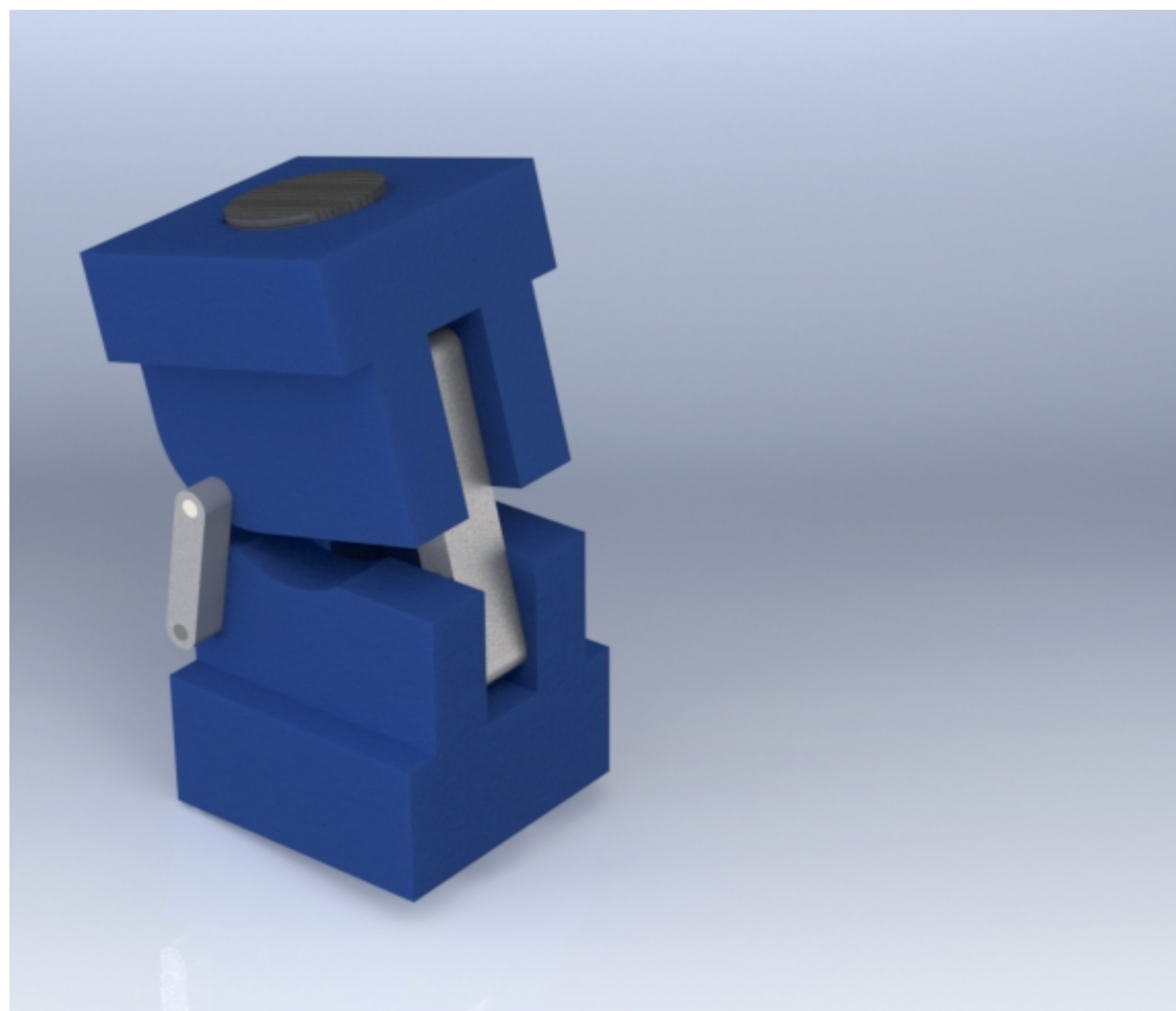


Designing a 3D-printed prosthetic knee

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Introduction

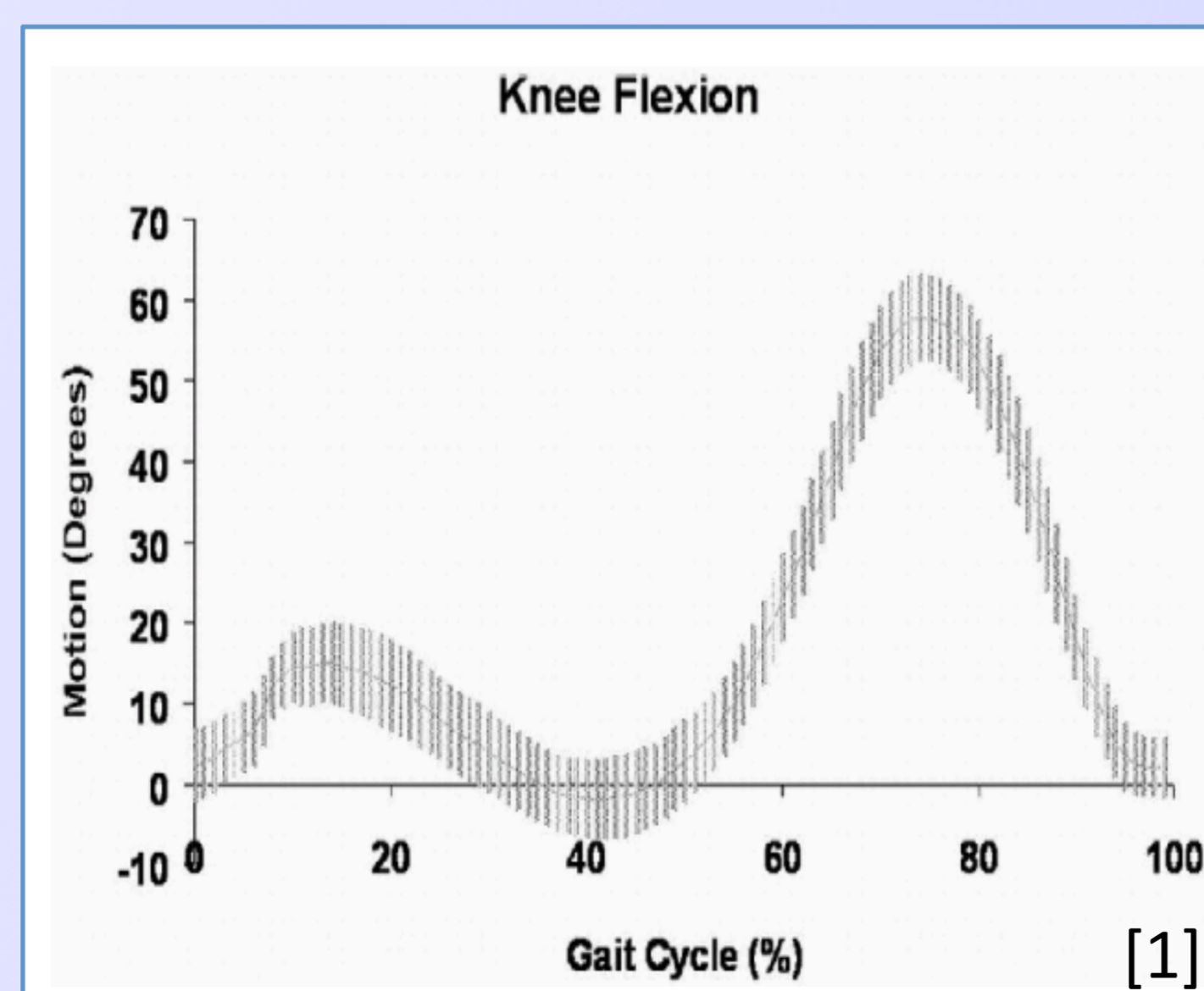
The design of high-quality prostheses is both costly and time consuming. Due to the lack of access to prosthetic clinics for lower-limb amputees in developing countries, it is desirable to formulate a method of designing functional prosthetic knees at a relatively low cost.

While many factors must be considered to accurately analyze the performance of a prosthetic knee, this project examines the feasibility of a 3D-printed knee with respect to its stability. A finite element analysis of the 3D-printed knee is also used to identify the regions of the knee most susceptible to failure.

Main Goals

Design a prosthetic knee that:

- Can be rapidly produced at a low-cost
 - Can be easily customized
- Is relatively stable (as a mechanically-passive knee)
- Provides its user with an acceptable range of motion (see image on right)



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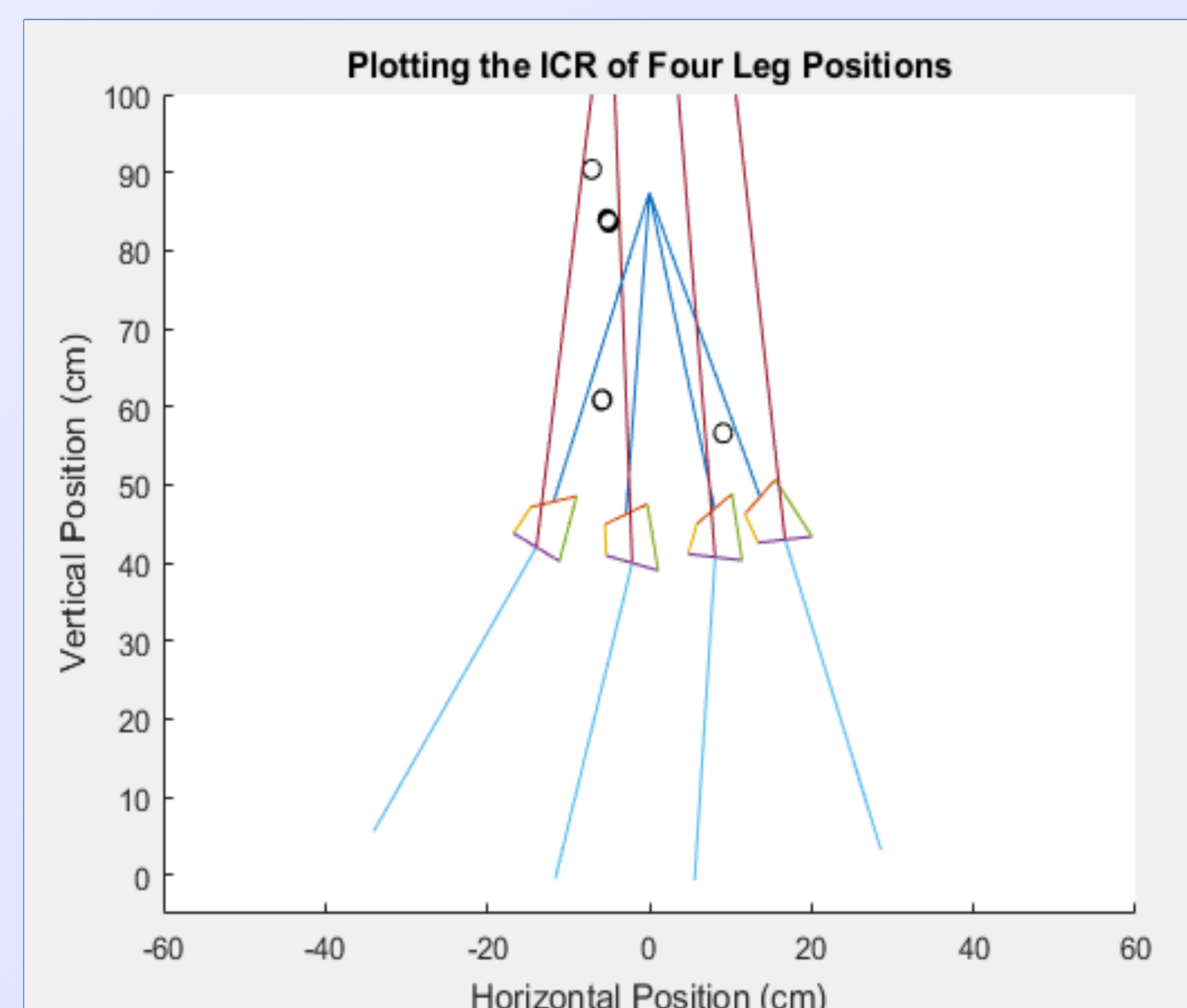
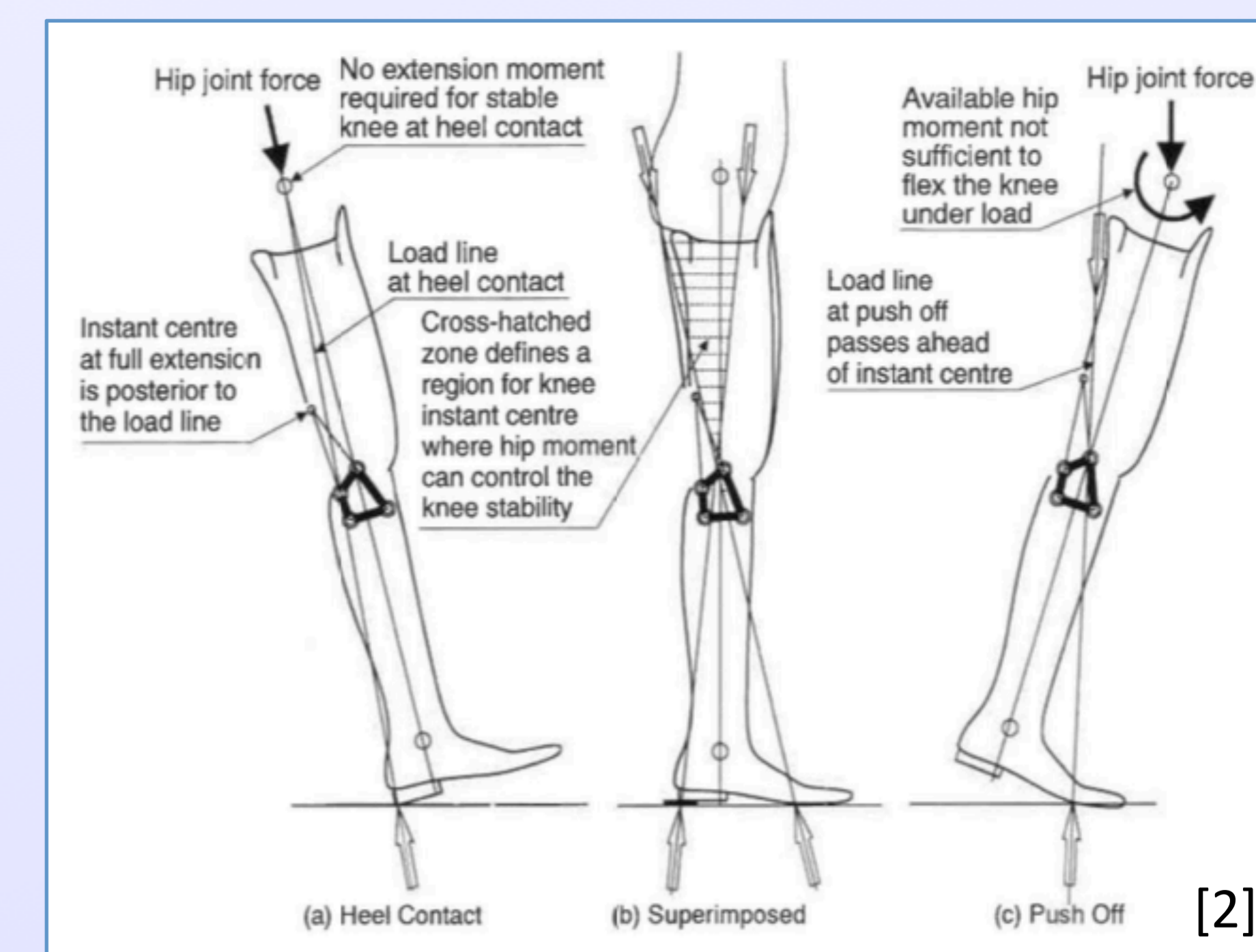


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Methodology

The functionality of the knee is directly related to the lengths of the links that make up the four-bar knee mechanism. Using SolidWorks and MATLAB in conjunction with experimental gait data, the link lengths of this knee mechanism were optimized in order to provide knee stability, particularly during initial heel contact.



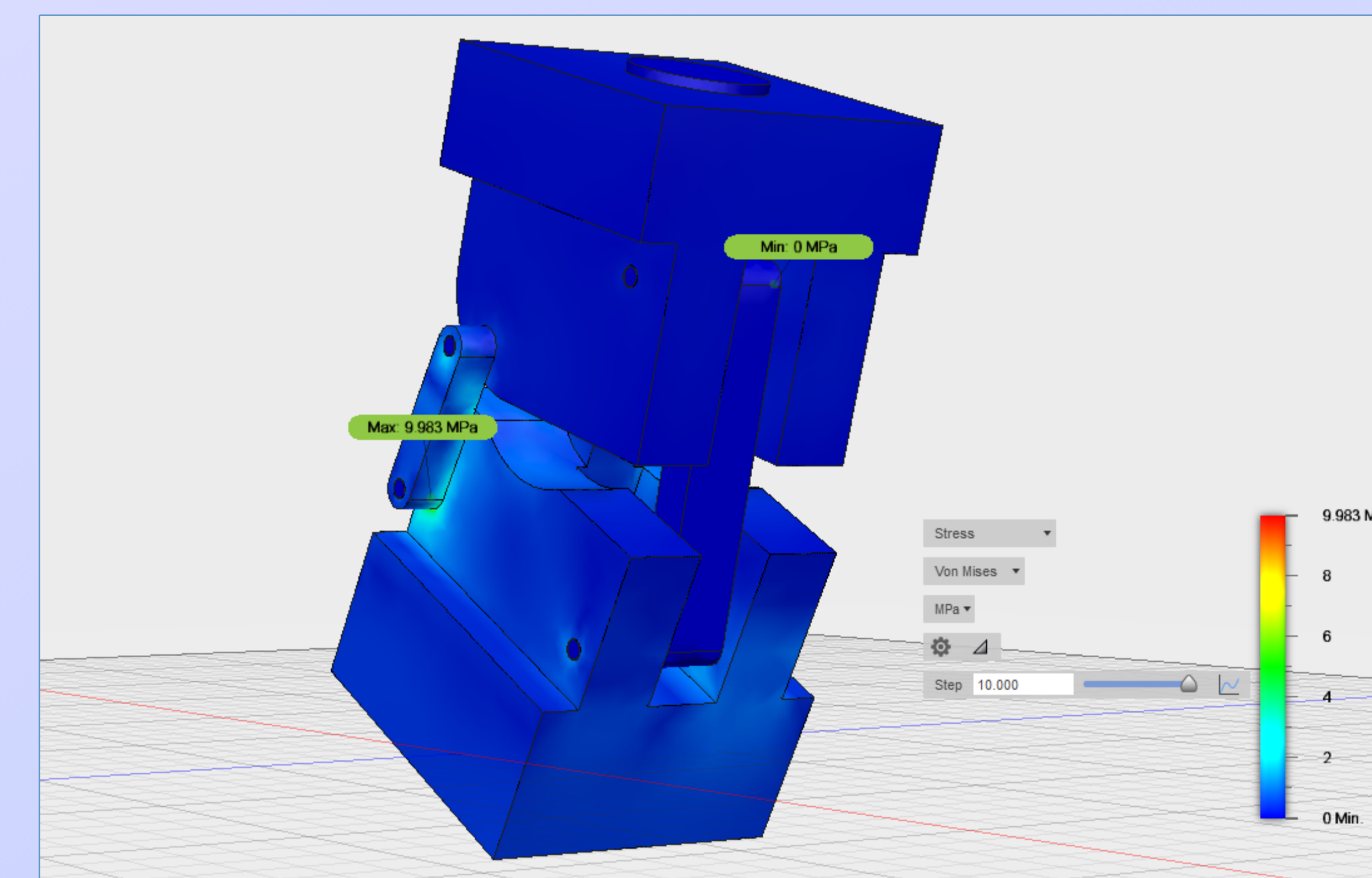
Results - ICR

Unlike a simple hinge joint, the point about which a knee joint rotates changes as an individual ambulates. This changing center of rotation, or *Instantaneous Center of Rotation* (ICR), is one of the primary determinants of knee stability. When designing a four-bar mechanism knee, it is important that the ICR of each knee remains posterior to the load line as its respective limb contacts the ground (see above image).

The image to the left shows the four-bar knee mechanism and its ICR (outlined by a circle) in four different positions. If the ICR is located posterior to (in this image, to the left of) the load line (in red), the knee can be considered stable.

Results (FEA)

Finite Element Analysis (FEA) is a popular tool used to visualize the different stresses that will arise in an object upon being subjected to applied forces. If this knee prosthesis is to be manufactured using 3D printers, it is necessary to ensure it can withstand the forces that will be applied to it during normal walking conditions. To the right is a visual representation of the stresses that are present in this knee prosthesis when it is subjected to the forces that arise upon heel contact.



Conclusion

Upon initial heel contact, the ICR of the knee is located well behind the load line. Stability during heel contact is critical to maintaining normal walking kinematics. As the knee flexes after initial heel contact, the load line is located slightly anterior to the load line, but within a reasonable range to still offer stability. Following this, the ICR is located well behind the load line, therefore continuing to provide stability to the user. Finally, shortly before toe-off, it is found that the ICR is not located in a position that would offer the user stability, yet this frame is the least important as the user's weight will already have started transferring to the other limb by this time.

The finite element analysis of the prosthetic knee shows that the connections between components would fail first given an excessive load. When subjected to the forces that arise during normal gait conditions, however, this simulation shows that the maximum stress in this knee mechanism is 9.983 MPa. Since the yield strength of ABS, a commonly-used 3D-printable material, is 34 MPa [3], it is reasonable to conclude that the knee is capable of supporting its user's weight.

Future Work

- Use the results of the FEA to minimize the overall size of the prosthesis without hindering its functionality.
- Adjust the link lengths of four-bar knee mechanism to create a design that offers more support.
- Mechanically test the performance of the knee prosthesis.

[1] Rose, Jessica, and James G. Gamble. *Human Walking*. Philadelphia: Lippincott Williams & Wilkins, 2006. Print.

[2] Radcliffe, CW. *Four-bar linkage prosthetic knee mechanisms: kinematics, alignment and prescription criteria*. *Prosthetics and Orthotics Int.* 1994; 18: 168.

[3] "Acrylonitrile Butadiene Styrene (ABS) Typical Properties." *Prospector*. UL, 2017. Web. 07 Mar. 2017.