

Delta printer geometry calibration using bed auto-leveling

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Initial setup

In [1]:

```
from mpl_toolkits.mplot3d import Axes3D
from matplotlib import cm
from matplotlib.ticker import LinearLocator, FormatStrFormatter
import matplotlib.pyplot as plt

import numpy as np
from scipy.optimize import leastsq, minimize
```

In [2]:

```
%matplotlib inline
```

Import calibration data. The calibration data should be acquired by first running commands "G28" and then "G29 V3" on the printer. To increase the amount of points, you can set AUTO_BED_LEVELING_GRID_POINTS to some larger value. I used 25.

In [3]:

```
in_data = """
< 21:10:41: Bed X: 0.000 Y: -70.000 Z: 1.370
< 21:10:42: Bed X: 25.000 Y: -65.000 Z: 1.280
< 21:10:42: Bed X: 20.000 Y: -65.000 Z: 1.390
< 21:10:43: Bed X: 15.000 Y: -65.000 Z: 1.430
```

```
< 21:10:43: Bed X: 10.000 Y: -65.000 Z: 1.500
< 21:10:44: Bed X: 5.000 Y: -65.000 Z: 1.530
< 21:10:44: Bed X: 0.000 Y: -65.000 Z: 1.590
< 21:10:45: Bed X: -5.000 Y: -65.000 Z: 1.610
< 21:10:45: Bed X: -10.000 Y: -65.000 Z: 1.640
< 21:10:46: Bed X: -15.000 Y: -65.000 Z: 1.610
< 21:10:46: Bed X: -20.000 Y: -65.000 Z: 1.580
< 21:10:47: Bed X: -25.000 Y: -65.000 Z: 1.520
< 21:10:48: Bed X: -35.000 Y: -60.000 Z: 1.420
< 21:10:48: Bed X: -30.000 Y: -60.000 Z: 1.510
< 21:10:49: Bed X: -25.000 Y: -60.000 Z: 1.590
< 21:10:49: Bed X: -20.000 Y: -60.000 Z: 1.620
< 21:10:50: Bed X: -15.000 Y: -60.000 Z: 1.660
< 21:10:50: Bed X: -10.000 Y: -60.000 Z: 1.680
< 21:10:51: Bed X: -5.000 Y: -60.000 Z: 1.660
< 21:10:51: Bed X: 0.000 Y: -60.000 Z: 1.660
< 21:10:52: Bed X: 5.000 Y: -60.000 Z: 1.660
< 21:10:52: Bed X: 10.000 Y: -60.000 Z: 1.620
< 21:10:53: Bed X: 15.000 Y: -60.000 Z: 1.570
< 21:10:53: Bed X: 20.000 Y: -60.000 Z: 1.510
< 21:10:54: Bed X: 25.000 Y: -60.000 Z: 1.430
< 21:10:54: Bed X: 30.000 Y: -60.000 Z: 1.350
< 21:10:55: Bed X: 35.000 Y: -60.000 Z: 1.260
< 21:10:56: Bed X: 40.000 Y: -55.000 Z: 1.350
< 21:10:56: Bed X: 35.000 Y: -55.000 Z: 1.360
< 21:10:57: Bed X: 30.000 Y: -55.000 Z: 1.450
< 21:10:57: Bed X: 25.000 Y: -55.000 Z: 1.560
< 21:10:58: Bed X: 20.000 Y: -55.000 Z: 1.620
< 21:10:58: Bed X: 15.000 Y: -55.000 Z: 1.670
< 21:10:59: Bed X: 10.000 Y: -55.000 Z: 1.710
< 21:10:59: Bed X: 5.000 Y: -55.000 Z: 1.730
< 21:11:00: Bed X: 0.000 Y: -55.000 Z: 1.740
< 21:11:00: Bed X: -5.000 Y: -55.000 Z: 1.740
< 21:11:01: Bed X: -10.000 Y: -55.000 Z: 1.740
< 21:11:01: Bed X: -15.000 Y: -55.000 Z: 1.730
< 21:11:02: Bed X: -20.000 Y: -55.000 Z: 1.700
< 21:11:02: Bed X: -25.000 Y: -55.000 Z: 1.650
< 21:11:03: Bed X: -30.000 Y: -55.000 Z: 1.580
< 21:11:04: Bed X: -35.000 Y: -55.000 Z: 1.510
< 21:11:04: Bed X: -40.000 Y: -55.000 Z: 1.430
< 21:11:05: Bed X: -45.000 Y: -50.000 Z: 1.430
< 21:11:05: Bed X: -40.000 Y: -50.000 Z: 1.480
< 21:11:06: Bed X: -35.000 Y: -50.000 Z: 1.540
< 21:11:06: Bed X: -30.000 Y: -50.000 Z: 1.620
< 21:11:07: Bed X: -25.000 Y: -50.000 Z: 1.690
< 21:11:07: Bed X: -20.000 Y: -50.000 Z: 1.740
< 21:11:08: Bed X: -15.000 Y: -50.000 Z: 1.780
< 21:11:08: Bed X: -10.000 Y: -50.000 Z: 1.790
< 21:11:09: Bed X: -5.000 Y: -50.000 Z: 1.830
< 21:11:09: Bed X: 0.000 Y: -50.000 Z: 1.840
< 21:11:10: Bed X: 5.000 Y: -50.000 Z: 1.840
< 21:11:10: Bed X: 10.000 Y: -50.000 Z: 1.820
< 21:11:11: Bed X: 15.000 Y: -50.000 Z: 1.780
< 21:11:12: Bed X: 20.000 Y: -50.000 Z: 1.720
< 21:11:12: Bed X: 25.000 Y: -50.000 Z: 1.680
< 21:11:13: Bed X: 30.000 Y: -50.000 Z: 1.590
< 21:11:13: Bed X: 35.000 Y: -50.000 Z: 1.500
< 21:11:14: Bed X: 40.000 Y: -50.000 Z: 1.440
```

```
< 21:11:14: Bed X: 45.000 Y: -50.000 Z: 1.370
< 21:11:15: Bed X: 50.000 Y: -45.000 Z: 1.490
< 21:11:15: Bed X: 45.000 Y: -45.000 Z: 1.500
< 21:11:16: Bed X: 40.000 Y: -45.000 Z: 1.550
< 21:11:16: Bed X: 35.000 Y: -45.000 Z: 1.630
< 21:11:17: Bed X: 30.000 Y: -45.000 Z: 1.700
< 21:11:18: Bed X: 25.000 Y: -45.000 Z: 1.790
< 21:11:18: Bed X: 20.000 Y: -45.000 Z: 1.840
< 21:11:19: Bed X: 15.000 Y: -45.000 Z: 1.900
< 21:11:19: Bed X: 10.000 Y: -45.000 Z: 1.910
< 21:11:20: Bed X: 5.000 Y: -45.000 Z: 1.930
< 21:11:20: Bed X: 0.000 Y: -45.000 Z: 1.910
< 21:11:21: Bed X: -5.000 Y: -45.000 Z: 1.920
< 21:11:21: Bed X: -10.000 Y: -45.000 Z: 1.880
< 21:11:22: Bed X: -15.000 Y: -45.000 Z: 1.870
< 21:11:22: Bed X: -20.000 Y: -45.000 Z: 1.810
< 21:11:23: Bed X: -25.000 Y: -45.000 Z: 1.750
< 21:11:23: Bed X: -30.000 Y: -45.000 Z: 1.690
< 21:11:24: Bed X: -35.000 Y: -45.000 Z: 1.620
< 21:11:24: Bed X: -40.000 Y: -45.000 Z: 1.520
< 21:11:25: Bed X: -45.000 Y: -45.000 Z: 1.460
< 21:11:26: Bed X: -50.000 Y: -45.000 Z: 1.410
< 21:11:26: Bed X: -55.000 Y: -40.000 Z: 1.360
< 21:11:27: Bed X: -50.000 Y: -40.000 Z: 1.440
< 21:11:27: Bed X: -45.000 Y: -40.000 Z: 1.530
< 21:11:28: Bed X: -40.000 Y: -40.000 Z: 1.580
< 21:11:28: Bed X: -35.000 Y: -40.000 Z: 1.670
< 21:11:29: Bed X: -30.000 Y: -40.000 Z: 1.750
< 21:11:29: Bed X: -25.000 Y: -40.000 Z: 1.820
< 21:11:30: Bed X: -20.000 Y: -40.000 Z: 1.880
< 21:11:30: Bed X: -15.000 Y: -40.000 Z: 1.920
< 21:11:31: Bed X: -10.000 Y: -40.000 Z: 1.950
< 21:11:31: Bed X: -5.000 Y: -40.000 Z: 2.010
< 21:11:32: Bed X: 0.000 Y: -40.000 Z: 2.010
< 21:11:32: Bed X: 5.000 Y: -40.000 Z: 2.030
< 21:11:33: Bed X: 10.000 Y: -40.000 Z: 2.010
< 21:11:34: Bed X: 15.000 Y: -40.000 Z: 2.010
< 21:11:34: Bed X: 20.000 Y: -40.000 Z: 1.960
< 21:11:35: Bed X: 25.000 Y: -40.000 Z: 1.920
< 21:11:35: Bed X: 30.000 Y: -40.000 Z: 1.820
< 21:11:36: Bed X: 35.000 Y: -40.000 Z: 1.770
< 21:11:36: Bed X: 40.000 Y: -40.000 Z: 1.670
< 21:11:37: Bed X: 45.000 Y: -40.000 Z: 1.610
< 21:11:37: Bed X: 50.000 Y: -40.000 Z: 1.640
< 21:11:38: Bed X: 50.000 Y: -35.000 Z: 1.740
< 21:11:38: Bed X: 45.000 Y: -35.000 Z: 1.750
< 21:11:39: Bed X: 40.000 Y: -35.000 Z: 1.810
< 21:11:39: Bed X: 35.000 Y: -35.000 Z: 1.870
< 21:11:40: Bed X: 30.000 Y: -35.000 Z: 1.940
< 21:11:41: Bed X: 25.000 Y: -35.000 Z: 2.010
< 21:11:41: Bed X: 20.000 Y: -35.000 Z: 2.060
< 21:11:42: Bed X: 15.000 Y: -35.000 Z: 2.100
< 21:11:42: Bed X: 10.000 Y: -35.000 Z: 2.110
< 21:11:43: Bed X: 5.000 Y: -35.000 Z: 2.100
< 21:11:43: Bed X: 0.000 Y: -35.000 Z: 2.090
< 21:11:44: Bed X: -5.000 Y: -35.000 Z: 2.090
< 21:11:44: Bed X: -10.000 Y: -35.000 Z: 2.030
```

```
< 21:11:45: Bed X: -15.000 Y: -35.000 Z: 2.020
< 21:11:45: Bed X: -20.000 Y: -35.000 Z: 1.950
< 21:11:46: Bed X: -25.000 Y: -35.000 Z: 1.910
< 21:11:46: Bed X: -30.000 Y: -35.000 Z: 1.830
< 21:11:47: Bed X: -35.000 Y: -35.000 Z: 1.760
< 21:11:47: Bed X: -40.000 Y: -35.000 Z: 1.660
< 21:11:48: Bed X: -45.000 Y: -35.000 Z: 1.570
< 21:11:49: Bed X: -50.000 Y: -35.000 Z: 1.510
< 21:11:49: Bed X: -55.000 Y: -35.000 Z: 1.450
< 21:11:50: Bed X: -60.000 Y: -35.000 Z: 1.350
< 21:11:50: Bed X: -60.000 Y: -30.000 Z: 1.380
< 21:11:51: Bed X: -55.000 Y: -30.000 Z: 1.500
< 21:11:51: Bed X: -50.000 Y: -30.000 Z: 1.540
< 21:11:52: Bed X: -45.000 Y: -30.000 Z: 1.640
< 21:11:52: Bed X: -40.000 Y: -30.000 Z: 1.720
< 21:11:53: Bed X: -35.000 Y: -30.000 Z: 1.830
< 21:11:53: Bed X: -30.000 Y: -30.000 Z: 1.920
< 21:11:54: Bed X: -25.000 Y: -30.000 Z: 2.000
< 21:11:55: Bed X: -20.000 Y: -30.000 Z: 2.050
< 21:11:55: Bed X: -15.000 Y: -30.000 Z: 2.110
< 21:11:56: Bed X: -10.000 Y: -30.000 Z: 2.150
< 21:11:56: Bed X: -5.000 Y: -30.000 Z: 2.210
< 21:11:57: Bed X: 0.000 Y: -30.000 Z: 2.200
< 21:11:57: Bed X: 5.000 Y: -30.000 Z: 2.220
< 21:11:58: Bed X: 10.000 Y: -30.000 Z: 2.230
< 21:11:58: Bed X: 15.000 Y: -30.000 Z: 2.230
< 21:11:59: Bed X: 20.000 Y: -30.000 Z: 2.200
< 21:11:59: Bed X: 25.000 Y: -30.000 Z: 2.120
< 21:12:00: Bed X: 30.000 Y: -30.000 Z: 2.080
< 21:12:00: Bed X: 35.000 Y: -30.000 Z: 1.990
< 21:12:01: Bed X: 40.000 Y: -30.000 Z: 1.930
< 21:12:01: Bed X: 45.000 Y: -30.000 Z: 1.890
< 21:12:02: Bed X: 50.000 Y: -30.000 Z: 1.870
< 21:12:03: Bed X: 50.000 Y: -25.000 Z: 2.000
< 21:12:03: Bed X: 45.000 Y: -25.000 Z: 1.990
< 21:12:04: Bed X: 40.000 Y: -25.000 Z: 2.040
< 21:12:04: Bed X: 35.000 Y: -25.000 Z: 2.100
< 21:12:05: Bed X: 30.000 Y: -25.000 Z: 2.170
< 21:12:05: Bed X: 25.000 Y: -25.000 Z: 2.240
< 21:12:06: Bed X: 20.000 Y: -25.000 Z: 2.280
< 21:12:06: Bed X: 15.000 Y: -25.000 Z: 2.280
< 21:12:07: Bed X: 10.000 Y: -25.000 Z: 2.310
< 21:12:07: Bed X: 5.000 Y: -25.000 Z: 2.300
< 21:12:08: Bed X: 0.000 Y: -25.000 Z: 2.280
< 21:12:08: Bed X: -5.000 Y: -25.000 Z: 2.260
< 21:12:09: Bed X: -10.000 Y: -25.000 Z: 2.210
< 21:12:09: Bed X: -15.000 Y: -25.000 Z: 2.170
< 21:12:10: Bed X: -20.000 Y: -25.000 Z: 2.120
< 21:12:11: Bed X: -25.000 Y: -25.000 Z: 2.060
< 21:12:11: Bed X: -30.000 Y: -25.000 Z: 1.990
< 21:12:12: Bed X: -35.000 Y: -25.000 Z: 1.900
< 21:12:12: Bed X: -40.000 Y: -25.000 Z: 1.810
< 21:12:13: Bed X: -45.000 Y: -25.000 Z: 1.720
< 21:12:13: Bed X: -50.000 Y: -25.000 Z: 1.640
< 21:12:14: Bed X: -55.000 Y: -25.000 Z: 1.560
< 21:12:14: Bed X: -60.000 Y: -25.000 Z: 1.450
< 21:12:15: Bed X: -65.000 Y: -25.000 Z: 1.350
< 21:12:16: Bed X: -65.000 Y: -20.000 Z: 1.420
```

```
< 21:12:16: Bed X: -60.000 Y: -20.000 Z: 1.520
< 21:12:17: Bed X: -55.000 Y: -20.000 Z: 1.630
< 21:12:17: Bed X: -50.000 Y: -20.000 Z: 1.710
< 21:12:18: Bed X: -45.000 Y: -20.000 Z: 1.770
< 21:12:18: Bed X: -40.000 Y: -20.000 Z: 1.880
< 21:12:19: Bed X: -35.000 Y: -20.000 Z: 2.000
< 21:12:19: Bed X: -30.000 Y: -20.000 Z: 2.070
< 21:12:20: Bed X: -25.000 Y: -20.000 Z: 2.130
< 21:12:20: Bed X: -20.000 Y: -20.000 Z: 2.200
< 21:12:21: Bed X: -15.000 Y: -20.000 Z: 2.260
< 21:12:21: Bed X: -10.000 Y: -20.000 Z: 2.300
< 21:12:22: Bed X: -5.000 Y: -20.000 Z: 2.350
< 21:12:22: Bed X: 0.000 Y: -20.000 Z: 2.380
< 21:12:23: Bed X: 5.000 Y: -20.000 Z: 2.400
< 21:12:24: Bed X: 10.000 Y: -20.000 Z: 2.390
< 21:12:24: Bed X: 15.000 Y: -20.000 Z: 2.400
< 21:12:25: Bed X: 20.000 Y: -20.000 Z: 2.370
< 21:12:25: Bed X: 25.000 Y: -20.000 Z: 2.330
< 21:12:26: Bed X: 30.000 Y: -20.000 Z: 2.280
< 21:12:26: Bed X: 35.000 Y: -20.000 Z: 2.220
< 21:12:27: Bed X: 40.000 Y: -20.000 Z: 2.170
< 21:12:27: Bed X: 45.000 Y: -20.000 Z: 2.140
< 21:12:28: Bed X: 50.000 Y: -20.000 Z: 2.130
< 21:12:28: Bed X: 50.000 Y: -15.000 Z: 2.220
< 21:12:29: Bed X: 45.000 Y: -15.000 Z: 2.270
< 21:12:30: Bed X: 40.000 Y: -15.000 Z: 2.250
< 21:12:30: Bed X: 35.000 Y: -15.000 Z: 2.310
< 21:12:31: Bed X: 30.000 Y: -15.000 Z: 2.380
< 21:12:31: Bed X: 25.000 Y: -15.000 Z: 2.430
< 21:12:32: Bed X: 20.000 Y: -15.000 Z: 2.470
< 21:12:32: Bed X: 15.000 Y: -15.000 Z: 2.500
< 21:12:33: Bed X: 10.000 Y: -15.000 Z: 2.490
< 21:12:33: Bed X: 5.000 Y: -15.000 Z: 2.480
< 21:12:34: Bed X: 0.000 Y: -15.000 Z: 2.440
< 21:12:34: Bed X: -5.000 Y: -15.000 Z: 2.380
< 21:12:35: Bed X: -10.000 Y: -15.000 Z: 2.380
< 21:12:35: Bed X: -15.000 Y: -15.000 Z: 2.330
< 21:12:36: Bed X: -20.000 Y: -15.000 Z: 2.290
< 21:12:36: Bed X: -25.000 Y: -15.000 Z: 2.220
< 21:12:37: Bed X: -30.000 Y: -15.000 Z: 2.150
< 21:12:38: Bed X: -35.000 Y: -15.000 Z: 2.060
< 21:12:38: Bed X: -40.000 Y: -15.000 Z: 1.980
< 21:12:39: Bed X: -45.000 Y: -15.000 Z: 1.880
< 21:12:39: Bed X: -50.000 Y: -15.000 Z: 1.790
< 21:12:40: Bed X: -55.000 Y: -15.000 Z: 1.730
< 21:12:40: Bed X: -60.000 Y: -15.000 Z: 1.630
< 21:12:41: Bed X: -65.000 Y: -15.000 Z: 1.520
< 21:12:41: Bed X: -65.000 Y: -10.000 Z: 1.570
< 21:12:42: Bed X: -60.000 Y: -10.000 Z: 1.670
< 21:12:43: Bed X: -55.000 Y: -10.000 Z: 1.770
< 21:12:43: Bed X: -50.000 Y: -10.000 Z: 1.870
< 21:12:44: Bed X: -45.000 Y: -10.000 Z: 1.940
< 21:12:44: Bed X: -40.000 Y: -10.000 Z: 2.040
< 21:12:45: Bed X: -35.000 Y: -10.000 Z: 2.130
< 21:12:45: Bed X: -30.000 Y: -10.000 Z: 2.220
< 21:12:46: Bed X: -25.000 Y: -10.000 Z: 2.300
< 21:12:46: Bed X: -20.000 Y: -10.000 Z: 2.370
< 21:12:47: Bed X: -15.000 Y: -10.000 Z: 2.410
```

```
< 21:12:47: Bed X: -10.000 Y: -10.000 Z: 2.470
< 21:12:47: Bed X: -10.000 Y: -10.000 Z: 2.470
< 21:12:48: Bed X: -5.000 Y: -10.000 Z: 2.530
< 21:12:48: Bed X: 0.000 Y: -10.000 Z: 2.540
< 21:12:49: Bed X: 5.000 Y: -10.000 Z: 2.560
< 21:12:49: Bed X: 10.000 Y: -10.000 Z: 2.590
< 21:12:50: Bed X: 15.000 Y: -10.000 Z: 2.600
< 21:12:50: Bed X: 20.000 Y: -10.000 Z: 2.570
< 21:12:51: Bed X: 25.000 Y: -10.000 Z: 2.530
< 21:12:52: Bed X: 30.000 Y: -10.000 Z: 2.480
< 21:12:52: Bed X: 35.000 Y: -10.000 Z: 2.410
< 21:12:53: Bed X: 40.000 Y: -10.000 Z: 2.350
< 21:12:53: Bed X: 45.000 Y: -10.000 Z: 2.340
< 21:12:54: Bed X: 50.000 Y: -10.000 Z: 2.310
< 21:12:54: Bed X: 50.000 Y: -5.000 Z: 2.430
< 21:12:55: Bed X: 45.000 Y: -5.000 Z: 2.410
< 21:12:55: Bed X: 40.000 Y: -5.000 Z: 2.450
< 21:12:56: Bed X: 35.000 Y: -5.000 Z: 2.490
< 21:12:56: Bed X: 30.000 Y: -5.000 Z: 2.560
< 21:12:57: Bed X: 25.000 Y: -5.000 Z: 2.600
< 21:12:57: Bed X: 20.000 Y: -5.000 Z: 2.650
< 21:12:58: Bed X: 15.000 Y: -5.000 Z: 2.660
< 21:12:59: Bed X: 10.000 Y: -5.000 Z: 2.670
< 21:12:59: Bed X: 5.000 Y: -5.000 Z: 2.650
< 21:13:00: Bed X: 0.000 Y: -5.000 Z: 2.630
< 21:13:00: Bed X: -5.000 Y: -5.000 Z: 2.590
< 21:13:01: Bed X: -10.000 Y: -5.000 Z: 2.550
< 21:13:01: Bed X: -15.000 Y: -5.000 Z: 2.490
< 21:13:02: Bed X: -20.000 Y: -5.000 Z: 2.440
< 21:13:02: Bed X: -25.000 Y: -5.000 Z: 2.370
< 21:13:03: Bed X: -30.000 Y: -5.000 Z: 2.300
< 21:13:03: Bed X: -35.000 Y: -5.000 Z: 2.210
< 21:13:04: Bed X: -40.000 Y: -5.000 Z: 2.110
< 21:13:04: Bed X: -45.000 Y: -5.000 Z: 2.030
< 21:13:05: Bed X: -50.000 Y: -5.000 Z: 1.960
< 21:13:06: Bed X: -55.000 Y: -5.000 Z: 1.870
< 21:13:06: Bed X: -60.000 Y: -5.000 Z: 1.760
< 21:13:07: Bed X: -65.000 Y: -5.000 Z: 1.650
< 21:13:07: Bed X: -70.000 Y: 0.000 Z: 1.610
< 21:13:08: Bed X: -65.000 Y: 0.000 Z: 1.730
< 21:13:08: Bed X: -60.000 Y: 0.000 Z: 1.820
< 21:13:09: Bed X: -55.000 Y: 0.000 Z: 1.920
< 21:13:09: Bed X: -50.000 Y: 0.000 Z: 2.000
< 21:13:10: Bed X: -45.000 Y: 0.000 Z: 2.090
< 21:13:11: Bed X: -40.000 Y: 0.000 Z: 2.180
< 21:13:11: Bed X: -35.000 Y: 0.000 Z: 2.280
< 21:13:12: Bed X: -30.000 Y: 0.000 Z: 2.360
< 21:13:12: Bed X: -25.000 Y: 0.000 Z: 2.460
< 21:13:13: Bed X: -20.000 Y: 0.000 Z: 2.530
< 21:13:13: Bed X: -15.000 Y: 0.000 Z: 2.570
< 21:13:14: Bed X: -10.000 Y: 0.000 Z: 2.650
< 21:13:14: Bed X: -5.000 Y: 0.000 Z: 2.670
< 21:13:15: Bed X: 0.000 Y: 0.000 Z: 2.710
< 21:13:15: Bed X: 5.000 Y: 0.000 Z: 2.740
< 21:13:16: Bed X: 10.000 Y: 0.000 Z: 2.750
< 21:13:16: Bed X: 15.000 Y: 0.000 Z: 2.750
< 21:13:17: Bed X: 20.000 Y: 0.000 Z: 2.750
< 21:13:17: Bed X: 25.000 Y: 0.000 Z: 2.700
```

```
< 21:13:18: Bed X: 30.000 Y: 0.000 Z: 2.660
< 21:13:18: Bed X: 35.000 Y: 0.000 Z: 2.590
< 21:13:19: Bed X: 40.000 Y: 0.000 Z: 2.540
< 21:13:20: Bed X: 45.000 Y: 0.000 Z: 2.540
< 21:13:20: Bed X: 50.000 Y: 0.000 Z: 2.530
< 21:13:21: Bed X: 50.000 Y: 5.000 Z: 2.610
< 21:13:21: Bed X: 45.000 Y: 5.000 Z: 2.620
< 21:13:22: Bed X: 40.000 Y: 5.000 Z: 2.640
< 21:13:22: Bed X: 35.000 Y: 5.000 Z: 2.690
< 21:13:23: Bed X: 30.000 Y: 5.000 Z: 2.730
< 21:13:23: Bed X: 25.000 Y: 5.000 Z: 2.790
< 21:13:24: Bed X: 20.000 Y: 5.000 Z: 2.810
< 21:13:24: Bed X: 15.000 Y: 5.000 Z: 2.820
< 21:13:25: Bed X: 10.000 Y: 5.000 Z: 2.830
< 21:13:25: Bed X: 5.000 Y: 5.000 Z: 2.810
< 21:13:26: Bed X: 0.000 Y: 5.000 Z: 2.780
< 21:13:27: Bed X: -5.000 Y: 5.000 Z: 2.750
< 21:13:27: Bed X: -10.000 Y: 5.000 Z: 2.700
< 21:13:28: Bed X: -15.000 Y: 5.000 Z: 2.660
< 21:13:28: Bed X: -20.000 Y: 5.000 Z: 2.600
< 21:13:29: Bed X: -25.000 Y: 5.000 Z: 2.520
< 21:13:29: Bed X: -30.000 Y: 5.000 Z: 2.450
< 21:13:30: Bed X: -35.000 Y: 5.000 Z: 2.360
< 21:13:30: Bed X: -40.000 Y: 5.000 Z: 2.260
< 21:13:31: Bed X: -45.000 Y: 5.000 Z: 2.180
< 21:13:31: Bed X: -50.000 Y: 5.000 Z: 2.090
< 21:13:32: Bed X: -55.000 Y: 5.000 Z: 2.000
< 21:13:33: Bed X: -60.000 Y: 5.000 Z: 1.890
< 21:13:33: Bed X: -65.000 Y: 5.000 Z: 1.800
< 21:13:34: Bed X: -65.000 Y: 10.000 Z: 1.840
< 21:13:34: Bed X: -60.000 Y: 10.000 Z: 1.940
< 21:13:35: Bed X: -55.000 Y: 10.000 Z: 2.050
< 21:13:35: Bed X: -50.000 Y: 10.000 Z: 2.150
< 21:13:36: Bed X: -45.000 Y: 10.000 Z: 2.230
< 21:13:36: Bed X: -40.000 Y: 10.000 Z: 2.310
< 21:13:37: Bed X: -35.000 Y: 10.000 Z: 2.410
< 21:13:37: Bed X: -30.000 Y: 10.000 Z: 2.510
< 21:13:38: Bed X: -25.000 Y: 10.000 Z: 2.600
< 21:13:38: Bed X: -20.000 Y: 10.000 Z: 2.660
< 21:13:39: Bed X: -15.000 Y: 10.000 Z: 2.720
< 21:13:40: Bed X: -10.000 Y: 10.000 Z: 2.780
< 21:13:40: Bed X: -5.000 Y: 10.000 Z: 2.840
< 21:13:41: Bed X: 0.000 Y: 10.000 Z: 2.860
< 21:13:41: Bed X: 5.000 Y: 10.000 Z: 2.910
< 21:13:42: Bed X: 10.000 Y: 10.000 Z: 2.920
< 21:13:42: Bed X: 15.000 Y: 10.000 Z: 2.920
< 21:13:43: Bed X: 20.000 Y: 10.000 Z: 2.900
< 21:13:43: Bed X: 25.000 Y: 10.000 Z: 2.870
< 21:13:44: Bed X: 30.000 Y: 10.000 Z: 2.830
< 21:13:44: Bed X: 35.000 Y: 10.000 Z: 2.790
< 21:13:45: Bed X: 40.000 Y: 10.000 Z: 2.750
< 21:13:45: Bed X: 45.000 Y: 10.000 Z: 2.740
< 21:13:46: Bed X: 50.000 Y: 10.000 Z: 2.750
< 21:13:47: Bed X: 50.000 Y: 15.000 Z: 2.860
< 21:13:47: Bed X: 45.000 Y: 15.000 Z: 2.840
< 21:13:48: Bed X: 40.000 Y: 15.000 Z: 2.830
< 21:13:48: Bed X: 35.000 Y: 15.000 Z: 2.860
< 21:13:49: Bed X: 30.000 Y: 15.000 Z: 2.880
```

```
< 21:13:49: Bed X: 25.000 Y: 15.000 Z: 2.920
< 21:13:50: Bed X: 20.000 Y: 15.000 Z: 2.950
< 21:13:50: Bed X: 15.000 Y: 15.000 Z: 2.970
< 21:13:51: Bed X: 10.000 Y: 15.000 Z: 2.970
< 21:13:51: Bed X: 5.000 Y: 15.000 Z: 2.970
< 21:13:52: Bed X: 0.000 Y: 15.000 Z: 2.930
< 21:13:52: Bed X: -5.000 Y: 15.000 Z: 2.880
< 21:13:53: Bed X: -10.000 Y: 15.000 Z: 2.840
< 21:13:53: Bed X: -15.000 Y: 15.000 Z: 2.790
< 21:13:54: Bed X: -20.000 Y: 15.000 Z: 2.740
< 21:13:55: Bed X: -25.000 Y: 15.000 Z: 2.650
< 21:13:55: Bed X: -30.000 Y: 15.000 Z: 2.570
< 21:13:56: Bed X: -35.000 Y: 15.000 Z: 2.490
< 21:13:56: Bed X: -40.000 Y: 15.000 Z: 2.380
< 21:13:57: Bed X: -45.000 Y: 15.000 Z: 2.310
< 21:13:57: Bed X: -50.000 Y: 15.000 Z: 2.220
< 21:13:58: Bed X: -55.000 Y: 15.000 Z: 2.110
< 21:13:58: Bed X: -60.000 Y: 15.000 Z: 2.000
< 21:13:59: Bed X: -65.000 Y: 15.000 Z: 1.910
< 21:13:59: Bed X: -65.000 Y: 20.000 Z: 1.920
< 21:14:00: Bed X: -60.000 Y: 20.000 Z: 2.040
< 21:14:01: Bed X: -55.000 Y: 20.000 Z: 2.160
< 21:14:01: Bed X: -50.000 Y: 20.000 Z: 2.280
< 21:14:02: Bed X: -45.000 Y: 20.000 Z: 2.370
< 21:14:02: Bed X: -40.000 Y: 20.000 Z: 2.450
< 21:14:03: Bed X: -35.000 Y: 20.000 Z: 2.530
< 21:14:03: Bed X: -30.000 Y: 20.000 Z: 2.630
< 21:14:04: Bed X: -25.000 Y: 20.000 Z: 2.720
< 21:14:04: Bed X: -20.000 Y: 20.000 Z: 2.780
< 21:14:05: Bed X: -15.000 Y: 20.000 Z: 2.860
< 21:14:05: Bed X: -10.000 Y: 20.000 Z: 2.920
< 21:14:06: Bed X: -5.000 Y: 20.000 Z: 2.970
< 21:14:06: Bed X: 0.000 Y: 20.000 Z: 3.010
< 21:14:07: Bed X: 5.000 Y: 20.000 Z: 3.050
< 21:14:07: Bed X: 10.000 Y: 20.000 Z: 3.050
< 21:14:08: Bed X: 15.000 Y: 20.000 Z: 3.070
< 21:14:09: Bed X: 20.000 Y: 20.000 Z: 3.050
< 21:14:09: Bed X: 25.000 Y: 20.000 Z: 3.020
< 21:14:10: Bed X: 30.000 Y: 20.000 Z: 2.980
< 21:14:10: Bed X: 35.000 Y: 20.000 Z: 2.960
< 21:14:11: Bed X: 40.000 Y: 20.000 Z: 2.920
< 21:14:11: Bed X: 45.000 Y: 20.000 Z: 2.930
< 21:14:12: Bed X: 50.000 Y: 20.000 Z: 2.950
< 21:14:12: Bed X: 50.000 Y: 25.000 Z: 3.080
< 21:14:13: Bed X: 45.000 Y: 25.000 Z: 3.010
< 21:14:13: Bed X: 40.000 Y: 25.000 Z: 3.010
< 21:14:14: Bed X: 35.000 Y: 25.000 Z: 3.020
< 21:14:15: Bed X: 30.000 Y: 25.000 Z: 3.040
< 21:14:15: Bed X: 25.000 Y: 25.000 Z: 3.060
< 21:14:16: Bed X: 20.000 Y: 25.000 Z: 3.090
< 21:14:16: Bed X: 15.000 Y: 25.000 Z: 3.100
< 21:14:17: Bed X: 10.000 Y: 25.000 Z: 3.100
< 21:14:17: Bed X: 5.000 Y: 25.000 Z: 3.080
< 21:14:18: Bed X: 0.000 Y: 25.000 Z: 3.050
< 21:14:18: Bed X: -5.000 Y: 25.000 Z: 3.010
< 21:14:19: Bed X: -10.000 Y: 25.000 Z: 3.030
< 21:14:19: Bed X: -15.000 Y: 25.000 Z: 2.900
< 21:14:20: Bed X: -20.000 Y: 25.000 Z: 2.840
```



```
< 21:14:20: Bed X: -20.000 Y: 25.000 Z: 2.840
< 21:14:20: Bed X: -25.000 Y: 25.000 Z: 2.780
< 21:14:21: Bed X: -30.000 Y: 25.000 Z: 2.680
< 21:14:22: Bed X: -35.000 Y: 25.000 Z: 2.580
< 21:14:22: Bed X: -40.000 Y: 25.000 Z: 2.500
< 21:14:23: Bed X: -45.000 Y: 25.000 Z: 2.410
< 21:14:23: Bed X: -50.000 Y: 25.000 Z: 2.310
< 21:14:24: Bed X: -55.000 Y: 25.000 Z: 2.230
< 21:14:24: Bed X: -60.000 Y: 25.000 Z: 2.120
< 21:14:25: Bed X: -65.000 Y: 25.000 Z: 2.010
< 21:14:25: Bed X: -60.000 Y: 30.000 Z: 2.150
< 21:14:26: Bed X: -55.000 Y: 30.000 Z: 2.260
< 21:14:27: Bed X: -50.000 Y: 30.000 Z: 2.360
< 21:14:27: Bed X: -45.000 Y: 30.000 Z: 2.460
< 21:14:28: Bed X: -40.000 Y: 30.000 Z: 2.550
< 21:14:28: Bed X: -35.000 Y: 30.000 Z: 2.640
< 21:14:29: Bed X: -30.000 Y: 30.000 Z: 2.720
< 21:14:29: Bed X: -25.000 Y: 30.000 Z: 2.810
< 21:14:30: Bed X: -20.000 Y: 30.000 Z: 2.890
< 21:14:30: Bed X: -15.000 Y: 30.000 Z: 2.960
< 21:14:31: Bed X: -10.000 Y: 30.000 Z: 3.030
< 21:14:31: Bed X: -5.000 Y: 30.000 Z: 3.070
< 21:14:32: Bed X: 0.000 Y: 30.000 Z: 3.110
< 21:14:32: Bed X: 5.000 Y: 30.000 Z: 3.150
< 21:14:33: Bed X: 10.000 Y: 30.000 Z: 3.150
< 21:14:33: Bed X: 15.000 Y: 30.000 Z: 3.160
< 21:14:34: Bed X: 20.000 Y: 30.000 Z: 3.150
< 21:14:34: Bed X: 25.000 Y: 30.000 Z: 3.130
< 21:14:35: Bed X: 30.000 Y: 30.000 Z: 3.110
< 21:14:36: Bed X: 35.000 Y: 30.000 Z: 3.100
< 21:14:36: Bed X: 40.000 Y: 30.000 Z: 3.090
< 21:14:37: Bed X: 45.000 Y: 30.000 Z: 3.120
< 21:14:37: Bed X: 50.000 Y: 30.000 Z: 3.140
< 21:14:38: Bed X: 50.000 Y: 35.000 Z: 3.210
< 21:14:38: Bed X: 45.000 Y: 35.000 Z: 3.190
< 21:14:39: Bed X: 40.000 Y: 35.000 Z: 3.160
< 21:14:39: Bed X: 35.000 Y: 35.000 Z: 3.140
< 21:14:40: Bed X: 30.000 Y: 35.000 Z: 3.160
< 21:14:40: Bed X: 25.000 Y: 35.000 Z: 3.170
< 21:14:41: Bed X: 20.000 Y: 35.000 Z: 3.180
< 21:14:41: Bed X: 15.000 Y: 35.000 Z: 3.190
< 21:14:42: Bed X: 10.000 Y: 35.000 Z: 3.190
< 21:14:43: Bed X: 5.000 Y: 35.000 Z: 3.170
< 21:14:43: Bed X: 0.000 Y: 35.000 Z: 3.140
< 21:14:44: Bed X: -5.000 Y: 35.000 Z: 3.100
< 21:14:44: Bed X: -10.000 Y: 35.000 Z: 3.060
< 21:14:45: Bed X: -15.000 Y: 35.000 Z: 3.010
< 21:14:45: Bed X: -20.000 Y: 35.000 Z: 2.930
< 21:14:46: Bed X: -25.000 Y: 35.000 Z: 2.850
< 21:14:46: Bed X: -30.000 Y: 35.000 Z: 2.770
< 21:14:47: Bed X: -35.000 Y: 35.000 Z: 2.680
< 21:14:47: Bed X: -40.000 Y: 35.000 Z: 2.600
< 21:14:48: Bed X: -45.000 Y: 35.000 Z: 2.520
< 21:14:49: Bed X: -50.000 Y: 35.000 Z: 2.410
< 21:14:49: Bed X: -55.000 Y: 35.000 Z: 2.310
< 21:14:50: Bed X: -60.000 Y: 35.000 Z: 2.200
< 21:14:50: Bed X: -55.000 Y: 40.000 Z: 2.330
< 21:14:51: Bed X: -50.000 Y: 40.000 Z: 2.450
```

```
< 21:14:51: Bed X: -45.000 Y: 40.000 Z: 2.530
< 21:14:52: Bed X: -40.000 Y: 40.000 Z: 2.650
< 21:14:52: Bed X: -35.000 Y: 40.000 Z: 2.720
< 21:14:53: Bed X: -30.000 Y: 40.000 Z: 2.810
< 21:14:53: Bed X: -25.000 Y: 40.000 Z: 2.900
< 21:14:54: Bed X: -20.000 Y: 40.000 Z: 2.980
< 21:14:54: Bed X: -15.000 Y: 40.000 Z: 3.040
< 21:14:55: Bed X: -10.000 Y: 40.000 Z: 3.100
< 21:14:56: Bed X: -5.000 Y: 40.000 Z: 3.150
< 21:14:56: Bed X: 0.000 Y: 40.000 Z: 3.180
< 21:14:57: Bed X: 5.000 Y: 40.000 Z: 3.200
< 21:14:57: Bed X: 10.000 Y: 40.000 Z: 3.230
< 21:14:58: Bed X: 15.000 Y: 40.000 Z: 3.240
< 21:14:58: Bed X: 20.000 Y: 40.000 Z: 3.230
< 21:14:59: Bed X: 25.000 Y: 40.000 Z: 3.230
< 21:14:59: Bed X: 30.000 Y: 40.000 Z: 3.230
< 21:15:00: Bed X: 35.000 Y: 40.000 Z: 3.220
< 21:15:00: Bed X: 40.000 Y: 40.000 Z: 3.250
< 21:15:01: Bed X: 45.000 Y: 40.000 Z: 3.260
< 21:15:01: Bed X: 50.000 Y: 40.000 Z: 3.280
< 21:15:02: Bed X: 50.000 Y: 45.000 Z: 3.330
< 21:15:03: Bed X: 45.000 Y: 45.000 Z: 3.310
< 21:15:03: Bed X: 40.000 Y: 45.000 Z: 3.290
< 21:15:04: Bed X: 35.000 Y: 45.000 Z: 3.270
< 21:15:04: Bed X: 30.000 Y: 45.000 Z: 3.250
< 21:15:05: Bed X: 25.000 Y: 45.000 Z: 3.260
< 21:15:05: Bed X: 20.000 Y: 45.000 Z: 3.260
< 21:15:06: Bed X: 15.000 Y: 45.000 Z: 3.260
< 21:15:06: Bed X: 10.000 Y: 45.000 Z: 3.240
< 21:15:07: Bed X: 5.000 Y: 45.000 Z: 3.240
< 21:15:07: Bed X: 0.000 Y: 45.000 Z: 3.210
< 21:15:08: Bed X: -5.000 Y: 45.000 Z: 3.190
< 21:15:08: Bed X: -10.000 Y: 45.000 Z: 3.130
< 21:15:09: Bed X: -15.000 Y: 45.000 Z: 3.080
< 21:15:10: Bed X: -20.000 Y: 45.000 Z: 3.010
< 21:15:10: Bed X: -25.000 Y: 45.000 Z: 2.930
< 21:15:11: Bed X: -30.000 Y: 45.000 Z: 2.860
< 21:15:11: Bed X: -35.000 Y: 45.000 Z: 2.790
< 21:15:12: Bed X: -40.000 Y: 45.000 Z: 2.670
< 21:15:12: Bed X: -45.000 Y: 45.000 Z: 2.580
< 21:15:13: Bed X: -50.000 Y: 45.000 Z: 2.470
< 21:15:13: Bed X: -45.000 Y: 50.000 Z: 2.620
< 21:15:14: Bed X: -40.000 Y: 50.000 Z: 2.720
< 21:15:14: Bed X: -35.000 Y: 50.000 Z: 2.810
< 21:15:15: Bed X: -30.000 Y: 50.000 Z: 2.880
< 21:15:16: Bed X: -25.000 Y: 50.000 Z: 2.960
< 21:15:16: Bed X: -20.000 Y: 50.000 Z: 3.030
< 21:15:17: Bed X: -15.000 Y: 50.000 Z: 3.090
< 21:15:17: Bed X: -10.000 Y: 50.000 Z: 3.150
< 21:15:18: Bed X: -5.000 Y: 50.000 Z: 3.200
< 21:15:18: Bed X: 0.000 Y: 50.000 Z: 3.230
< 21:15:19: Bed X: 5.000 Y: 50.000 Z: 3.260
< 21:15:19: Bed X: 10.000 Y: 50.000 Z: 3.260
< 21:15:20: Bed X: 15.000 Y: 50.000 Z: 3.270
< 21:15:20: Bed X: 20.000 Y: 50.000 Z: 3.290
< 21:15:21: Bed X: 25.000 Y: 50.000 Z: 3.290
< 21:15:21: Bed X: 30.000 Y: 50.000 Z: 3.290
< 21:15:22: Bed X: 35.000 Y: 50.000 Z: 3.330
```

```
< 21:15:22: Bed X: 40.000 Y: 50.000 Z: 3.350
< 21:15:23: Bed X: 45.000 Y: 50.000 Z: 3.370
" " "
```

Format the raw data as x, y, z vectors.

In [4]:

```
lines = in_data.strip().splitlines()

x = []
y = []
z = []
for line in lines:
    cols = line.split()
    x.append(float(cols[4]))
    y.append(float(cols[6]))
    z.append(float(cols[8]))
x = np.array(x)
y = np.array(y)
z = np.array(z)
```

Set x and y axis offsets (X_PROBE_OFFSET_FROM_EXTRUDER and Y_PROBE_OFFSET_FROM_EXTRUDER)

In [5]:

```
# note that the offset values actually aren't used in delta leveling, but
# we want to use them to improve calibration accuracy

x_offset = 0.
y_offset = -17.5

x = x + x_offset
y = y + y_offset
```

In [6]:

```
# limit the radius of the analysis to bed centre
d = np.sqrt(x**2 + y**2)

x = x[d < 50]
y = y[d < 50]
z = z[d < 50]
```

z values acquired:

In [7]:

```
z
```

Out[7]:

```
array([ 2.11,  2.15,  2.21,  2.2 ,  2.22,  2.23,  2.23,  2.24,
        2.28,
```

2.06,	2.28,	2.31,	2.3 ,	2.28,	2.26,	2.21,	2.17,	2.12,
2.39,	2.07,	2.13,	2.2 ,	2.26,	2.3 ,	2.35,	2.38,	2.4 ,
2.5 ,	2.4 ,	2.37,	2.33,	2.28,	2.31,	2.38,	2.43,	2.47,
2.15,	2.49,	2.48,	2.44,	2.38,	2.38,	2.33,	2.29,	2.22,
2.53,	2.06,	2.04,	2.13,	2.22,	2.3 ,	2.37,	2.41,	2.47,
2.35,	2.54,	2.56,	2.59,	2.6 ,	2.57,	2.53,	2.48,	2.41,
2.63,	2.45,	2.49,	2.56,	2.6 ,	2.65,	2.66,	2.67,	2.65,
2.09,	2.59,	2.55,	2.49,	2.44,	2.37,	2.3 ,	2.21,	2.11,
2.71,	2.18,	2.28,	2.36,	2.46,	2.53,	2.57,	2.65,	2.67,
2.54,	2.74,	2.75,	2.75,	2.75,	2.7 ,	2.66,	2.59,	2.54,
2.81,	2.62,	2.64,	2.69,	2.73,	2.79,	2.81,	2.82,	2.83,
2.26,	2.78,	2.75,	2.7 ,	2.66,	2.6 ,	2.52,	2.45,	2.36,
2.78,	2.18,	2.23,	2.31,	2.41,	2.51,	2.6 ,	2.66,	2.72,
2.79,	2.84,	2.86,	2.91,	2.92,	2.92,	2.9 ,	2.87,	2.83,
2.97,	2.75,	2.74,	2.84,	2.83,	2.86,	2.88,	2.92,	2.95,
2.57,	2.97,	2.97,	2.93,	2.88,	2.84,	2.79,	2.74,	2.65,
2.78,	2.49,	2.38,	2.31,	2.37,	2.45,	2.53,	2.63,	2.72,
3.02,	2.86,	2.92,	2.97,	3.01,	3.05,	3.05,	3.07,	3.05,
3.06,	2.98,	2.96,	2.92,	2.93,	3.01,	3.01,	3.02,	3.04,
2.84,	3.09,	3.1 ,	3.1 ,	3.08,	3.05,	3.01,	3.03,	2.9 ,
2.72,	2.78,	2.68,	2.58,	2.5 ,	2.41,	2.46,	2.55,	2.64,
3.16,	2.81,	2.89,	2.96,	3.03,	3.07,	3.11,	3.15,	3.15,
3.14,	3.15,	3.13,	3.11,	3.1 ,	3.09,	3.12,	3.19,	3.16,
3.06,	3.16,	3.17,	3.18,	3.19,	3.19,	3.17,	3.14,	3.1 ,
2.72,	3.01,	2.93,	2.85,	2.77,	2.68,	2.6 ,	2.52,	2.65,
3.23,	2.81,	2.9 ,	2.98,	3.04,	3.1 ,	3.15,	3.18,	3.2 ,
3.25,	3.24,	3.23,	3.23,	3.23,	3.22,	3.25,	3.29,	3.27,
3.08,	3.26,	3.26,	3.26,	3.24,	3.24,	3.21,	3.19,	3.13,
	3.01,	2.93,	2.86,	2.79,	2.67,	2.81,	2.88,	2.96,

```
3.03,
      3.09,  3.15,  3.2 ,  3.23,  3.26,  3.26,  3.27,  3.29,
3.29,
      3.29,  3.33])
```

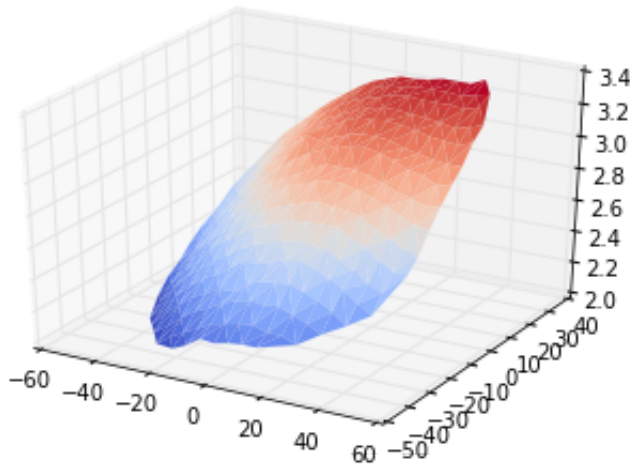
Plane calibration

First, let's level the bed. Optimally, you should adjust physical bed leveling, but we can also do it in the software. Note that this is precisely what the "G29" command does.

Plot the raw values. Nice!

In [8]:

```
fig = plt.figure()
ax = fig.gca(projection='3d')
surf = ax.plot_trisurf(x, y, z, cmap=cm.coolwarm, linewidth=0)
```



Solve (OK, we're lazy - optimize) the plane equation.

In [9]:

```
def f(k_x, k_y, b):
    return z + k_x * x + k_y * y + b
```

In [10]:

```
def fopt(k):
    k_x, k_y, b = k
    return f(k_x, k_y, b)
```

In [11]:

```
res = leastsq(fopt, [0, 0, 0])
```

In [12]:

```
res
```

Out[12]:

```
(array([-0.00570786, -0.01282366, -2.78900522]), 3)
```

In [13]:

```
k_x, k_y, b = res[0]
```

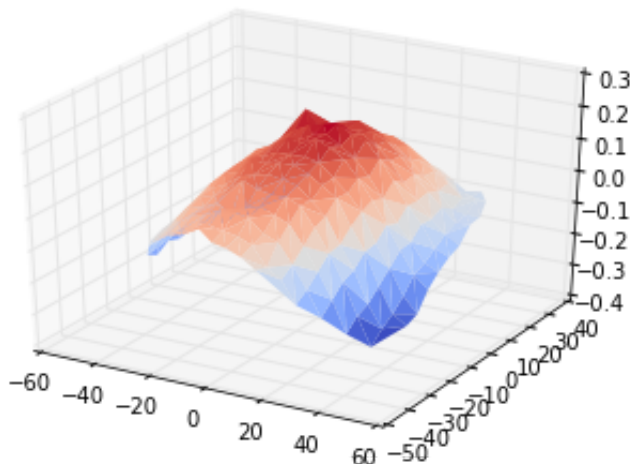
Once we have flattened the print bed, this is the residual curve:

In [14]:

```
z2 = f(k_x, k_y, b)
```

In [15]:

```
fig = plt.figure()
ax = fig.gca(projection='3d')
surf = ax.plot_trisurf(x, y, z2, cmap=cm.coolwarm, linewidth=0)
```



Cool, eh? Verify that the center point (highest or lowest point of the dome or the cup) is really close to 0, 0 - if not, adjust the offset values.

In my example, the curve has a distinct saddle-like shape. This is most likely due to some skew in printer frame geometry - I'm still finishing the printer construction and haven't had time to fix everything. I'll ignore that for the moment.

Geometry calibration

Next, let's flatten the residual curve. We'll assume that the diagonal rod length is known and accurate (add the carbon rod length to the steel ball diameter, in case of the magnetic arms). Hence, we'll only have to solve the delta radius error.

The delta printer kinematics is described here:

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http://reprap.org/wiki/File:Rostock_Delta_Kinematics_3.pdf
(http://reprap.org/wiki/File:Rostock_Delta_Kinematics_3.pdf)

In [16]:

```
# Known variables
# DELTA_DIAGONAL_ROD
L = 210.0
# DELTA_RADIUS
DR = 105.3
```

Inverse kinematics equations:

In [17]:

```
def inv_kin(L, DR, x, y):
    Avx = 0
    Avy = DR

    Bvx = DR * np.cos(30.0 / (2*np.pi))
    Bvy = -DR * np.sin(30.0 / (2*np.pi))

    Cvx = -DR * np.cos(30.0 / (2*np.pi))
    Cvy = -DR * np.sin(30.0 / (2*np.pi))

    Acz = np.sqrt(L**2 - (x - Avx)**2 - (y - Avy)**2)
    Bcz = np.sqrt(L**2 - (x - Bvx)**2 - (y - Bvy)**2)
    Ccz = np.sqrt(L**2 - (x - Cvx)**2 - (y - Cvy)**2)

    return Acz, Bcz, Ccz
```

In [18]:

```
Acz, Bcz, Ccz = inv_kin(L, DR, x, y)
```

For true L and DR, these return the zero height locations. For our imperfect dimensions, we need to calculate the actual x,y,z coordinates with forward kinematics. Since we're lazy, we solve the forward kinematic equations numerically from the inverse ones.

In [19]:

```
def fwd_kin_scalar(L, DR, Az, Bz, Cz):

    # now, solve the inv_kin equation:
    # Acz, Bcz, Ccz = inv_kin(L, DR, x, y, z)
    # for x, y, z

    def fopt(x_):
        x, y, z = x_
        Aczg, Bczg, Cczg = inv_kin(L, DR, x, y)
        #print("F: ", Aczg, Bczg, Cczg)
        return [Aczg+z-Az, Bczg+z-Bz, Cczg+z-Cz]
    res = leastsq(fopt, [0, 0, 1])
    x, y, z = res[0]

    return x, y, z
fwd_kin = np.vectorize(fwd_kin_scalar)
```

Test fwd_kin correctness

In [20]:

```
def test_fwd_kin_reciprocity():
    xs = np.linspace(-100, 70, 51)
    ys = np.linspace(60, -50, 51)
    zs = np.linspace(0, 50, 51)
    for i, (x, y, z) in enumerate(zip(xs, ys, zs)):
        Acz, Bcz, Ccz = inv_kin(L, DR, x, y)
        xi, yi, zi = fwd_kin(L, DR, Acz+z, Bcz+z, Ccz+z)
        assert np.abs(x-xi) < 1e-5
        assert np.abs(y-yi) < 1e-5
        assert np.abs(z-zi) < 1e-5
test_fwd_kin_reciprocity()
```

Now for the beef. Define the error incurred by incorrect delta radius value.

In [21]:

```
def z_err(e):
    # idealized inverse kinematics (this is what the firmware calculates)
    Acz, Bcz, Ccz = inv_kin(L, DR, x, y)
    # and this is where the extruder ends up in real world
    x_e, y_e, z_e = fwd_kin(L, DR+e, Acz, Bcz, Ccz)

    return z_e
```

Define the optimization function.

In [22]:

```
def fopt(x):  
    e, = x  
    zerr = Z_err(e)  
    # ignore any constant offset  
    zerr = zerr - np.mean(zerr)  
    return np.sum((z2-zerr)**2)
```

Run the optimization. This might take a few moments.

In [23]:

```
res2 = minimize(fopt,  
                np.array([-2]),  
                method='COBYLA',  
                options={"disp": True})  
res2
```

Out[23]:

```
maxcv: 0.0  
    x: array([ 2.22597422])  
message: 'Optimization terminated successfully.'  
status: 1  
    fun: 1.4616350668425031  
success: True  
    nfev: 26
```

In [24]:

```
e, = res2.x  
e
```

Out[24]:

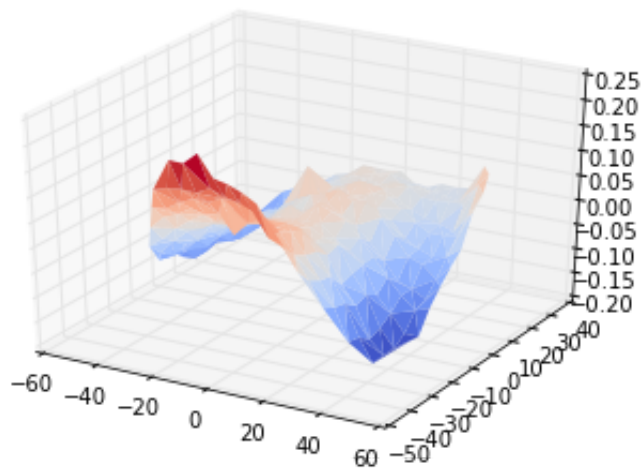
```
2.2259742187499998
```

In [25]:

```
zerr = Z_err(e)  
zerr = zerr - np.mean(zerr)
```

In [26]:

```
fig = plt.figure()
ax = fig.gca(projection='3d')
surf = ax.plot_trisurf(x, y, z2-zerr, cmap=cm.coolwarm, linewidth=0)
```



Note the z axis values. The residual has flattened quite a bit. Take the e value and add that to DELTA_RADIUS and upload the new firmware. You still need to re-run calibration and most likely also readjust Z_PROBE_OFFSET_FROM_EXTRUDER to ensure you get a perfect first layer height.