Shayla Reid (skr59) and Olivia Tolliver (ot64), Final HW, 12/8/2025

Final HW

5.1.1 Results

1. Script used for hand calculation.

```
% Baseline Design Parameters
M = 600; % max torque (in-lbf)
L = 16; % length from drive to where load applied (inches)
h = 0.75; % width
b = 0.5; % thickness
c = 1.0; % distance from center of drive to center of strain gauge

% Material Properties
name = 'M42 Steel'; % material name
E = 32.E6; % Young's modulus (psi)
nu = 0.29; % Poisson's ratio
su = 370.E3; % tensile strength use yield or ultimate depending on material (psi)
KIC = 15.E3; % fracture toughness (psi sqrt(in))
sfatigue = 115.e3; % fatigue strength from Granta for 10^6 cycles

% Design Constraints
a = 0.04; % Assumed crack depth (inches)
GF  = 2.0; % Assumed Gauge Factor

% Required Safety Factors
XO_req = 4.0; % Static strength safety factor
XK_req = 2.0; % Crack growth safety factor
XS_req = 1.5; % Fatigue stress safety factor
Senstivity_req = 1.0; % mV/V output at rated torque

P = M/L;
I = (b*h^3)/12;
sa = (M*h/2)/I; % max normal stress
delta = (P * L^3)/(3*E*I); % deflection
K = 1.12*sa*sqrt(pi*a);

% Stress and deflection analysis
fprintf('load point deflection: %.3f in\n', delta); % deflection
fprintf('max normal stess: %.2f ksi\n', sa/1000); % max normal stress

% Calculate safety factors
XO = su/sa; % safety factor for strength
XK = KIC/K; % safety factor for crack growth
XS = sfatigue/sa; % safety factor for fatigue

% Display safety factor results
fprintf('safety factor for strength: %.2f\n', XO);
fprintf('safety factor for crack growth: %.2f\n', XK);
fprintf('safety factor for fatigue: %.2f\n', XS);

% Calculate the strain at the gauge
Mg = P*(L-c);
strainAtGauge = Mg*(h/2)/(E*I);
fprintf('strain at gauge: %.0f microstrain\n', strainAtGauge*10^6);

% Calculate output voltage based on strain gauge sensitivity
outputVoltage = 0.5*GF*strainAtGauge*1000;
fprintf('output voltage at 600 in-lbf using half bridge: %.2f mV/V\n', outputVoltage);

% Check if safety factors meet requirements
if XO < XO_req
    fprintf('Warning: Safety factor for strength (%.2f) is below the required (%.2f).\n', XO, XO_req);
end
% Check if crack growth safety factor meets requirements
if XK < XK_req
    fprintf('Warning: Safety factor for crack growth (%.2f) is below the required (%.2f).\n', XK, XK_req);
end
% Check if fatigue safety factor meets requirements
if XS < XS_req
    fprintf('Warning: Safety factor for fatigue (%.2f) is below the required (%.2f).\n', XS, XS_req);
end
% Check if strain gauge output meets sensitivity requirements
if outputVoltage < Senstivity_req
    fprintf('Warning: Output voltage (%.2f mV/V) is below the required (%.2f mV/V).\n', outputVoltage, Senstivity_req);
end
% Final assessment of safety factors and output voltage
if XO >= XO_req && XK >= XK_req && XS >= XS_req && outputVoltage >= Senstivity_req
    fprintf('All safety factors and output voltage meet the required standards.\n');
else
    fprintf('Some safety factors or output voltage do not meet the required standards.\n');
end
```

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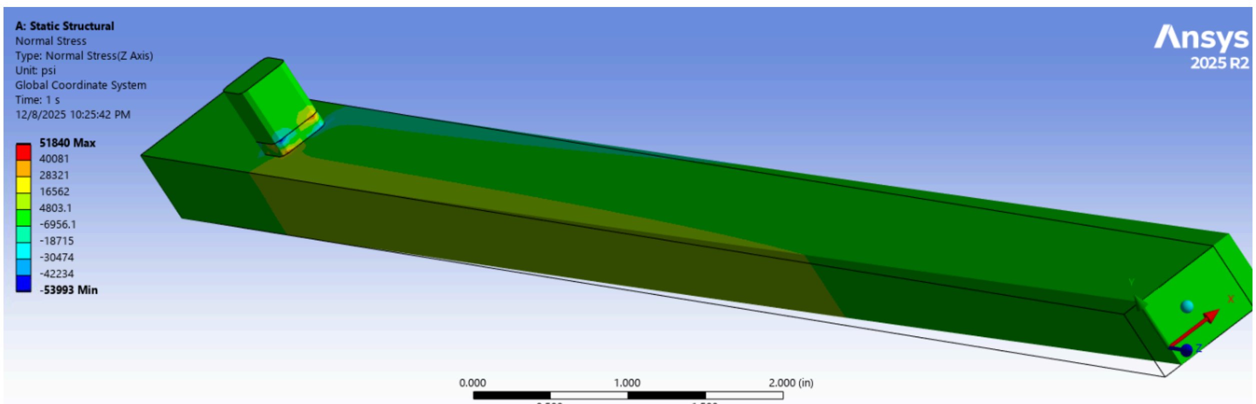
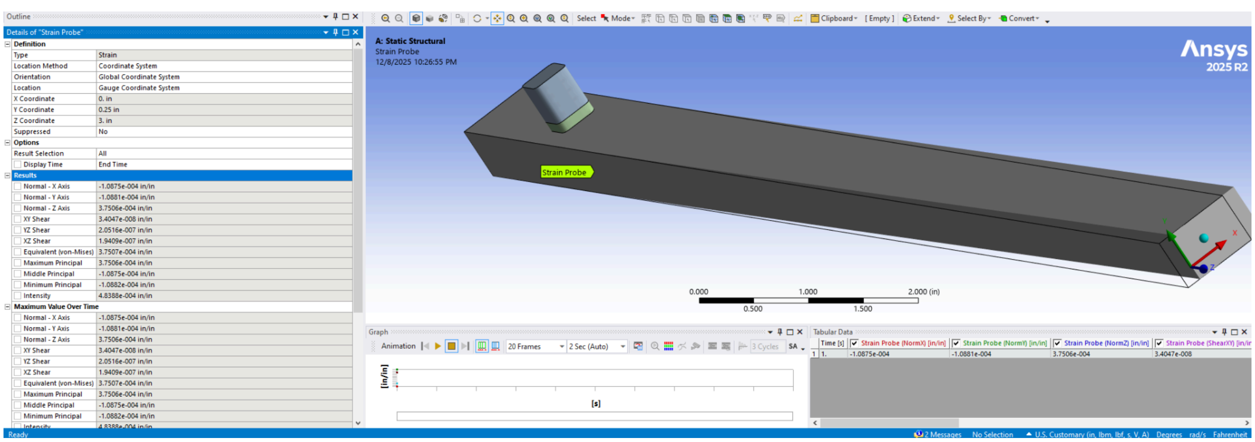
2. Results from hand calculation of base design showing maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.

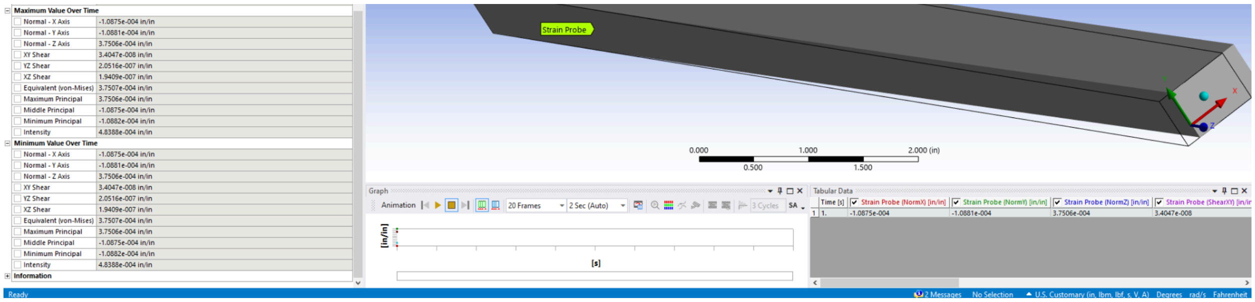
```
>> MAE_3270_Final_HW
load point deflection: 0.091 in
max normal stess: 12.80 ksi
safety factor for strength: 28.91
safety factor for crack growth: 2.95
safety factor for fatigue: 8.98
strain at gauge: 375 microstrain
output voltage at 600 in-lbf using half bridge: 0.38 mV/V
Warning: Output voltage (0.38 mV/V) is below the required (1.00 mV/V).
Some safety factors or output voltage do not meet the required standards.
```

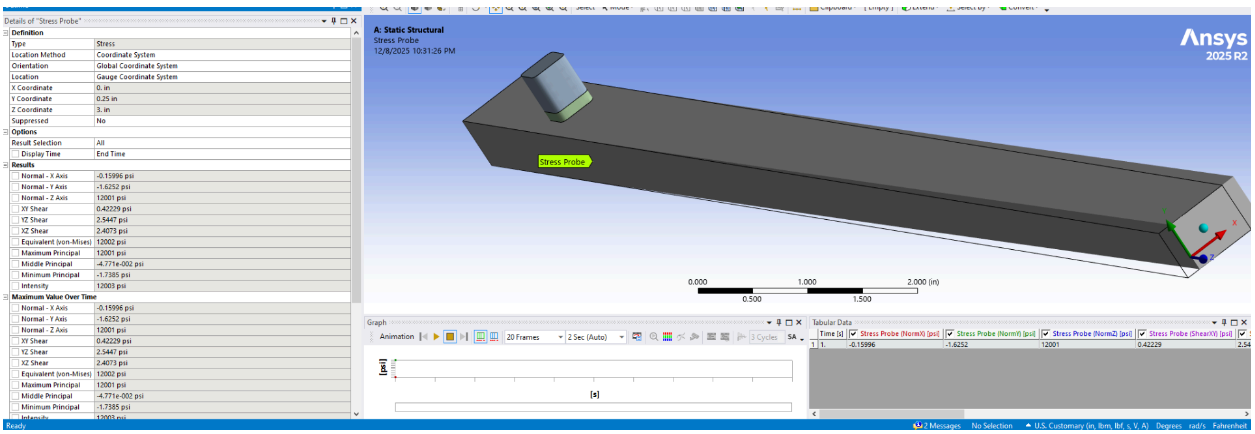
3. Results from FEM calculation of base design. From the FEM find the maximum normal stress (anywhere), strains at the strain gauge locations and deflection of the load point.

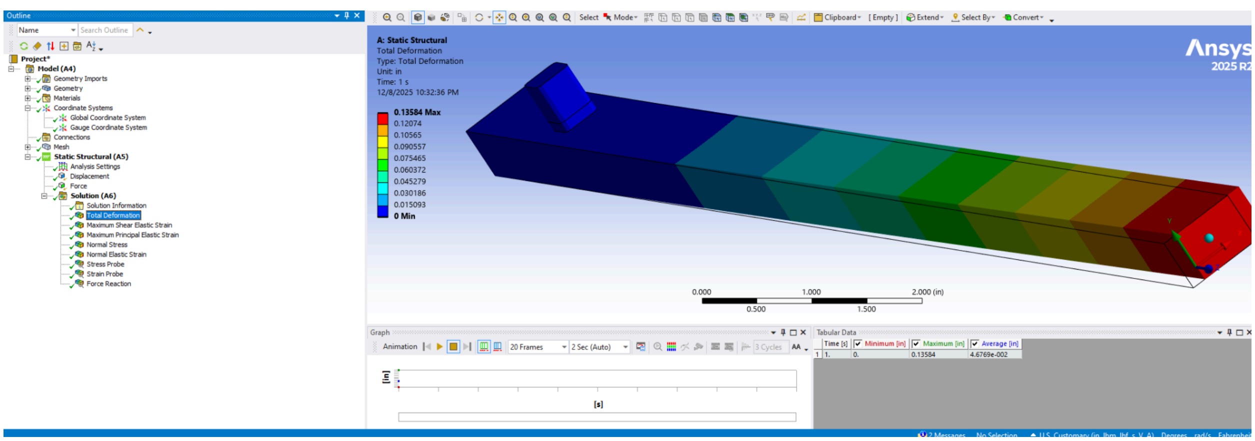




Shayla Reid (skr59) and Olivia Tolliver (ot64), Final HW, 12/8/2025





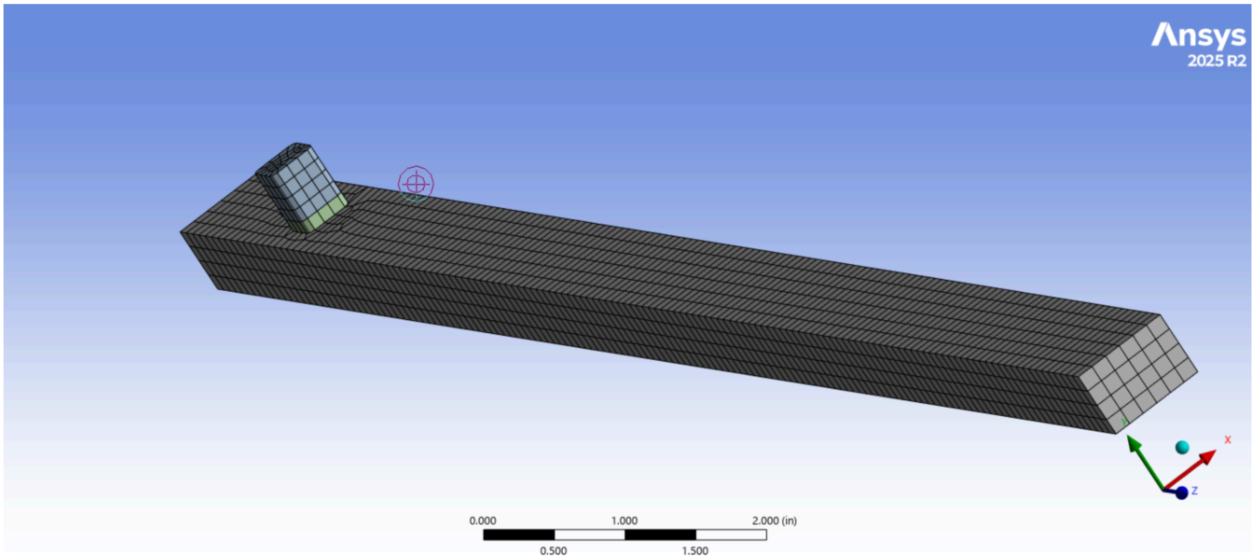


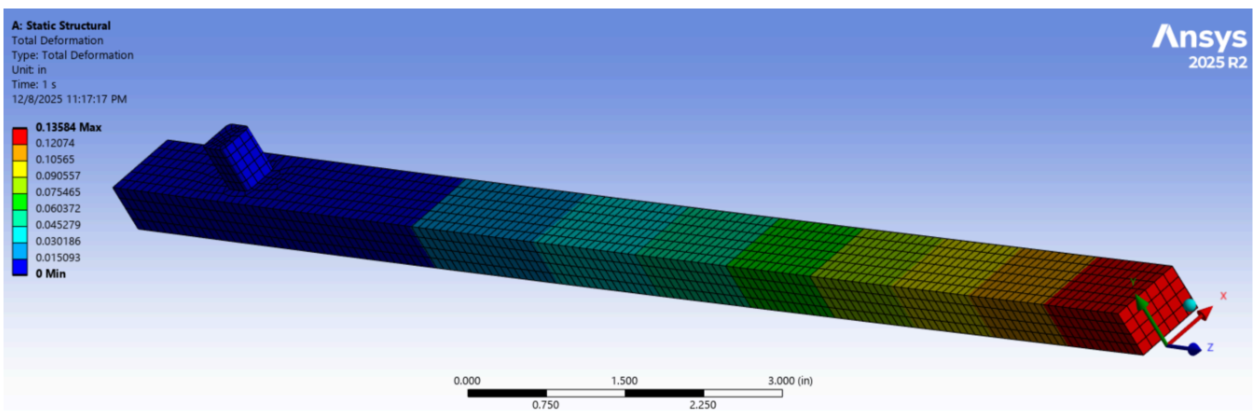
Maximum Normal stress: 51840
Strain at strain gauge: 3.75*10^4
Deflection at load point: 0.13584in

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?

Shayla Reid (skr59) and Olivia Tolliver (ot64), Final HW, 12/8/2025





The mesh at the tip of the beam handle remains as straight lines. The mesh at the base of the driver deformed because of the fillets. The beam theory is reasonably accurate at regions outside of the drive. So overall, beam theory gives a reasonably accurate picture for the straight, uniform part of the handle, but it's not as reliable right at the transition into the driver body where the geometry changes.

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

The FEM maximum normal stress was 51,840 psi, while the hand-calculated value was 12.80 ksi (12,800 psi), so the FEM result is about four times larger. This is expected because the hand calculation is based on simple beam theory, which assumes no fillets and a uniformly distributed stress over the cross section. On the other hand, the FEM model factors in 3D effects, clamps, and stress concentrations near the fillets. The maximum FEM stress occurs near the fillet, while the hand calculation gives an average bending stress away from these features.

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

The FEM displacement at the load point is 0.13584 in, while the hand-calculated displacement at the load point is 0.091 in. They differ because the FEM model captures flexibility that the hand calculations ignore. In the hand calcs, we assume ideal conditions such as uniform cross-sections and linear elastic behavior. These assumptions often neglect other effects like shear deformation, stress concentrations, and geometric discontinuities. The FEM solution also divides the structure into multiple elements and evaluates stiffness and deformation more accurately along the geometry. The difference arises because FEM provides a more realistic representation of the structure's behavior, while the hand calculations are based on idealized assumptions.

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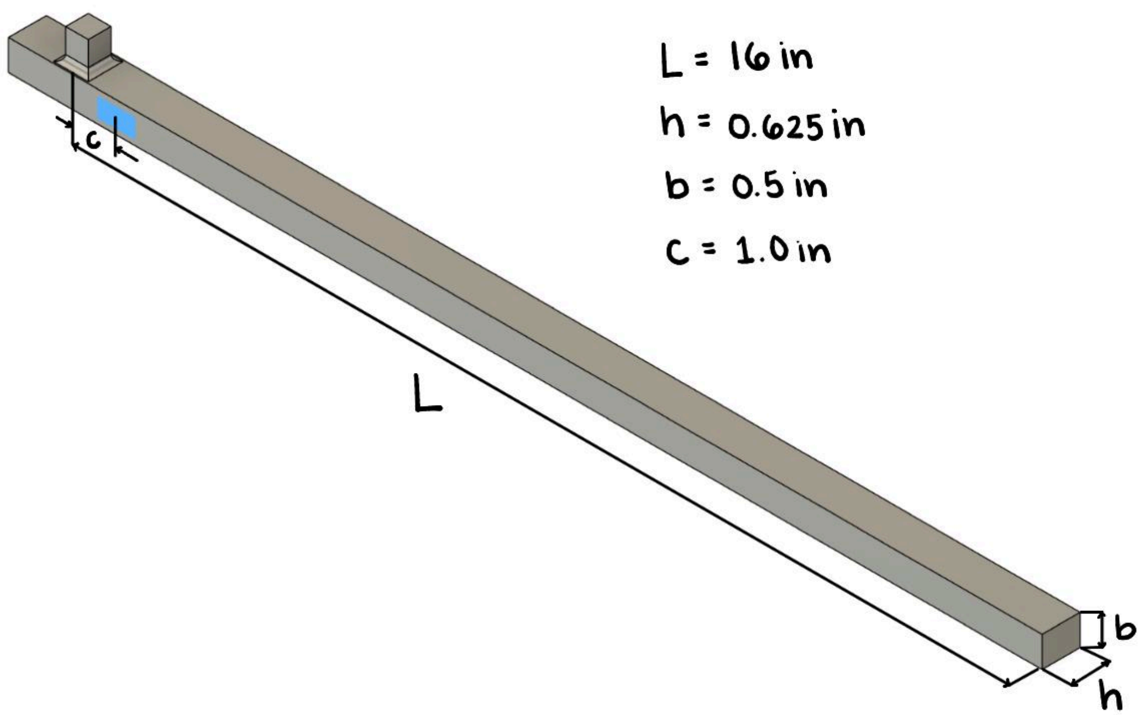
5.2 Your Design, Upload to portfolio

5.2.1 Results

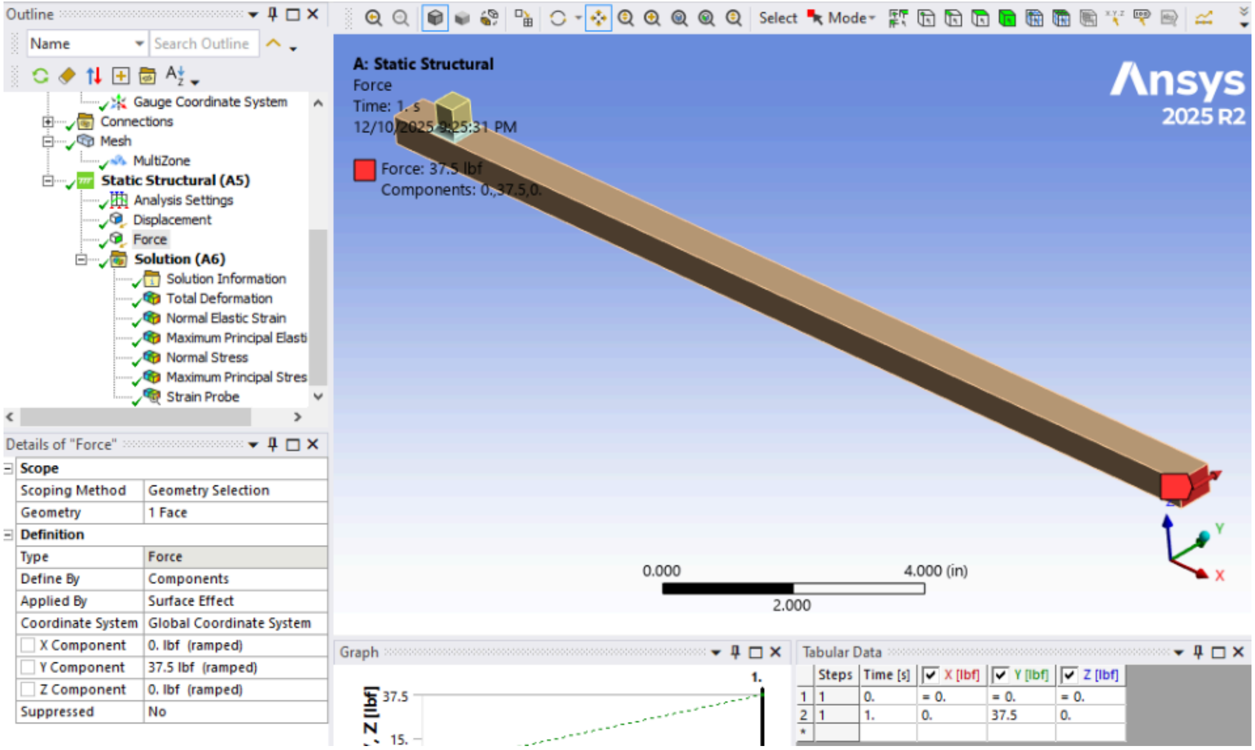
1. Image(s) of CAD model. Must show all key dimensions.

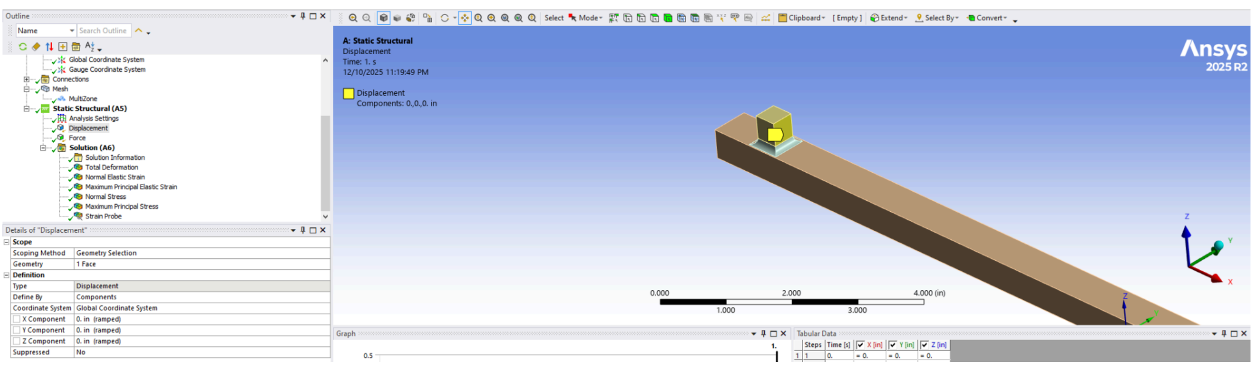


2. Describe material used and its relevant mechanical properties.

```
% Material Properties
name = 'Aluminum 7449'; % material name
E = 10.E6; % Young's modulus (psi)
nu = 0.323; % Poisson's ratio
su = 82.E3; % tensile strength use yield or ultimate depending on material (psi)
KIC = 25.E3; % fracture toughness (psi sqrt(in))
sfatigue = 29.e3; % fatigue strength from Granta for 10^6 cycles
```

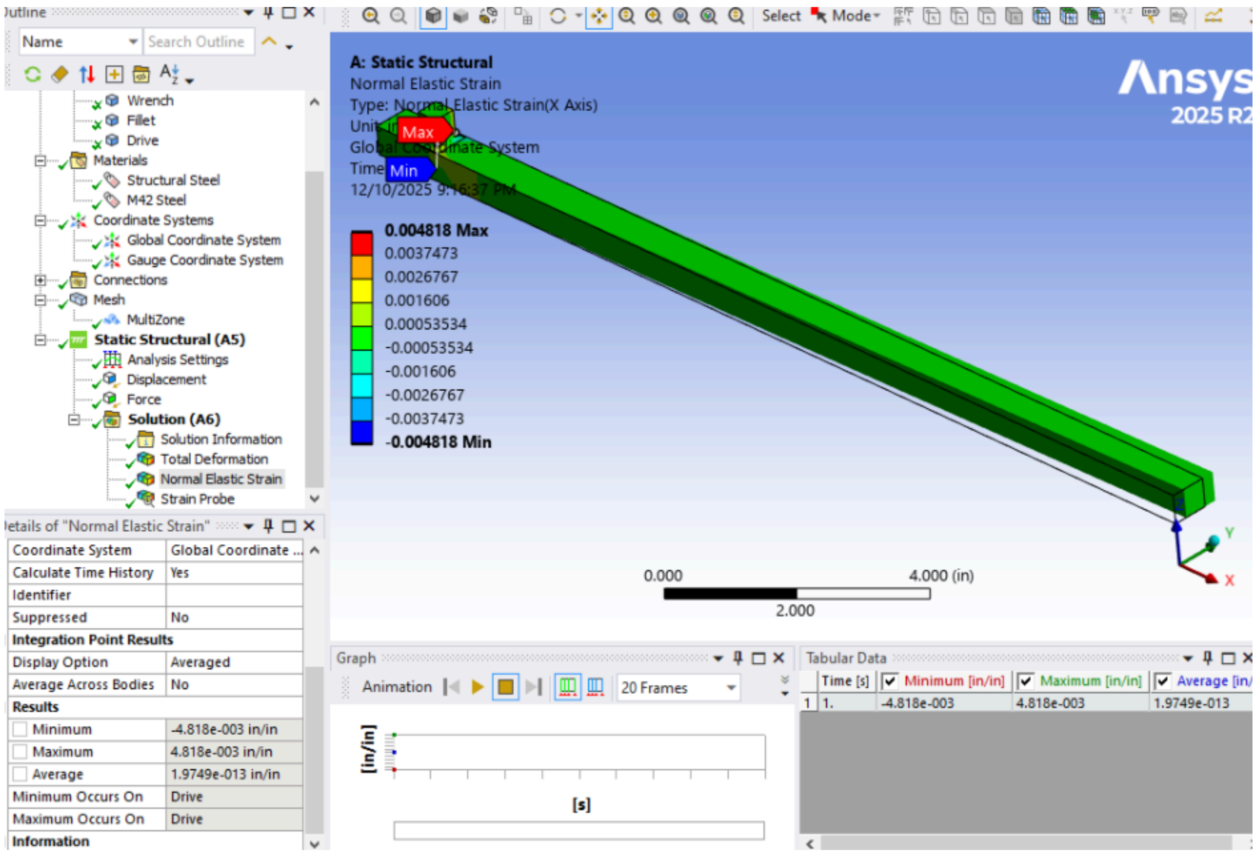
3. Diagram communicating how loads and boundary conditions were applied to your FEM model.



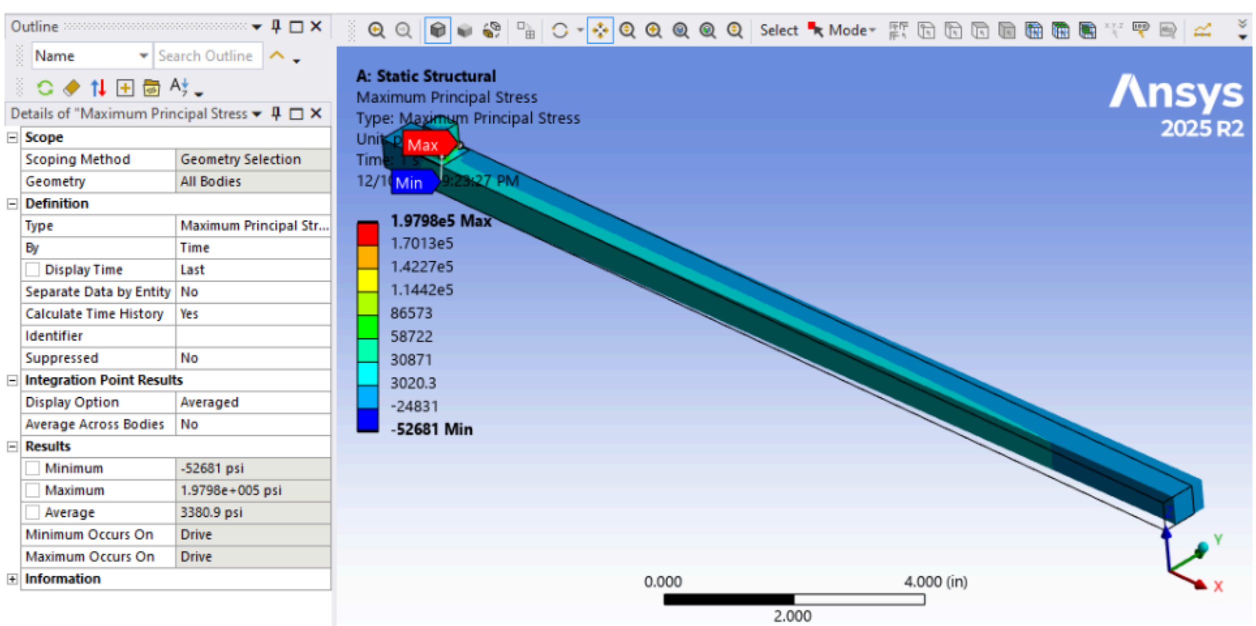


4. Normal strain contours (in the strain gauge direction) from FEM

Shayla Reid (skr59) and Olivia Tolliver (ot64), Final HW, 12/8/2025



5. Contour plot of maximum principal stress from FEM



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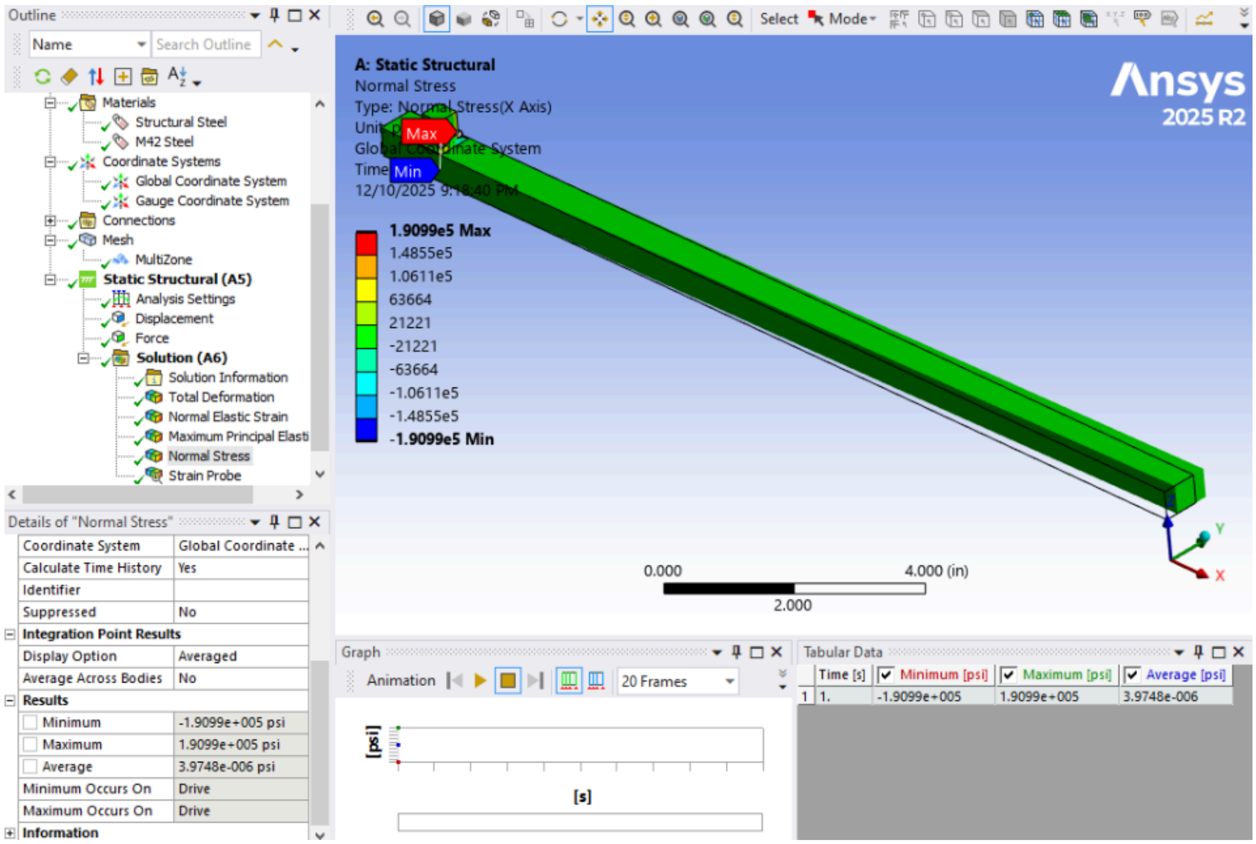
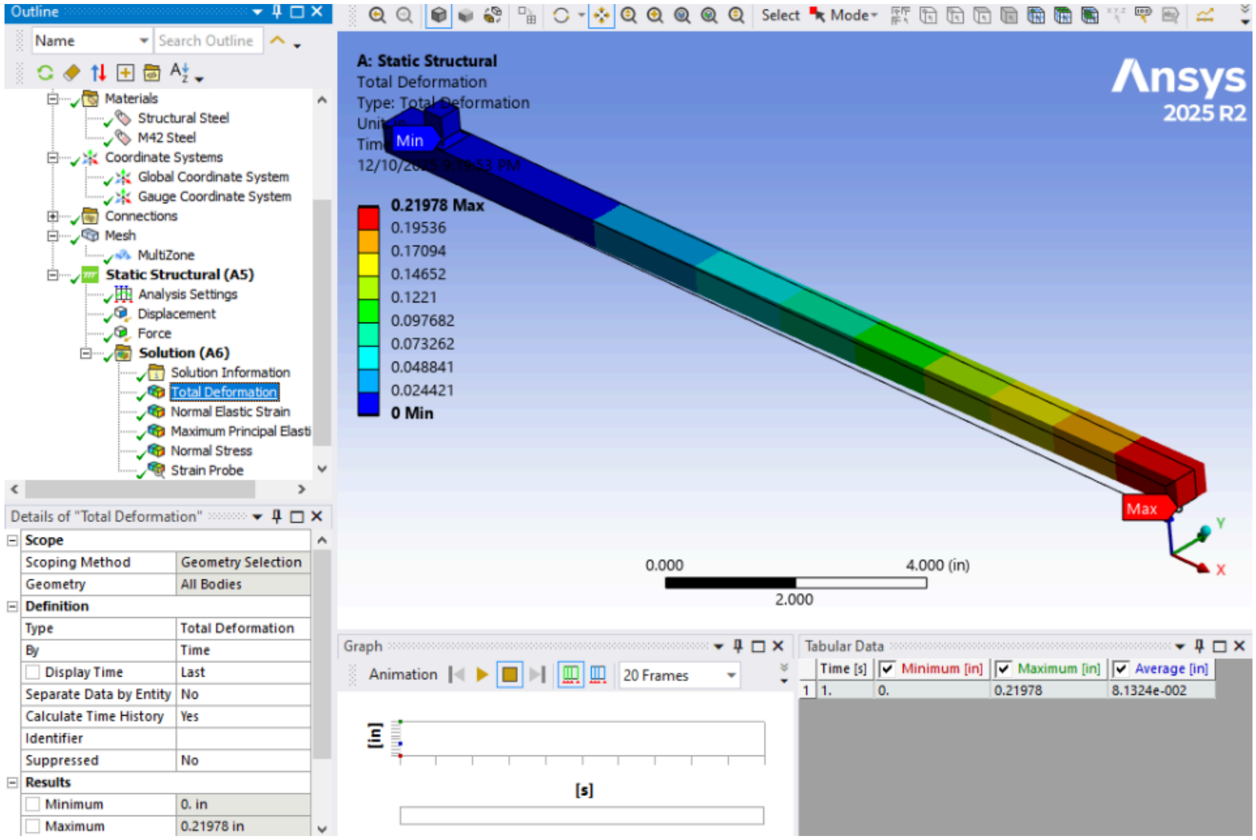
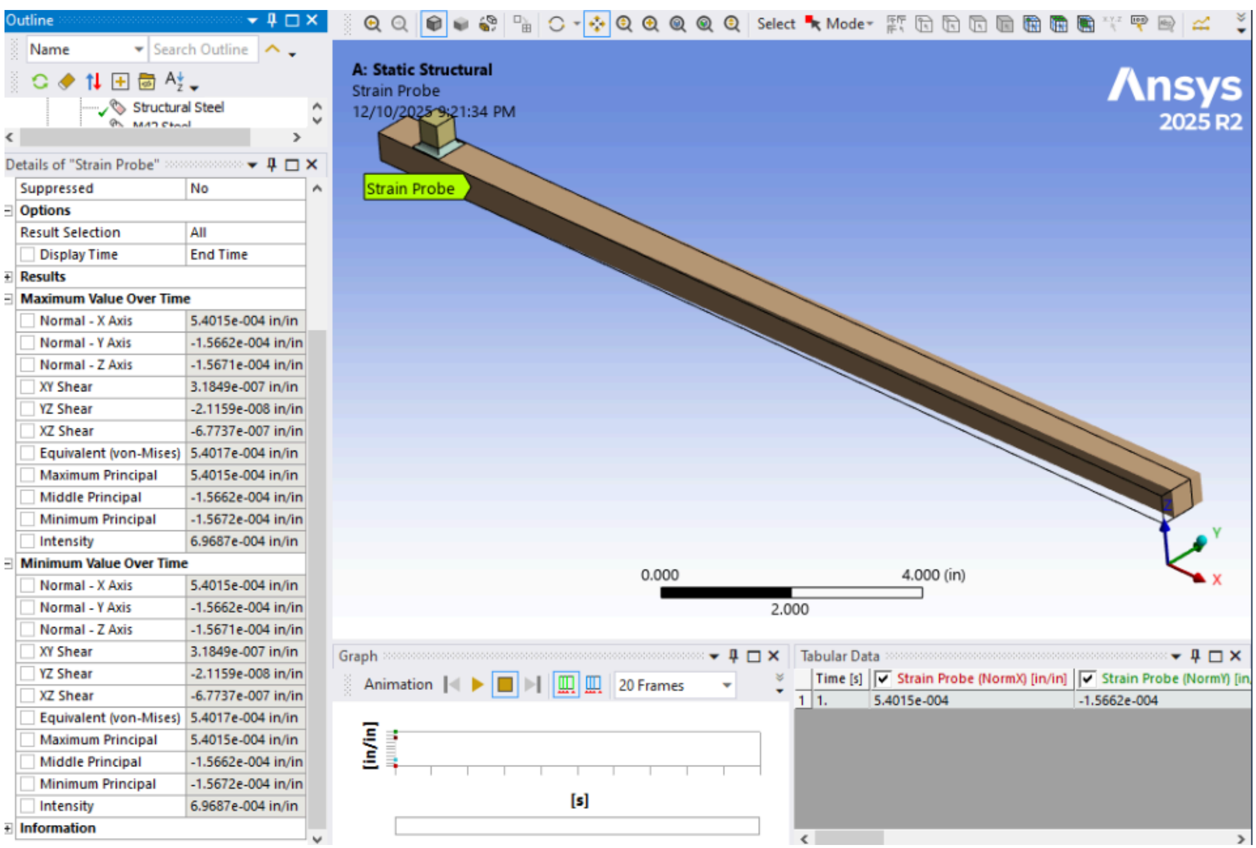
6. Summarize results from FEM calculation showing maximum normal stress (anywhere), load point deflection, strains at the strain gauge locations



Shayla Reid (skr59) and Olivia Tolliver (ot64), Final HW, 12/8/2025





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

$\frac{V_{out}}{V_{in}} = \frac{k}{4}2\varepsilon$, k=2

$1\frac{mV}{V} = 0.001$

$\varepsilon = 5.4015x10^{-4}$

$\frac{V_{out}}{V_{in}} = \frac{k}{4}2\varepsilon = 2.70075 \times 10^{-4}$

Sensitivity: 0.270 mV/V

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

SGD-3/350-LY11 (3mm Grid Length, 1.5 mm Grid Width, 120 □ Resistance)