



# Directional Magnetic Bearing: Revising and Updating Original Concept

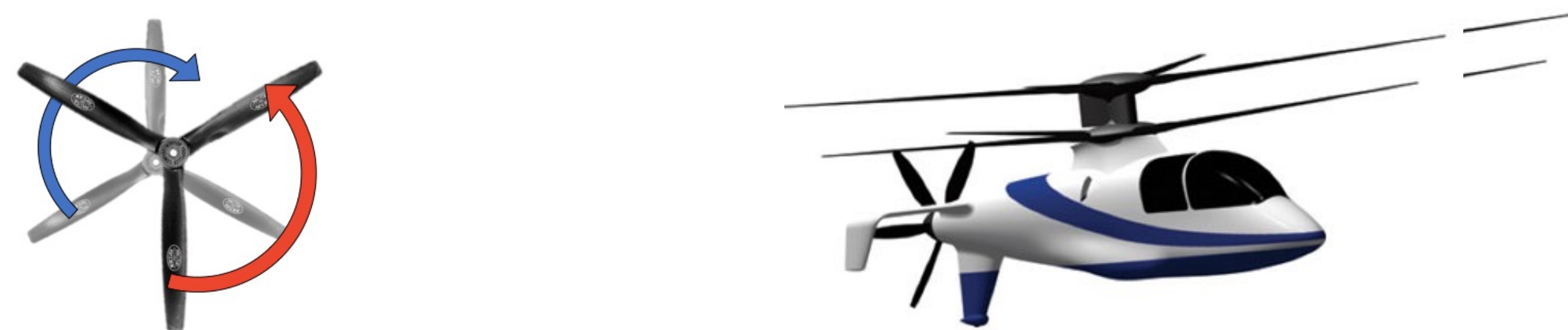
Martin Dimo, Matthew Diamond, Bill Welsh\*

Berkshire School, Sheffield MA; Lockheed Martin, Stratford CT

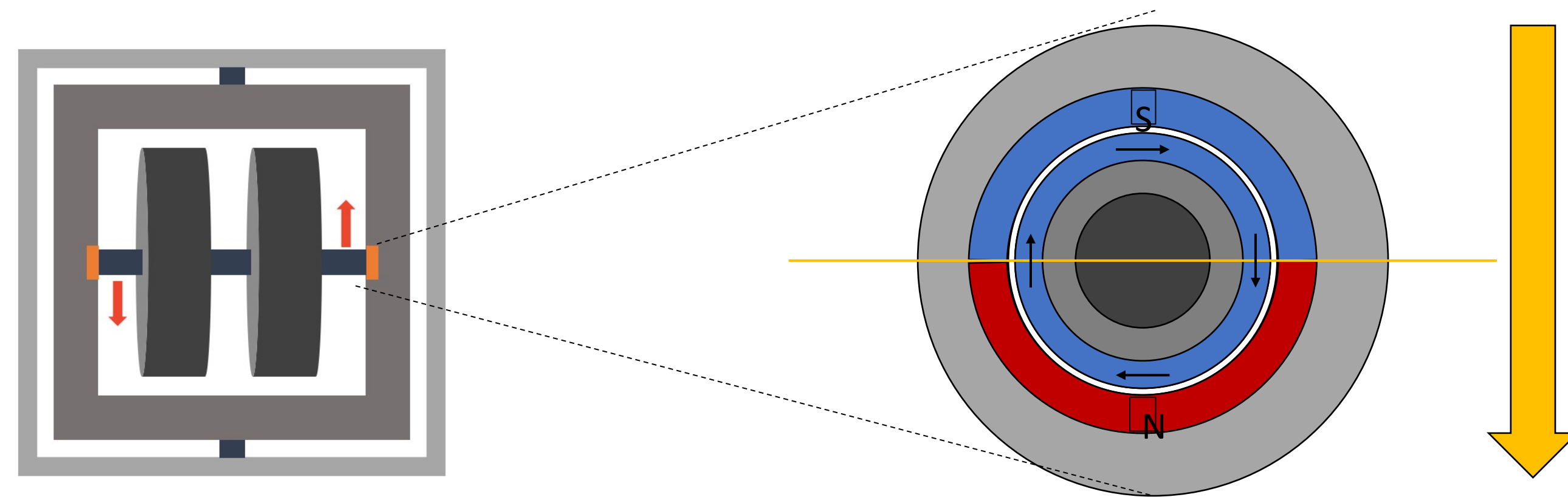


## Introduction

The Sikorsky X2 is an experimental helicopter designed for high speeds that features coaxial rotors and a horizontal propeller. Due to unstable rotation in the opposing rotors, a gyroscope was under development to relieve vibrations in the rotating shaft. However, the gyroscope itself experienced instability due to opposing forces of lift.

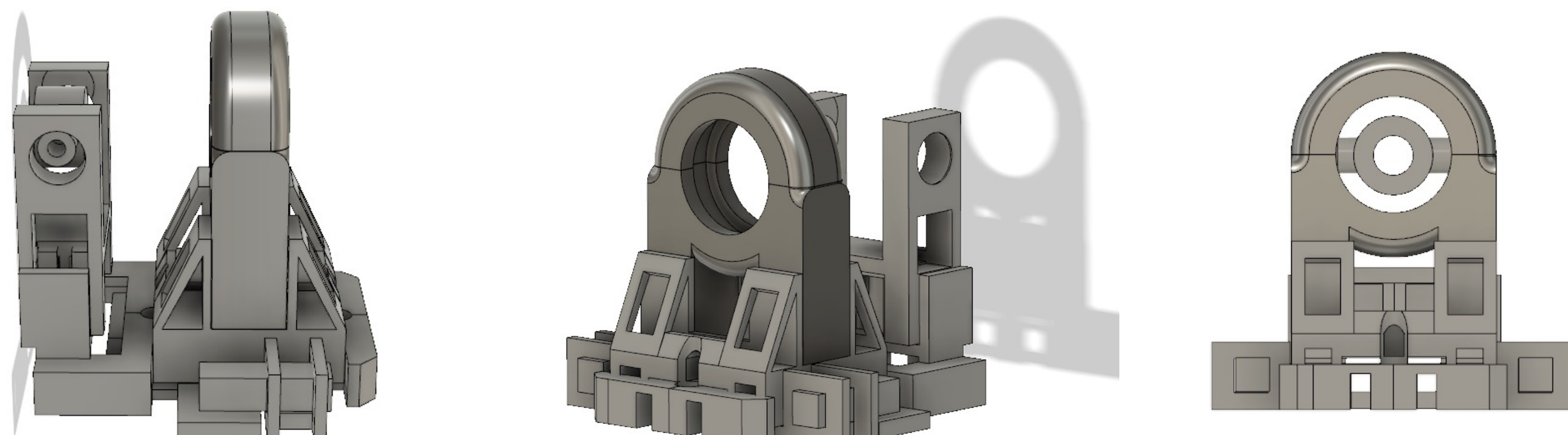


A magnetic bearing was proposed to counter the vertical rotation of the inner shaft of the gyroscope in order to increase stability and efficiency.

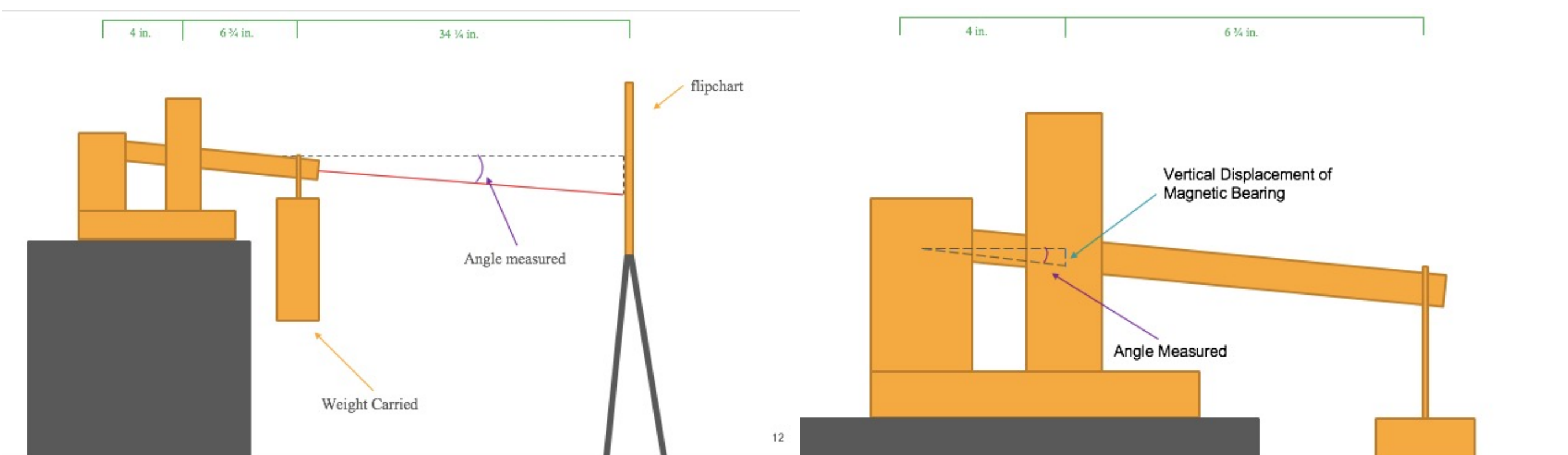


## Revision Process

Based off Matthew Diamond '18 CAD models, a smoother, more massive model was conceived. The outer magnetic ring was altered to house the arc magnets and the rest of the rig was then scaled to fit the greater circumference.



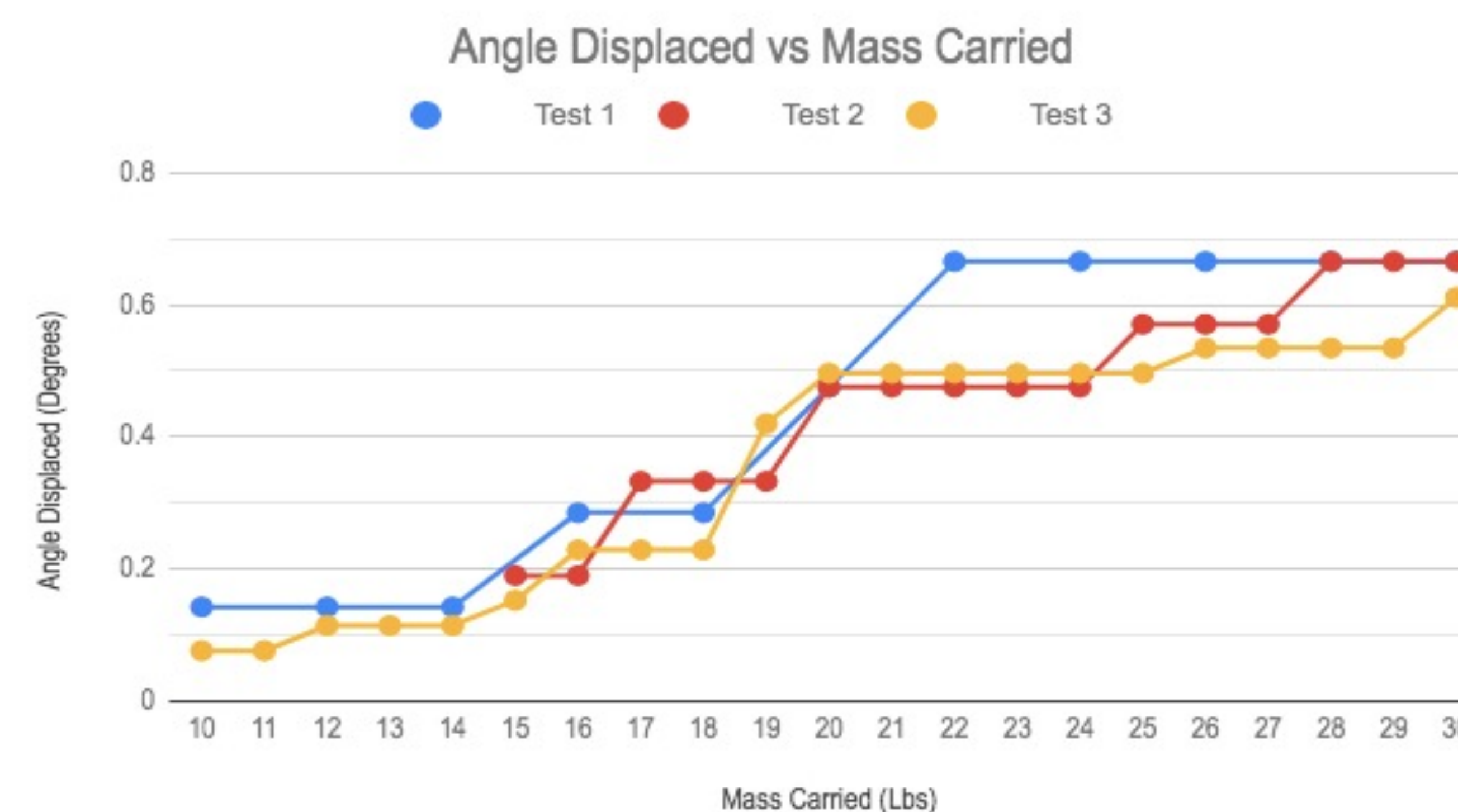
## Results



Based on the visuals provided above, one can understand the procedure for determining angle at which the shaft tilts and what vertical distance that angle yields respectively.

| TOTAL | TEST 1 |              |                     |                             | TEST 2              |                             |                     |                             | TEST 3              |                             |                     |                             |
|-------|--------|--------------|---------------------|-----------------------------|---------------------|-----------------------------|---------------------|-----------------------------|---------------------|-----------------------------|---------------------|-----------------------------|
|       | Lb     | N            | angle measure (deg) | vertical displacement (in.) | angle measure (deg) | vertical displacement (in.) | angle measure (deg) | vertical displacement (in.) | angle measure (deg) | vertical displacement (in.) | angle measure (deg) | vertical displacement (in.) |
| 0     | 0      | 0            | 0                   | 0                           | 0                   | 0                           | 0                   | 0                           | 0                   | 0                           | 0                   | 0                           |
| 10    | 44.5   | 0.1426447995 |                     | 0.009958506224              |                     |                             | 0.07639432741       | 0.005333333333              |                     |                             |                     |                             |
| 11    | 48.95  |              |                     |                             |                     |                             | 0.07639432741       | 0.005333333333              |                     |                             |                     |                             |
| 12    | 53.4   | 0.1426447995 |                     | 0.009958506224              |                     |                             | 0.1145914062        | 0.008                       |                     |                             |                     |                             |
| 13    | 57.85  |              |                     |                             |                     |                             | 0.1145914062        | 0.008                       |                     |                             |                     |                             |
| 14    | 62.3   | 0.1426447995 |                     | 0.009958506224              |                     |                             | 0.1145914062        | 0.008                       |                     |                             |                     |                             |
| 15    | 66.75  |              |                     |                             | 0.1901927604        | 0.0132780083                | 0.1527883832        | 0.01066666667               |                     |                             |                     |                             |
| 16    | 71.2   | 0.2852878308 |                     | 0.01991701245               | 0.1901927604        | 0.0132780083                | 0.2291818958        | 0.016                       |                     |                             |                     |                             |
| 17    | 75.65  |              |                     |                             | 0.3328348093        | 0.02323651452               | 0.2291818958        | 0.016                       |                     |                             |                     |                             |
| 18    | 80.1   | 0.2852878308 |                     | 0.01991701245               | 0.3328348093        | 0.02323651452               | 0.2291818958        | 0.016                       |                     |                             |                     |                             |
| 19    | 84.55  |              |                     |                             | 0.3328348093        | 0.02323651452               | 0.4201615181        | 0.02933333333               |                     |                             |                     |                             |
| 20    | 89     | 0.4754727324 |                     | 0.03319502075               | 0.4754727324        | 0.03319502075               | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 21    | 93.45  |              |                     |                             | 0.4754727324        | 0.03319502075               | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 22    | 97.9   | 0.6656471569 |                     | 0.04647302905               | 0.4754727324        | 0.03319502075               | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 23    | 102.35 |              |                     |                             | 0.4754727324        | 0.03319502075               | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 24    | 106.8  | 0.6656471569 |                     | 0.04647302905               | 0.4754727324        | 0.03319502075               | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 25    | 111.25 |              |                     |                             | 0.5705615162        | 0.0398340249                | 0.4965509905        | 0.03466666667               |                     |                             |                     |                             |
| 26    | 115.7  | 0.6656471569 |                     | 0.04647302905               | 0.5705615162        | 0.0398340249                | 0.5347450817        | 0.03733333333               |                     |                             |                     |                             |
| 27    | 120.15 |              |                     |                             | 0.5705615162        | 0.0398340249                | 0.5347450817        | 0.03733333333               |                     |                             |                     |                             |
| 28    | 124.6  | 0.6656471569 |                     | 0.04647302905               | 0.6656471569        | 0.04647302905               | 0.5347450817        | 0.03733333333               |                     |                             |                     |                             |
| 29    | 129.05 |              |                     |                             | 0.6656471569        | 0.04647302905               | 0.5347450817        | 0.03733333333               |                     |                             |                     |                             |
| 30    | 133.5  | 0.6656471569 |                     | 0.04647302905               | 0.6656471569        | 0.04647302905               | 0.6111318044        | 0.04266666667               |                     |                             |                     |                             |

The goal was to discover the force applied at which the net force within the bearing equaled zero. This would happen when the bearing shifted from being in contact with the upper hemisphere the lower hemisphere, meaning the magnets have capped out on their magnetic load.

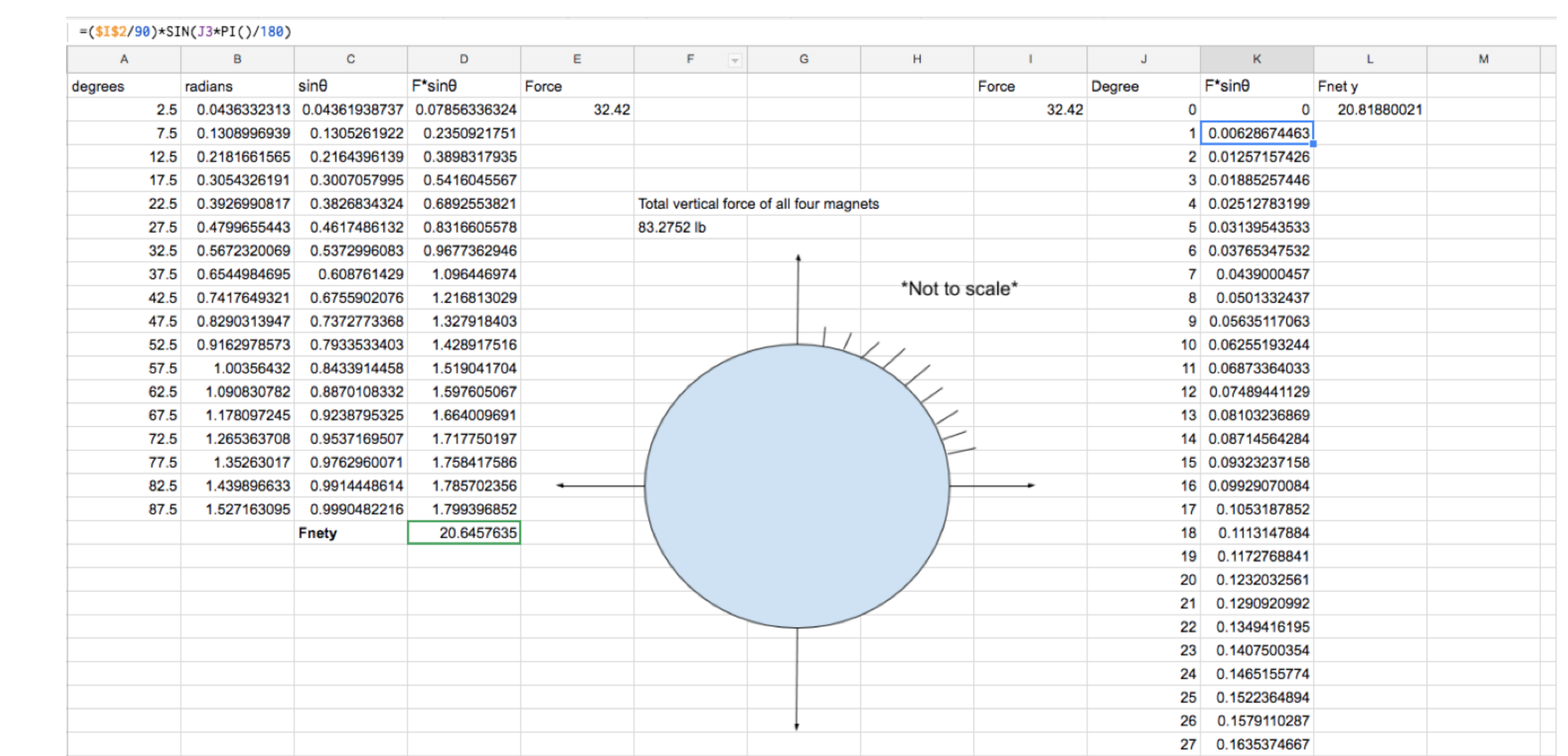


## Comparing Performance

The data Matthew Diamond collected indicated that the bearing tipped over at approximately 15.5 Newtons.

|    | A                                     | B | C | D | E                     | F                            | G       | H      | I                     | J                            | K      | L       | M                     | N                            | O    | P      | Q       | R      |
|----|---------------------------------------|---|---|---|-----------------------|------------------------------|---------|--------|-----------------------|------------------------------|--------|---------|-----------------------|------------------------------|------|--------|---------|--------|
| 1  | mass of tube + rope + laser = 419.4 g |   |   |   | mass hangin Force (N) | distance from level (meters) |         |        | mass hangin Force (N) | distance from level (meters) |        |         | mass hangin Force (N) | distance from level (meters) |      |        |         |        |
| 2  |                                       |   |   |   | 0                     | 0                            | 0       | 0.066  |                       | 0                            | 0      | 0.043   |                       | 0                            | 0    | 0      | 0.066   |        |
| 3  | short triangle = .0775 m              |   |   |   | 100                   | 0.5194                       | 5.09012 | 0.065  |                       | 100                          | 0.5194 | 5.09012 | 0.0355                |                              | 100  | 0.5194 | 5.09012 | 0.0355 |
| 4  |                                       |   |   |   | 200                   | 0.6194                       | 6.07012 | 0.061  |                       | 200                          | 0.6194 | 6.07012 | 0.0312                |                              | 200  | 0.6194 | 6.07012 | 0.0312 |
| 5  | full distance = 7.33 m                |   |   |   | 300                   | 0.7194                       | 7.05012 | 0.052  |                       | 300                          | 0.7194 | 7.05012 | 0.0312                |                              | 300  | 0.7194 | 7.05012 | 0.0312 |
| 6  |                                       |   |   |   | 400                   | 0.8194                       | 8.03012 | 0.052  |                       | 400                          | 0.8194 | 8.03012 | 0.027                 |                              | 400  | 0.8194 | 8.03012 | 0.027  |
| 7  |                                       |   |   |   | 500                   | 0.9194                       | 9.01012 | 0.052  |                       | 500                          | 0.9194 | 9.01012 | 0.027                 |                              | 500  | 0.9194 | 9.01012 | 0.027  |
| 8  |                                       |   |   |   | 600                   | 1.0194                       | 9.99012 | 0.052  |                       | 600                          | 1.0194 | 9.99012 | 0.027                 |                              | 600  | 1.0194 | 9.99012 | 0.027  |
| 9  |                                       |   |   |   | 700                   | 1.1194                       | 10.9701 | 0.042  |                       | 700                          | 1.1194 | 10.9701 | 0.0225                |                              | 700  | 1.1194 | 10.9701 | 0.0225 |
| 10 |                                       |   |   |   | 800                   | 1.2194                       | 11.9501 | 0.042  |                       | 800                          | 1.2194 | 11.9501 | 0.0225                |                              | 800  | 1.2194 | 11.9501 | 0.0225 |
| 11 |                                       |   |   |   | 900                   | 1.3194                       | 12.9301 | 0.0365 |                       | 900                          | 1.3194 | 12.9301 | 0.0225                |                              | 900  | 1.3194 | 12.9301 | 0.0225 |
| 12 |                                       |   |   |   | 1000                  | 1.4194                       | 13.9101 | 0.0365 |                       | 1000                         | 1.4194 | 13.9101 | 0.019                 |                              | 1000 | 1.4194 | 13.9101 | 0.019  |
| 13 |                                       |   |   |   | 1100                  | 1.5194                       | 14.8901 | 0.025  |                       | 1100                         | 1.5194 | 14.8901 | 0.007                 |                              | 1100 | 1.5194 | 14.8901 | 0.007  |
| 14 |                                       |   |   |   | 1180                  | 1.5994                       | 15.6741 | 0.019  |                       | 1150                         | 1.5694 | 15.3801 | -0.0025               |                              | 1200 | 1.6194 | 15.8701 | 0.017  |
| 15 |                                       |   |   |   | 1190                  | 1.6094                       | 15.7721 | 0.019  |                       |                              |        |         |                       |                              | 1250 | 1.6694 | 16.3601 | 0.012  |
| 16 |                                       |   |   |   | 1200                  | 1.6194                       | 15.8701 | -0.001 |                       |                              |        |         |                       |                              | 1255 | 1.6699 | 16.365  | -0.005 |
| 17 |                                       |   |   |   |                       |                              |         |        |                       |                              |        |         |                       |                              | 1300 | 1.7194 | 16.8501 | -0.048 |

This years data and resulting graph show that at a weight of approximately 20 lbs, the inner bearing shifted the greatest distance. This isn't the true maximum load, however, as the moment of rotation between the point at which the weight is carried and the point at which the rotation begins must be taken into account.



The theoretical weight that should've been carried was estimated at 83.28 lbs through numerical integration. With the calculations of the moment of inertia taking into account, the actual weight equals 53.75 lbs, thus resulting in a 35.5% error.