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ME 476C

To: Professor David Willy & TA Gray Becker

From: Henry Benedictus

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Re: Homework 4

Introduction:

The Active Rocket Control system will have a modular motor ring to easily take the aft end of the rocket and its associated components out for ease of maintenance and assembly. The motor rings have a hole in the middle for the motor to be in, and then on the outer edges, there are 4 screw holes on each ring (3 rings in total). On the rocket fuselage, there are associated holes in which the screw will go to connect to the motor ring. These 12 screws will then hold the entire motor system to the fuselage. The purpose of this analytical assignment is to find the shear stress of the screws to properly choose a correct diameter and material.

Assumptions:

The I500 rocket motor that was chosen for launch produces a maximum force of 640 N according to its manufacturer, AeroTech [1]. Since all three motor rings are connected to the motor itself, it is assumed that each of the top screws is undergoing 640 N, with a factor of safety (FS) of 2. The tables for screw size and material properties are found within Shigley's Mechanical Engineering Design, Eighth Edition, "Chapter 4, Deflection and Stiffness," and Chapter 8, "Screws, Fasteners, and the Design of Nonpermanent Joints [2]. Equations 1 and 2 will be used to find the shear stress that the screw undergoes and the maximum shear that it can withstand. Equations 3 and 4 are to find the maximum deflection of the screw to compare it to the FEA model.

$\tau = \frac{\nu}{A_s}$ (1) $\tau_{Allow} = \frac{\tau_{Shear}}{F.S}$ (2) $\delta_{max} = \frac{PL^3}{3EI}$(3) $I = \frac{\pi r^4}{16}$(4

Shear Force (ν)	1280 N
Radius (r)	0.125in
Force (P)	1280 N
Length (L)	0.748 in

Table 2: Mathematical Modeling Units

Besides using mathematical modeling to determine the screws that will need to be used, the built-in Finite Element Analysis (FEA) stress modeling within SolidWorks is used. To perform this test, the fuselage (Figure 1) that is planned to be used for the system is modified within SolidWorks and will have fiberglass as its assigned material. For the motor ring (Figure 2), its material will be Polylactic Acid (PLA) since, at the moment, those parts will be 3D printed. The ¼ in screw (Figure 3) that will be used for the simulation was modeled by Carlos Lopez and open-sourced from Grab CAD [3]. The material of the screw will be based on readily available ¼ in screws that can be bought commercially (Walmart, Home Depot, Lowes, etc). The scrw that is used is a hex screw that is readily available at Home Depot. A ¼ in screw and a larger screw adapter for ¼ are readily available if need be.

Material Properties:

Within Table 1, the material properties for each material that will be used for this simulation are presented in standard units. Each property is entered in as a custom material within SolidWorks since it does not have these specific materials prelisted.

	PLA	G12 Fiber Glass	A574 Alloy Steel
Elastic Modulus (psi)	290075	$12.3282 * 10^6$	180000
Poisson's Ratio	0.3	0.23	0.3
Shear Modulus (psi) (τ_{shear})	350000	$5.22136 * 10^6$	72000
Density (lb/in^3)	0.047	0.09375	0.284
Tensile Strength (psi)	5801.5	$297.327 * 10^3$	180000
Citation	[4]	[5]	[6]

Table 2: Material Properties

CAD Drawings:

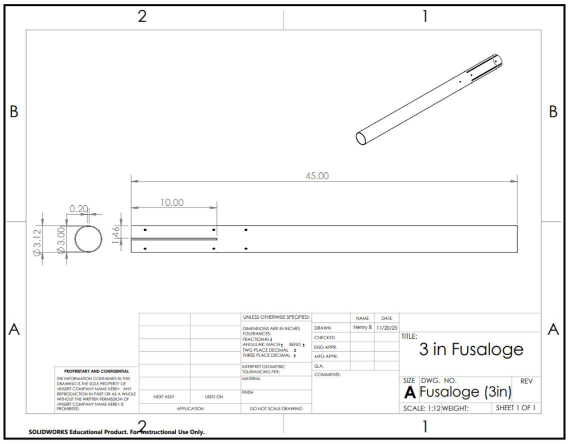

Figure 1: Fuselage Drawing

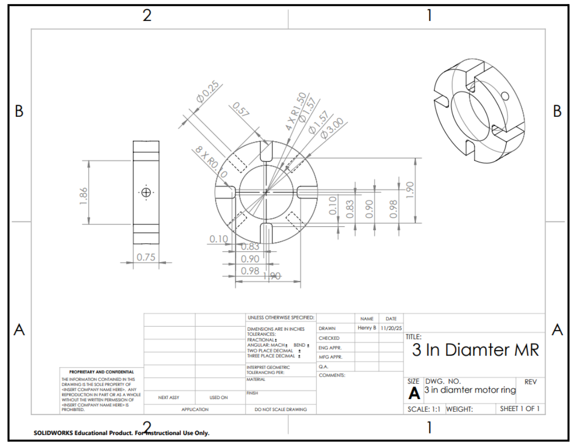

Figure 2: Motor Ring Drawing

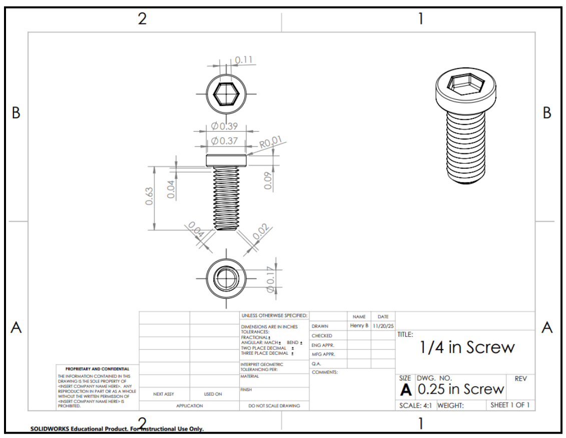

Figure 3: ¼ in Screw Drawing

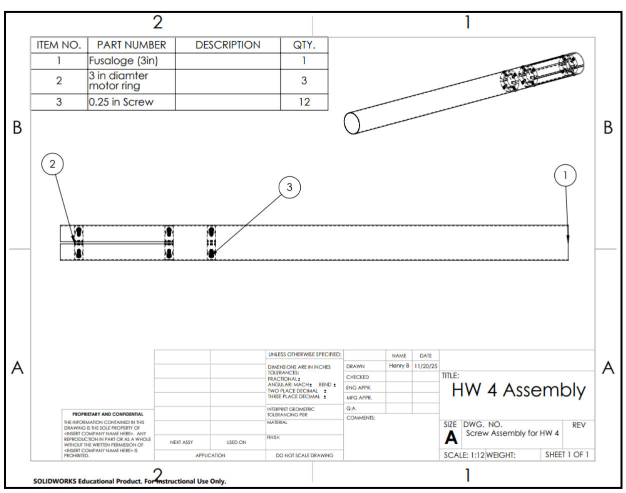

Figure 4: Assembly Drawing

SolidWorks FEA:

After entering all the associated values into the SolidWorks Material, a 1280 N distributed force was applied to one of the rings. The fuselage had a static boundary condition applied to it in all directions. However, when testing this within SolidWorks FEA, it couldn't detect the connection between the bolts and the inner motor ring.

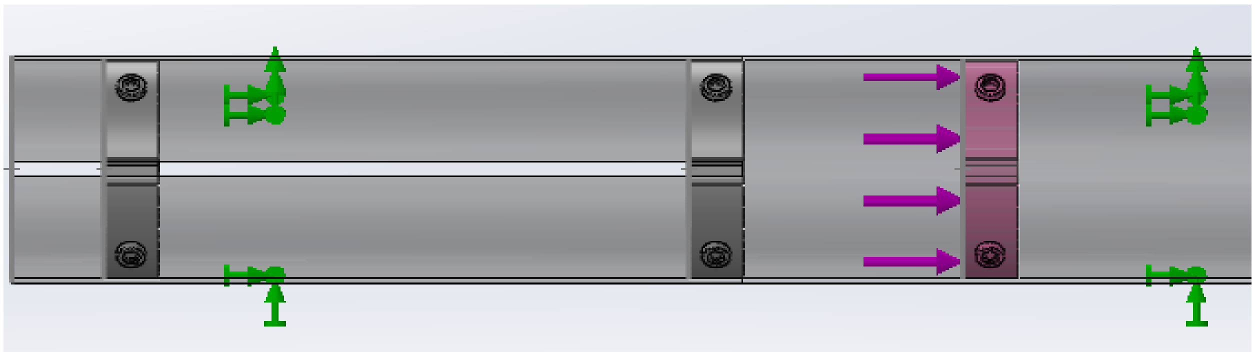

Figure 5: Applied Boundary Conditions of Motor Rings and Bolts

Since the initial test didn't work, a bending force test was performed for a single bolt, undergoing a force of 1260 N along the entire mid-length of the bolt. A displacement boundary condition was applied to the head of the bolt since it will not be undergoing any noticeable forces. This can be seen within Figure 6 with the generated mesh with a fineness between fine and medium.

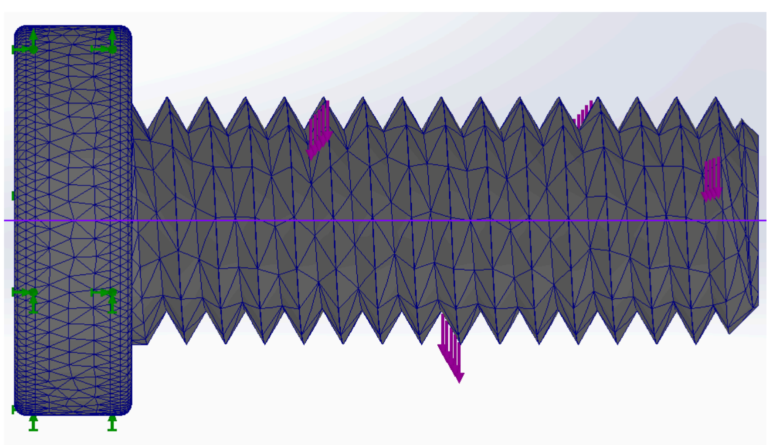

Figure 6: Applied Boundary Conditions and Mesh of Screw

After the boundary conditions were applied and the mesh created, the simulation ran. It took approximately 5 minutes to complete. Once complete, it generated the displacement (Figure 7), Stain (Figure 8), and Stress (Figure 9) experienced by the screw. It experienced a maximum displacement of 1.386 mm (0.055in), maximum stress of 3.170E4 N/m^2, and maximum strain of 5.195E-5. Based on the simulation, the chosen screws are strong enough to withstand double the force they would be estimated to be undergoing.

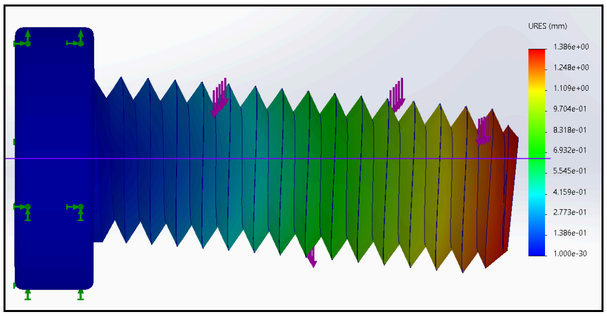

Figure 7: Displacement of Screw

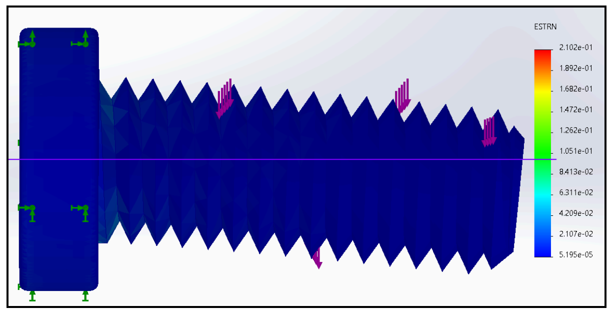

Figure 8: Strain of Screw

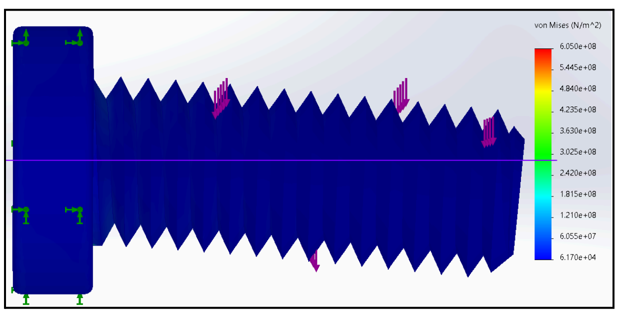

Figure 9: Strain of Screw

Mathematical Modeling:

First, finding the Shear Force of the screw, equations 1 and 2 were used. Based on the results, the estimated shear force experienced by the bolt is over 6 times the allowed shear stress of the bolt.

$$\tau = \frac{v}{A_s} = \frac{1280N}{(1/4in)/25.4\ (mm/in)} = 40.5MPa \qquad \tau_{Allow} = \frac{72000psi\ */145\ (MPa/psi)}{2} = 248\ MPa$$

To compare the results from the FEA simulations, equation 3 was used, which simulates a cantilever beam with a load at the end of the beam. After the calculation was done, it had an absolute error of 1.4%. This value could increase by not

$$\delta_{max} = \frac{PL^3}{3EI} = \frac{1260N*0.225\ (lbs/N) * (0.748in*39.37\ (m/in))^3}{3*180E3psi/(145\ (MPa/psi))*7.67E-4in^4*(4.16*10^{-7}in^4/m^4)} = 0.0014m = 1.4mm$$

Conclusion:

The results from the FEA and Mathematical Modeling show that a singular screw chosen from Home Depot can withstand the entire force exerted by the rocket. This means that the entirety of the 12 screws is plenty strong enough to secure the rocket to the fuselage, especially during launch, where the maximum force appears. It can also be concluded that a screw that is slightly smaller in diameter or weaker material could also be used if need be. The tests conducted also prove that attaching the motor and motor rings to the fuselage through a screw is feasible.

Work Cited

[1] I. Apogee Components, “Apogee components - Aerotech 38mm HP SU DMS motor - I500T-14A,” I500 Blue Thunder Disposable Motor System, https://www.apogeerockets.com/Rocket_Motors/AeroTech_Motors/38mm_Motors_Single_Use/Aerotech_38mm_Motor_I500T-14A_HP_SU (accessed Nov. 20, 2025).

[2] R. G. Budynas and J. K. Nisbett, *Shigley’s Mechanical Engineering Design*, 8th ed. New York, NY, USA: McGraw-Hill, 2008 (accessed Nov. 20, 2025).

[3]“Free CAD designs, Files & 3D models: The grabcad community library,” Free CAD Designs, Files & 3D Models | The GrabCAD Community Library, https://grabcad.com/library/screw-1-4-1 (accessed Nov. 20, 2025).

[4] Polylactic acid (PLA) filament for 3D printing:Uses & Applications, https://www.divbyz.com/knowledge-center/materials/pla (accessed Nov. 20, 2025).

[5]“G12 fiberglass filament wound tube,” frp insulation material factory, https://www.frpinsulation.com/index.php/2020/08/27/g12-fiberglass-filament-wound-tube/ (accessed Nov. 20, 2025).

[6] “1/4-20 x 4 A574 alloy steel socket head Cap Screw,” STS Industrial, https://www.stsindustrial.com/products/0-25-20x4-alloy-steel-socket-head-cap-screw/?head_type=Socket#:~:text=Chemical%20PropertiesAlloy%20Steel%20Socket%20Head%20Cap%20Screw&text=1.,(55%20%C3%97%20carbon%20content). (accessed Nov. 21, 2025).

[7]https://www.homedepot.com/p/Prime-Line-1-4-in-20-x-1-1-4-in-Black-Oxide-Coated-Steel-Hex-Allen-Drive-Socket-Head-Cap-Screws-10-Pack-9178581/311491926?MERCH=REC-_-rv_nav_plp_rr-_-n%2Fa-_-2-_-n%2Fa-_-n%2Fa-_-n%2Fa-_-n%2Fa-_-n%2Fa (accessed Nov. 21, 2025).