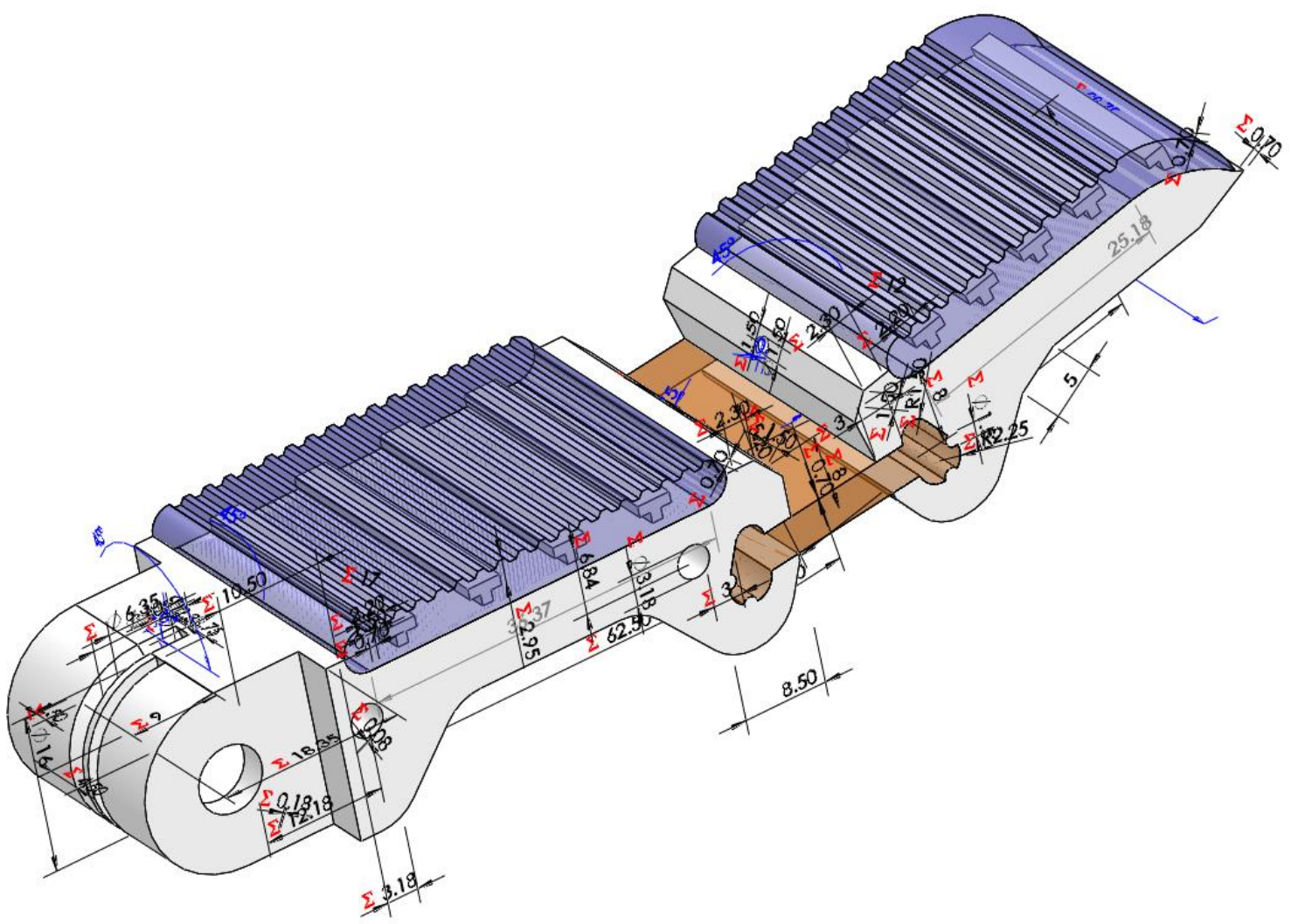




OPENHAND CAD GUIDE

VERSION 1.0



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FOREWORD (YES, ACTUALLY)

From the beginning of the Yale OpenHand Project in Fall 2012 through Spring 2015, I have been the only one modifying the associated CAD files. This means that at the very least, the source files will be consistent, but they're also all susceptible to the same shortfalls and inefficiencies if I have done anything wrong. One of the project's main goals is to provide a set of files that researchers can easily update and improve. I've tried, wherever possible, to minimize the number of features in each part, and all features have descriptive names to make future modifications easier.

The part files are dependent on two main sets of global variables: one set for print parameters and another for finger design parameters. Print parameters include: minimal wall thicknesses, minimal structural wall thicknesses, clearance dimensions for common fasteners in the final assembly, etc. These may be tweaked to accommodate different 3D printers or another set of desired fastener sizes. Finger design parameters include: linkage lengths, flexure sizes, flexure angular offsets, and transmission ratios. These determine the performance of the underactuated fingers and are commonly analyzed/discussed in research literature.

Now, it would make sense to use Solidworks' default global variables, but the program slows to a crawl once you get beyond 10-20 equations. This has been documented [\[here\]](#) and [\[here\]](#), with no official answer other than to upgrade the system GPU. Fortunately, linking dimension values to those in an existing sketch works just as well, so I use two separate part files (ie. *params_finger_t.sldprt*, *params_print_t.sldprt*) that each contain only a single sketch with several dimensioned lines. These dimensions are tied to a Design Table that can be modified, after which the dimensional changes are propagated through the dependent parts during the next rebuild. This is why many parts will contain these parameter parts inserted in their feature tree. I've read that we're generally supposed to avoid dependencies, as that can make future edits more difficult, but in the context of what we've done with the OpenHand Project, it still makes sense.

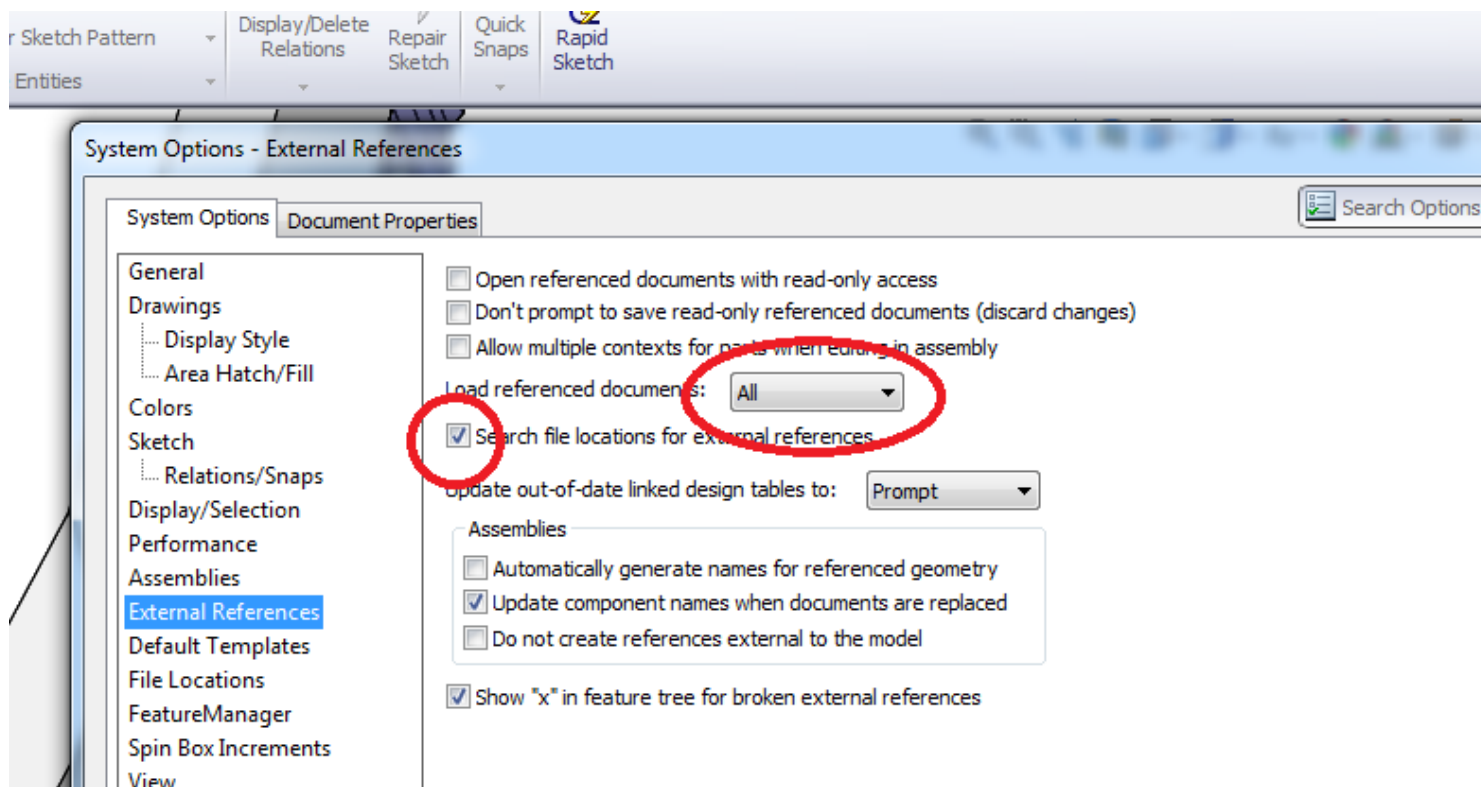
The rest of this document will try to clarify some of the common questions our beta users have asked me when trying to edit the source files. If you have any questions not answered by this document or have any suggestions on how to better organize our source files, feel free to (try to) contact me at raymond.ma@yale.edu.

* I apologize ahead of time for any snark or sarcasm you may experience while reading this document. I have been working on this project alone for quite a long time and am dubious that anyone will actually read this document in-depth. *

Godspeed,
Raymond Ma



PREREQUISITES



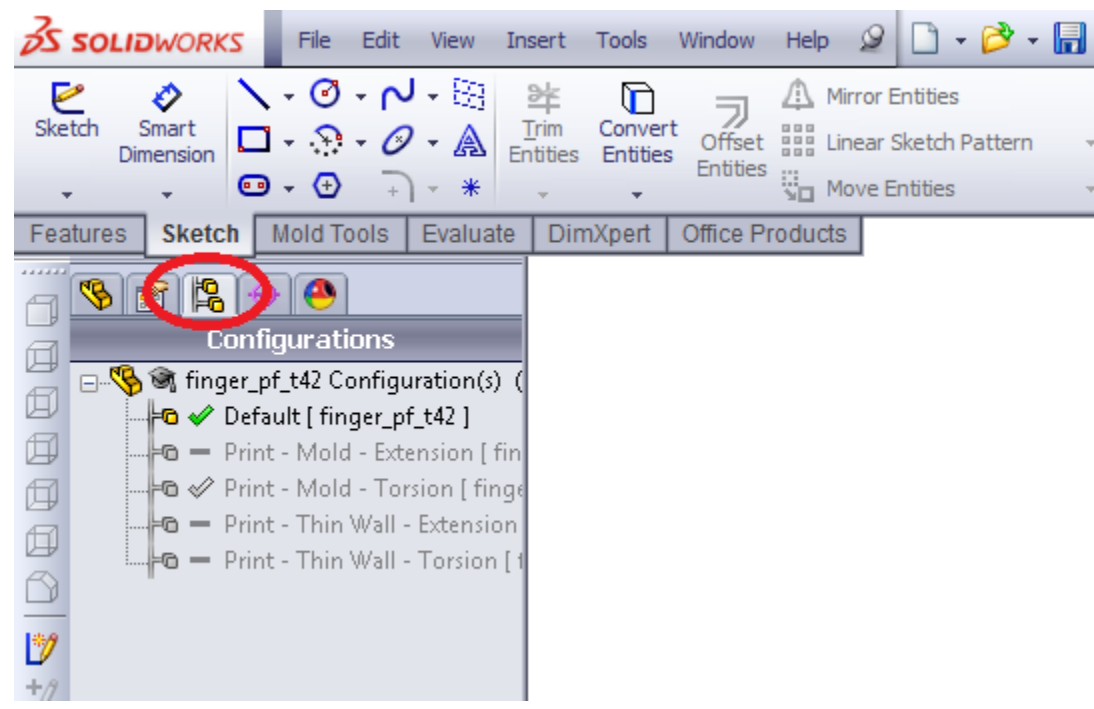
First, please check that under Options>>External References, you have Solidworks set to automatically load all referenced documents. Solidworks will throw an error if part tries to rebuild without its reference parts already loaded.

This will most commonly happen if you don't have the parameter files open and try to open a dependent part. With this option selected, the referenced parts will load automatically and avoid errors.

After this, the easiest way for you to start playing with the CAD files is to open an hand assembly. They should be named *hand_[model name].sldasm*. For example, *hand_m.sldasm* for the Model M hand.



CONFIGURATIONS



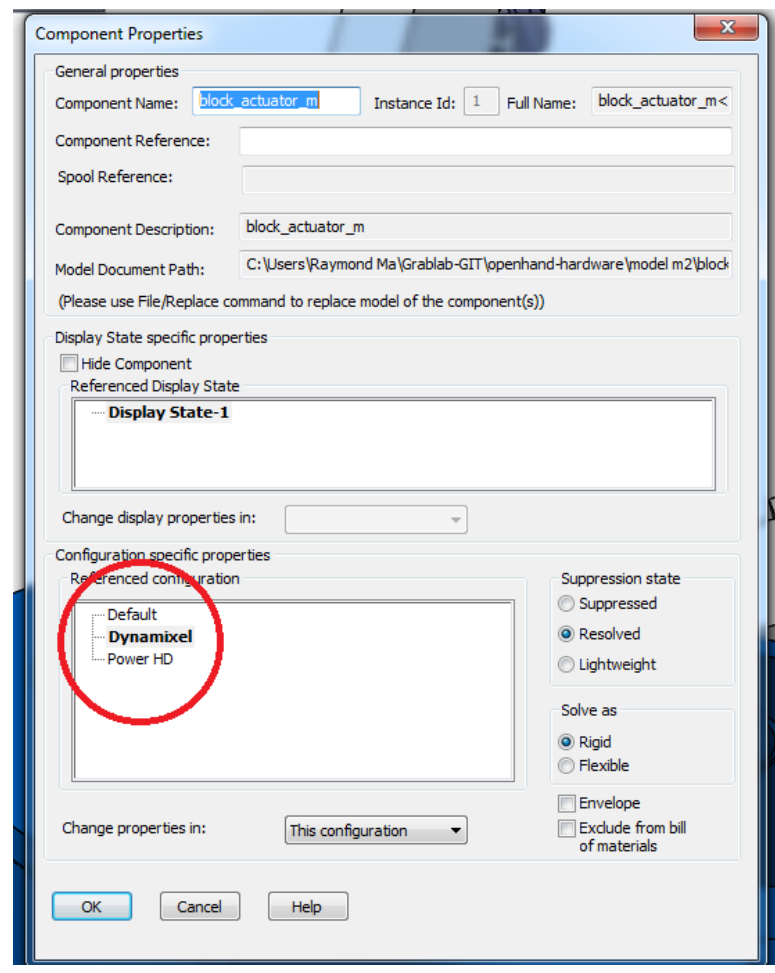
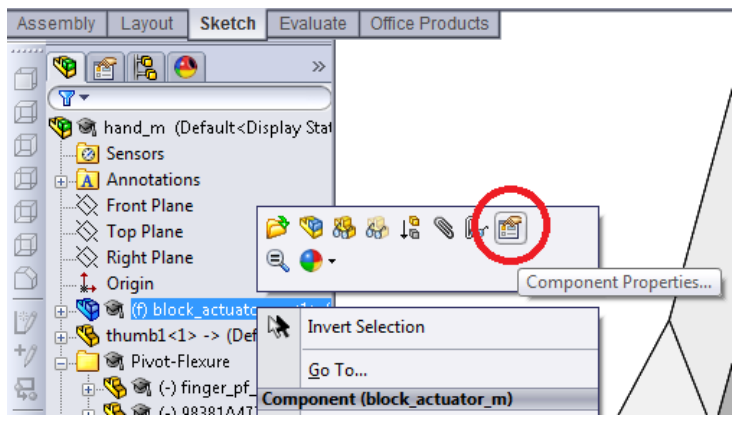
Please check the Configurations tab for the assemblies and parts that you open! To cut down the number of parts I needed to maintain in the CAD library, and to make it easier to update sets of parts that have many commonalities, I've used configurations extensively in the OpenHand repository. To switch to another configuration, just double click on the name.

The different configurations mostly suppress/unsuppress different subsets of features, so you shouldn't have to switch between different configurations if you just want to see the full set of features.

The [OpenHand Github repository](#) should have a full directory of stl's that have been generated from all possible configurations. Going this route has cut down the size of our CAD library in half, and it has also preserved the remnants of my sanity.



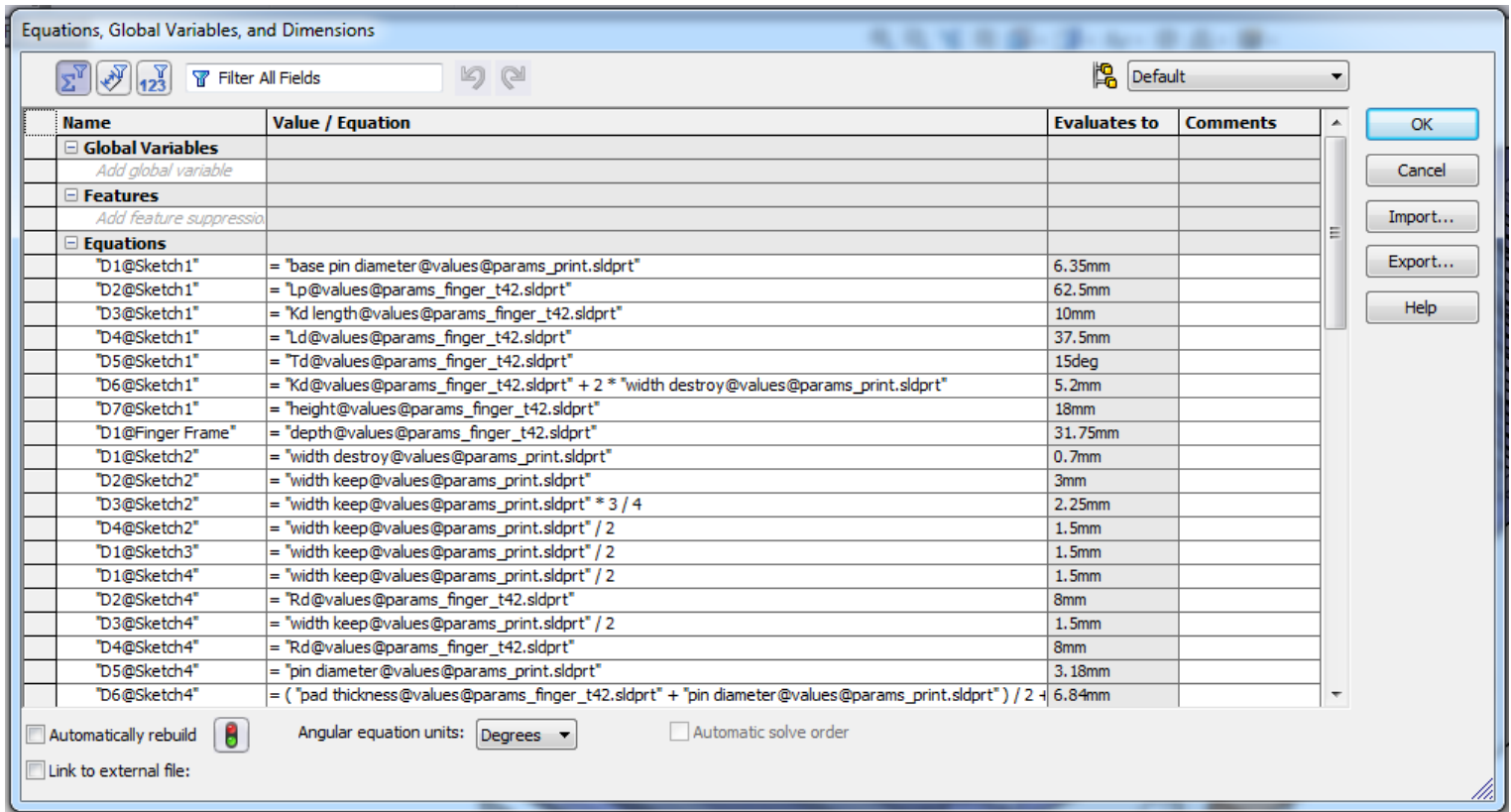
SUB-CONFIGURATIONS



If you need to select a particular configuration for a sub-assembly inserted into another assembly, right-click on the sub-assembly name and select *Component Properties...* to bring up a dialog for the sub-assembly. You can select the desired configuration for the sub-assembly in the bottom half of the dialog box, as shown above.



EQUATIONS



The Equations dialog can be loaded through Tools>>Equations...

The parameters files each contains a single sketch named *values*. The global parameters can commonly be directly referenced in a link value by “[variable name]@values@[parameter file name].sldprt”. Through the Smart Dimension tool, the variable should turn from red to blue once you have typed in the full reference name correctly.

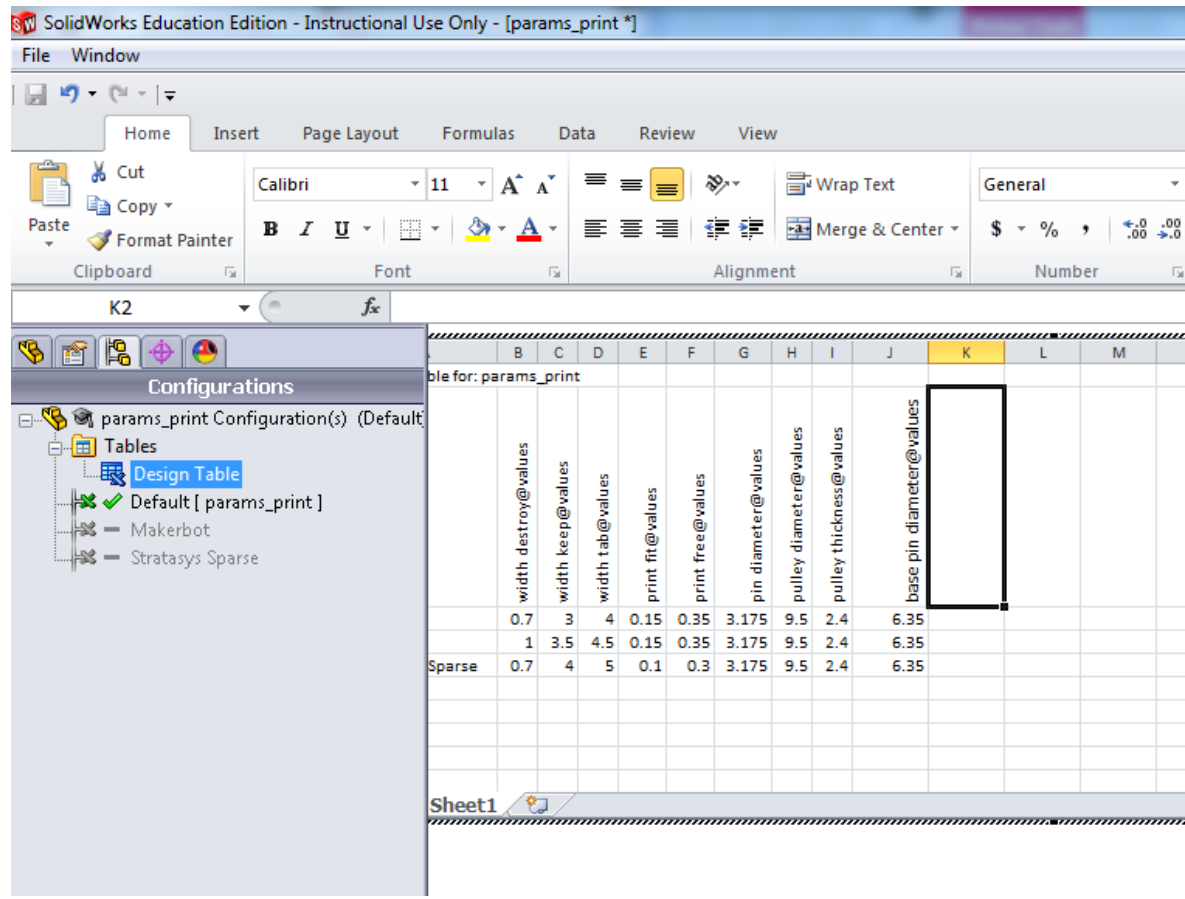
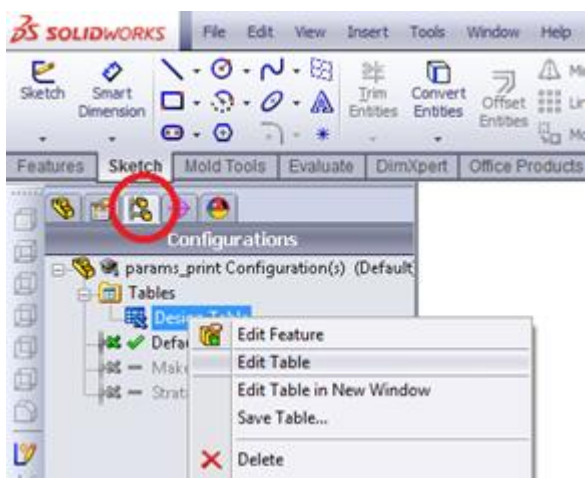
If you absolutely cannot stand to use these equations but also do not want to re-make the parts from scratch, the easiest work-around is probably to go through the Equations dialog box and delete all the equations here.

It is typically only the finger part files that will have more than 5-10 equations.

Though my initial intent with using so many equations was to make modifications through design parameters much easier and completely automatic, the truth is that the part file is very likely to break in some form or another once certain parameters are changed too much. However, looking through the Equations dialog will go a long way to helping you hunt down the error. Every element in each sketch should be fully defined.



DESIGN TABLE



To tweak the global parameter values in each parameter file, open up the Design Table under the Configurations tab on the left. There may be some pre-set configurations already there, but no guarantees there.

We had originally hoped to fully populate the Design Tables with configurations that other labs/users had tested on their own machines, but due to low user participation/adoption, that hasn't been possible.

After making a change, save the parameter file and rebuild the dependent files. The changes should propagate accordingly. Hopefully you can understand that it's impossible for me to check even a small range of all possible parameter combinations, so experiment with the parameters at your own peril.



PRINT PARAMETERS

There is a file *params_print.sldprt* that should be common to all parts in the OpenHand library. This contains values related to the 3D printer capabilities and fastener selection

Parameter Name	Default Value	Description
width destroy	0.7 (mm)	Minimal wall thickness that the printer can produce. Typically 2x the nozzle diameter. This value is usually used for sacrificial walls or temporary elements.
width keep	3 (mm)	Minimal structural wall thickness. This is the minimal dimensional value I'll typically use for a structural component, such as the thickness of ribbing or a framing wall.
width tab	4 (mm)	Thickness of the tabs that keep the fingers in place.
print fit	0.15 (mm)	Printed parts tend to be smaller than you specify. Print fit is the amount to increase certain dimensions for features that need to be press fit (ie. clearances for dowel pins)
print free	0.35 (mm)	Amount to increase certain dimensions for features that need to have a free clearance, such as a freely rotating joint.
pin diameter	3.125 (mm)	We use 1/8" diameter steel pins
base pin diameter	6.35 (mm)	We use 1/4" diameter steel pins for pivot joints
pulley diameter	9.5 (mm)	Some of our designs use small nylon pulleys from McMaster
pulley thickness	2.4 (mm)	Thickness of the nylon pulleys



FINGER PARAMETERS

There are two main finger parameter files: *params_finger_t.sldprt* for the thinner fingers found on the Model T and O, and *params_finger_t42.sldprt* for deeper fingers found on the Model T42 and M2/M.

Parameter Name	Default Value	Description
Lp, Ld	62.5, 37.5 (mm)	Proximal and distal linkage lengths.
Kp, Kd	Varies	Thickness of the flexural joints
Kp length, Kd length	10 (mm)	Length of the flexure joints
Rp, Rd	8 (mm)	Transmission radius of each joint. Approximately the distance from the center of rotation of the joint to the centerline of the actuating tendon.
height	18 (mm)	Height of the finger links
depth	16, 31.75 (mm)	Depth of the finger links, should be approximately 5/8" and 1-1/4"
pad thickness	4.5 (mm)	Thickness of the fingerpads
Lb	Varies	Separation between the proximal joints of opposing sets of fingers
Tp, Td	15 (degrees)	Rest angle of each of the joints, where 0 is the finger starting in a fully linear orientation