PROJECT REPORT FOR A PRODUCT REDESIGN INITIATIVE OF A SHOE-BENDING TESTING APPARATUS

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Engineering Design

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A Report By

Akash Agrawal, Siddharth Jhawar, Jayant Mathur
from EDSGN 582: Design Studio II

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ABSTRACT

The goal for this project was to redesign and fabricate a testing apparatus used to measure the bending flexion of a variety of shoes. Testing done on the beta prototype apparatus showed reliable performance with system deviation in the obtained results to be within +/-1% of the mean value. The results therefore suggest that the design fabricated by the team met the reliability, robustness, and user fidelity design criteria as requested under the problem statement. Due to unforeseen circumstances, the design while effective was delivered incomplete, therefore future recommendations and improvements are additionally provided.

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PROBLEM STATEMENT

Redesign the testing apparatus (previously designed and fabricated by Samuel Masters) that allows robust, reliable, and consistent flexion testing for running shoes of variable form factors. The system designed should be user friendly and user independent, easy to maintain, and not deviate too much from expected functionality.

STAKEHOLDER ANALYSIS AND DERIVED PROBLEM CONSTRAINTS

The client presented us with requirements that helped the team identify the client's concerns, project requirements, client expectations, and required deliverables. The derived problem constraints from these needs were as follows:

- Don't change the apparatus connection with the MTS. Have a durable connection.
- The base plate should be flat at t_0 with a range of motion of 45 degree.
- Minimal friction, if present, for mechanism.
- The shoe position should be undisturbed at t_0.
- Bending movement should happen exactly at the critical line.
- Shoe should be fixed behind the critical line/No extra forces between toe and critical line.
- Design to accommodate different shoe sizes and form [Women 7, Men 9].
- Try not to damage the sole.
- Don't introduce any changes to the computational code used by the program to calculate final bending flexion values.
- Easy maintenance, spares.
- Cost Constraint (Budget of $200)
- Consistency in testing.

PROPOSED TIMELINE WITH KEY DELIVERABLES

The project deliverables were stretched to a timeframe of three months between Feb 3rd and April 20th, 2020. Figure 1 highlights how the team planned work on this project during this dedicated timeframe and shows the key deliverables planned for the project.

Date	Deliverable
02/03	Begin ideation stage.
02/10	Finish CAD and proof of concept testing for alpha prototypes.
02/17	Finalize virtual beta-prototype (i.e., CAD).
03/05	Fabricate beta prototype.
03/25	Commence physical testing for robustness and durability of beta prototype, assess viability and results, and proceed accordingly.
04/20	Finish testing and design improvement stages.
04/27	Finish poster, report, presentation material, and final deliverable product.

Figure 1.a: Initial proposed timeline for the project listing the key deliverables.

Date	Deliverable
02/03	Begin ideation stage.
02/10	Finish CAD and proof of concept testing for alpha prototypes.
02/17	Finalize virtual beta-prototype (i.e., CAD).
03/05	Fabricate beta prototype.
03/25	Commence testing and simulation of, and future design improvements to, beta prototype.
04/20	Finish testing and design improvement stages
04/27	Finish report, presentation material, and final deliverable product

Figure 1.b: Modified timeline for the project highlighting the changed deliverables.

Out of the deliverables, two important and definitive deliverables were finalizing the beta prototype by March 5th and testing and evaluating the prototype within one week from March 23rd. Due to the COVID 19 pandemic that occurred mid March, the team was only able to complete the project upto the step of conducting testing to validate the functionality of the design; however, the team was able to meet these two important deliverables within satisfactory conditions and proposed minor improvements to the beta prototype for the final product design.

CONCEPTUAL DESIGN

The design decisions made here were majorly driven by the problem constraints presented to us by the stakeholder as well as some self imposed requirements that we deemed necessary on critical analysis of the current apparatus being used by the stakeholder. These self imposed constraints included conditions like:

- The apparatus should be lightweight
- Ease of usability
- Minimal number of moving parts

The formulation of these requirements was majorly driven by our understanding of the key problem areas in the current apparatus and induction of these constraints improved the system performance.

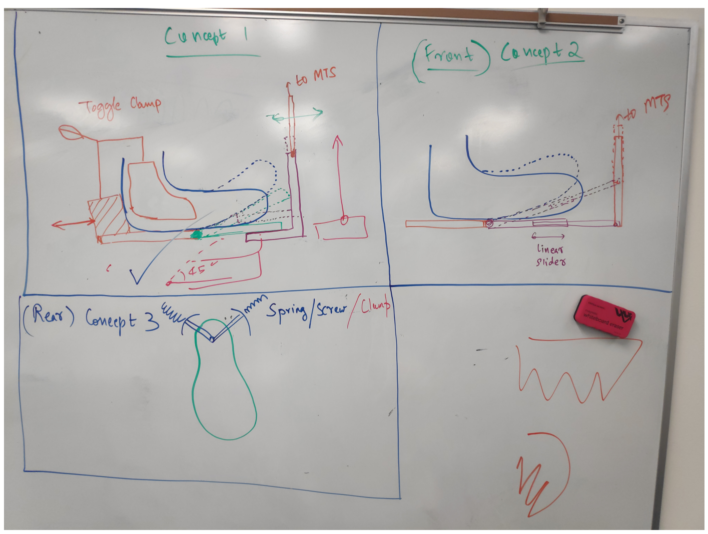


Figure 2: Brainstormed Concepts

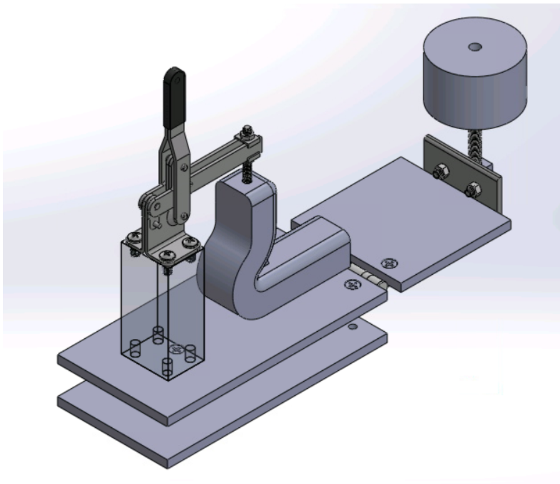
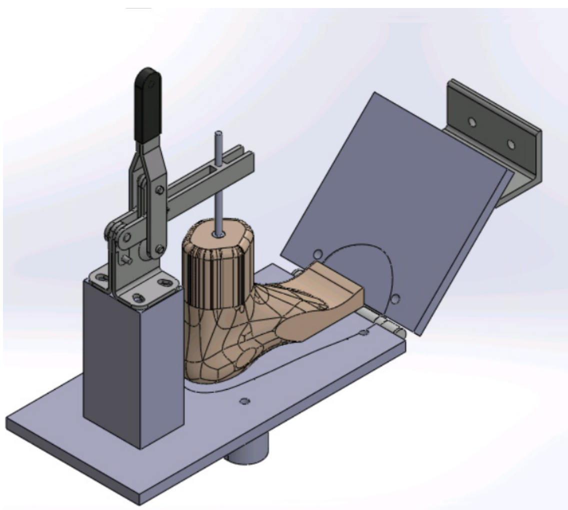
The team spent almost three weeks conducting ideation sessions to explore and evaluate different prototype designs. The ideas that were alpha tested or analyzed as proof of concepts, ranged from designs that leveraged linear sliders (like the original design), mechanical lifters, side grippers, and even flexible hinges. Figure 2 shows the key concepts that the team narrowed down to after several ideation sessions. These concepts took elements from ideas discussed earlier. Eventually, Concept 1 was selected after a discussion with the stakeholder.

Concept 1 incorporates a functional combination of mechanical lifters and clamping mechanisms to bend the shoe and keep it in place respectively. Firstly, an L-bracket is proposed which when linearly actuated by the MTS rotates a rigid plate thereby bending the shoe. This primarily serves to reduce the number of moving parts as compared to the previous apparatus. Secondly, a foot-like clamping geometry, around which the user could mount the shoe, is proposed. This attempts to make the apparatus user independent when placing the shoe accurately to bend at the critical line. This feature simulates realistic shoe bending as driven by a person's foot thereby also making the system accommodating to any shoe design for a given foot size. Lastly, a toggle clamp is proposed to rigidly clamp the foot-like geometry.

PROTOTYPING, TESTING, AND RESULTS

The prototyping stage of the project consisted of the team presenting and evaluating subdesign components of the overall design, highlighting the pros and cons of the subdesign. This process evaluated alpha prototypes of subdesigns to validate and evaluate their viability and functionality. The process was a rigorous breakdown of subdesign components to ensure that the overall design met the client needs and best fit within the problem constraints.

The first step towards the realization of the project was creation of a CAD model that was reiterated upon regular discussions to add and improve areas that had shortcomings. Moreover, some of the basic subcomponents were chosen to be standardized products abundantly available through external sources in interest of fast manufacturing and design robustness that's difficult to attain in custom in-house manufacturing.

	Fig. 3(a) : Initial CAD Prototype
	Fig. 3(b) : Beta Prototype
Figure 3: Prototype Iterations	

The beta prototype consisted of the approved subdesign components and the team redesigned the prototype to accomodate for manufacturability and cost effectiveness. The beta prototype therefore met the clients cost and functional requirements and is showcased in Figure 4.

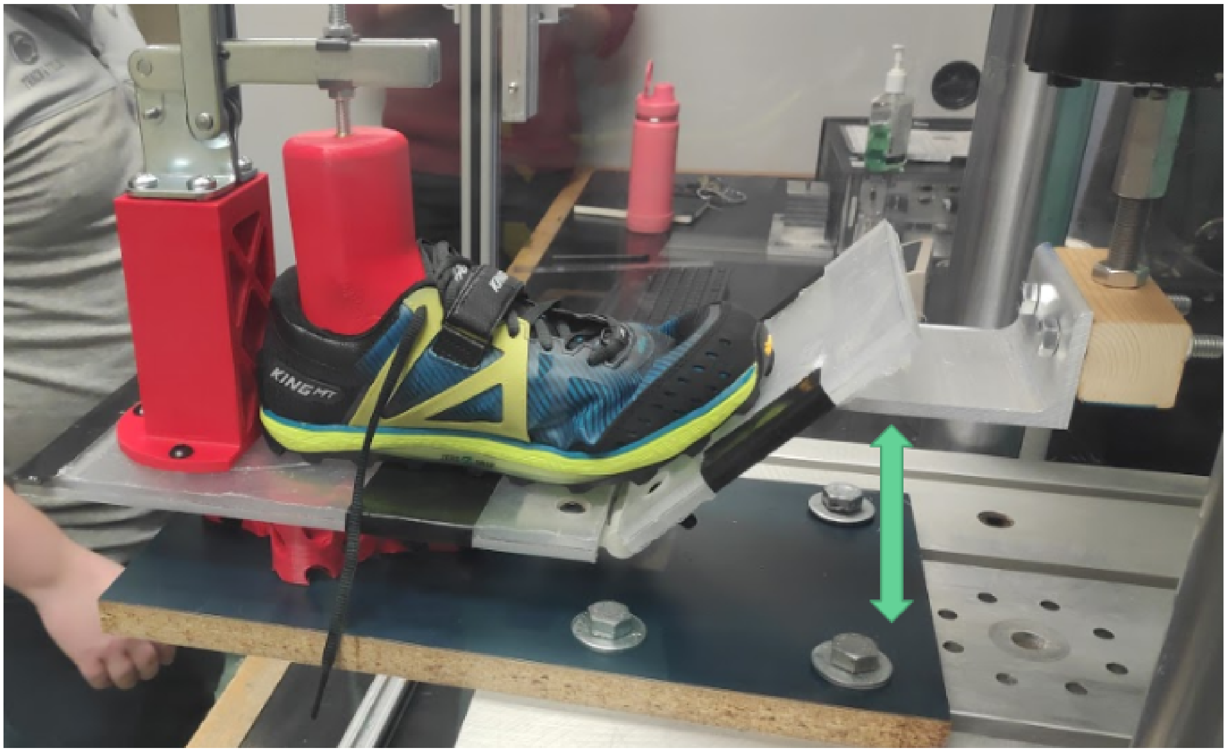
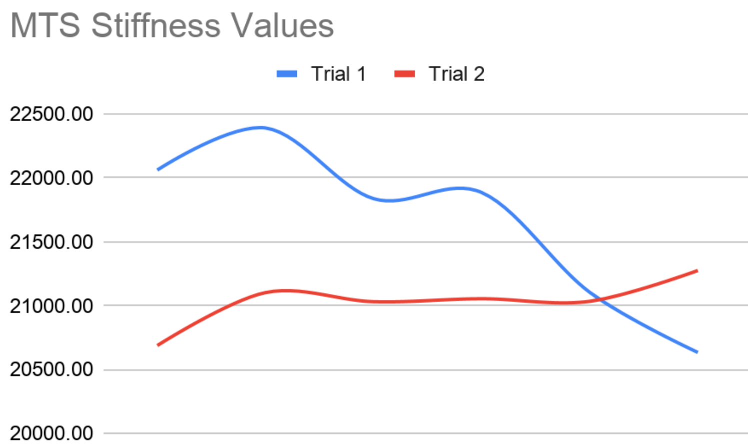


Figure 4: Showcasing the concepts driving the functionality of the beta prototype.

The cost breakdown for the beta prototype included external purchases amounting to $75 for components such as the toggle clamp, fasteners, and L-brackets. While the team was able to procure raw material such as stock wood and acrylic from the client and miscellaneous sources, the team estimates an additional cost of raw material to amount to $53. Therefore, the team spent only $75 from the budget to fabricate the beta prototype but estimates future recreation of the beta prototype to amount to $130, including taxes and shipping.

Testing of the beta prototype was conducted at the client's laboratory setup. Two trials were conducted to evaluate best case and worst case scenarios where the apparatus was set up ideally and not ideally respectively. Figure 5 highlights the results obtained from these two trials.



	MTS Values (N/m.rad)	
	Trial 1	**Trial 2**
Mean	21652.83	21031.67
Std. dev	653.77	**191.19**
Std. dev(%)	3.02%	**0.91%**

Figure 5: Highlighting flexion behaviour observed during preliminary testing. Two trials indicate max and min standard deviation in results as affected by setup.

During testing, it was observed that the expected “true” flexion values and maximum deviation in the testing results obtained were well within the clients expectations for testing accuracy and performance. These expectations were defined and verified by evaluating the results from the new design with the results from the old apparatus design.

While the team hoped to conduct a form of durability testing as well, where the apparatus would be subjected to a rigorous life-cycle testing, due to obstructions in the proposed timeline the team was unable to do so.

Key takeaways from Testing:

1. There was observable bending at the ends of the polycarbonate sheets.
2. The contact between the foot mold and the toggle clamp tended to rotate because of a single point contact.
3. Shoes with bigger back heels were difficult to accommodate given the congestion due to the design of the PLA block at the back of the apparatus.
4. The spacer block could not appropriately support the entire polycarbonate plate.

REDESIGN AND VALIDATION

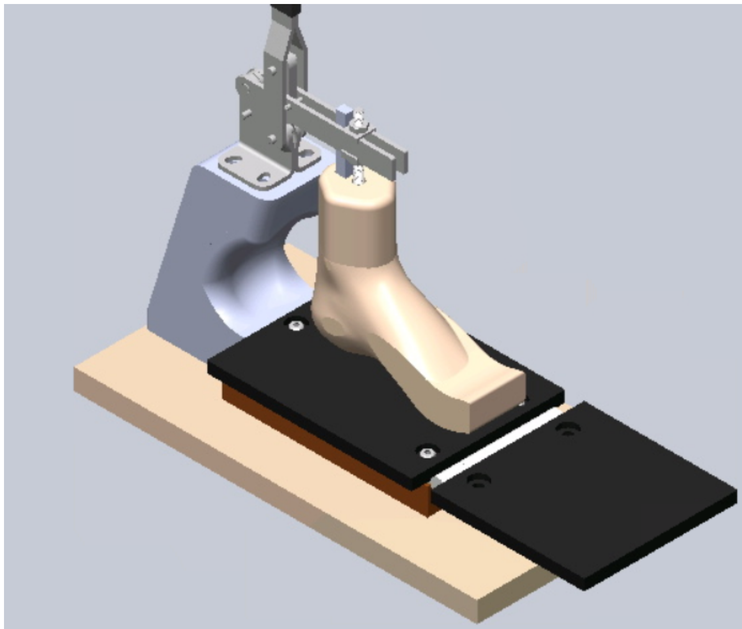


Figure 6: Final Prototype

Even though the beta testing met the client expectations for testing accuracy, there were limitations in terms of accommodating various shoes and apparatus robustness. Thereby, the team proposed a modified design to address the same as shown in Fig. 6. The key changes incorporated are as follows:

1. The PLA block was redesigned to accommodate shoes with bigger back heels
2. A key is introduced to lock the rotation of the foot mold relative to the toggle clamp
3. The plus-shaped spacer block is replaced with a cuboidal wooden block to better support the polycarbonate plates and prevent bending.

The team resorted to Finite Element Simulations to identify the failure points as observed during the apparatus testing and compare the results of the beta and final prototype.

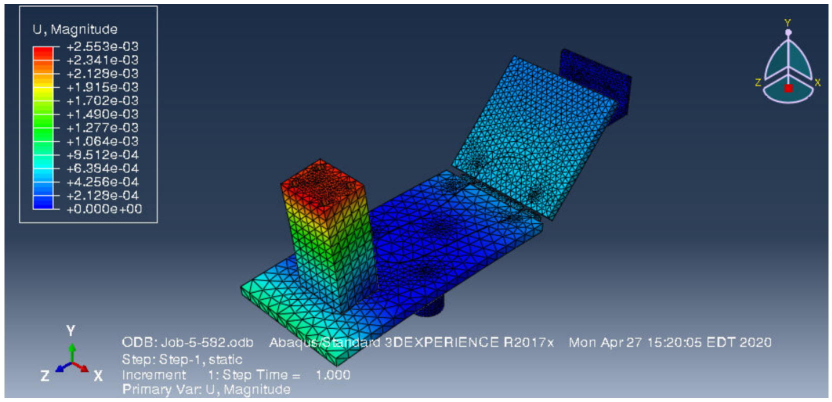


Figure 7: Static Deformation Simulation for Beta Prototype

In order to simplify the simulation, a static analysis was conducted at the position of maximum deflection i.e. when the rigid plate rotates by an angle of 45 degrees. Secondly, the foot mold, shoe and toggle clamp were eliminated from the simulation. To simulate the effect of the same, a typical shoe bending stiffness[1] value of 0.3 N-m/deg. was used to compute the pressure values on the polycarbonate plates and PLA block. Figure 7 shows the displacement magnitude obtained from the simulation. There was considerable bending in the system which was coherent with the observations in the testing. Thus, the focus for future improvement was to minimize such a systemic flaw.

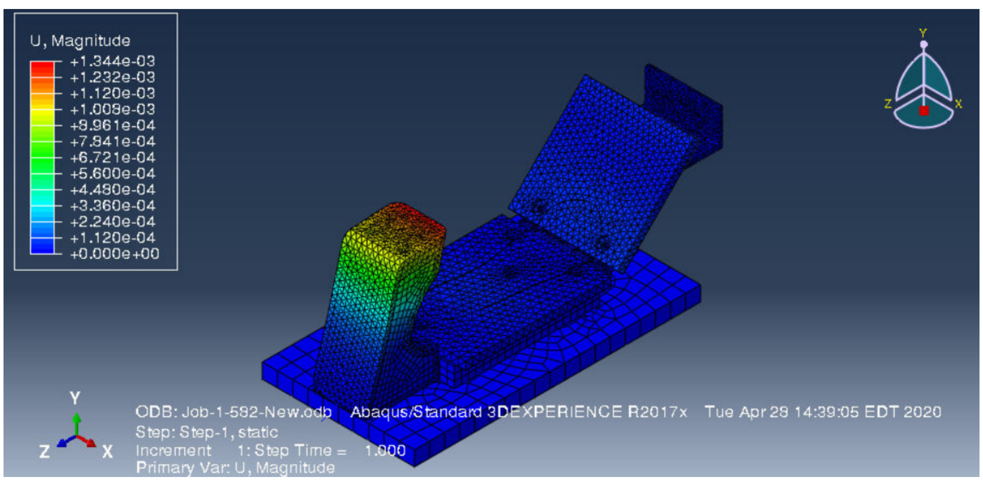


Figure 8: Static Deformation Simulation for Final Prototype

A similar simulation was carried out on the final prototype to evaluate the deformation values of the components as can be seen in Figure 8. This indicated improved robustness in the design as shown in Table 1 below.

[1] Flores, Nicolas & Rao, Guillaume & Berton, Eric & Delattre, Nicolas. (2019). The stiff plate location into the shoe influences the running biomechanics. Sports Biomechanics. 1-16. 10.1080/14763141.2019.1607541.

Table 1: Deformation Values

Deformation Values	Beta Prototype (in mm)	Future Design (in mm)
Polycarbonate Plate 1	1.49	0.11
Polycarbonate Plate 2	0.63	0.11
PLA Block	2.55	1.34

CONCLUSION

The team was able to meet the key project requirements and delivered a product that satisfied the clients needs and performed within negligible deviation and fatigue on product use. The testing results and simulation results helped evaluate scope for improvement of the beta prototype and these improvements will be implemented during the following Fall, 2020 semester when the team reconvenes to continue the project.

FUTURE WORK

Improvements that the team hopes to address in future revisions for the design are as follows:

- Minimize systemic deviation further in testing results to improve durability.
- Evaluate robustness and durability for at least five hundred cycles.
- Simplify design features and improve user interaction with apparatus.
- Improve accomodation to high variability in shoe form factor and size.

Figure 9: Render of the Final Prototype.

ANNEXURE

BILL OF MATERIALS

Cost of BOM	$74.50						
					Put 0 if not applied		
Part Number	**Part Name**	**Vendor**	**Qty**	**# in Pkg (if batch)**	Cost per unit	Cost (if batch)	Total Cost
8982K585	Multipurpose 6061 Aluminum 90 Degree Angle W/Round Edge, 1/4" Thk., 2" Ht X 4" Wd Outside, 1' Lg	McMaster Carr	1	1	17.24	0.00	17.24
1502A14	Mortise-Mount Template Hinge with Bearings, Removable Pin, Primed Steel, 4-1/2" x 2" x 0.134" Leaves	McMaster Carr	1	1	10.94	0.00	10.94
91771A582	18-8 Stainless Steel Phillips Flat Head Screw, Passivated, 5/16"-18 Thread Size, 7/8" Long	McMaster Carr	8	10	0.00	3.72	3.72
92395A030	Brass Screw-to-Expand Inserts for Plastic, 5/16"-18 Thread Size, 0.563" Installed Length	McMaster Carr	9	10	0.00	6.95	6.95
97149A150	18-8 Stainless Steel Hex Nut, Black-Oxide, 5/16"-18 Thread Size	McMaster Carr	6	25	0.00	4.90	4.90
5126A730	Hold-Down Toggle Clamp, Open Arm, Steel, 1050 lbs. Holding Capacity, 6-1/8" Overall Length	McMaster Carr	1	1	20.37	0	20.37
90272a575	Steel Pan Head Phillips Screws, 5/16"-18 Thread, 1/2" Long	McMaster Carr	4	25	0.00	7.47	7.47
98750a449	Grade B7 Medium-Strength Steel Threaded Rod, 5/16"-18 Thread Size, 8" Long	McMaster Carr	1	1	2.91	0.00	2.91