## Assignment for Week 6 readings: (due Tues Feb 18)

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Goal: Compute forces and twists for manipulation with sliding and Coulomb friction

* [Jun En and Tony’s Google presentation](https://drive.google.com/open?id=1_yTo9gAF8dRGa2IwZMHVFjMDoRVDU1NvuQd7WUthWfg)

### Q1.

One of the ways to determine when and how an object under Coulomb friction will start sliding is to use the Maximum Power inequality. A nice example comes from the PhD thesis of H. Sakurai at MIT who, like Soo-Hong Lee at Stanford, considered the problem of a clamped part subject to cutting forces. In pages [90-100 of his thesis (linked)](https://drive.google.com/open?id=14mlSM1LuhdFloB1YG75CE5yyJ5IPgNBb) he works an example with a part held by 3 clamps. The (x,y) locations of the clamping points are known. Each results in a frictional contact. The location and direction of the external force are also assumed known.

1.1 How many *unknowns* are there and what are they, exactly?

1.2 How many equations (equality and inequality) are there and what are they?

1.3 Use the Maximum Power inequality to solve the problem. Sakurai treats it as a linear programming problem and he calls it the “Maximum Friction Wrench Theorem.” The file on Canvas, “SakuraiFriction.py” gives you a head start on setting up the problem for linprog( ). Please finish the script and see how your results compare with Sakurai’s. If there are differences, what do you attribute them to?

### Q2.

Let us try the same problem using the ellipsoidal Limit Surface concept from Howe & Cutkosky. The script “LScalcs.py” pretty much does everything, so it’s more a matter of walking through the file and checking that it all makes sense.

1.1 The particular situation addressed in Sakurai’s example is a special case of the more general planar sliding behavior. What is going on and why does it lead to linear equations in this particular case?

1.2 Now consider the more general case. Suppose the cutting force is applied at a different location. How much larger might it need to be in the maximum case before sliding commences?

### Q3.

A FlyCroTug[[1]](#footnote-0) is a small quadrotor that can attach a cable to an object, fly some distance away, anchor itself using microspines or adhesives, and pull on the cable. An ambitious FlyCroTug has decided to move a divan by attaching a cable to one of its rear legs. The dimensions and forces are shown in the schematic figure below. 

Compute the necessary force in the cable and the instantaneous unit twist (direction of motion) using:

3.1 The Maximum Power method, adapting the script from Q1.

3.2 Try the Maximum Power method again, now assuming that theta = 0deg. Does the square friction-cone approximation work better in this case?

3.3 The Ellipsoidal Limit Surface method, letting theta = 30, and adapting the script from Q2. Is it rotating about a leg, or do you need to do the general case for an ellipsoid?

3.4 Try the Limit Surface again, now letting theta = 0deg.

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1. Estrada, M. A., et al. (2018). Forceful manipulation with micro air vehicles. *Science Robotics*, *3*(23), eaau6903. [↑](#footnote-ref-0)