Dynamic Equations

1. 27 simultaneous equations of motion based on FBD
2. Torque summation about arbitrary ground point to remove virtual inertial forces
3. Solved using matrices to represent torque (8) and limb force (16) equations
4. Assumes knowledge of forces acting on foot
5. Assumes pure torque applied at joints
6. Verified using static poses
7. Foot forces approximated for foot swing, drag, and impulse
8. –FBDs and diagrams-
9. Results verified with ‘common sense’ and literature checks
10. **Results and conclusions**

Motion Study

1. Determine maximum mounting position based on geometry
2. Calculating minimum and maximum leg extension
3. Determine maximum stroke length from difference in extension
4. Determine minimum piston compression from specifications
5. Adjust mounting and stroke length to optimize gait
6. Ensure pistons are usable for future iterations
7. **Results and conclusions**

Pneumatic/Compressor Specifications

1. Maximum and average torque converted to pressures and flow rates
2. Moment arm and desired torque calculates maximum required piston force
3. Piston bore diameter and stroke selected based on cost and geometry
4. Maximum air pressure calculated from moment arm and piston area
5. Average flow rate calculated from stroke length
6. Compressor and air storage selected based on average flow rate and maximum pressure
7. Piston selected based on bore size, stroke length, and maximum pressure/force output
8. **Results and conclusions**

FEA of Legs

1. Finite element analysis based on worst case scenario of leg joints seizing up during maximum forces applied
2. 2D analysis used due to simple 2D planar geometry of joint and fewer vertices
3. Automatically generated ANSYS mesh using primarily quad elements due to increased accuracy over CST
4. Manual mesh refinement in areas with structural error – generally region where forces were applied
5. **Results and conclusions**

Dynamics

To determine the internal forces felt in the joints and the required torques for locomotion a dynamic mathematical model of the robot was constructed. From the specifications the robot was known to have four legs with two links each all attached to a main chassis. Summing the force and torque around each link of the robot resulted in 27 simultaneous equations used to calculate the state of the robot. To simplify the calculations it was assumed that the foot forces were known and that the robot exhibited purely planar motion. A diagram of the mathematical notation and free body diagrams are shown in **appendix/figure X**.

After summing the forces and torques for the robot joints the equations were split into two systems of equations. Eight equations were put into matrix form to solve for each of the hip and knee torques required at each joint, and sixteen equations were put into matrix form to solve for the reactionary forces in the hip and knee joints in the x and y direction. The sum of the force and torque equations about the body were not used in these calculations because the body’s state can be calculated entirely based on the hip reaction forces and torques. The 24 developed equations were all in terms of the kinematic and inertial state of the robot.

An initial Solidworks model of the robot was developed to determine the inertial state of the robot. The geometry of the robot was based off of the final design chosen after the fall phase of the project, and iterative changes were made based off of dynamic simulations, mechanical failure analyses, and motion studies. **A diagram of the robot/leg/stuff is shown in appendix X, Figure Y.**

With a known geometry for the legs a walking simulation was run to determine the kinematic state of the robot. The simulation was used to find the required angular accelerations of each joint to satisfy the minimum speed specification of 0.5 m/s. A half ellipse was selected as the foot path to test due to the ease of changing the step length and height as well as its similarity to the reversed Pear-Shaped Quadratic, which closely resembles paths found in animal steps. **An image of the step simulation is shown in XYZ.**

After calculating the inertial and kinematic states of the robot for an elliptical step gait was selected for the dynamic simulation. The three gaits to be implemented on the robot are the drag, creep, and walk gaits. The drag gait is the simplest and involves one leg moving and dragging the rest of the robot along the ground. This gait is the simplest to implement and the most stable due to only a single leg actuating. Dragging is the least efficient gait.

The creep gait involves leaning the robot forward then actuating one leg at a time to center the body over the legs. The creep gait is more efficient than the drag because extra energy is not required to overcome the friction of dragging the robot. The creep gait is still relatively stable and simple compared to the drag, but there is extra complexity from leaning the body forward and actuating all four legs in series.

The walk gait involves actuating all four legs at once. Two diagonal legs move forward while the opposite push backward, moving the robot forward. Walking is the most complicated gait that will be attempted due to actuating all four legs simultaneously. It is also the fastest gait because the robot is constantly moving forward. **A diagram of actuation for each gait is given in APPENDIX X section Y.**

The inertial and kinematic data was then used in the dynamic simulation to calculate the maximum torques required on the joints as well as the internal forces felt by the joints. The initial simulated gait used was the drag gait due to the simplicity of the gait to simulate and the extra forces felt from dragging the robot chassis. It was assumed that the three static legs were completely vertical and the feet felt a third of the total robot weight as force in the Y direction, and no force in the X. These simplifying assumptions are mostly accurate, and the forces felt by the stationary legs were so incredibly small in comparison to the swinging leg that the error was negligible.

The torques and forces were calculated for every instant of a 0.5 m drag step lasting one second. The states at the maximum torque and maximum total force were saved and used to determine cylinder specifications and mechanical stress on the leg. Because the simulation assumed pure torque applied to each joint intermittent calculations were required based on the position of the legs and piston attachment points to calculate the equivalent moment arm, and therefore force exerted by the piston on the leg. The maximum forces and torques were found to be during the swing phase of the step, which is intuitive because the legs are undergoing rapid acceleration requiring large inertial forces to compensate.

Appendix Items



Figure : Kinematic model animation of a single leg following a semi ellipse path

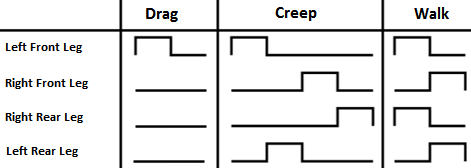


Figure : Leg actuation pattern of different walking gaits