Test on New Prop Rod Design

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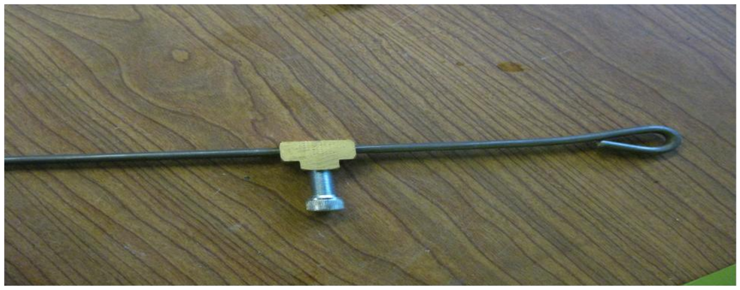


New Prop Rod Design

Description of the Design

As stated by the Fall 2010 Solar Lovin' Team, forces from the wind in Nicaragua often break the wooden prop rods and loosen the hinges attaching the oven lids to the oven body. In the fall, the team designed a 3/8" metal pole with a hydraulic fitting and a screw to tighten the rod in place. Additionally, a hole was drilled into the flat side of the tee so that it could be attached to the oven wall. The rod slides through the straight part of the tee and a screw is used to secure the rod in place at the chosen height. In the early weeks of the Spring 2011 semester, we retrofit an oven with the new prop rods and devised tests to predict how well the prop rods would perform in the wind. Although the fall team fit the rods with large brass tees, smaller brass tees, and PVC tees, we only tested the large brass tee.

Experimental set-up

We removed the glass window frame from a 30'' x 30'' oven and attached the reflector to the oven. We drilled holes and attached one hydraulic fitting (tee) on either side of the oven. We drilled holes and attached the loop-end of a rod to the mid-point on either side of the reflector. We tightened the prop rod screws to hold the reflector at 90 degrees with respect to the oven.

We clamped the oven to a steady platform and attached a clamp near each upper corner of the reflector. For the North and South side trials, we hooked one end of a ratchet-tie-down-strap to an upper-corner clamp on the reflector and hooked the other end of the strap to a spring-pull secured in place. For the center trial, we hooked the end of the strap through the midpoint of a bar in between the reflector clamps. A JP1000 load cell recorded the force exerted by the ratchet-tie-down strap on the reflector.

Behind the oven, we placed two linear variable differential variable transformers (LVDT's) 16 inches above the bottom of the reflector and 5.5 inches from either side of the reflector. Both of the LVDT's began with their sensors extended 3.5 inches to touch the back of the reflector.

Then, we tightened the ratchet-tie-down strap while measuring the force and displacement in the oven/lid configuration.

Figure 1: Experimental set-up of oven and prop rods

Figure 2: Experimental set-up of oven, prop rods, LDVT's, clamps, and ratchet-tie-down strap

Figure 3: Close-up views of the loop-end of the prop rod and the tee-end of the prop rod

The forces applied in these tests could be associated with a wind speed, according to the fluids calculation below. *Please see Appendix A for additional background on the force calculations

$$F_{wind} = A * P * C_D$$

Where

A = area of reflector = 30in * 30in = 900in^2

P = atmospheric pressure = (.00256 * V^2) Psf

V = wind speed in miles per hour

C_D = drag coefficient for a body facing the wind = 2

Thus, we could estimate the slip at the tee due to a particular wind speed acting on an oven in Nicaraugua as follows:

Wind Speed, V, in miles per hour	Force on reflector, in lbs	Force on each prop rod, in lbs	Angular deflection of reflector, in degrees
30	14.4	10.2	.806
40	25.6	18.1	1.25
50	40	28.3	1.36
60	57.6	40.7	1.43

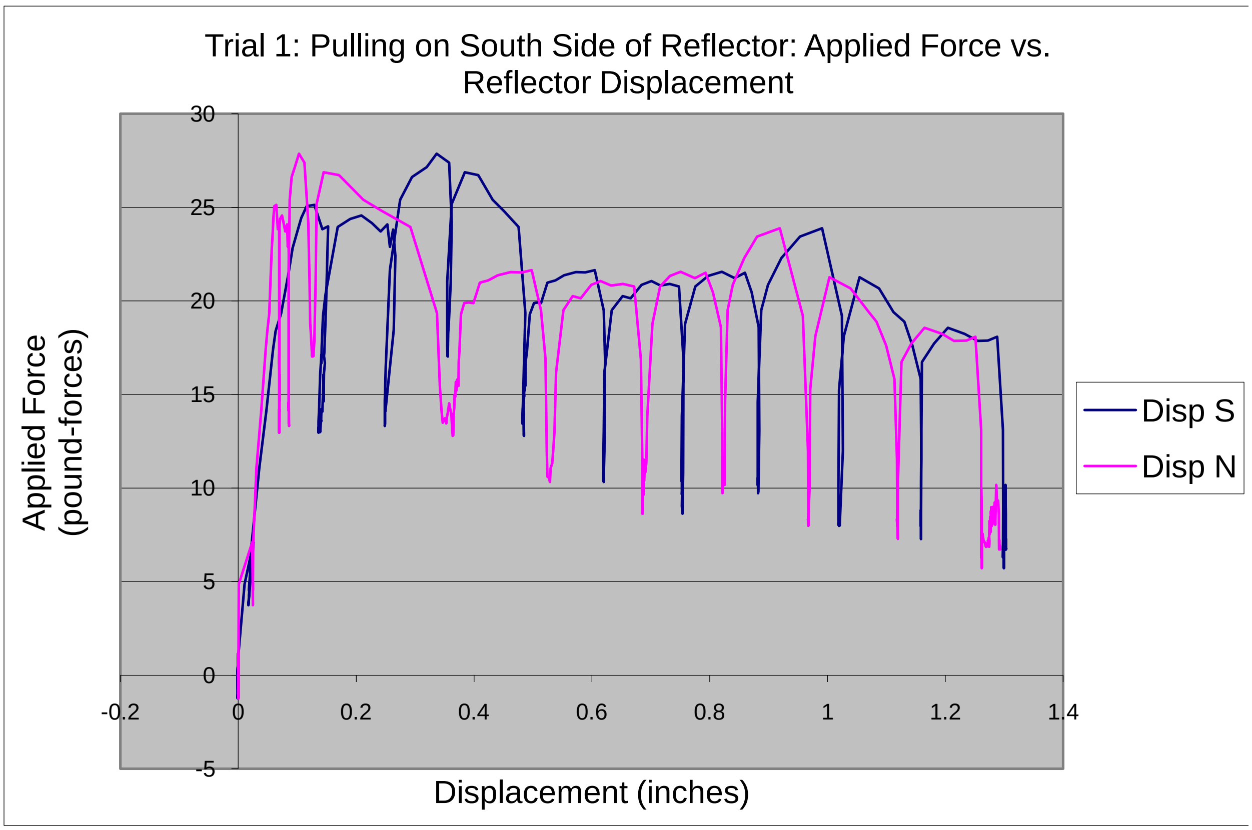
The resulting force on each prop rod was included in the third column. As explained in appendix A, the force in each prop rod equaled $\frac{F_{wind}}{\sqrt{2}}$. Additionally, we could use data from the "pulling on center" test (shown below) to add a column that shows the estimated average reflector deflection for each wind speed.

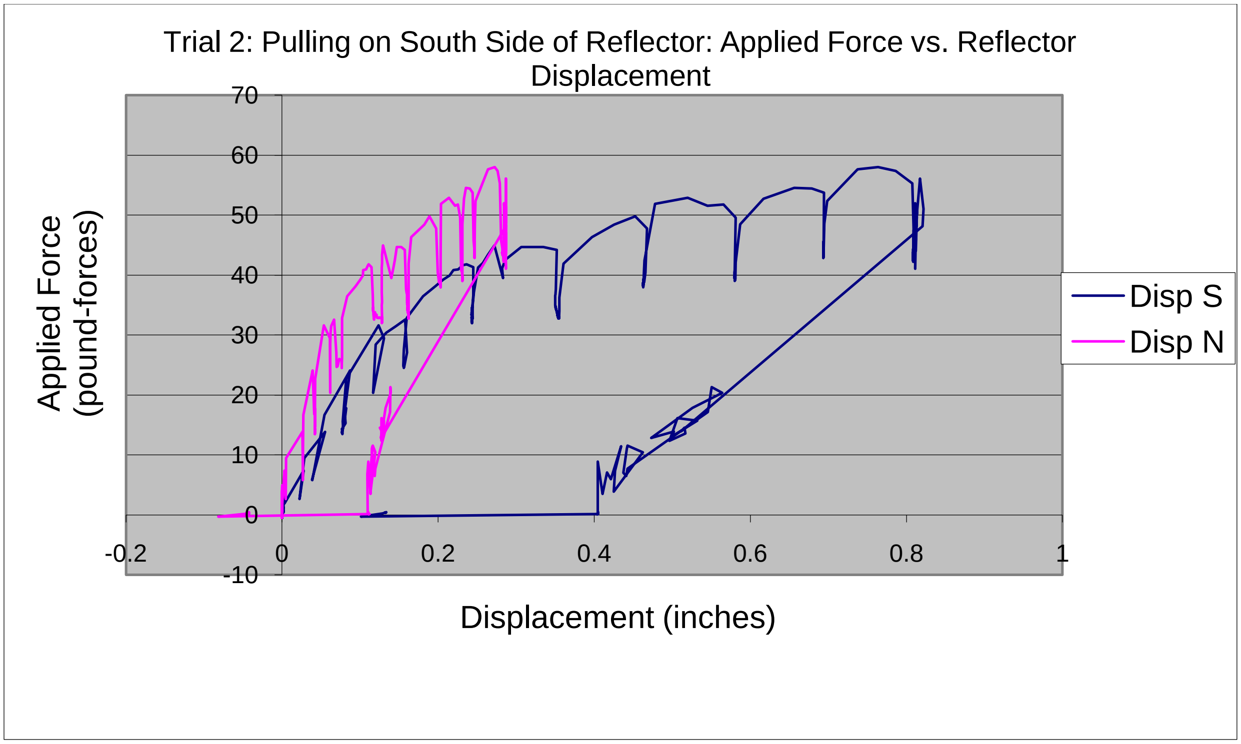
Data Analysis

In the data below, vertical drops in the applied force correspond to slippage of the tees. The vertical drops occurred because when a particular amount of force was too large for the tees to hold, the rods slipped in the tees. This slippage reduced the amount of force required to pull back the reflector to a particular distance.

In the first trial of pulling on the south side of the reflector, the sides of the reflector displaced nearly equal amounts, and the applied force remained less than 30 lbs. This indicated that the tees were not adequately tightened.

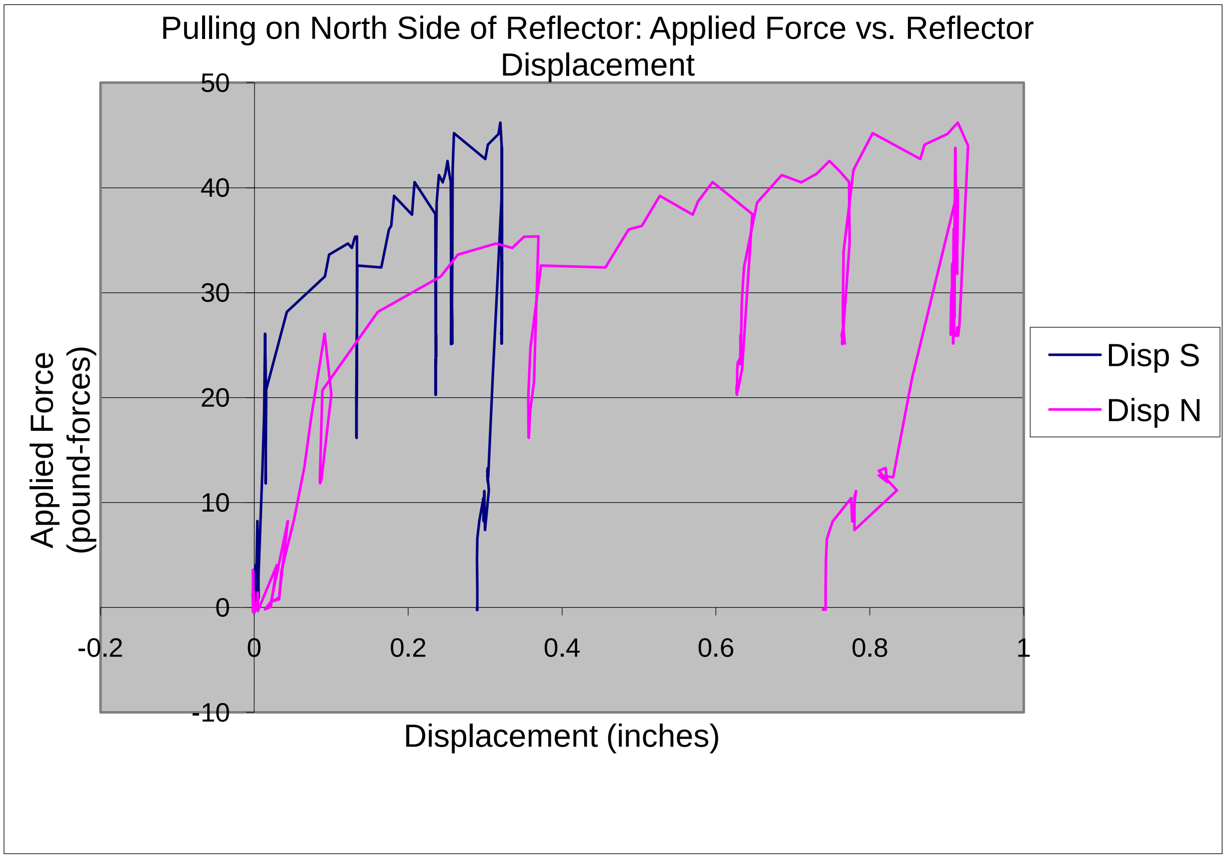
The tees were tightened further for a second trial. As shown in the second trial of pulling on the south side, the south side displaced by a maximum of 0.8 inches while the north side displaced by 0.3 inches when about 60 lbs were applied. The tees had smaller slips during this trial than during the first trial.





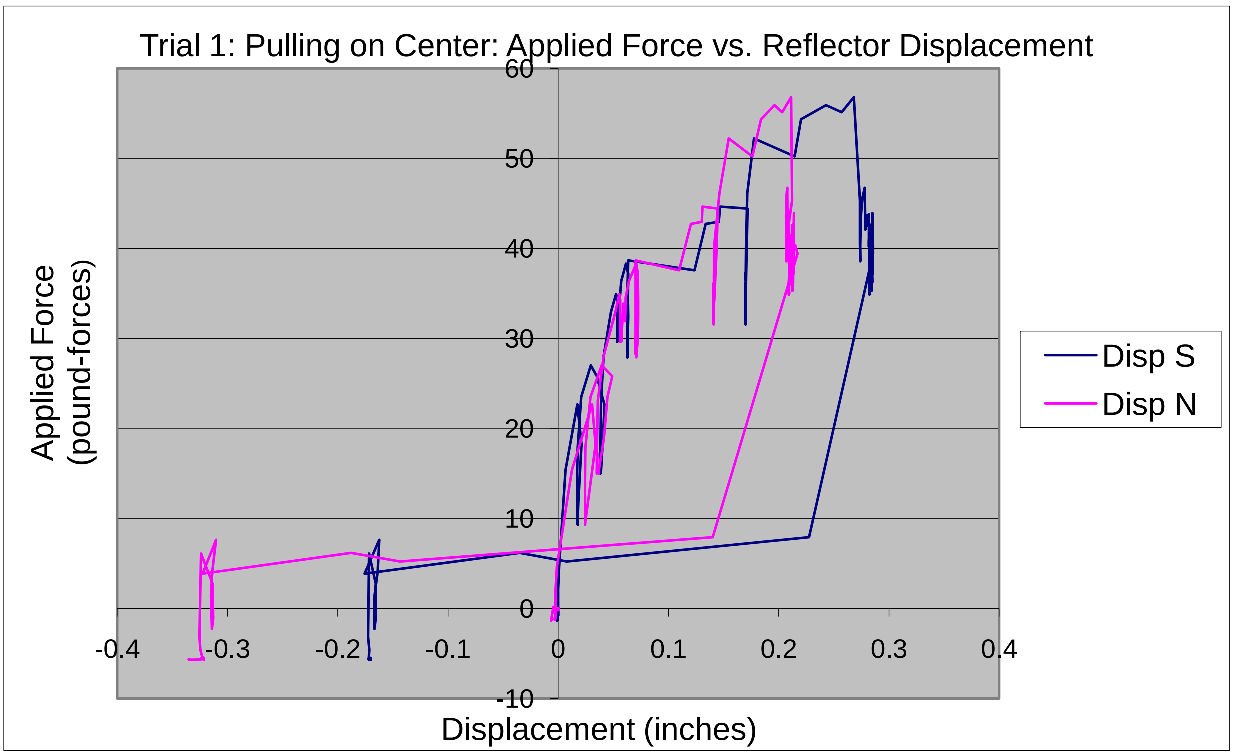
Trial 2: Pulling on South Side of Reflector: Applied Force vs. Reflector Displacement
70
60
50
40
30
20
10
0
-10
-0.2
0
0.2
0.4
0.6
0.8
1
Applied Force (pound-forces)
Displacement (inches)
Disp S
Disp N

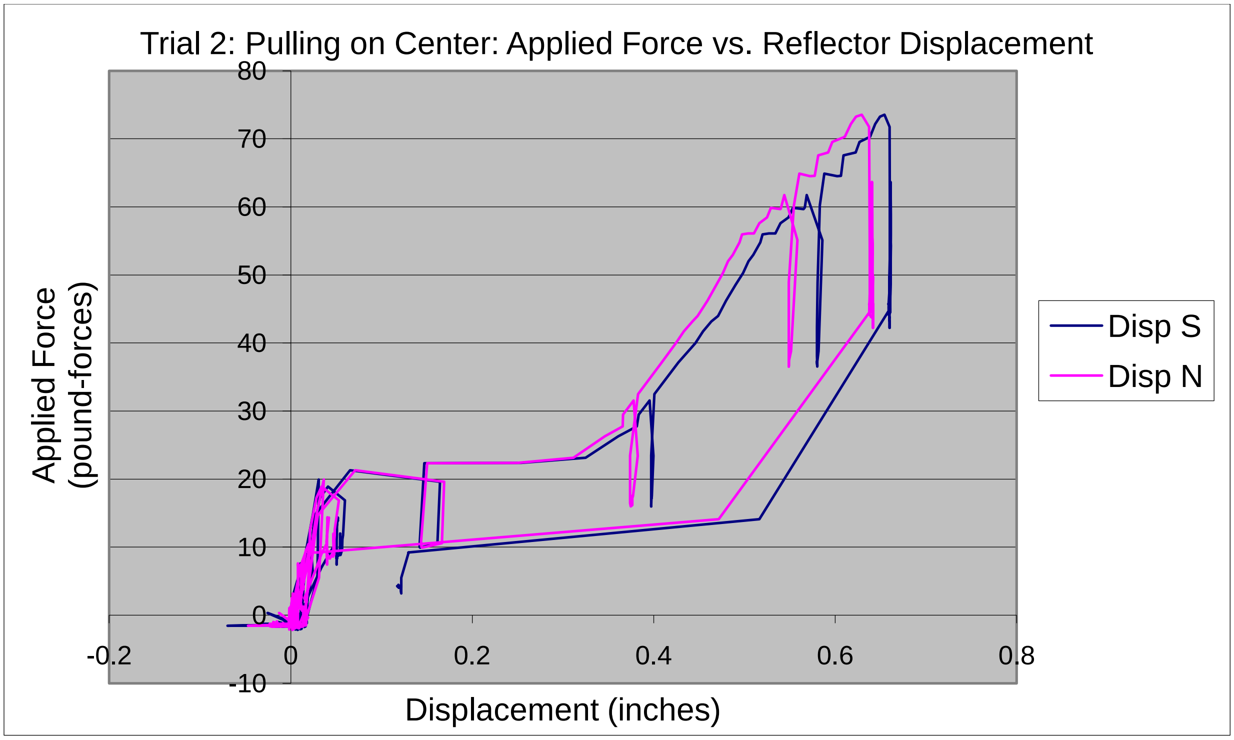
When pulling on the north side of the reflector, the same relationship between displacement and force occurred as in the south trial: the north side (the side on which the force was applied) displaced by about 0.8 inches while the south side displaced by 0.3 inches when 45 lbs were applied.



As shown in trial 1 of pulling on the center of the top of the reflector, no major slips of the tees occurred until a little over 40 lbs were applied to the reflector. When 40 lbs were applied to the reflector, the LVDT's measurement changed by 0.08 inches. With the LVDT's located 16 inches above the hinges, this displacement correlated to an angular change of 0.3^{o} for the reflector. When more than 40 lbs were applied, the south side of the reflector began to slip more than the north side. This could have been due to differing amounts of tightness in the tee's or applying the force slightly more towards the south side of the reflector. When the maximum amount of force of 55 lb was applied, the reflector displaced by about 0.2 inches, or 0.72^{o}.

In trial 2, the displacements on either side of the reflector matched each other almost identically until about 25 lbs were applied to the reflector. Then, the south tee slipped by about 0.01 inch, but did not significantly slip after that. The tees did not significantly slip until 70 lbs were applied.





Future Work

Future work on developing the prop rods includes testing a smaller brass fitting and a plastic fitting. We may also consider the forces exerted on the prop rods when the rods are connected to the reflector and oven in different locations, and when the reflector is at an angle other than 90^o.

Additionally, we would like to construct a device to bend the loops at the ends of the rods. This device will most likely be several heavy-duty screws threaded into a steel block that is clamped to the table. The loops can be formed by bending the rods by hand, taking advantage of leverage when inserting the rod between screws.

Appendix A

As shown in figure 1, the rods are angled at 45 degrees with respect to both the reflector and the oven. Each rod exerts a force along its length. Each hinge exerts forces in the x, y, and z directions, and moments in the x and z directions, where the z-direction points up, the x-direction points out from the front of the oven, and the y-direction points from the north to the south side of the oven. The force of gravity acts down at the reflector's center of mass. In the "Pulling on Center" tests, the force "P" is exerted at the center-top of the reflector. The length of the reflector sides is referred to as "h."

As shown in figures below, the force P applied at the top of the reflector can be converted into an equal force P and a moment M_c applied at the center of mass of the reflector.

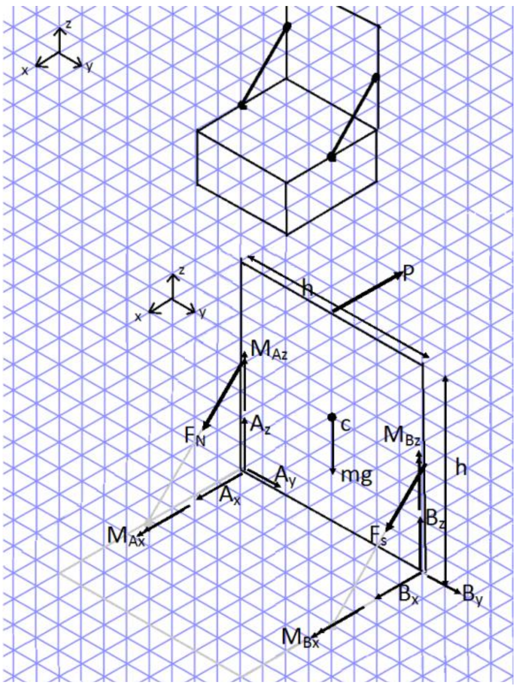


Figure 5: Free Body Diagram for the reflector from the tests "Pulling on Center"

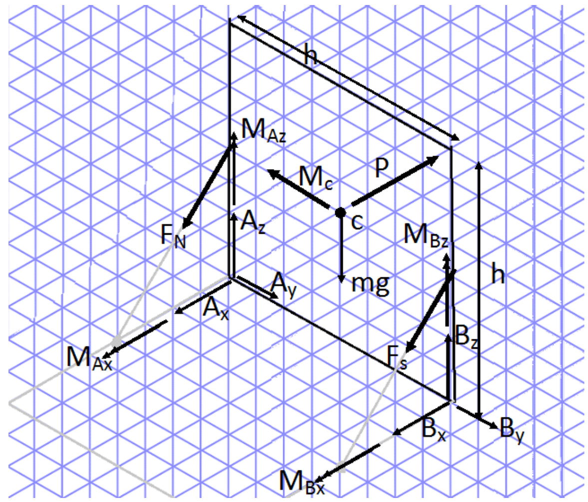


Figure 4: Modified Free Body Diagram for the reflector from the tests "Pulling on Center"

The following assumptions are made due to symmetry:

(1) $A_x = B_x$
(2) $F_N = F_S$
(3) $A_z = B_z$
(4) $M_{AZ} = -M_{BZ}$
(5) $M_{BX} = -M_{AX}$

Then:

(6) $\sum M_{cy} = 0 = -hA_x \rightarrow \boldsymbol{A_x = 0}$

(7) $\sum F_x = 0 = A_x + B_x + \frac{\sqrt{2}}{2}F_N + \frac{\sqrt{2}}{2}F_s - P \rightarrow 2A_x + \sqrt{2}F_s - P = 0 \rightarrow \boldsymbol{F_S = F_N = \frac{P}{\sqrt{2}}}$

Thus, the force applied to each prop rod equals $\frac{P}{\sqrt{2}}$, where P is the net force of the wind applied to the center of mass of the reflector. M_c does not affect the force exerted on each prop rod.

For the experiments where P was applied to the corners of the reflector, a similar method of calculation would be used to find the force applied to each prop rod. Due to the asymmetry, these calculations are more complex and the solution is statically indeterminate.

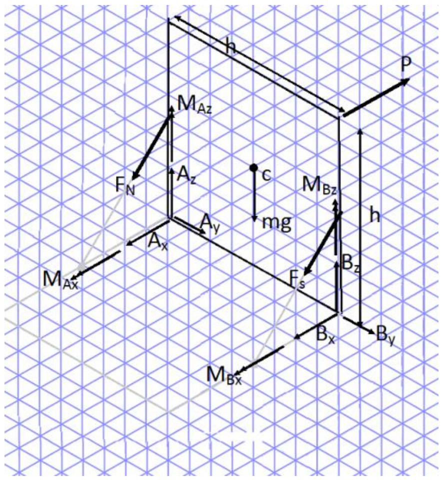


Figure 6: Free Body Diagram for the reflector from the tests "Pulling on Side"