EM121 PROJECT: Weightlifting Equipment Re-Design

Summary:

Your objective is to **design a safe link** for a piece of weight-lifting equipment that will allow users to raise the arm of the device to lift a set of weights off of the base. For a successful design, the lifting arm will begin at the specified angle, the link will assemble to the device, and not break, nor stretch more than 10% of its original length as the weights are slowly lifted by 6 inches. Designs with lower embedded CO_2 are considered better designs.

Details:

Figure 1 shows a weight-lifting machine that is similar to one that is currently available in the SRC. In this machine, the entire structure is made of welded square tubing, and the equipment is quite expensive. (You can find it, used, for around $1000 on eBay.)

We hope to compete in this market by creating a similar machine that performs a similar function, but which uses less material, is less expensive, and is easier to ship. Figure 2 shows a solid model of the prototype design, one half of the total mechanism.

Figure 1. The "Life Fitness Hammer Strength Squat Lunge" Weight Lifting Machine is sturdy, but heavy. (Picture from http://www.safe-usa.com/usedgear.html)

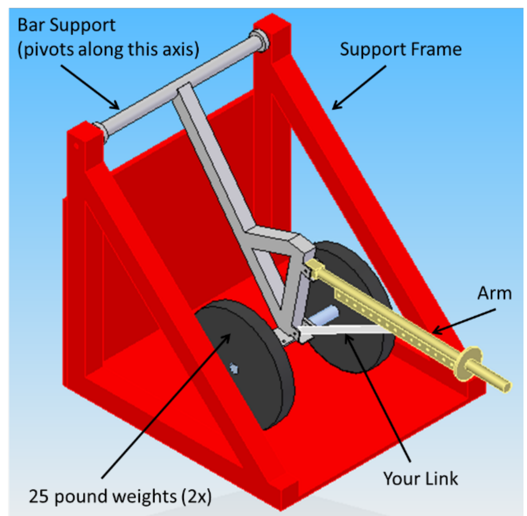


Figure 2. Our solid model predicts a much lighter design.

One part of the redesign has been left to your team—**you will design the 2D profile of the link** that connects the arm to the bar support near the weights, and allows the weights to be raised by the user. The upper end of the link is pinned to the arm by a shoulder screw at one of 16 possible hole locations. You will get to choose which hole you will use. The lower end of the link is joined (again by a shoulder screw) to the bar support. The diameter of the shoulder screws is nominally 0.250". Note that if the link was removed, the arm would pivot on the bar support at the upper hole and the weights wouldn't move at all.

The arm must be horizontal to within ±5° at the start of the lift, and it must be possible to *very slowly* lift the weights off of the support frame lower surface by 6 inches without breaking the link or permanently stretching it more than 10% of the original length. You do not need to consider buckling when the arm is not being supported—only the tensile loads when the machine is in use.

The drawings that describe the geometry of the mounting holes will be shared, but the overall engineering drawings will not. The device will be made available for inspection during business hours. Do not disassemble the device or attempt to experimentally determine your design—this project is about analysis, not experiment. However, you may measure lengths and distances with a tape measure or caliper to figure out the geometry, or take measurements to create a solid model of the device using your SolidWorks skills. Be careful.

Your link will be laser cut from a sheet of Nylon 6/6 sheet (a rigid plastic). We supply the material, and the thicknesses available to you are 0.062 inches, 0.094 inches and 0.124 inches. Part of your design choice is which sheet thickness to use. The manufacturer's material property data sheet will be shared, along with tensile test results for specimens fabricated from Nylon sheets purchased for these projects over the last few years. Think carefully about which set of data to use for your design.

You will work in teams on this project, determined by your instructor. You must fairly and evenly distribute the tasks, make sure everyone understands the analysis and decisions, and coordinate your deliverables. If teammates are behaving unprofessionally, talk to me. I will adjust individual student scores based on how they behave as a teammate.

Deliverables

The following gives the deliverables for the project.

- An **email** to your instructor (due Monday of 8th week by 8:00 AM) with the following
    - Subject line "EM121 link design Team #" where # is your team number.
    - An indication of which hole to use on the arm. Hole #1 is near the weights, hole #16 is near the handle grip.
    - A CAD file of your link design in .dxf format, not .sldprt, .slddrw, etc.
        - The CAD file must be in .dxf format, defining the outline of your link in a way that is appropriate for our laser cutting machine (see attached FAQs).
        - The name of the file **must** be given as Sec#Team#_thickness.dxf (for example: "Team311_094.dxf" for team 11 in section 3, using 0.094" plastic)
- A **written memo** (due in hard copy to your instructor Friday of 10th week in class) with summary of the design and technical analysis attachments providing documentation of your analysis and design process. The template and grading rubric for the memo are attached.

Testing (Contest Day)

There will be a contest to determine whether or not your link meets the design requirements without failing, as well as to determine the performance portion of your grade.

Testing procedure:

- The length and weight of the link are measured by the instructor (this will probably be completed before the contest). The embedded energy will be calculated.
- The team has one minute to assemble their link to the device, being careful not to let the arm compress the link (this might cause buckling failure, which we do not learn in this class).
- The instructor will check the initial arm angle when the link is just barely in tension—as felt in the handle grip—to make sure the specified starting angle is correct.
- One team member then slowly lifts the arm until the weights rise at least 6" (verified by instructor), then lowers the arm.
- The team removes their link and the instructor measures the new length to test for permanent deformation.

Grading

Your project grade will be based on two components with the following percentages:

Written memo & analysis	70% max	(see template & rubric)
Performance	30% max	(see below)
	100%	

Written memo & analysis grade

The memo template and grading rubric are attached. The memo is likely different from what you're used to and it cannot be successfully completed at the last minute. Please read all instructions.

Performance grade:

The performance portion of your grade is based on whether or not your team passes the test, and how your design compares to other designs in your section based on the criteria that *a link with lower embedded CO_2 is desirable.*

The project performance score is based upon the following system:

- If your link does not assemble to the device: performance grade = 15%
- If your link fails by fracture at any time during the test, or permanent deformation as measured after the test: performance grade = 17%
- If the link fails by not holding the arm at the initial angle (± 5°): performance grade = 20%
- If the link does not fail, then your grade will be determined based on a normalized link embedded CO_2 of all surviving links ($\frac{CO2_{yours}-CO2_{min}}{CO2_{max}-CO2_{min}}$). The surviving link with $CO2_{min}$ gets 30%, best third gets 28%, middle third gets 26%, and worst third gets 24%.

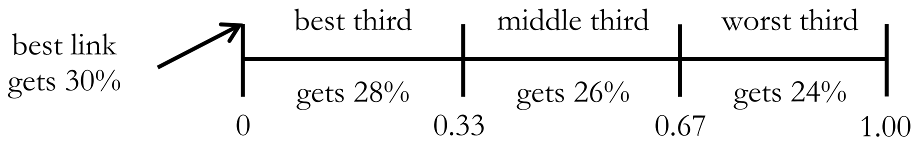


Table 1 summarizes the important dates regarding the project and its deliverables.

Table 1: Important dates

	Monday	Tuesday	Wed	Thursday	Friday
8th week	Email with .dxf file and hole choice by 8am				
9th week					
10th week		Moseley test day	Adams test day	Bernal test day	

To: Dr. Thom
From: *Your names & team number*
Date: February 17th, 2023
Re: Link Design for Weight Device, EM121

Delete this box and replace all the red text below with the appropriate information. Add words and sentences to make the writing sensible. Change the color back to black before printing. Also delete the comments that discuss the memo.

Our link *survived/failed* testing day. After testing, our link showed *no measurable elongation or the amount of elongation* so we believe it never passed the yield point. OR During testing, our link failed due to *elongation or fracture*. Our overall objective was *extreme light weight / balance of light weight and FOS / extreme FOS*. We analyzed geometry and forces *at the beginning of the test / over the entire range of motion*.

Our theoretical FOS was X.XX. Our analysis indicated that the maximum force in the link would be *put your max load here* during the test, so with a cross-sectional area of X.XXX in^2, the actual tensile stress in the link was *put your actual stress prediction here*. We estimated Nylon's yield strength as *put yield strength here* psi, by considering the *maximum/average/minimum test case*. Thus, the theoretical FOS against yielding was *put FOS here.* Our link's embedded CO_2 was X.XX pounds. The force analysis of the device is contained in the work documentation that follows. Figure 1 shows the geometry of our link design.

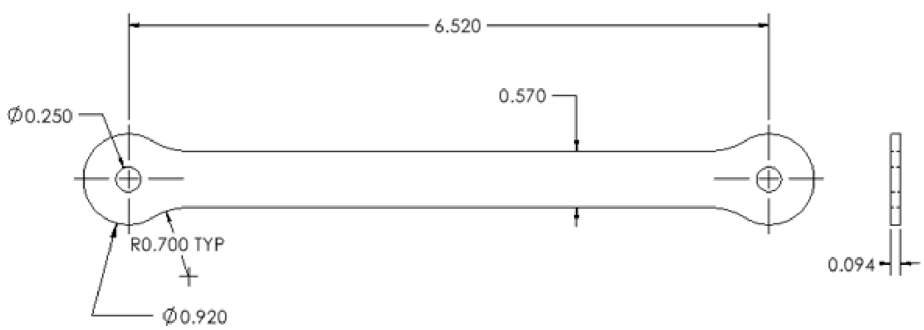


Figure 1: The dimensions of our link geometry are given here with measurements using inch units. Our link design has a cross-sectional area of _____ in^2.

In retrospect, *put key reflection here.* *Add more details like "The link survived the test, but the small FOS made us nervous. We were aiming for the smallest link, but got worried during test day. The consequences of a failed link seem to require a much higher FOS for a real-world design." Or "Our initial analysis contained an algebra error so our design was wildly overdesigned. We got "lucky" because the error could easily have caused an inadequate design. I now see how important careful work is when engineering real devices." Or "Our team decided to overdesign the link to avoid failure. But the extra embedded* CO_2 *seemed like a waste. There's likely a nice middle ground that balances reasonable safety and avoids extravagant material usage." Or "I learned that the geometry analysis was made easier in SolidWorks versus working it all out by hand."*

Signatures

Attachment 1 – Engineering Drawing
Attachment 2 – Analysis

Expected attachments & grading rubric

General notes:

- The memo must be printed (not handwritten). Images should be professionally prepared—cell phone pictures of handwritten work are not acceptable unless they are indistinguishable from actual scans of the work. Make sure the images are legible when printed.
- Attachment 1 must be created in a drafting package. Hand-drawings are not allowed.
- Attachment 2 may be handwritten on green engineering paper if you write clearly and use sufficient space for diagrams and explanations. Illegible or poorly documented work will be considered missing.
- Each attachment must start on a new page, and have a clear title.

Link geometry details (attachment 1)

A fully dimensioned engineering drawing of the link, including thickness and material specification. This should be printed on white paper from SolidWorks or a similar drafting package. This is NOT the dxf file you submitted to get the part cut on the laser cutter. Use your EM104 skills.

Engineering analysis work (attachment 2)

A complete engineering analysis of the expected loads on the link and the calculations used to decide the link dimensions. Clearly stated system boundaries and FBDs are expected. Show your FOS for failure in the main link body as well as near the holes. Use sentences, paragraphs, and appropriate equilibrium equations, *as if you were writing an example problem in the textbook*. Give enough detail for someone to understand how you arrived at your link design and why you made your design choices—use words, phrases, annotations, and sentences. No design decisions should be made without justification. Convince me that your design is a good one!

Grading rubric

Memo [15 pts]	[0] Memo is missing or substantially incomplete. Poor or rushed attempt.	[5] Parts of the memo make sense and images are used, but not effectively. Some expected information is missing.	[10] Memo makes sense with mostly clear writing and somewhat useful images. All expected information is included.	[15] Memo makes sense with clear writing and useful images. All expected information is included.
Attachment 1 [10 pts]	[0] Link geometry not shown, or hand-drawn.	[5] Link geometry shown with an attempt at relevant standards, but much is missing.	[8] Link geometry given according to relevant standards, almost sufficient for manufacture.	[10] Link geometry given according to relevant standards, sufficient for manufacture.
Attachment 2 [45 pts]	[10] Explanation barely attempted,	[25] Explanation of link analysis and	[35] Good-quality explanation of link	[45] Textbook-quality explanation of

	appears to be scratch work, or fundamental technical errors exist.	design is lacking, moderate technical errors exist.	analysis and design, but something's unclear or a small technical error exists.	link analysis and design. Correct technical analysis.

Laser cutter and .dxf file FAQ

Question: What is the tolerance on the laser cutter?

± 0.005"

Question: What is the minimum size for the links (that is, the smallest width we can manufacture)?

The minimum should be 0.032".

Question: What is the size of the laser beam?

The laser beam is 0.006" dia. and cuts at the center of the line. If two lines are drawn 0.032" apart the cut part will be .026" wide.

Question: Does the laser cutter make perfectly straight lines?

No. Very small "waviness" is seen for some cuts, particularly for very thin or small features.

Question: How do you create a .dxf file from an existing model in SolidWorks?

1. Make sure the solid model is scaled correctly so the resulting link is the correct size. If your link should be 3 inches long, make sure the model is also 3 inches long.
2. Right click on the surface that is to be the profile of the link and select "Export to dxf".
3. Under "Options" change the version to "R12", click OK.
4. Select a folder and filename (see deliverables for the filename convention).
5. On the left-side toolbar there's a green check mark—click that.
6. A preview should show up on a black background. Make sure the 2D profile shows up with no dimensions at all (a coordinate system is okay).
7. Save. This is the .dxf file to attach to your email.

Question: I'm afraid I created the .dxf incorrectly. How can I check it?

1. Open the .dxf file in SolidWorks.
2. Use a drawing template with inch units.
3. The import dialog will open with lots of options. Just click Finish.
4. Use Smart Dimension to verify the sizes are all correct (don't forget the mounting holes!)
5. When you're satisfied the geometry is correct, close the drawing file and don't save it. Your .dxf file should still be there—you're just deleting the temporary file you created.

Question: What is Nylon 6/6?

Nylon 6/6 is in the polyamide (PA) family of polymers. The CO_2 footprint is 7 lb/lb with a density of 0.04 lb/in^3. Together, this gives a CO_2 footprint of 0.28 lb/in^3. [Granta EduPack 2023].

Experimental material properties

The nylon material used for the links has been tested in the past, with the following test results. You will need to perform some calculations to convert the dimensions and peak pull forces into stresses.

Nylon 6/6

published yield strength per ASTM D638 10000 psi

2007 sample test results

actual pull speed inches/minute 2.3

sheet thickness [in]	specimen width [in]	peak pull 1 [lbs]	peak pull 2 [lbs]
0.192	0.200	373.0	379.0
0.192	0.100	175.0	171.0
0.124	0.200	260.0	270.0
0.124	0.100	120.0	126.0
0.094	0.200	175.0	176.0
0.094	0.100	83.0	90.0
0.065	0.200	105.0	108.0
0.065	0.100	48.7	50.0

2008 sample test results

actual pull speed inches/minute 2.0

sheet thickness [in]	specimen width [in]	peak pull 1 [lbs]
0.198	0.200	447.0
0.198	0.100	208.0
0.123	0.200	220.0
0.123	0.150	181.8
0.123	0.150	182.5

0.123	0.100	105.0
0.123	0.100	116.2
0.123	0.100	117.5
0.123	0.050	50.0
0.123	0.050	50.6
0.092	0.200	162.0
0.092	0.088	70.0
0.063	0.200	115.0
0.063	0.070	37.5

CO_2 footprint

"CO_2 footprint" refers to a change in the state of the climate that can be identified by shifts in the mean and/or the variability of its properties, and that persists for an extended period - typically decades or longer. It is calculated based on global warming potential (GWP), developed by the Intergovernmental Panel on Climate Change (IPCC). The GWP model allows comparisons of the global warming impacts of different gases, reported as carbon dioxide equivalents (CO_2-eq.). The indicator is based on an IPCC method published in 2013.

The embedded CO_2 footprint of the material is comprised of:

- The embodied energy used in the mining or harvest of the raw material
- The energy associated with collecting the manufacturing waste
- The 'credit' for recovering the manufacturing waste
- The details of how the material is manufactured.

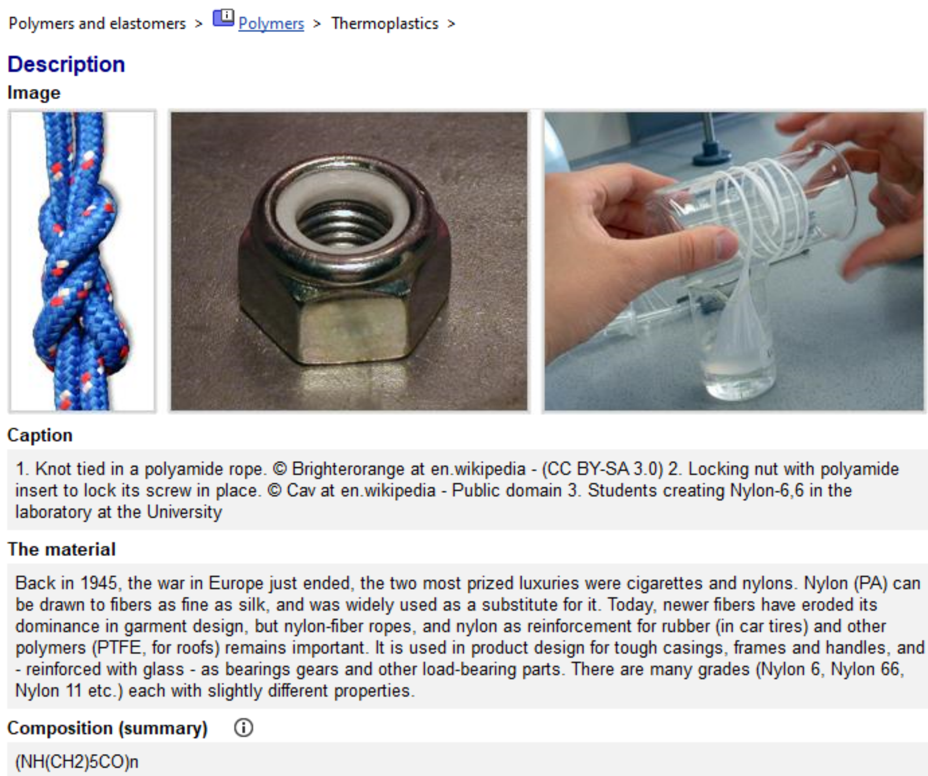
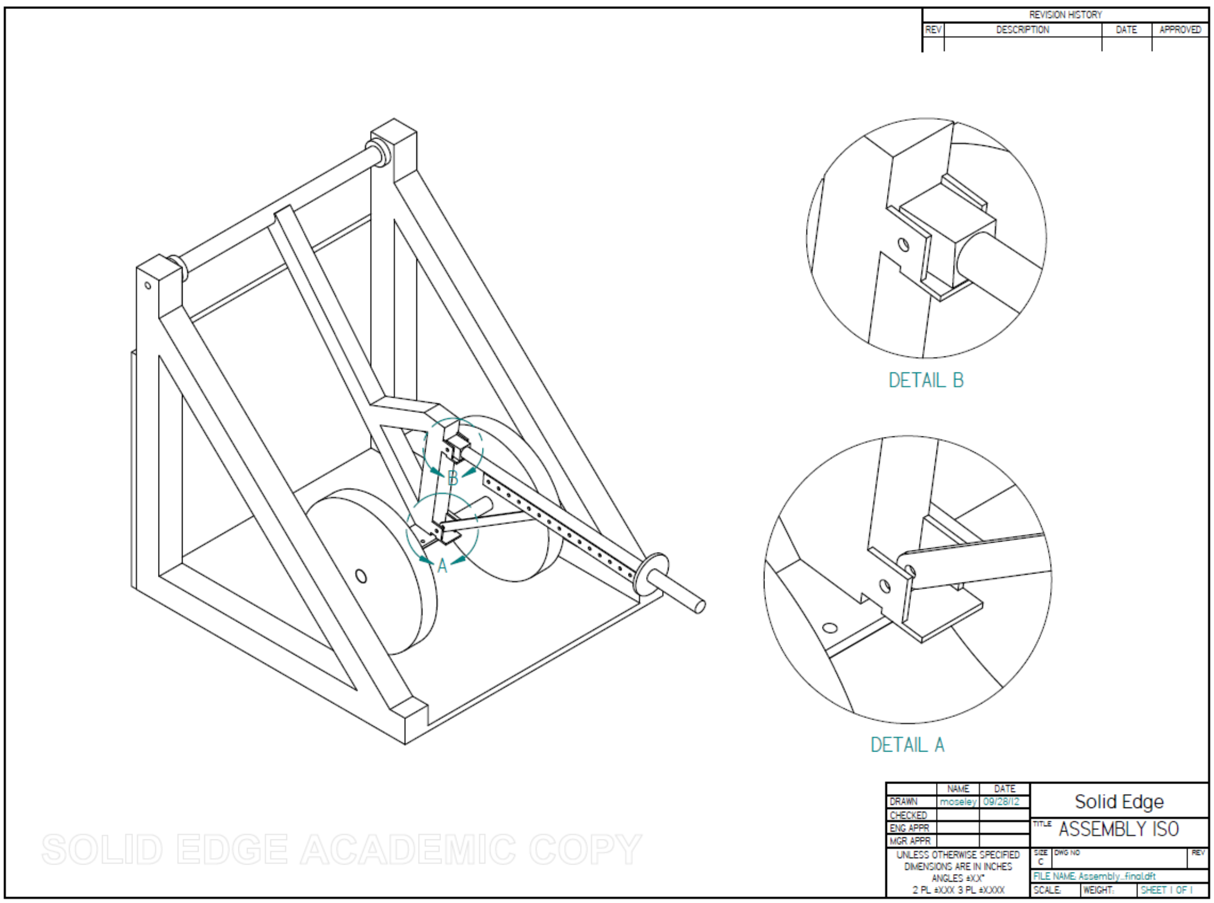
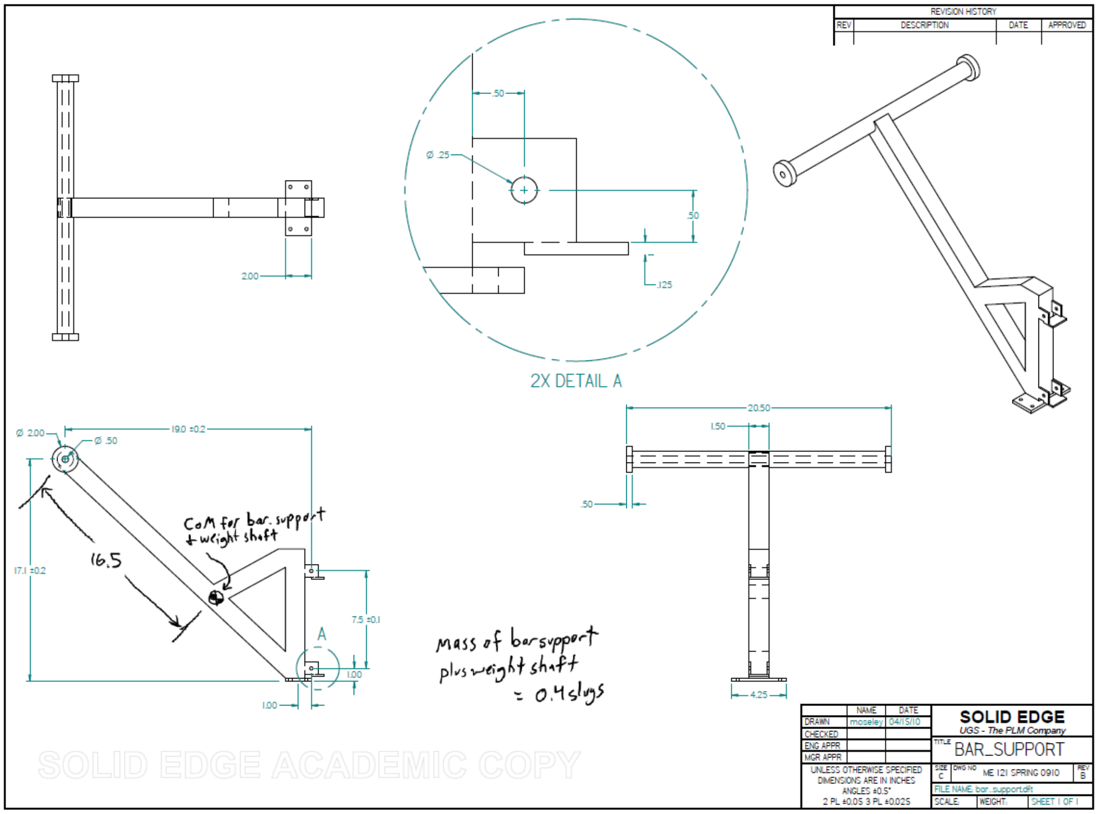


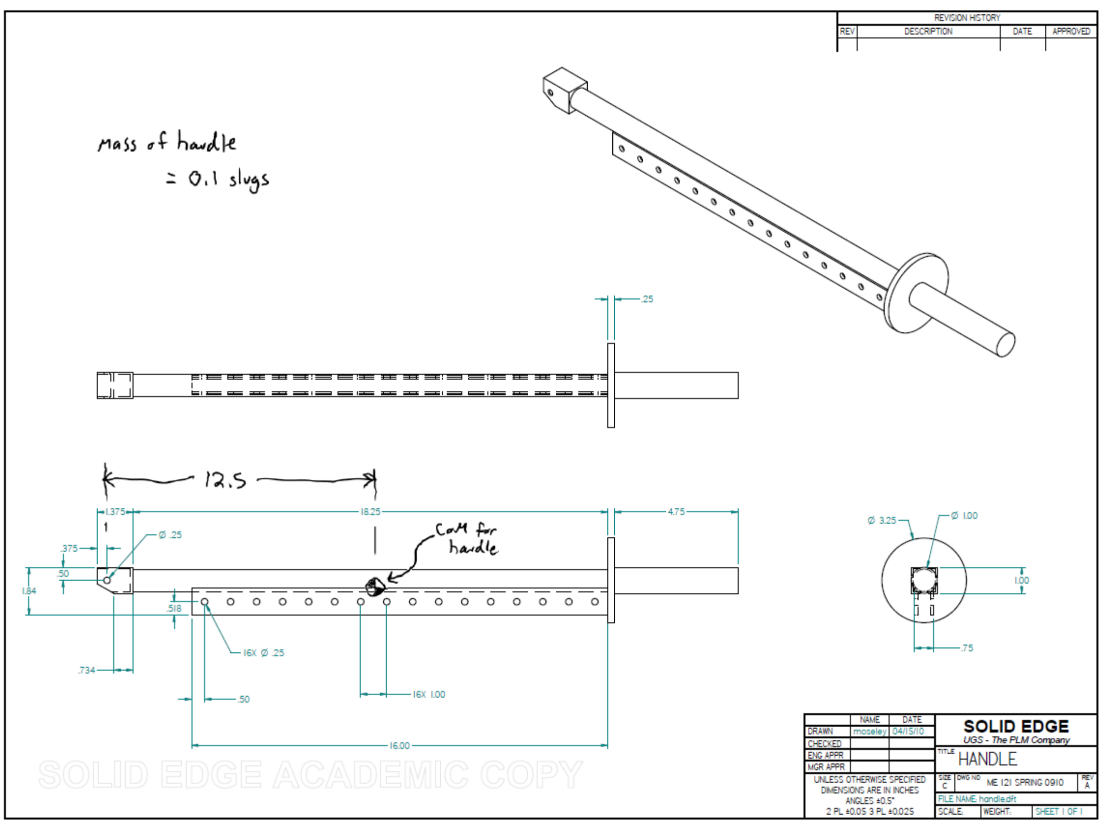
Figure 3: A screenshot from the Granta EduPack software describing Nylon. The Granta EduPack software contains useful descriptions of common engineering materials along with property summaries like embedded CO_2. The value for embedded CO_2 used in this project is taken from EduPack data.

Hole locations & device geometry

These drawings were created in a good-faith attempt at modeling the actual device, with measurements given in inches. Actual measurements from the actual device might vary from these.




REVISION HISTORY
REV DESCRIPTION DATE APPROVED
2X DETAIL A
CoM for bar support + weight shaft
16.5
Mass of barsupport plus weight shaft = 0.4 slugs
SOLID EDGE ACADEMIC COPY
SOLID EDGE
UGS - The PLM Company
TITLE BAR_SUPPORT
DRAWN moseley 04/15/10
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES ANGLES ±0.5° 2 PL ±0.05 3 PL ±0.025
ME 121 SPRING 0910
FILE NAME: bar_support.dft
SHEET 1 OF 1


REVISION HISTORY
REV DESCRIPTION DATE APPROVED
Mass of handle = 0.1 slugs
12.5
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SOLID EDGE ACADEMIC COPY
SOLID EDGE
UGS - The PLM Company
TITLE HANDLE
DRAWN moseley 04/15/10
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES ANGLES ±0.5° 2 PL ±0.05 3 PL ±0.025
ME 121 SPRING 0910
FILE NAME: handle.dft
SHEET 1 OF 1