After winnowing down the motor types we can use to DC and stepper, we needed to perform a technical analysis on quantitative requirements for the hard-constraint system. In order to choose the correct motor, a power rating had to be specified. This power rating depends on the torque the motor must be able to provide and the speed the motor must be able to operate at.

**Torque:**

According to last year’s group, the torque the motor needed to supply was 7.5 Nm: “After researching various motor and motor controller combinations, the Maxon EC-Max 25W Brushless DC motor (Figure 47) matched with a 66:1 gearbox was selected. It was selected because it provided sufficient nominal torque, acceleration, and maximum velocity for the experimentally derived expected moment of 7.5 Nm (50 N force at 15cm) discussed in Section 3.” We preformed our own analysis on the newer linkage design and came up with a substantially smaller value of around 1 Nm. This result if most likely due to the fact that the newer linkage design reduces the amount of force needed to be applied at the hard constraint, due to the action of friction on the vertical rod and the partial load-carrying of the rod and linkages. The analysis was preformed with the following linkage design:

L2

Load

Θ1

Θ2

Load

L1

A spreadsheet was made to compute the value of the hard-constraint force that is need at Link 1 (L1) with varying θs. Knowing the moment arm o the motor at that point, we can figure out the motor torque required. This spreadsheet proved to be very useful, as we could easily change the link lengths, the load, and the motor arm and immediately get the corresponding data. With link lengths of L1 = 15 cm and L2 = 10 cm, a load of 15 kg (hand force and the weight of the system), and a motor moment arm of 1 cm, we got back the following torque-theta curve:

\****θ1 (deg) is does not go below 48 degrees due to the different link lengths***

With the same load and moment values, but equal link length of 7 cm, the following curve is obtained (with a max torque of 1.5 Nm). Since the analysis of an optimized size for the workspace has yielded a result of equal linkage length of 7 cm, the maximum torque the motor must be able to counter is confirmed to be 1.5 Nm. The spreadsheet with all the values of thetas, distances and forces can be found in Appendix.

**Speed:**

An excel spreadsheet was made for the analysis of the change in link angles for movements of 0.5mm (up or down) of the tool attached to link 5. The link design figure used for the torque vs. theta relationship also illustrates the different links and how they move relative to the load. When the load moves up or down at an increment of 0.5mm, the angle θ changes. However, depending on the initial and final position of the load (and thus the length of the vertical link, shown in dark grey), the angle θ changes by different increments.

∆θ sees it’s largest value when the load is moving between it’s highest and second highest points (essentially near 14cm relative height); this corresponds to a 2˚ ∆θ. The in-depth calculations can be seen in the excel spreadsheet in the Appendix attached to this report. Two methods were used:

1. A manual change in increments and then evaluation of the corresponding ∆θ values.
2. Using *Excel’s* built-in solver to maximize the ∆θ cell value by changing the height cell value. This quickly and automatically finds the largest ∆θ for the setup.

Working based upon the largest ∆θ value, 2o, work backwards to find the minimum required speed of the hard-constraint movement. Approximating the surgeon’s motion at a speed of 10cm/s, the angle θ will change at approximately 40˚/s. This translates to a minimum of 6.67 rpm for the hard-constraint motion. Adding a sufficient safety factor to ensure the correct performance of the motor, we thus found the minimum speed of the hard constraint to be 30 rpm.

Knowing the torque and speed required of the motor, we can compute the power rating of the motor. Compared to the design used by last year’s group, the new linkage design has the overall advantage of requiring a lower torque and comparable speeds – thus, the power rating of the motor we need will be less. Last year used a pricey 25 Watt Maxon EC Max precision Motor in set with a 66:1 planetary gear head and a basic optical encoder. Since our desired power rating is considerably less than 25 Watts, and since the motor already present is functional, we choose to re-use the same motor as last year. We have proved, through calculations, our required torque and speed, and the current motor we have meets our functional requirements.

