Part 1– Baseline Design

5.1.1 Results

1. Script used for hand calculation.

```
T = 600;
L = 15;
c = 1.0;
b = 0.4;
h = 0.5;
E = 30.5e6;
nu = 0.29;
G = E/(2*(1+nu));

sy = 232e3;
su = 232e3;
sfatigue = 94.4e3;
KIC = 96.5e3;
a0 = 0.04;
Y = 1.12;
GF = 2;
min_output_required = 1.0;

F = T / L;

I = b * h^3 / 12;
y = h / 2;

M_g = F * (L - c);
sigma_max = M_g * y / I;
epsilon = sigma_max / E;
output_mV_per_V = GF * epsilon / 2 * 1000;
delta = F * L^3 / (3 * E * I);
sigma_equiv = sigma_max;
K_at_a0 = Y * sigma_equiv * sqrt(pi * a0);
SF_fatigue = sfatigue / sigma_equiv;
SF_strength = sy / sigma_equiv;
SF_crack = KIC / K_at_a0;
```

```
fprintf('Applied torque T = %.1f in-lbf, equivalent end load F = %.3f lbf\n', T, F);
fprintf('Moment at gauge M_g = %.3f in-lbf\n', M_g);
fprintf('Max normal stress (sigma_max)      = %.3f ksi\n', sigma_max/1000);

fprintf('Equivalent stress for strength     = %.3f ksi\n', sigma_equiv/1000);

fprintf('Gauge axial strain (epsilon)       = %.1f microstrain\n', epsilon*1e6);
fprintf('Output (half-bridge)               = %.3f mV/V\n', output_mV_per_V);
fprintf('Tip deflection                     = %.6f in\n', delta);

fprintf('\n--- Safety Factors ---\n');
fprintf('SF_strength (required >= 4)        = %.3f\n', SF_strength);
fprintf('SF_crack   (required >= 2)        = %.3f\n', SF_crack);
fprintf('SF_fatigue (required >= 1.5)      = %.3f\n', SF_fatigue);
```

2. Results from hand calculation of base design showing maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.

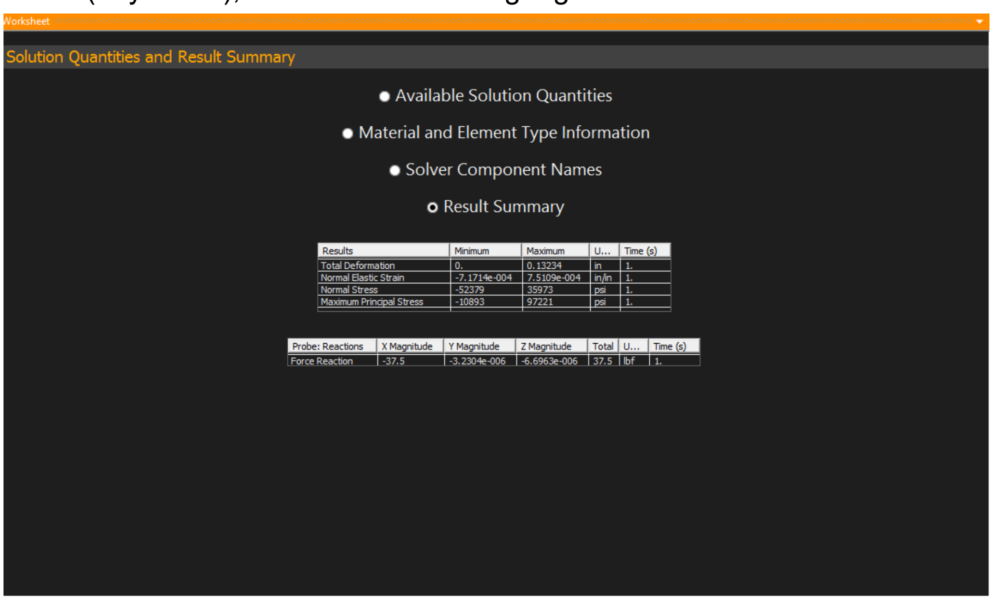
```
Applied torque T = 600.0 in-lbf, equivalent end load F = 40.000 lbf
Moment at gauge M_g = 560.000 in-lbf
Max normal stress (sigma_max)      = 33.600 ksi

Equivalent stress for strength     = 33.600 ksi

Gauge axial strain (epsilon)       = 1101.6 microstrain
Output (half-bridge)               = 1.102 mV/V
Tip deflection                     = 0.354098 in

--- Safety Factors ---
SF_strength (required >= 4)        = 6.905
SF_crack   (required >= 2)        = 7.234
SF_fatigue (required >= 1.5)      = 2.810
```

3. Results from FEM calculation of base design. From the FEM find the maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.



Worksheet

Solution Quantities and Result Summary

- Available Solution Quantities
- Material and Element Type Information
- Solver Component Names
- Result Summary

Results	Minimum	Maximum	U...	Time (s)
Total Deformation	0.	0.13234	in	1.
Normal Elastic Strain	-7.1714e-004	7.5109e-004	in/in	1.
Normal Stress	-52379	35973	psi	1.
Maximum Principal Stress	-10893	97221	psi	1.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	U...	Time (s)
Force Reaction	-37.5	-3.2304e-006	-6.6963e-006	37.5	lbf	1.

5.1.2 Reflections

1. Beam theory assumes that plane sections remain plane. View the deformed mesh and check if mesh lines that cut across the beam handle remain as straight lines. Do you think that beam theory is reasonably accurate?

The beam theory has limitations but is reasonably accurate at the end of the beam where there was an applied force and maximum displacement. However, the beam theory starts to break down in the areas closer to the drive as the mesh lines are no longer orthogonal to the neutral axis and straight.

2. How do the FEM and hand calculated maximum normal stresses compare? If they differ significantly, why?

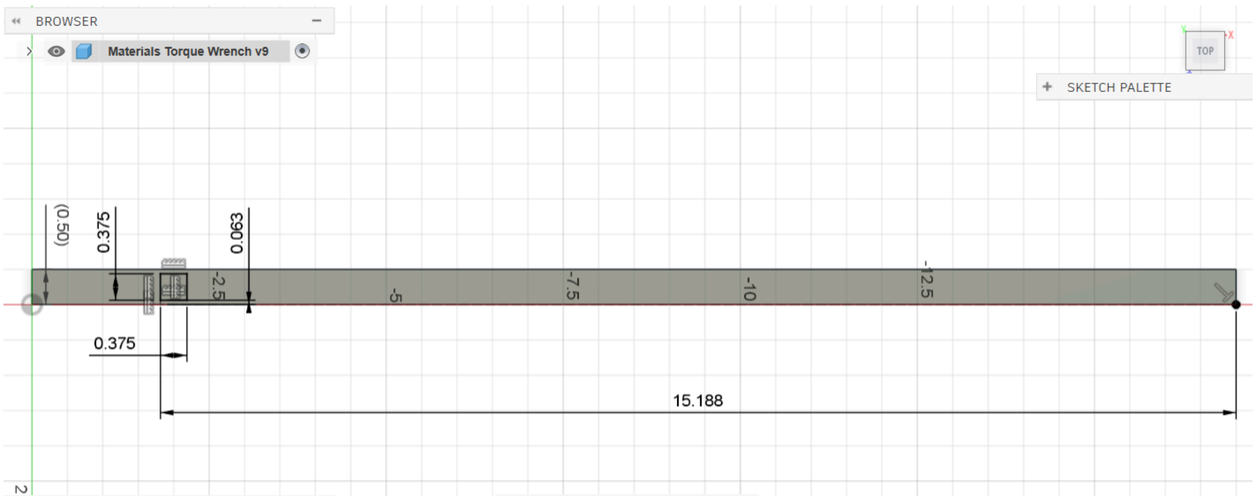
The FEM and hand calculations for the base design are pretty different. For instance, the hand calculations for the baseline design gave 12.8 ksi as the max normal stress value, while FEM provided a value of 35.6 ksi for the max.

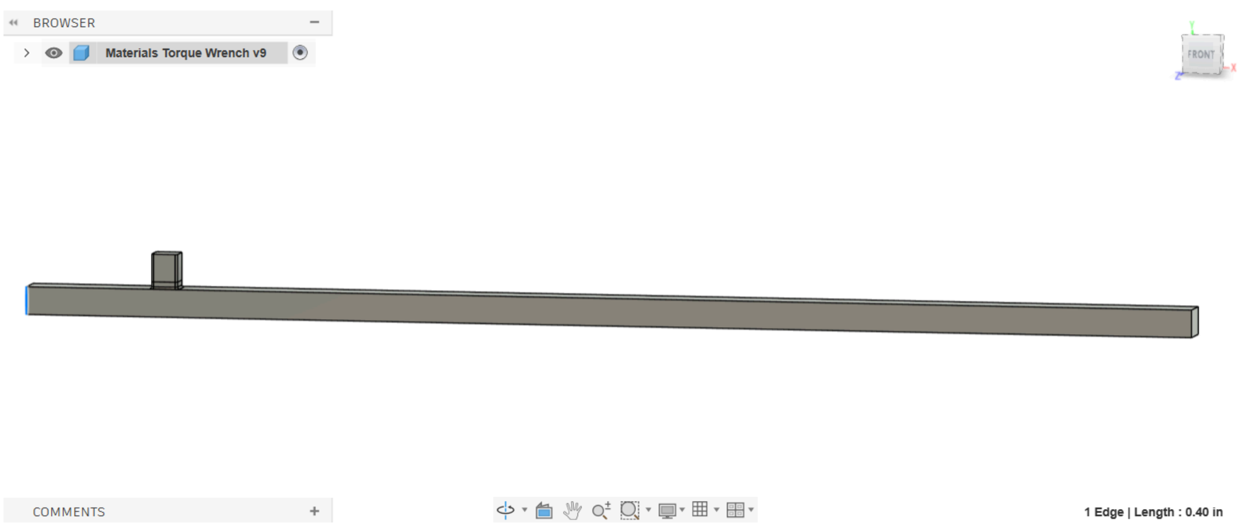
3. How do the FEM and hand calculated displacements compare? If they differ, why?

Very similar. Hand calculations said deformation would be around 0.09in and FEM gave us 0.1in. The minor difference in values is mainly due to the fillets in the FEM design as the hand calculation can not account for the boundary condition of the clamping on the drive. For our own design's FEM, we got that the maximum deformation was 0.38808 in., while the hand calculations gave 0.3541 in. They are relatively similar, with the FEM value being slightly higher. This is once again most likely due to the fillets in our design, which the hand calculations do not account for.

Part 2– Our Design

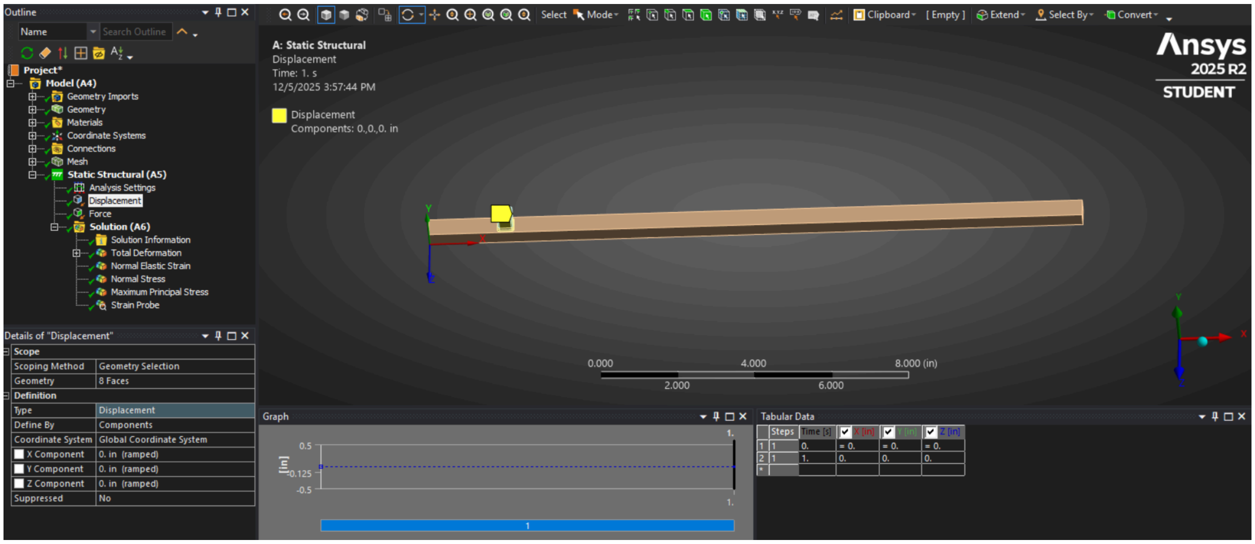
1. CAD Images



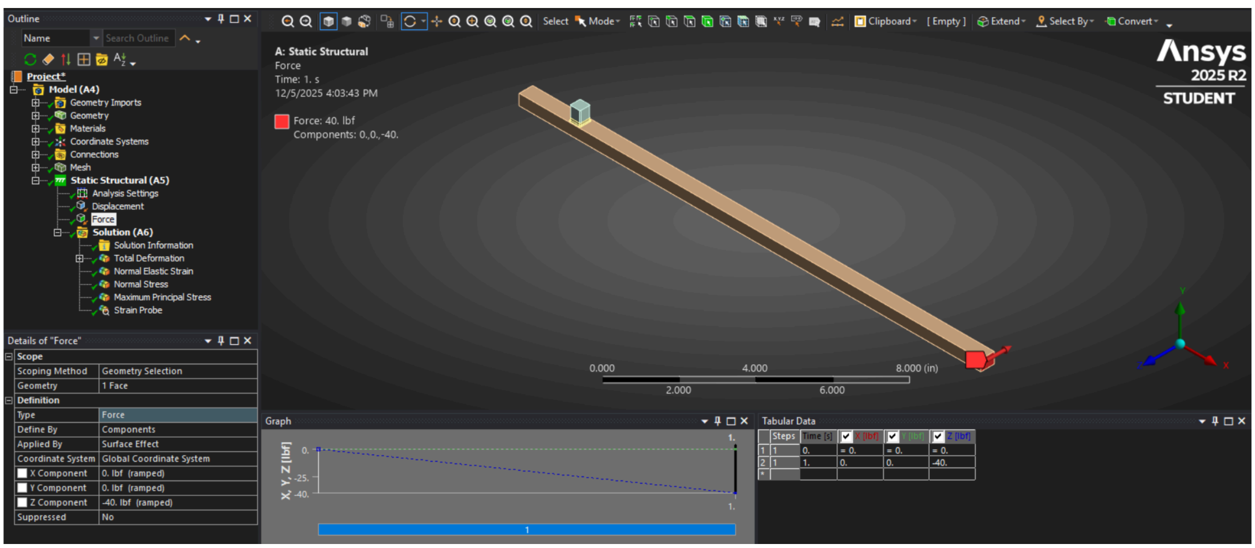


2. We used low-alloy steel for our material, which contains a small percentage of alloying elements. This allows for the material to have improved mechanical properties compared to regular carbon steel, such as a high yield strength, fatigue strength, and fracture toughness.
3.

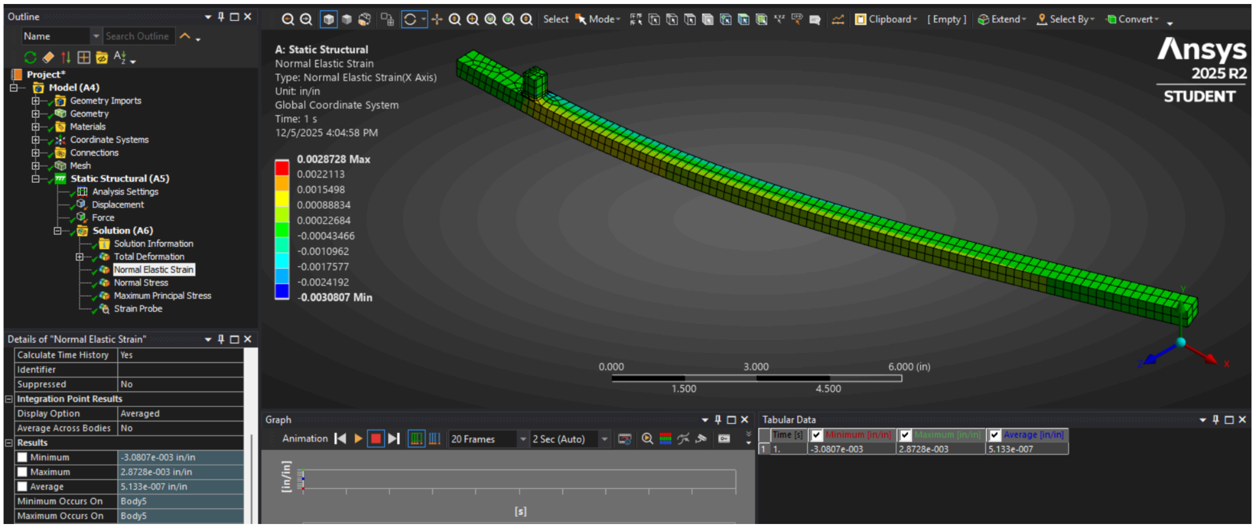
Boundary Conditions:



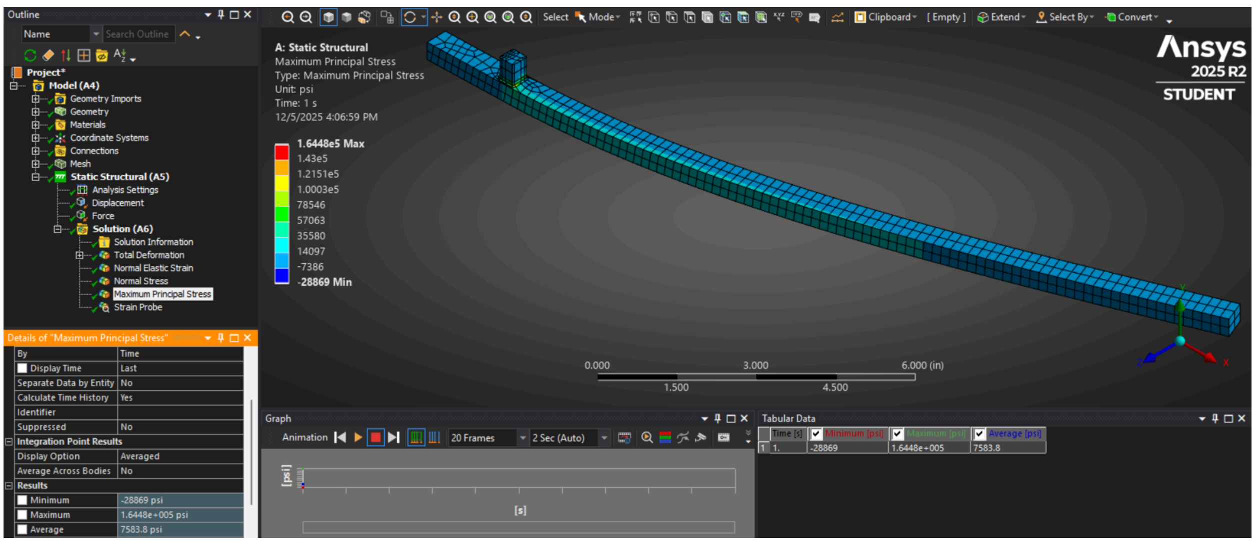
Applied Load:



4. Normal strain contours (in the strain gauge direction) from FEM



5. Contour plot of maximum principal stress from FEM



6. Summarize results from FEM calculation showing maximum normal stress (anywhere), load point deflection, strains at the strain gauge locations

   Our hand calculations were pretty close to the FEM calculations. Our design's FEM produced a maximum normal stress of about 35 ksi, a load point deflection of 0.38808 inches, and a strain at the strain gauge location of 1090 microstrain. This almost matches our hand calculations, which produced a maximum normal stress of about 33.6 ksi, a load point deflection of 0.3541 inches, and a strain at the strain gauge location of 1101.6 microstrain. The small discrepancies are to be expected, with the hand calculations outputting higher values since they don't account for the fillets in our design.

7. Torque wrench sensitivity in mV/V using strains from the FEM analysis

Using the strain at the center of the strain gauge from the FEM, we found the torque wrench sensitivity to be 10.9 mV/V.

8. Strain gauge selected (give type and dimensions). Note that design must physically have enough space to bond the gauges.

Additional Features 1	Transducer quality
Carrier Length	9.2 mm
Carrier Width	6 mm
Commodity Code	9026.20.0000
DepthValue	8.1
ECCN	EAR99
Electrical Connection	Wire Leads
Grid Length	1.5 mm
Grid Style	Wide Linear Pattern, Dual Grid
Grid Width	4.8 mm
GrossWeightValue	0.15
HeightUoM	IN
HeightValue	0.6

https://www.dwyeromega.com/en-us/uniaxial-half-bridge-strain-gauges-with-transducer-quality/SGT-Half-Bridge-Uniaxial/p/SGT-1LH-1000-TY11