INTRODUCTION

Obesity is a growing public health concern. According to the World Health Organization (WHO), over **650 million adults worldwide** are classified as obese, with physical inactivity being a major contributing factor (WHO, 2021). Strength training plays a crucial role in weight management and metabolic health, yet many individuals lack access to effective resistance training due to financial and logistical constraints.

Strength training is a critical component of physical fitness, aiding in **muscle development, injury prevention, and overall health**. However, accessibility to strength training equipment remains a significant barrier due to **cost, space requirements, and reliance on external power sources** in modern resistance training systems.

Traditional weightlifting methods, such as **free weights and resistance bands, present various challenges**. Free weights require **dedicated storage** and can cause **strain if used improperly**, while resistance bands provide **inconsistent force output**. Modern resistance training systems address some of these limitations but often come with **high costs and installation requirements**, making them inaccessible to many users.

To address these issues, this project explores the development of a **compact, battery-powered motor-based resistance system** that eliminates the need for mounting, external power, or bulky weights. The goal is to provide an **affordable, portable, and effective** alternative to traditional resistance training, making strength training more accessible to a wider population.

Table 1. Decision Matrix

Feature	Free Weights	Resistance	Tonal	This System
Portability	No	Yes	No	**Yes**
Adjustable Resistance	Yes	No	Yes	**Yes**
Requires Mounting	No	No	Yes	**No**
Requires External Power	No	No	Yes	**No**
Smooth, Controlled Resistance	No	No	Yes	**Yes**
Max Resistance	High	Low	Medium-High (125 lbf)	**Medium (17 lbf)**
Suited for Rehab/PT	No	Sometimes	Yes	**Yes**
Total Cost Estimate	\$300–\$1,500	\$10–\$50	\$3,495 + \$49/month	**\$214.95**

RESEARCH OBJECTIVES

Primary Goals:

• Develop a **cost-effective, fully portable resistance system**.

• Ensure **smooth, adjustable resistance without external power**.

• Make it **affordable** compared to existing high-end alternatives.

Hypothesis:

• **Null:** The system will not offer measurable resistance across PWM levels.

• **Alternative:** Resistance will **increase proportionally with PWM input**, making it **viable for strength training**.

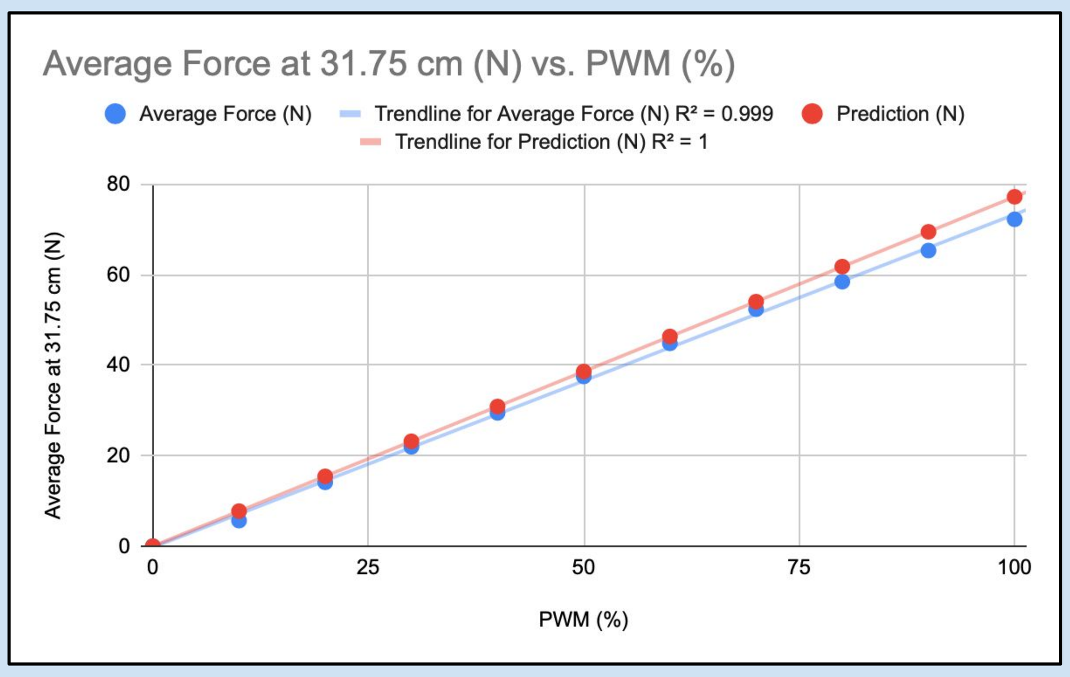

Figure 1. Average Tested Force (N) compared to Predicted

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ENGINEERING PROCESS

Version 1: 3D-printed

Figure 15. V1 Resistance Mechanism

- Used Eddy-Current breaking via electromagnet and an aluminum disk (figure 15)
- Failed due to very low and inconsistent resistance.

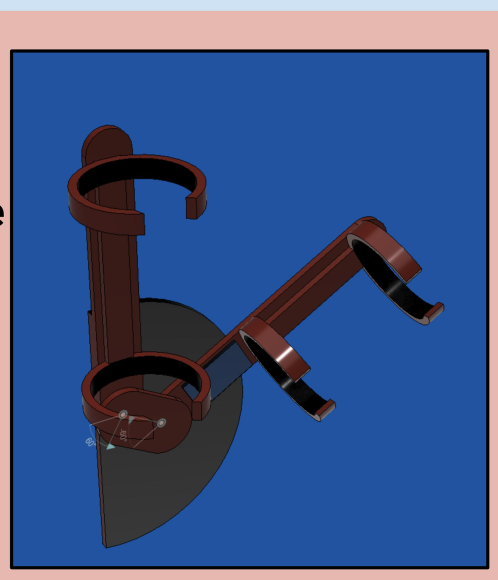

Figure 16. V1 CAD Design

Version 2:

- Chain-driven metal prototype
- Introduced backlash and mechanical bending as predicted in figure 18 and shown in figure 17 while testing

Figure 17. V2 after max load test

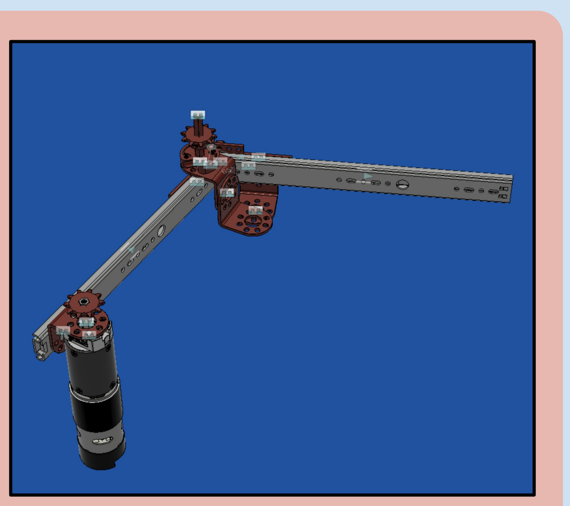

Figure 18. V2 CAD Design

Final Prototype:

- 188:1 geared motor for high torque.
- Drawer slides for smooth motion.
- PWM-controlled resistance via a microcontroller.
- More than strong enough to handle max load as shown in figure 19.

Figure 19. V3 CAD Design

CONCLUSIONS

The results demonstrate that the motor-based resistance system offers a linear increase in resistance with PWM input as shown in figure 8, validating the hypothesis of adjustable and consistent resistance. With minimal variation (<0.22N per setting) as shown in table 2 across trials, the system reliably maintains force output, essential for strength training. The regression analysis as shown in figure 11, ($R^2 = 0.993$) shows a strong correlation between PWM input and resistance force, confirming the device's predictability across varying intensities.

1. **Impact on Strength Training:** The motor-based system offers a consistent and adjustable resistance, providing an effective alternative to traditional weightlifting and resistance bands. This ensures more controlled strength training by maintaining constant resistance throughout movement.

2. **Affordable and Accessible:** Priced at just \$214.95, the device is an affordable solution compared to commercial motor-based systems (\$2,000-\$3,000). Its portability and ability to operate without external power make it more accessible than bulky, fixed equipment.

3. **Broader Applications:** Beyond fitness, the system has potential applications in rehabilitation and physical therapy. Its ability to offer customizable resistance levels provides a versatile and affordable tool for patient recovery, making it an appealing alternative to traditional weight-based systems.

FUTURE WORK

I am excited about the results achieved so far and have many ideas for future investigations and improvements. Here are a few directions I am eager to explore:

• **Enhance Motor Functionality:** I plan to refine the motor's gearing system to achieve higher resistance and ensure normal-speed limb movement during exercise, which will improve the user experience and make the system even more versatile.

• **Universal Joint Integration:** By adding a universal joint, I can engage stabilizer muscles, offering a broader range of exercises and enhancing the system's potential for comprehensive workouts.

• **Optimize Battery Life & Smart Features:** I am interested in improving battery efficiency and exploring real-time feedback systems that dynamically adjust resistance based on the user's performance, providing a more personalized training experience.

• **Expand Applications Beyond Fitness:** The potential for this device extends beyond strength training. I aim to investigate how this system could be adapted for rehabilitation and physical therapy, where customized resistance levels are crucial for patient recovery.

AFFORDABLE, PORTABLE, ACCESSIBLE EXERCISE

Motor-Based Resistance System for Strength Training

All images, figures, and tables used in this presentation were created the Researcher.

ENGINEERING METHODOLOGY

Construction

Figure 4. Core Components

1. Drawer Slides: 240mm with 174mm travel steel drawer slides
2. Motor: 12V RS-555
3. 8mm Hex shaft hub
4. Gearbox: Planetary(188:1)
5. Bucket: 5 gallon
6. Microcontroller: Arduino Uno
7. Motor Controller: Roboclaw Rx7A
8. 8 AA Batteries

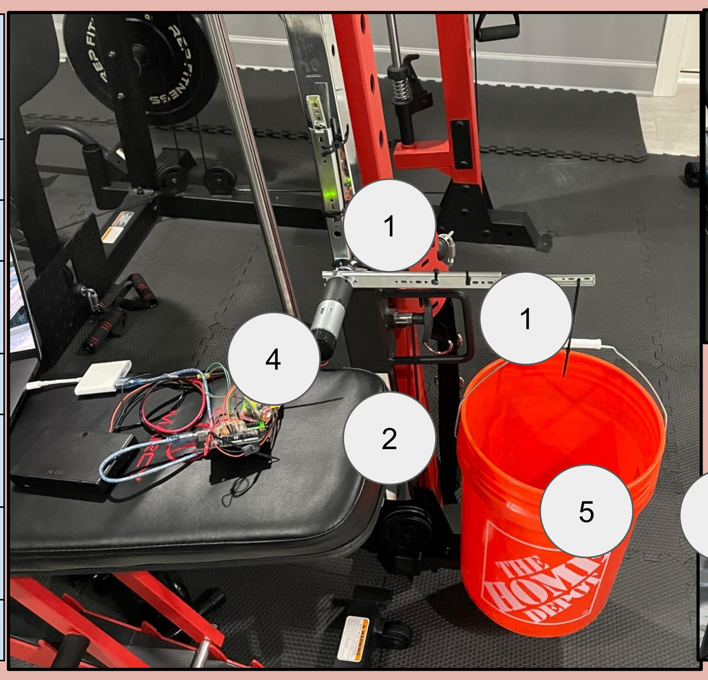

Figure 2. Testing Setup

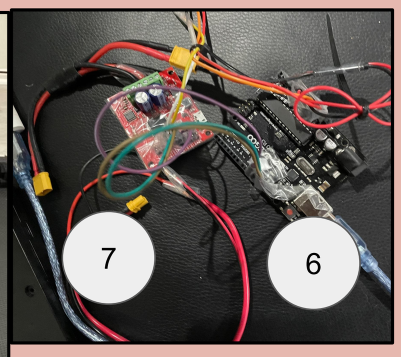

Figure 3. Microcontroller + Motor controller

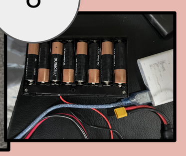

Figure 5. Battery

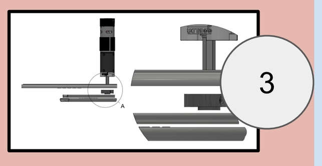

Figure 6. Hub

A. **A 9mm hole was drilled** in one drawer slide for the motor shaft, along with **two mounting holes** to secure the motor with screws.
B. **The second drawer slide was attached** to an **8mm hex shaft hub** using screws, positioned **close to the first slide without contact**. (Figure 6)
C. **Two Velcro straps were evenly attached** to each slide for secure limb attachment. (Figure 8)
D. **The motor was wired** to a microcontroller for **PWM-regulated resistance**. (Figure 3)
E. **All electrical connections were insulated** to prevent short circuits.

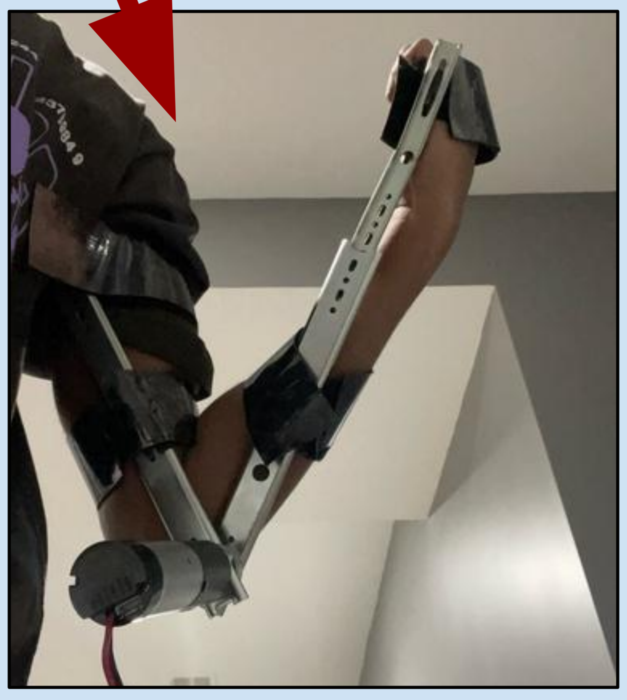

Figure 8. Researcher wearing device

Programing

```
// Includes required to use Roboclaw library
#include <SoftwareSerial.h>
#include "RoboClaw.h"

// See limitations of Arduino SoftwareSerial
SoftwareSerial serial(10, 11);
RoboClaw roboclaw(&serial, 10000);

#define address 0x80

void setup() {
  // Open roboclaw serial ports
  roboclaw.begin(38400);
}

void loop() {                    //Change this value to a
  roboclaw.BackwardM1(address, 63.5); // This value is the 7 bit PWM being sent to the motor. 0-127
}
```

```
void readEncoder(){
  int b = digitalRead(ENCB);
  if(b > 0){
    posi++;
  }
  else{
    posi--;
  }
}
```

Figure 8. Encoder reading

Figure 7. PWM input program

In an effort to minimize variables, this script seen in figure 7 was simplified to its core function . It makes the arduino send a signal to the motor controller to give the motor specific pulses with varying wavelength and amplitude based on the number given, in a range from 0-127 (PWM). 75% PWM sends a pulse that is 75% maximum voltage and 25% 0 voltage. As the percent keeps increasing, the time the pulse is at maximum voltage is longer with 100% always being at maximum voltage and 0% always being at 0 voltage. This allows for near analog levels of control allowing me to be certain that my results accurately reflect the capabilities of this device. The script seen in Figure 8 constantly prints the encoder ticks of the motor, so testing can be as accurate as possible.

Testing

Testing

a. Attach one end of the device to the leg of a fixed object, such as a table leg, using **at least 10 zip ties** to provide a stable reference point. (Figure 10)
b. Secure a bucket to the other end **at a known distance** from the center of rotation using a **carabiner** to apply consistent force. (Figure 9)
c. Adjust the angle of the non-stationary drawer slide to ensure that **gravitational force remains tangent** to the motion throughout rotation. (Figure 9)

Data Collection Protocol

a. Start with **0% PWM** (independent variable) and gradually increase in **10% increments** up to **100%**.
b. Load the bucket with a **5 lb base weight** to keep the motor from moving and to level the forearm.
c. At each increment, **record the maximum weight** the motor can sustain before failure, determined by **adding sand to the bucket until the motor encoder changes by 1 tick**.
d. Conduct **three trials** for each PWM setting to ensure **accuracy and consistency**.
e. Measure the **force of the bucket in Newtons**.

Safety Considerations

a. Inspect all **mechanical connections** before each test to prevent **structural failures**.
b. Wear **protective gloves and safety goggles** when handling moving parts.
c. Ensure testing is conducted in an **open area** to prevent **accidental impact injuries**.
d. Implement **emergency shutoff mechanisms** in case of **electrical malfunctions**.

Figure 9. Bucket hanging position

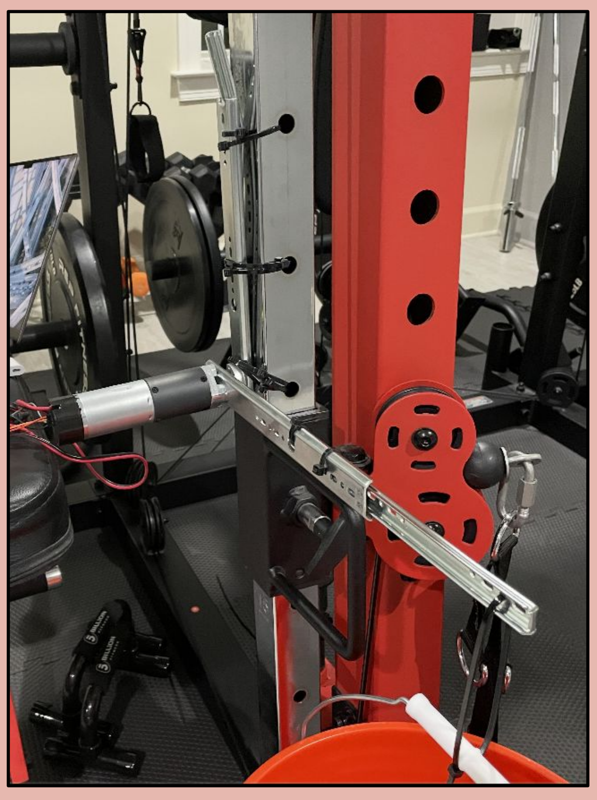

Figure 10. Mounting the device

RESULTS

Table 2. Testing data

PWM (%)	Prediction (N)	Trial 1 (N)	Trial 2 (N)	Trial 3 (N)	**Average Force (N)**	Prediction (lbs)	Trial 1 (lbs)	Trial 2 (lbs)	Trial 3 (lbs)	**Average(lb)**
0	0.00	0	0	0	0	0	0	0	0	0.00
10	7.74	5.52	6.18	5.25	5.65	1.74	1.24	1.39	1.18	1.27
20	15.44	15.08	13.17	14.06	14.10	3.47	3.39	2.96	3.16	3.17
30	23.18	23.93	21.00	20.95	21.96	5.21	5.38	4.72	4.71	4.94
40	30.87	32.12	28.07	28.20	29.46	6.94	7.22	6.31	6.34	6.62
50	38.61	39.59	36.16	36.79	37.51	8.68	8.9	8.13	8.27	8.43
60	46.35	46.71	44.17	43.59	44.82	10.42	10.5	9.93	9.8	10.08
70	54.05	53.82	51.33	51.96	52.37	12.15	12.1	11.54	11.68	11.77
80	61.79	56.94	59.74	58.72	58.46	13.89	12.8	13.43	13.2	13.14
90	69.48	62.28	67.03	66.72	65.34	15.62	14	15.07	15	14.69
100	77.22	66.72	74.91	75.09	72.24	17.36	15	16.84	16.88	16.24

Equation: $y = 0.7357x - 0.2444$

Parameters: $r^2 = 0.993$ slope = 0.7357 x-intercept = 0.3322 y-intercept = -0.2444 rho = 0.995

Figure 11. Regression Equation

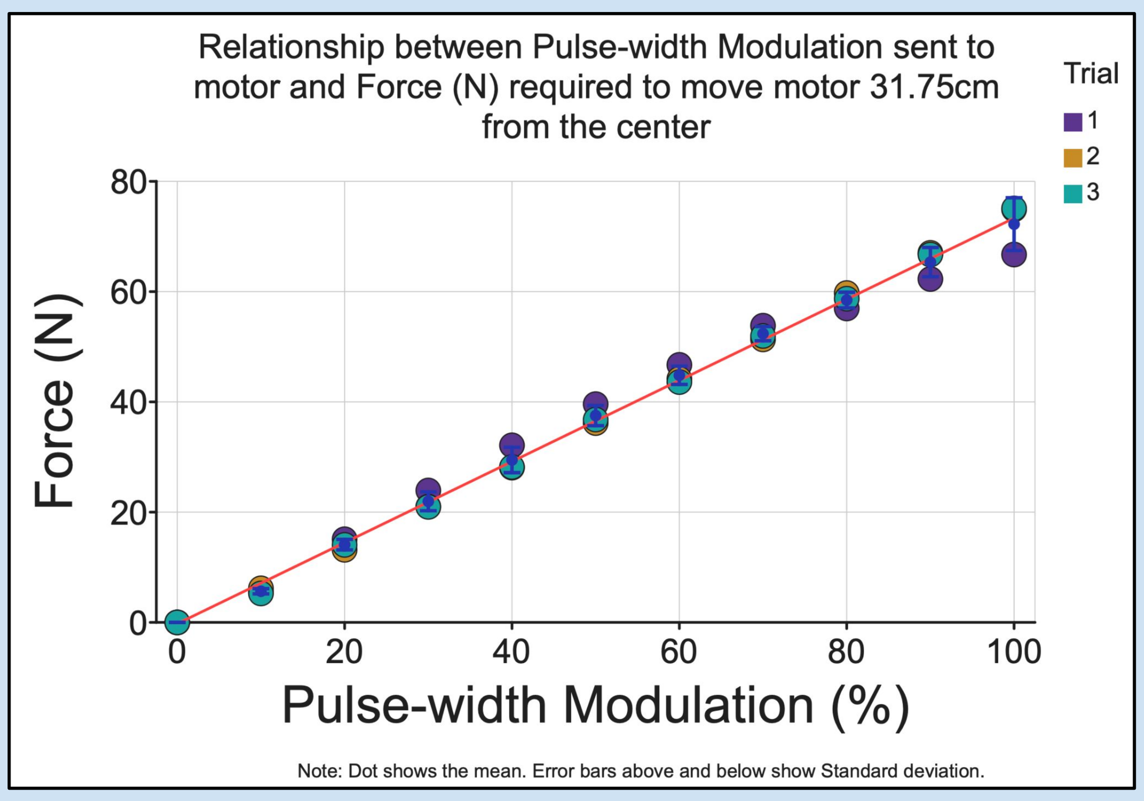

Figure 12. Relationship between PWM and Average tested force required to move motor

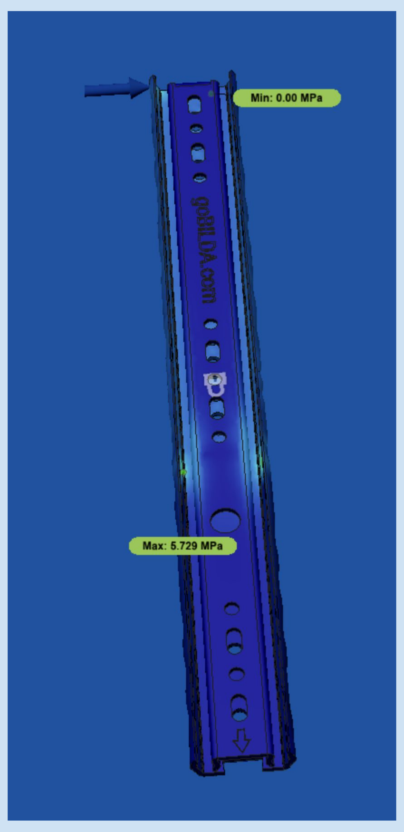

Figure 13. CAD Simulation of horizontal force on drawer slides

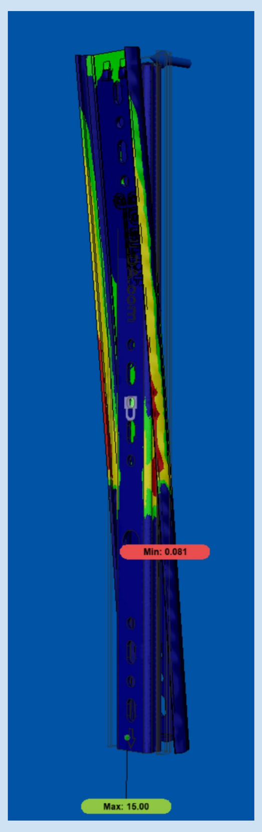

Figure 14. CAD Simulation of horizontal force on drawer slides