Updates from the Lab And More Testing with MHTestAn

More Thorough Measurements and Main Lessons Learned

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U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

More Deliveries at the Lab

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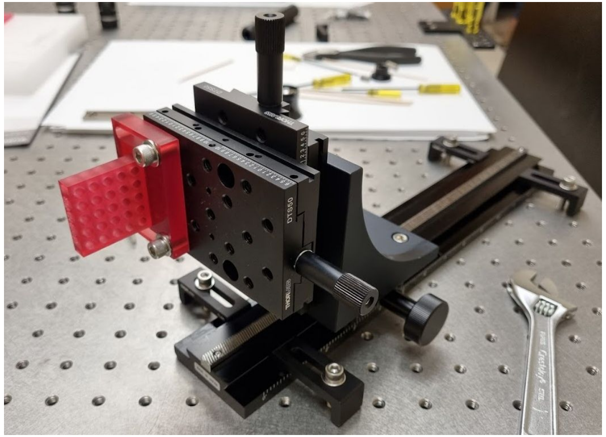
- Thorlabs linear stages
  - Combined to make a 3D stage
  - Range: 12” × 2” × 2”
  - Had to go with 90deg rotation, because the 12” stage is not a vertical stage
- Digital Caliper
  - Accuracy: 25.4um
  - Mirror thicknesses were measured
    - All within caliper accuracy
    - Thickness: ~2.15mm
    - Diameter: ~4.95mm
    - Mirror error might be much smaller than expected



Digital Caliper

DIGC6

- Measures Dimensions up to 6.00" (150 mm)
- Provides 3 Methods of Measurement
- Knurled Grip Thumb Wheel
- Converts from English to Metric with the Push of a Button
- Thumbscrew Locks Caliper Position

The DIGC6 Digital Caliper has an engraved scale and a linearly encoded digital readout that can be switched between imperial and metric scales. The max extension of the caliper is 6.00" (150 mm).

Specifications	
Measurement Range	6.00" (150 mm)
Resolution	10 µm (0.0005")
Accuracy[a]	±25.4 µm (±0.001")
Contact Points	Carbide-Tipped

a. Excludes Quantization Errors

Since Last Thursday

Preliminary results presented last week:

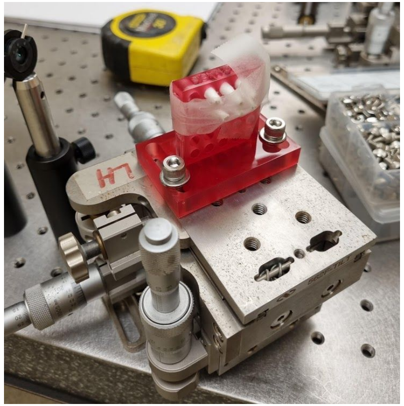
- $\Delta\theta = 0.1\text{deg} \Rightarrow \Delta d = \sim 14\text{mm}$ at the wall (4m away)
- **Friction holding will NOT work**, even with the 5.2mm holes
  - 5.2mm holes allow significant angular deviation, order of few degrees
- We need to **push in from the back**
  - If properly pushed to the front surface, we should get:
    - Maximum of $\Delta\theta = 0.573\text{deg}$ for 5mm mirrors
- We should get to **2^{nd} round** of 3D printing

Main Updates:

- **More thorough tests** of loose ends from last week
  - Mounting errors
  - Mirror-to-mirror errors
  - Hole-to-hole errors
- **Design for 2^{nd} round** of 3D printed test boards

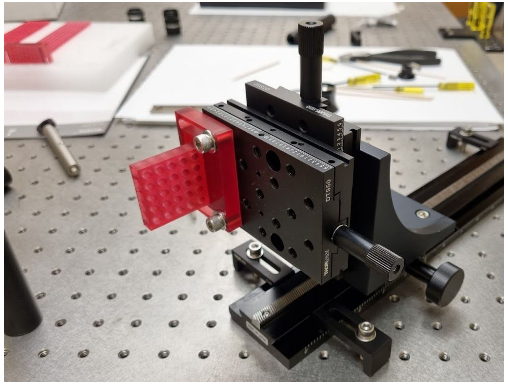
Push-in Mechanism

First thing to test and confirm is that, **when properly pushed into the front-stop, the mirror is properly aligned** within the angular precision



- This was difficult during early last week's preliminary tests
  - Not enough time
  - Tapes & q-tips weren't stable enough

- Temporary solution: use our thick (0.8mm) board and keep the pressure on manually
  - Is the human hand stable enough?
  - Can this possibly demonstrate consistent loading procedure?



Sounds silly, but it works!

- A mirror was mounted in a 5.4mm hole on `MHTestA1th` (0.8mm thick board)
- The mirror was pushed to the front-most surface and was held their with manual pressure
  - Murtaza was holding a screwdriver with cotton layer cushioning
  - With the thick board, this was actually quite stable and not too difficult

  ⇒ **The front stop does define a flat surface to align the mirror against**
- The same mirror was unmounted and remounted in the same hole for statistics
  - The beamspots stayed quite consistent across different mounting attempts
  - This was observed with several different mirrors

  ⇒ **Mounting error is not very large with the push-in mechanism**

Testing the Push-in Mechanism

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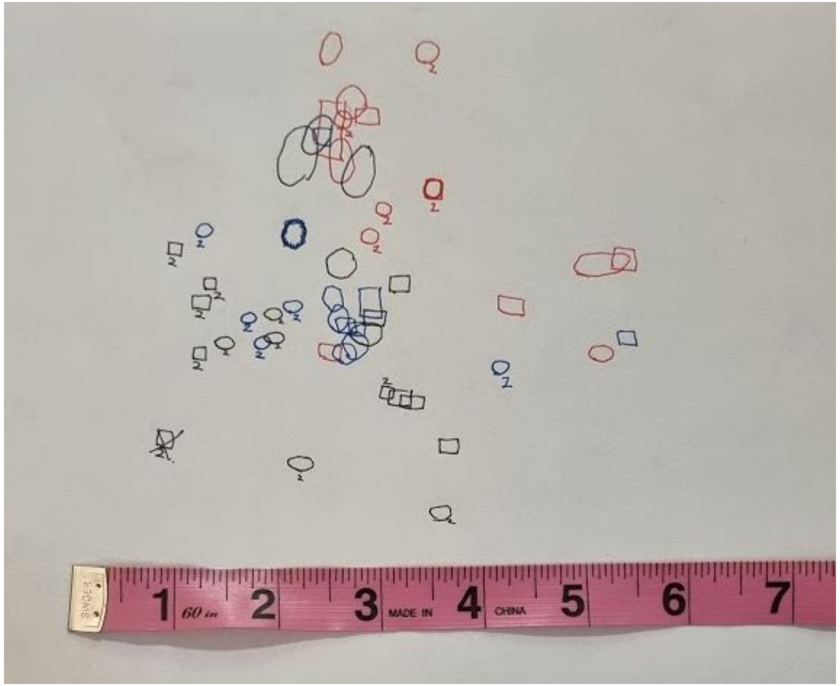
Results

- Movement while holding pressure: < 1in
  - Mirrors 1 & 3 seemed most unstable

  (i.e. Murtaza's hand and our set-up are quite stable!)
- Errors across mounting attempts
  - Mostly within ~1in
  - Some outliers that span ~2in
- This is low statistics, but we can conservatively assume mounting error of:

$$\Delta d = 1.5\text{in} \Rightarrow \Delta\theta = 0.28\text{deg}$$

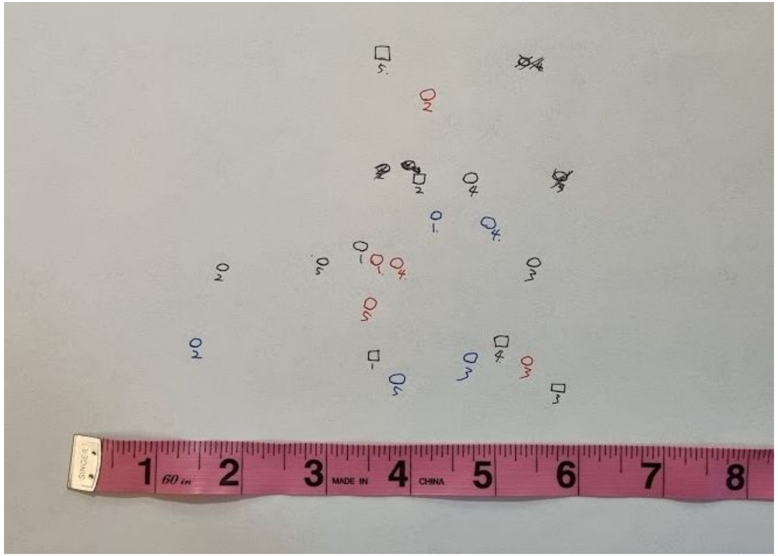
- Not a major concern, given our tolerance



○ : Mirror 1
○ : Mirror 2
○ : Mirror 3
□ : Mirror 4
□ : Mirror 5
□ : Mirror 6

Measuring Other Errors

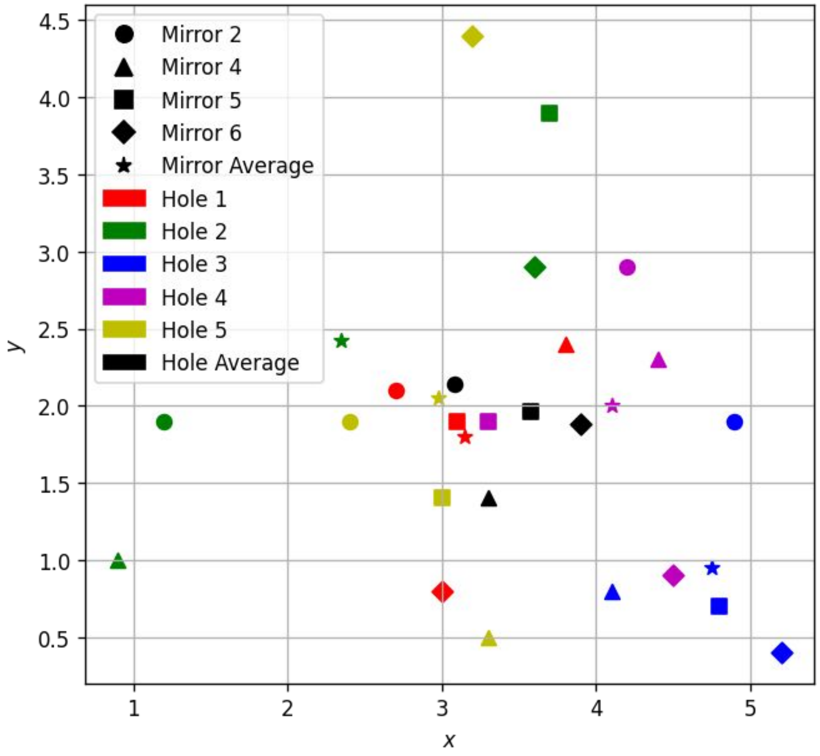
- Once it was demonstrated that manual pressure was good enough, tests were **repeated with different mirrors & different holes**
- Average across different holes
  - ⇒ focus on errors across mirrors
- Average across different mirrors
  - ⇒ focus on errors across holes
- 4 Mirrors × 5 Holes = 20 data points
  - No repeated mounting
  - Mounting error is not a major concern
- Still low statistics, but should give us some intuition for next steps



Results: Mirror-to-mirror Error

Main observations:

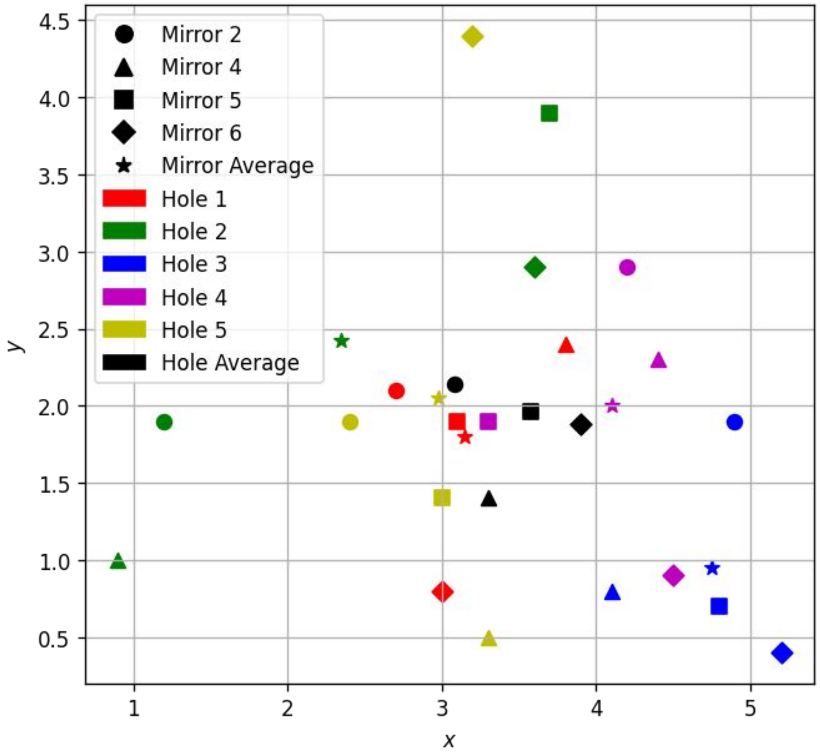
- Each color (hole) is generally localized,
  (except greens and one yellow outlier)
  - Within 2in total span
  - Hole 2 is suspicious?
- Black markers are localized
  - Average across different holes
    ⇒ focus on errors across mirrors
  - All within 1in
- Mirror-to-mirror error is 1-2in or less



Results: Hole-to-hole Error

Main observations:

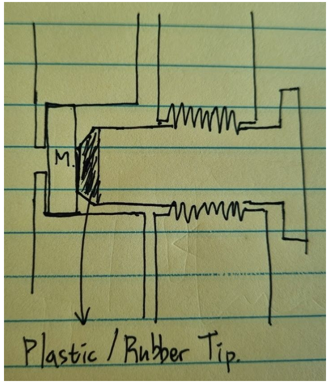
- Focus on each type of marker (mirror)
  - 4in total span
  - Generally worse than color (hole) localization
  - No mirror is particularly better
- Focus on ★ markers
  - Average across different mirrors ⇒ focus on errors across holes
  - Still spans 3in
- Hole-to-hole error is 3-4in

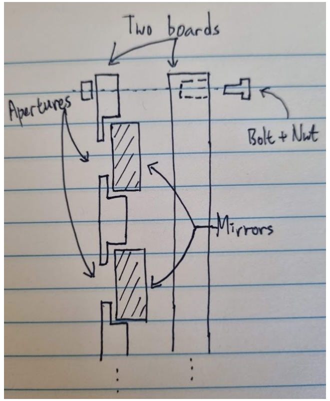


New Holder Designs

2 main design aspects needed to maintain active pressure from the back

- How the pressure is actually maintained
  - Tapped holes with screws
  - Two boards combined with bolt & nut
- Protect the mirrors from pressure
  - Plastic/rubber-tipped screws
  - A layer of plastic/rubber cushion



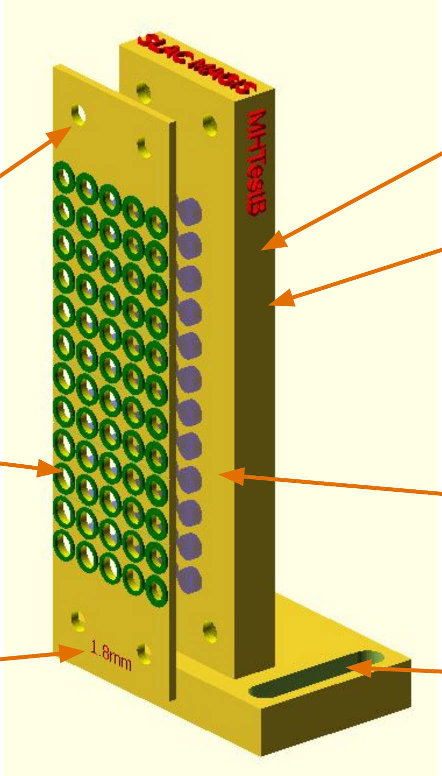


MHTestB

Space for #8 screws
- 0.16in / 4.2mm diam.
- 0.1695in / 4.3mm clearance

"Local Support" Board

Dimensions:
- 10mm × 35mm × 121mm
- 99mm between top & bottom screws



"Front" Board

Rubber sheet in between
- 1/64", 1/32", 1/16"

Slightly thinner than the mirrors

¼" holes as usual

Main Parameters for MHTestB

Front board thickness

- {1.8, 1.9, 2.0, 2.1} mm

Mirror hole diameter

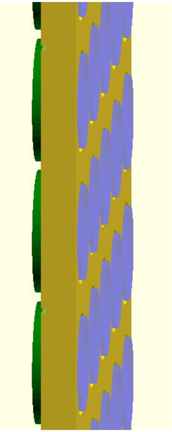
- {5.3, 5.4} mm

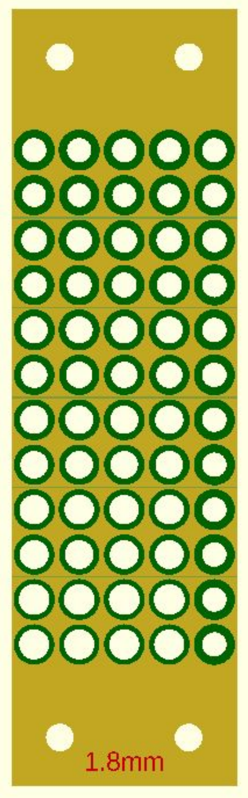
Front-stop overlap

- {0.3, 0.4, ..., 0.8} mm

Different columns

- Repeated 4 times for statistics
- Last column reserved for board-to-board comparison
  - 5.4mm diameter & 0.8mm overlap





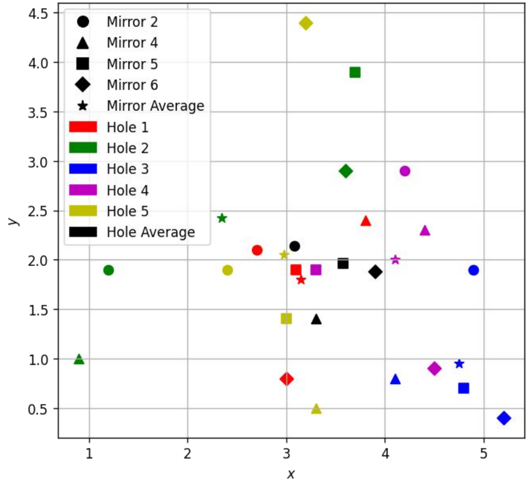
Summary

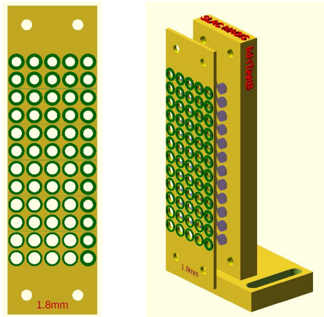
More tests with MHTestA* boards

- With a thicker (0.8mm) board, we could manually keep the pressure on the mirrors (quite stable!)
  - Mounting error < 1.5in (0.28deg)
  - “Push-in” mechanism seems like a viable option so far
- More tests
  - Mirror-to-mirror error < 2in (0.37deg)
  - Hole-to-hole error = 3-4in (0.56-0.74deg)
  - **Total error roughly 1deg or less**

Next steps

- Need to verify these with more statistics, better systematics
  - New 3D print with more reliable push-in mechanism
  - Already ordered, should arrive next week
- Verify the new holder design
  - Screw-holding the support & front boards





Some slides from last week

Sensitivity to Angular Alignment

$\boldsymbol{\theta}$ = Mirror alignment (w.r.t. laser)

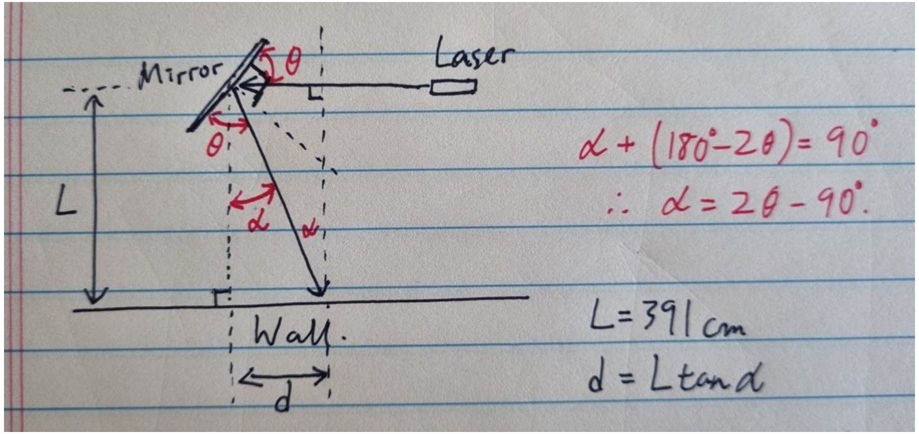
$\boldsymbol{\alpha}$ = Angular position of the beamspot @ wall

L = Distance between optics & wall

d = Linear position of the beamspot @ wall

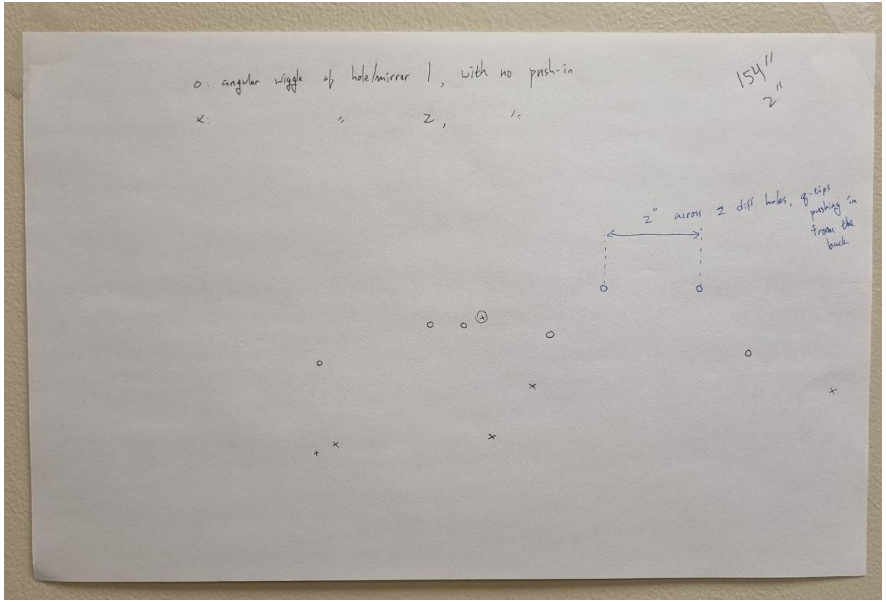
$$\Delta\theta = 0.1^\circ \implies \Delta d = 13.66\,\text{mm}$$

We want all our beamspots within ~10cm!



Mirror “Wiggle” inside 5.2mm Holder

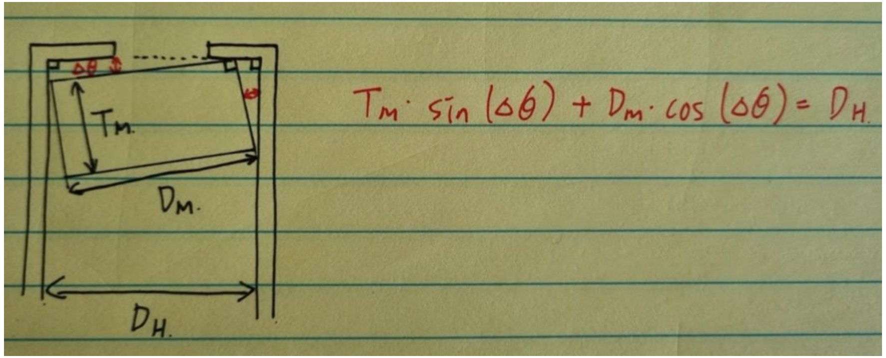
- With the small q-tip, it was **easy to push the edges and tilt** the mirror inside a holder
  - This was felt throughout other practice insertions
  - Observed with beam and measured with 2 different holes and mirrors
- This caused a huge deviation in beamspot
  - At max. difference: $\Delta d_{max} = 30\text{cm}$
    $\Rightarrow \Delta\alpha_{max} = 4.4\text{deg} \Rightarrow \Delta\theta_{max} = 2.2\text{deg}$
- Simple friction-holding **will NOT work**
- The mirrors can easily wiggle
  a few degrees with small force or
  as an error across mounting processes



Hypothesis for the Mirror "Wiggle"

Since holes are slightly bigger than our mirrors, the mirrors can be **mis-aligned**

- Maximum when the mirror is tilted all the way to the edge
- Mirror thickness = 2mm
- Mirror diameter = 5mm
- Hole diameter (or whatever extra space)
  - 5.2mm ⇒ $\Delta\theta$ = 6.73deg
  - 5.1mm ⇒ $\Delta\theta$ = 3.07deg
  - 5.05mm ⇒ $\Delta\theta$ = 1.48deg
- This alone goes beyond our tolerance of ~1deg

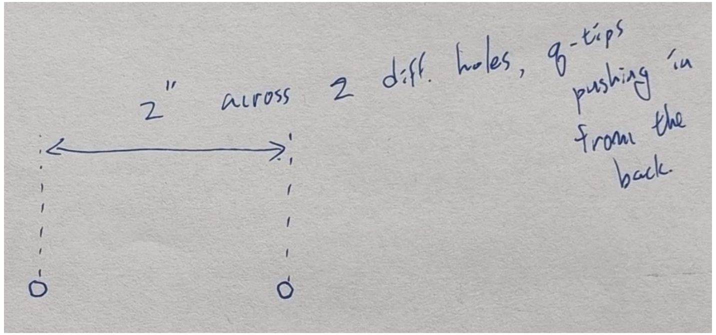


We want the alignment defined by the front-stop surface, not by the small extra space inside the hole. That is, **we need to push the mirrors** from the back.

Quick-fix: Q-tips + Tapes

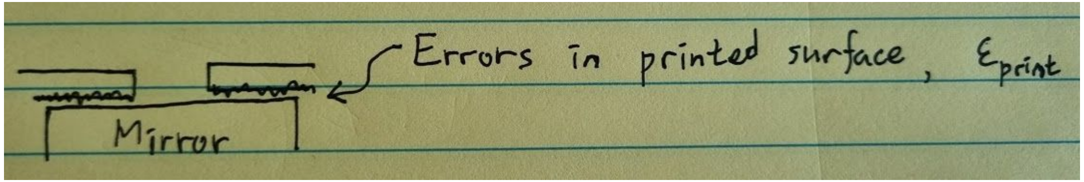
5mm q-tips + tapes to push the mirrors in from the back

- Seemed to work pretty well with 2 holes
- Observed Δd = 2” $\Rightarrow$ $\Delta\theta$ = 0.366deg



If we pushed in properly, the angle is defined by the printed quality of the front-stop surface

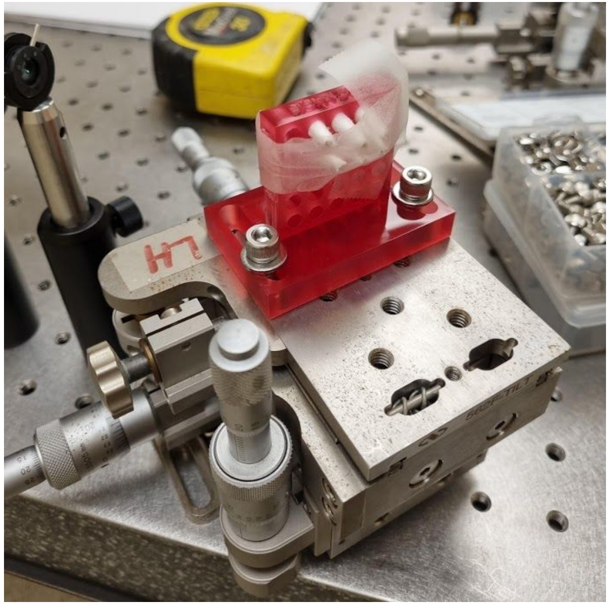
- Printing error of ε_{print} = 50um $\Rightarrow$ $\Delta\theta$ = 0.573deg

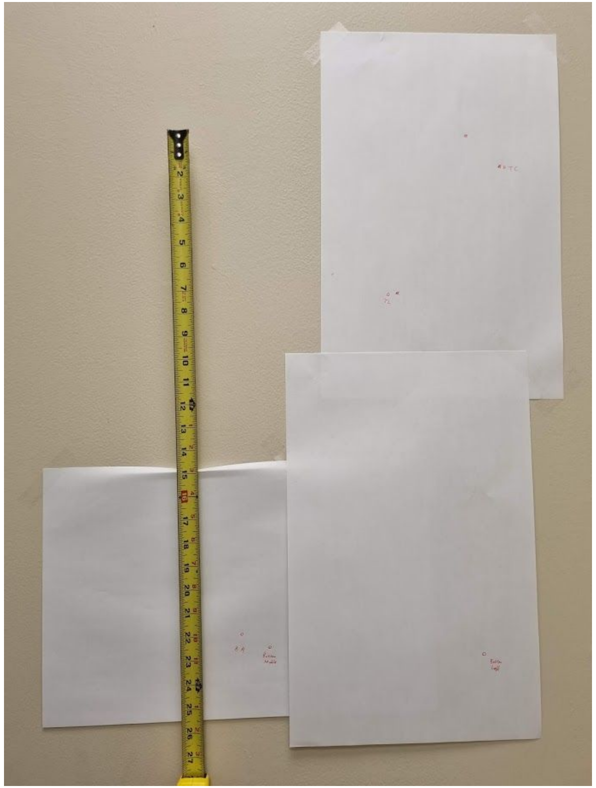


Scaling the Quick-Fix to multiple mirrors

Tried this with 6 mirrors, but was kind of difficult…

- Over 50cm of max. Deviation
- The tapes are probably not pushing properly





Short-term, Temporary Fix

Use plastic rods with diameter ~5mm, not q-tips

- 3/16” = 4.7625mm
- Will have to cut them ourselves though…
- McMaster-Carr Link

Long-term Solution

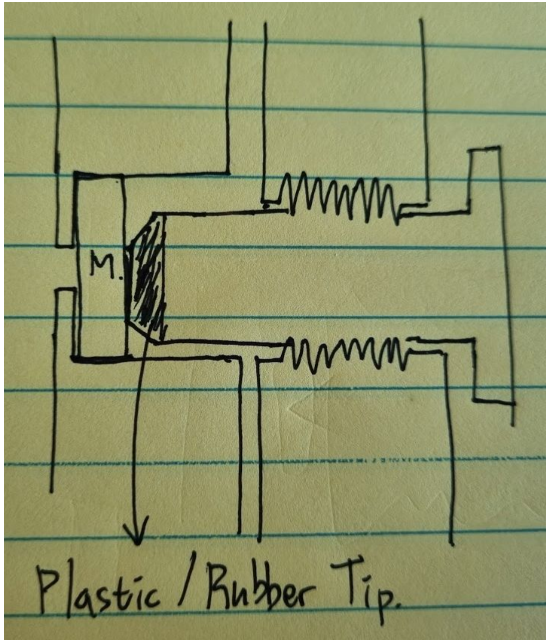
- Additional part behind with tapped holes
- Screws with plastic tips
    - Extra-soft nylon tips to minimize contact damage
    - McMaster-Carr Link

Alloy Steel Nylon-Tip Set Screws

An extra-soft nylon tip minimizes the damage that can occur from metal-on-metal contact. Use these set screws on soft surfaces such as aluminum. The body has a black-oxide finish to resist corrosion in dry environments. Length listed does not include the tip.

CAD For technical drawings and 3-D models, click on a part number.

	Tip				Drive		Specifications	Pkg.		
Lg.	Dia.	Lg.	Temp. Range, °F	Color	Size	Hardness	Met	Qty.		Pkg.
Black-Oxide Alloy Steel										
2-56										
1/8"	0.031"	0.031"	-50° to 250°	Green	0.035"	Rockwell C28	ASME B18.3	10	94115A051	$13.80
1/4"	0.031"	0.031"	-50° to 250°	Green	0.035"	Rockwell C28	ASME B18.3	10	94115A056	14.11
4-40										
1/8"	0.063"	0.031"	-50° to 250°	Green	0.050"	Rockwell C28	ASME B18.3	10	94115A103	11.66
3/16"	0.063"	0.031"	-50° to 250°	Green	0.050"	Rockwell C28	ASME B18.3	10	94115A105	8.34
1/4"	0.063"	0.031"	-50° to 250°	Green	0.050"	Rockwell C28	ASME B18.3	10	94115A106	6.85
3/8"	0.063"	0.031"	-50° to 250°	Green	0.050"	Rockwell C28	ASME B18.3	10	94115A107	8.34
6-32										
1/8"	0.063"	0.031"	-50° to 250°	Green	1/16"	Rockwell C28	ASME B18.3	10	94115A142	13.12
3/16"	0.063"	0.031"	-50° to 250°	Green	1/16"	Rockwell C28	ASME B18.3	10	94115A143	8.40
1/4"	0.063"	0.031"	-50° to 250°	Green	1/16"	Rockwell C28	ASME B18.3	10	94115A144	6.71
3/8"	0.063"	0.031"	-50° to 250°	Green	1/16"	Rockwell C28	ASME B18.3	10	94115A164	7.92
1/2"	0.063"	0.031"	-50° to 250°	Green	1/16"	Rockwell C28	ASME B18.3	10	94115A184	8.48
8-32										
1/8"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	10	94115A188	9.06
3/16"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	10	94115A189	8.40
1/4"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	25	94115A190	17.39
3/8"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	10	94115A192	8.12
1/2"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	10	94115A198	8.78
5/8"	0.094"	0.047"	-50° to 250°	Green	5/64"	Rockwell C28	ASME B18.3	10	94115A196	9.17



Conclusion

Summary

- 5mm mirrors cannot fit through 5.0mm or smaller holes
- Friction holding will NOT work, even with the 5.2mm holes
    - 5.2mm holes allow significant angular deviation, order of few degrees
- 5.4mm holes are loose, no apparent friction
- We need to push in from the back
    - If properly pushed to the front surface, we should get:
        - $\Delta\theta$ = 0.573deg for 5mm mirrors
        - $\Delta\theta$ = 0.955deg for 3mm mirrors
    - Additional layer with tapped holes + plastic-tip screws
    - Additional board with male rods + compressible buffers (rubber disks?)
- We should get to 2nd round of 3D printing