Follow calibration steps in order as some steps rely on prints, outputs, or calibrations from the previous step.

Total Time: 4 Hours and 8 minutes
Total Filament: 34g
Total Cost (approx): 0.84

1. Extruder Calibration

a. When?

i. Only when there are major system changes.

b. Measuring

i. First measure out 120mm of filament from where it enters your extruder and mark it with a pen or marker. This will be the reference point.
ii. Connect your computer to your printer and open up a program that allows you to send individual gcode commands to it.
iii. Heat up your hotend to your regular printing temperature and ensure that the nozzle is in a position above the bed where it can freely extrude filament.
iv. Send the command M83. This will ensure that your printer is interpreting the following extrusion commands in relative mode.
v. Set the extrusion feedrate to 50mm/minute with the command G1 F50.
vi. Extrude 100mm of plastic with the command G1 E100.
    1. This will take 120 seconds until it's finished extruding. The reason for extruding so slowly in this step is to ensure that the resistance of the plastic further down in the hotend does not affect how much is fed in by the stepper motor. It also helps to take the temperature out of the equation, again by reducing the effects of pressure in the nozzle.
vii. Once the machine has finished extruding the 100mm, switch off the hotend heater.
viii. Measure the distance between the point that you marked before we started, and where the plastic enters the extruder (the same point from which you measured the initial 120mm).

c. Tuning

i. To get the existing steps/mm value, send the command M503.

1. We're only interested in the E value, highlighted in the picture below. Locate it and record it.

```
SENDING:M503
echo:SD card ok
echo:Steps per unit:
echo:  M92 X100.00 Y100.00 Z400.00 E161.30
echo:Maximum feedrates (mm/s):
echo:  M203 X500.00 Y500.00 Z12.00 E25.00
echo:Maximum Acceleration (mm/s2):
echo:  M201 X9000 Y9000 Z500 E10000
```

2.

ii. Calculate the new values:
    1. Desired extruded distance / actual extruded distance = correction multiplier:
        a. 100 / 94 = 1.0638
    2. Correction multiplier × original extruder steps/mm = calibrated extruder steps/mm:
        a. 1.0638 × 161.3 = 171.6

iii. To enter and save it to your printer use the commands M92 E###.# (replace the hashes with your calibrated extruder steps/mm value) and then M500 to save it.

2. Filament Diameter

a. When?
    i. Every print, or at least every new roll of filament.
b. Measuring
    i. Measure the filament with calipers in at least three positions. Divide to get the average diameter
c. Tuning
    i. Enter the average as the material diameter in slicer material settings.

3. Extrusion Multiplier/Flow Rate (Cura)

a. When?

i. Every print, or at least every new roll of filament. Possibly every new brand if a brand has shown to be quite reliable.

b. Measuring

i. Print out a 20mmx20mm cube in vase mode.
    1. Make sure extrusion multiplier is set to 1.
    2. Set extrusion width to be the same as the width of your nozzle.

ii. Measure the wall thickness with a caliber in at least 4, preferably 8 places and take an average.

c. Tuning

i. Set your extrusion multiplier with the new value.
    1. New multiplier = old multiplier x (extrusion width/average measurement).
    2. For a 0.4mm nozzle, the width should be 0.42mm
ii. Repeat these cubes as many times as necessary.

4. PID Tune Bed and Hotend

a. When?

i. When you change fans or major seasonal changes.

b. Measuring

i. N/A, part of tuning.

c. Tuning

i. Send the M303 command to the printer with the format:
    1. M303 E(0 for hotend, -1 for bed) C(# of cycles, 3-8) S(Desired Temperature)
    2. Example:
        a. M303 E0 C5 S180 = PLA tuned over 5 cycles.

5. Calibrate Temperatures

a. When?

i. Every new filament (color, brand, material, etc.)

b. Measuring

i. Print a temperature calibration tower where the material is extruded in 5 degree increments from hot to cold.
    1. This should cover the whole temperature range recommended by the manufacturer.
    2. Ideally, the tower should include bridging, stringing and overhang tests.

c. Tuning

i. Inspect for stringing, droopage and zits. Select the best visual quality and set the material nozzle temp in your slicer to this value.

6. Calibrate Fan Speed

a. When?

i. Every new filament (color, brand, material, etc.)

b. Measuring

i. Print the same calibration tower as previously used to measure temperature, only this time print at optimal temperature for the entire tower and only vary fan speed.
   1. Edit lines 26 and 3581 in the provided G-Code step 6 file.

c. Tuning

i. As before, inspect for the highest visual quality.
   1. Bear in mind that some materials will still need differing fan speeds at different heights in order to prevent warping and other defects.

7. Final PID Hotend Tune

a. When?

i. Any time your fan would affect hot end temperatures. So always after fan speed.

b. Measuring

i. N/A, part of tuning.

c. Tuning

i. Send the M303 command to the printer with the format:
   1. M303 E0 C(# of cycles, 3-8) S(Desired Temperature)
   2. Example:
      a. M303 E0 C5 S180 = PLA tuned over 5 cycles.

8. X/Y Stepper Calibration

a. When?

i. Only on major changes, or when using a new roll to check for consistency. Highly dependent on how tight the belts are.

b. Measuring

i. Print a cube that is meant to be precisely 20x20x20mm, with a lower (10%) infill setting. The cube should have the respective axis marked on it's faces to prevent confusion.

ii. Using the 8-9 STL provided, enter in the fan, temperature, diameter, and extrusion values from previous tests.

iii. Measure each axis and calculate its inaccuracy from expected value as described below.

c. Tuning

i. Send M501 command to printer. This should return the M92 value for each axis (steps-per-mm).
   1. New M92 = (expected / measured) * Current M92.
   2. Send:
      a. M92 X(new value) for x axis update.
   3. Save to EEPROM with M500 command.
   4. Repeat for y-axis.

9. Elephant's Foot Compensation/Initial Layer Horizontal Expansion

a. When?

i. Every new filament (color, brand, material, etc.)

b. Measuring

i. Using the same cube as in X/Y Stepper calibration, measure the average size of the first layer relative to the layers in the middle and top. Measure at least 4 points for each height.

c. Tuning

i. In Cura, set Initial Layer Horizontal Expansion to equal the average of the elephant's foot measurement minus the average of the measurements from above the first layer.

10. Stringing Calibration

a. Not using this yet.

11. KDM Standardized Test

a. When?

i. When you believe you are tuned and want to show off.

b. Measuring

i. Print the KSR-FDM test jig with your optimal settings.
ii. Measure and score as per this guide: https://github.com/kickstarter/kickstarter-autodesk-3d/tree/master/FDM-protocol
iii. The highest possible score is 30, indicating a very well-calibrated system. For reference, a Prusa i3 MK3 scores 22.5 and a Makerbot Replicator 2 scores 18.

iv. Adds 5 hours and 46 minutes, 35g and $0.89 to the cost of setup.

c. Tuning

i. N/A