MAE3270: Final Homework
Design Project
Part 1

Group Members: Angus Chang (sc3295), Poon Jeerapat (pj259)

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1 Base Design Results

1.1 Script used for hand calculation.

```matlab
clear; clc;
M = 600;
L = 16;
h = 0.75;
b = 0.50;
c_g = 1.0;
E = 32e6;
su = 370e3;
K_IC = 15e3;
s_fatigue = 115e3;
a0  = 0.040;
Y_K = 1.12;
GF = 2.0;
bridge = 0.5;
I = b*h^3/12;
c = h/2;
F = M/L;
M_max = M;
M_g = F*(L-c_g);
sigma_max = M_max*c/I;
sigma_g = M_g*c/I;
delta_tip = F*L^3/(3*E*I);
n_strength = su/sigma_max;
K_applied = Y_K*sigma_max*sqrt(pi*a0);
n_K = K_IC/K_applied;
n_fatigue = s_fatigue/sigma_max;
eps_g = sigma_g/E;
eps_g_micro = eps_g*1e6;
Vout_over_Vin = GF * eps_g*bridge;
Vout_mV_per_V = Vout_over_Vin*1e3;

fprintf('=== Simple Torque Wrench Check ===\n\n');
fprintf('Geometry:\n');
fprintf('  L = %.3f in\n', L);
fprintf('  h = %.3f in\n', h);
fprintf('  b = %.3f in\n', b);
fprintf('  c_g = %.3f in  (gauge location)\n\n', c_g);
fprintf('Section properties:\n');
fprintf('  I = %.5f in^4\n', I);
fprintf('  c = %.3f in\n\n', c);
fprintf('Loads:\n');
fprintf('  Torque M  = %.1f in-lbf\n', M);
fprintf('  End force F = %.3f lbf\n\n', F);
fprintf('Stresses and deflection:\n');
fprintf('  sigma_max (at drive) = %.2f ksi\n', sigma_max/1e3);
fprintf('  sigma_g (at gauge) = %.2f ksi\n', sigma_g/1e3);
fprintf('  tip deflection = %.3f in\n\n', delta_tip);
fprintf('Safety factors:\n');
fprintf('  n_strength (static) = %.2f\n', n_strength);
fprintf('  n_K (fracture) = %.2f\n', n_K);
fprintf('  n_fatigue = %.2f\n\n', n_fatigue);
fprintf('Strain gauge:\n');
fprintf('  strain at gauge = %.0f microstrain\n', eps_g_micro);
fprintf('  bridge output = %.2f mV/V\n\n', Vout_mV_per_V);
```

```
X0_min = 4.0;
XK_min = 2.0;
XS_min = 1.5;
S_min  = 1.0;
fprintf('Spec checks:\n');
if n_strength >= X0_min
    txt1 = 'PASS';
else
    txt1 = 'FAIL';
end
fprintf('  Strength SF (%.2f) >= %.2f ?  --> %s\n', n_strength, X0_min, txt1);
if n_K >= XK_min
    txt2 = 'PASS';
else
    txt2 = 'FAIL';
end
fprintf('  Fracture SF (%.2f) >= %.2f ?  --> %s\n', n_K, XK_min, txt2);
if n_fatigue >= XS_min
    txt3 = 'PASS';
else
    txt3 = 'FAIL';
end
fprintf('  Fatigue  SF (%.2f) >= %.2f ?  --> %s\n', n_fatigue, XS_min, txt3);
if Vout_mV_per_V >= S_min
    txt4 = 'PASS';
else
    txt4 = 'FAIL';
end
fprintf('  Sensitivity (%.2f mV/V) >= %.2f mV/V ?  --> %s\n', ...
        Vout_mV_per_V, S_min, txt4);
```

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

We obtained the maximum normal Stress for hand calculation to be 12.80 ksi. The strains at the strain gauge locations is 375 με. The deflection of the load point is computed to be 0.091 inches.

```
Loads:
  Torque M     = 600.0 in-lbf
  End force F = 37.500 lbf

Stresses and deflection:
  sigma_max (at drive) = 12.80 ksi
  sigma_g   (at gauge) = 12.00 ksi
  tip deflection       = 0.091 in

Safety factors:
  n_strength (static)  = 28.91
  n_K (fracture)       = 2.95
  n_fatigue            = 8.98

Strain gauge:
  strain at gauge      = 375 microstrain
  bridge output        = 0.38 mV/V

Spec checks:
  Strength SF (28.91) >= 4.00 ?  --> PASS
  Fracture SF (2.95) >= 2.00 ?  --> PASS
  Fatigue  SF (8.98) >= 1.50 ?  --> PASS
  Sensitivity (0.38 mV/V) >= 1.00 mV/V ?  --> FAIL
```

1.3 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.

We obtain our maximum normal stress for FEM analysis to be 140.3 ksi. The strains at the strain gauge locations is 375.3με. We obtain the deflection of the load point from ANSYS to be 0.13652 inches.

2. Base Design Reflections

2.1. 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?

When the mesh line crosses the handle to the drive, it remains almost straight, with slightly rotated and wrapping shape to pass over the discontinuity. This means that the beam theory would still apply here as the plane sections remain plane. We could still get reasonable predictions of stresses, strain, and deflection. However, the uncertainty might present more largely on the section where discontinuity happens.

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

Maximum Normal Stress:
Hand Calculated: 12.8 ksi
FEM: 56.248 ksi

As we can see from these values, the hand calculated underestimate the maximum normal stress a lot compared to the FEM. This could be that the hand calculation assumes a simple rectangular beam; however, in reality, the torque wrench consists of fillet, transitions and localized loading near the head. These additional variables contribute to why the FEM reads a lot more maximum stress on the device. The percent difference between the two is approximately 368.73 percent.

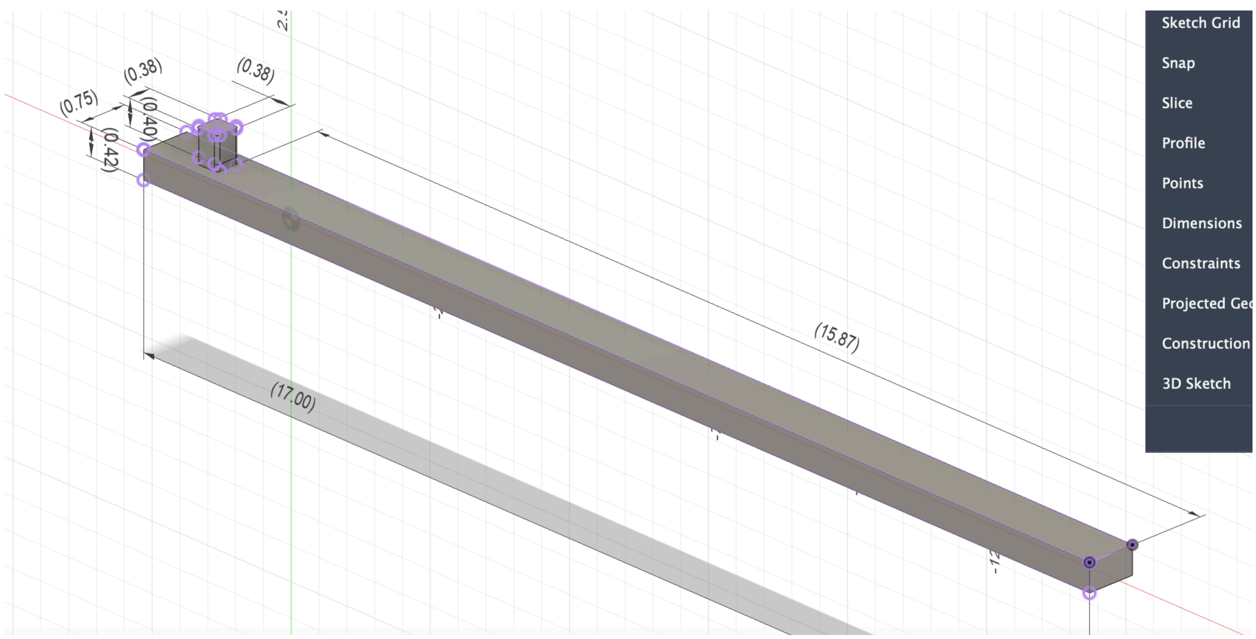
2.3 How do the FEM and hand calculated displacements compare? If they differ, why?

Displacement:
Hand Calculated: 0.091
FEM: 0.13652 in.

The FEM tip deflection is about 50 percent larger than the hand calculated value. This is because the hand calculation uses simple Euler-Bernoulli beam theory with ideal cantilever and uniform cross-section, which tend to underestimate flexibility. On the other hand, the FEM has a design that includes geometry, contact region, gauge pocket and fillets, allowing it to predict more realistic tip deflection.

3. Our Design

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



3.2 Describe material used and its relevant mechanical properties.

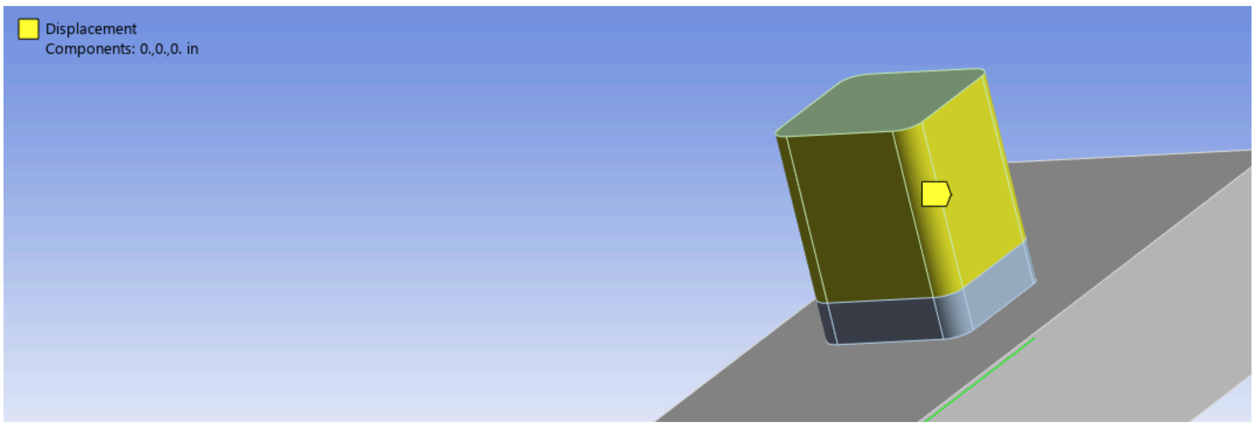
Aluminum 7075-T6 (properties from Granta)

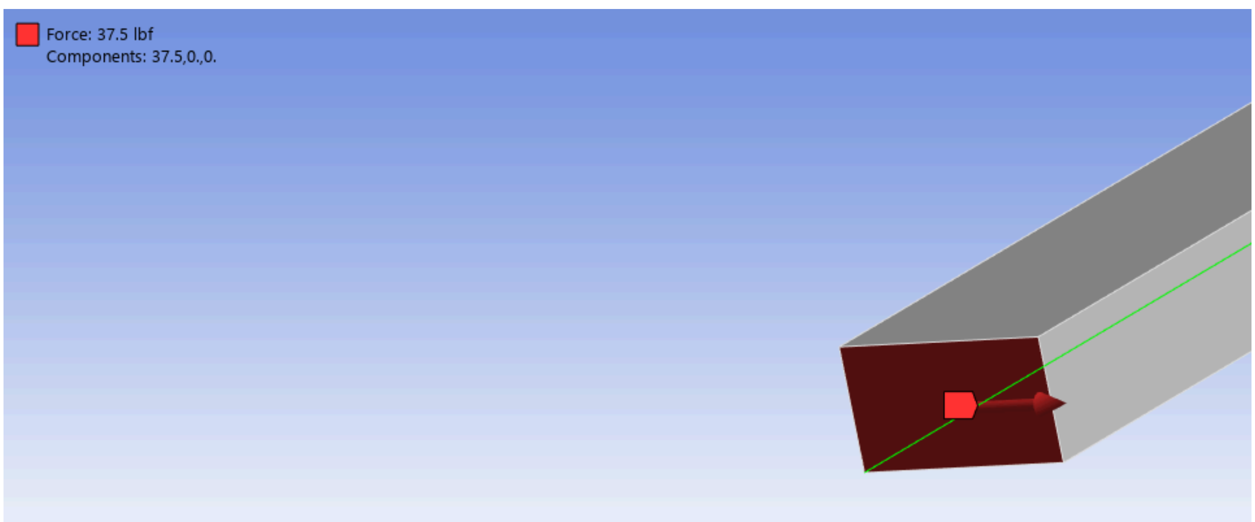
We choose this material because it is a very strong and lightweight alloy. It has strength similar to some steel but is a lot lighter.

→Young's Modulus: $1.1\ x\ 10^{7}$psi

→Poisson's Ratio: 0.33

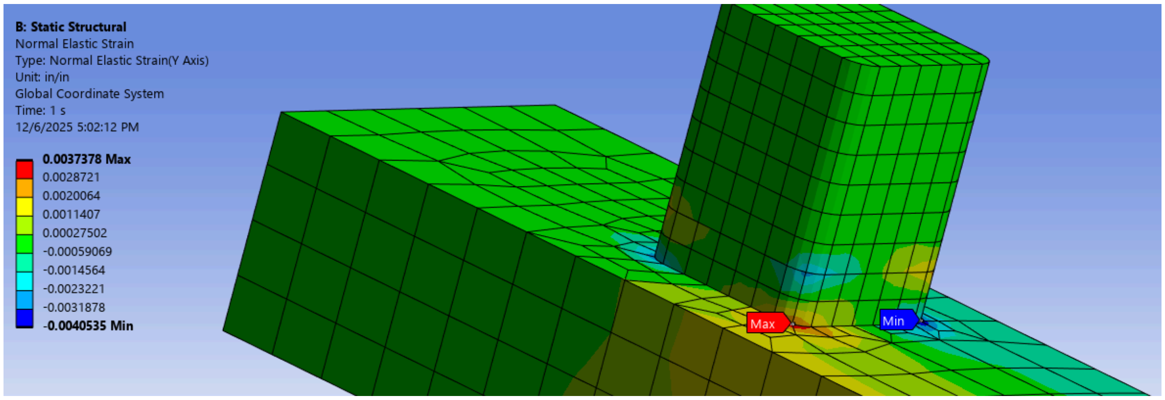
3.3 Diagram communicating how loads and boundary conditions were applied to your FEM model.



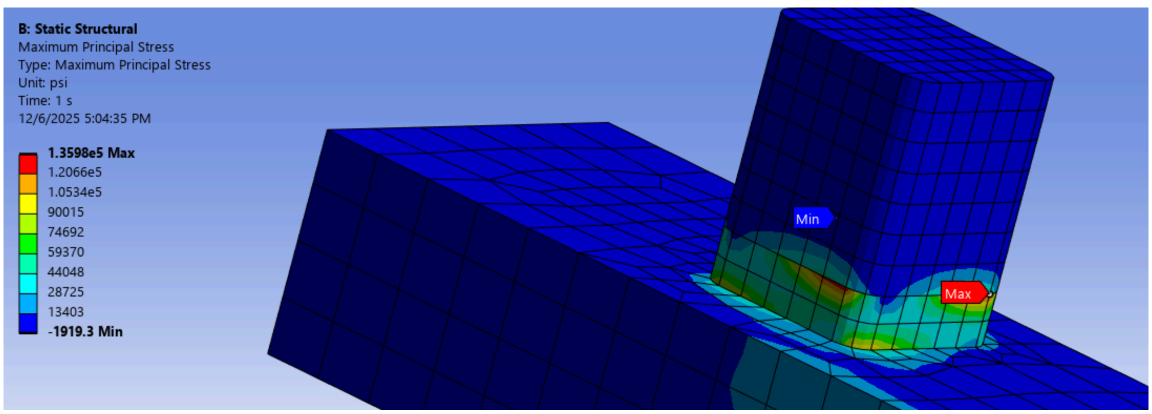


Boundary condition is set at the drive to restrict its movement while the force is being put at the face at the end of the torque wrench at 37.5 lbf, which is the result of 600lbf / 16 inch.

3.4 Normal strain contours (in the strain gauge direction) from FEM



3.5 Contour plot of maximum principal stress from FEM



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

Maximum normal stress: 55442 psi

Load point deflection: 0.44955 inch

Strains at strain gauge location:

Results	
Normal - X Axis	-4.2857e-004 in/in
Normal - Y Axis	1.2987e-003 in/in
Normal - Z Axis	-4.2862e-004 in/in
XY Shear	-6.7846e-007 in/in
YZ Shear	-4.9403e-007 in/in
XZ Shear	7.0875e-008 in/in
Equivalent (von-Mises)	1.2987e-003 in/in
Maximum Principal	1.2987e-003 in/in
Middle Principal	-4.2855e-004 in/in
Minimum Principal	-4.2864e-004 in/in
Intensity	1.7274e-003 in/in

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

We would use the Equivalent(von-Mises) strain value: $\varepsilon_{FEM} =$

$1.2987\ x\ 10^{-3}\ in/in$

Now Calculate for $\frac{V_{out}}{V_{in}}$:

$$\frac{V_{out}}{V_{in}} = GF\varepsilon_{FEM} x(bridge\ factor) = 2 \text{ x } 1.2987 \text{ x } 10^{-3} \text{x} 0.5 = 1.2987 \text{ x } 10^{-3}$$

Finally, calculate for sensitivity:

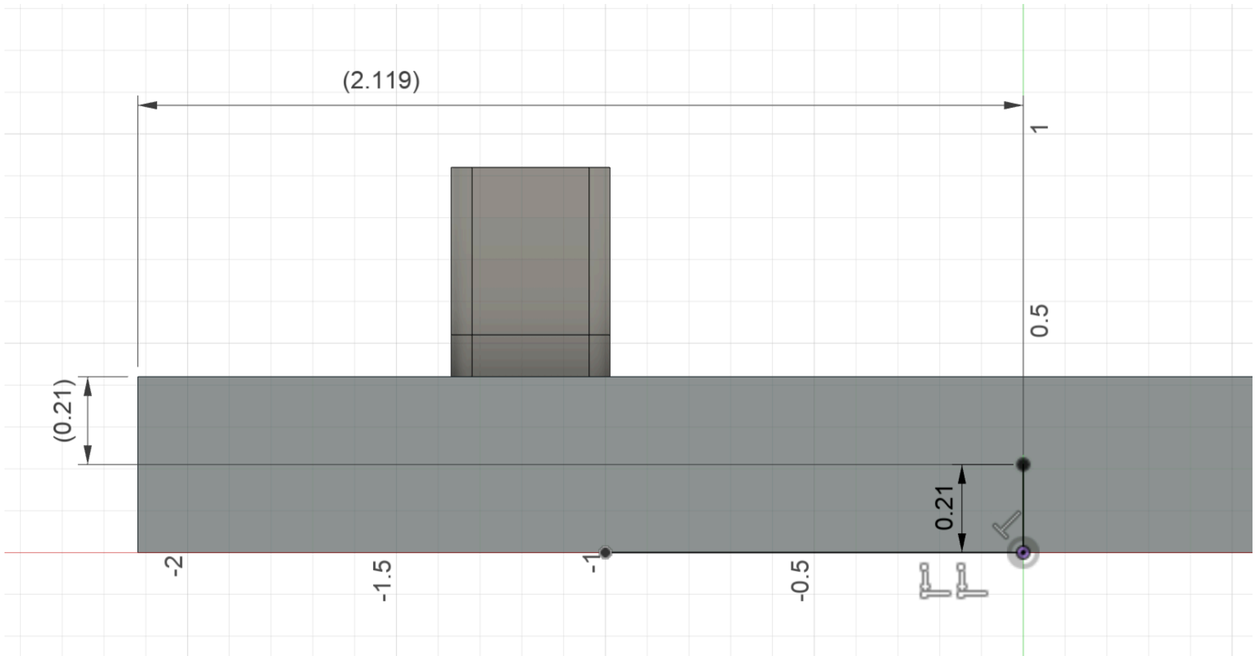
$$S = \frac{1.2987\ x\ 10^{-3}}{600} = 2.2\ x\ 10^{-3} mV/V$$

or

1.3 mV/V at 600 in-lbf

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

Our selected strain gauge locates at 15 inches from the edge of the handle bar and 1 inch apart from the top block, according to the homework guidance. It is a single strain with 0 degrees of tilt along the side of the handle bar in Y-Z plane.


(2.119)
1
0.5
(0.21)
0.21
-2
-1.5
-1
-0.5