(I,N+1)-Sum1)/A(I,I)
1980  NEXT Nn
1990  SUBEND
2000  !
2010  !
2020  !
2030          SUB Printmat(Array(*))
2040  !
2050  !       THIS SUBROUTINE PRINTS OUT THE INPUT MATRIX
2060  !
2070          OPTION BASE 1
2080          FOR Row=BASE(Array,1) TO SIZE(Array,1)+BASE(Array,1)-1
2090            FOR Column=BASE(Array,2) TO SIZE(Array,2)+BASE(Array,2)-2
2100              PRINT USING "DDD.DD,XX,#";Array(Row,Column)
2110            NEXT Column
2120            PRINT
2130          NEXT Row
2140          SUBEND
2150  !
2160  !
2170  SUB Invar(Mfemur,Ifemur,Flen,Mtibia,Itibia,Tlen,R,Mbody,Ibody)
2180  !
2190  !       THIS SUBROUTINE DETERMINES THE INERTIA FOR THE VARIOUS MEMBERS
2200  !       ABOUT THEIR AXES
2210  !
2220  Ifemur=.0252+Mfemur*(Flen/2)^2
2230  Itibia=.01495+Mtibia*(Tlen/2)^2
2240  !
2250  !     IBODY IS DETERMINED ASSUMING THE BODY OF SKITTER IS SPHERICAL
2260  !     AND THAT THE LEGS DO NOT CONTRIBUTE SIGNIFICANTLY TO THE INERTIA
2270  !
2280  Ibody=2*Mbody*(9.16/12)^2/5+Mbody*((15.194/12)^2+(20.9817/12)^2)
2290  !
2300  !    RETURN TO PROGRAM
2310  !
2320  SUBEND
2330  !
2340  !
2350      SUB Findthetas(R1,R2,R3,R4,Theta2,Theta3,Theta4)
2360  !
2370  !       THIS SUBROUTINE FINDS THE OTHER JOINT ANGLES GIVEN ONE ANGLE
```

```
2380  !        FOR A 4-BAR LINK
2390  !
2400  L=SQR(R1^2+R2^2-2*R1*R2*COS(PI-Theta4))
2410  Beta=ACS((R1^2+L^2-R2^2)/(2*R1*L))
2420  Psi=ACS((R3^2+L^2-R4^2)/(2*R3*L))
2430  Lamda=ACS((R4^2+L^2-R3^2)/(2*R4*L))
2440  IF (PI-Theta4)>=0 AND (PI-Theta4)<=PI THEN
2450     Theta2=-1*(Psi-Beta)
2460     Theta3=PI-(PI-Lamda-Beta)
2470  ELSE
2480     Theta2=-1*(Psi+Beta)
2490     Theta3=PI-(PI-Lamda+Beta)
2500   END IF
2510   !
2520   !      RETURN TO PROGRAM
2530   !
2540   SUBEND
```