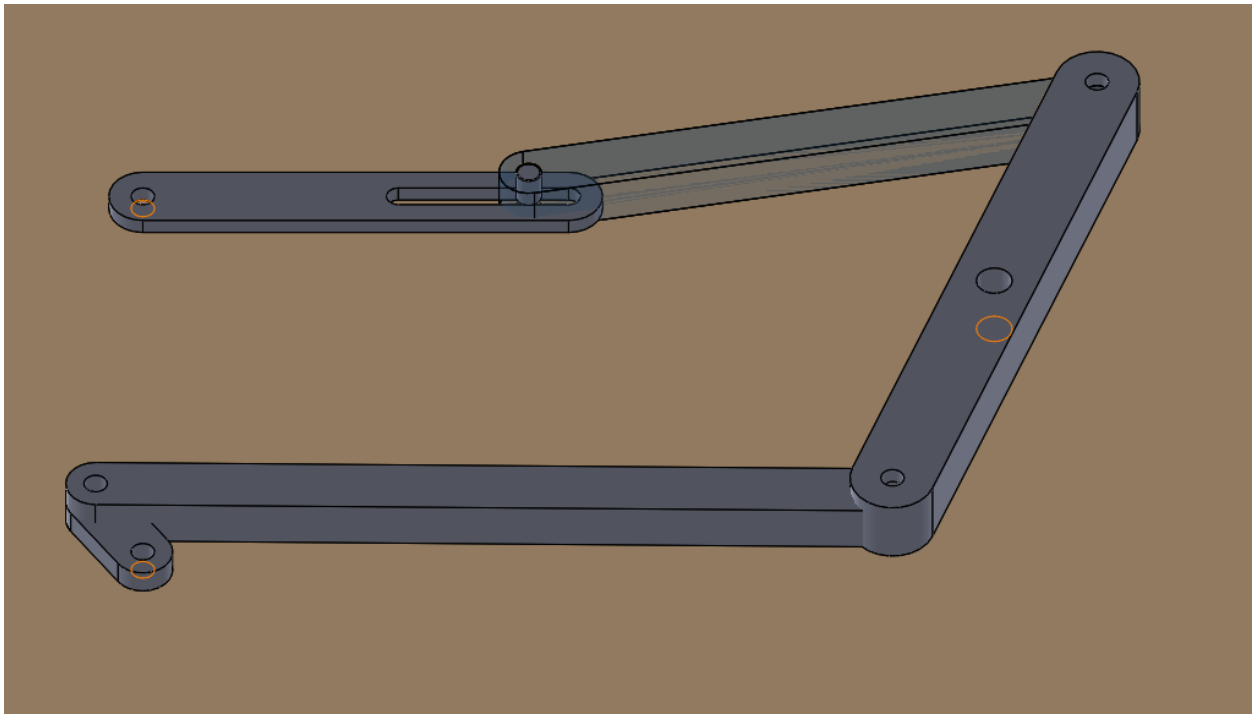Prof. Knezevic

ME 643

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Deliverable 2

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Beam Equations

Maximum and Minimum Axial Stress:

$$\sigma_{axial\ max} = \frac{F_{ax\ max}}{Area}$$

$$\sigma_{axial\ min} = \frac{F_{ax\ min}}{Area}$$

Maximum and Minimum Bending Stress:

$$\sigma_{bending\ max} = \frac{M_{max}y}{I}$$

$$\sigma_{bending\ min} = \frac{M_{min}y}{I}$$

Maximum and Minimum Combined Stress:

$$\sigma_{combined\ max} = \sigma_{bending\ max} + \sigma_{axial\ max}$$

$$\sigma_{combined\ min} = \sigma_{bending\ min} + \sigma_{axial\ min}$$

Mean & Alternating Stress:

$$\sigma_{mean} = \frac{\sigma_{combined\ max} + \sigma_{combined\ min}}{2}$$

$$\sigma_{alternating} = \frac{\sigma_{combined\ max} - \sigma_{combined\ min}}{2}$$

Buckling

$$P_{critical} = \frac{\pi^2 EI}{L^2}$$

Deflection

$$\delta = \frac{M_{max}L^2}{9\sqrt{3}EI}$$

$$\delta_{max} = \frac{L}{360}$$

$$N_{1,fatigue} = \frac{S_f \sigma_{UTS}}{\sigma_{alternating} \sigma_{UTS} + \sigma_{mean} \sigma_{Sf}}$$

$$N_{2,fatigue} = \frac{S_f}{\sigma_{alternating}}$$

$$N_{tension} = \frac{S_y}{\sigma_{alternating} - \sigma_{mean}}$$

$$N_{compression} = \frac{S_y}{\sigma_{alternating} + \sigma_{mean}}$$

$$N_{buckling} = \frac{\delta_{max}}{\delta}$$

$$N_{deflection} = \frac{P_{critical}}{\sigma_{max,axial}}$$

Pin Equations

Pin Shear Stress

$$\tau_{pin,shear} = \frac{\sqrt{3} F_{max,pin}}{\frac{d^2 \pi}{4}}$$

Pin Bearing Stress

$$\sigma_{pin,bearing} = \frac{F_{max,pin}}{\frac{\pi d l}{4}}$$

Pin Tear-Out Stress

$$\sigma_{pin,tearout} = \frac{\sqrt{3} F_{max,axial}}{2bd}$$
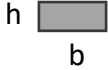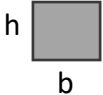
Factor of Safety's

$$N_{pin,shear} = \frac{S_y}{\tau_{pin}}$$

$$N_{pin,bearing} = \frac{S_y}{\sigma_{bear}}$$

$$N_{pin,tearout} = \frac{S_y}{\sigma_{tear}}$$

Beam Dimensions

Table 1 - Beam Dimensions

Link	Length (in)	Base (in)	Height (in)	Schematic Drawing
OA	0.5	0.35	0.15	h ▭ b
AB	4.68	0.35	0.3	h ▭ b
BD	3.5	0.5	0.4	h ▭ b
DE	3.4	0.35	0.3	h ▭ b

Beam Calculations and Values

Table 2 - Beam Stresses and Factor of Safety's

	Member OA	Member AB	Member BD	Member DE
Maximum Stress (psi)	434.3	14.2	76.9	14.3
Minimum Stress (psi)	418.9	5.0	20.6	5.1
Mean Stress (psi)	426.6	9.6	48.7	9.7
Alternating Stress (psi)	7.7	4.6	28.2	4.6
Tearout Stress (psi)	6.6	12.3	1.6	12.4
$N_{1,fatigue}$	6.5	98.7	17.0	98.4
$N_{2,fatigue}$	85.6	144.4	23.4	144.4
$N_{tension}$	6.0	495.3	121.7	486.1
$N_{compression}$	5.8	176.2	32.5	175.0
$N_{buckling}$	117.3	5.7	274.5	10.8
$N_{deflection}$	3.5	Infinite	2.8	Infinite
$N_{pin,tearout}$	270.6	145.3	1283.0	144.3
Failure Mode	**Deflection**	**Buckling**	**Deflection**	**Buckling**

Pin Calculations and Values

Table 3 - Pin Dimensions, Forces, and Factor of Safety's

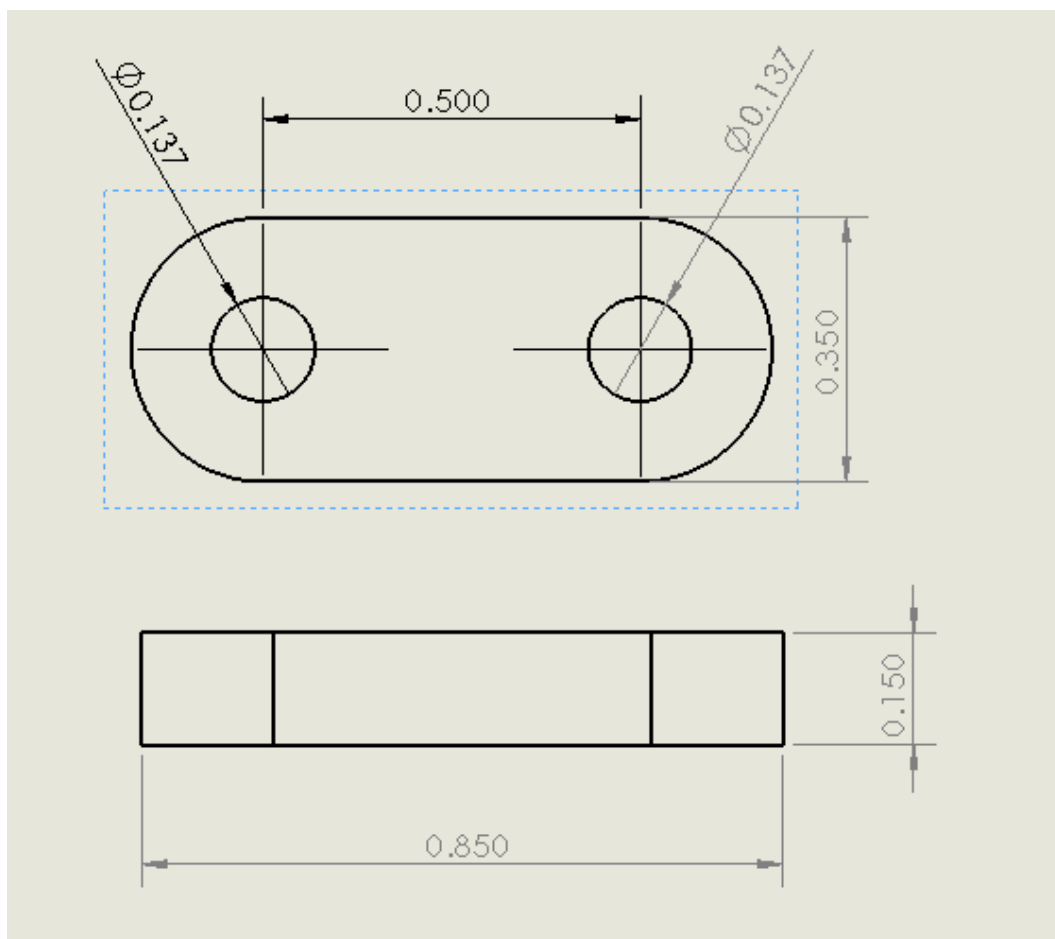| Pin	A	B	C	D	E
Diameter (in)	0.1	0.1	0.2	0.1	0.1
Length (in)	0.2	0.2	0.2	0.2	0.2
Max Force (lb)	1.5	1.5	3.0	1.5	1.5
Shear Stress (psi)	10.8	10.8	9.3	10.9	10.9
Bending Stress (psi)	69.9	69.9	91.5	70.4	70.4
$N_{pin,shear}$	231.1	231.1	269.3	229.6	229.6
$N_{pin,bearing}$	35.7	35.7	27.3	35.5	35.5
Failure Mode	**Bearing**	**Bearing**	**Bearing**	**Bearing**	**Bearing**

Solidworks Drawings of Members

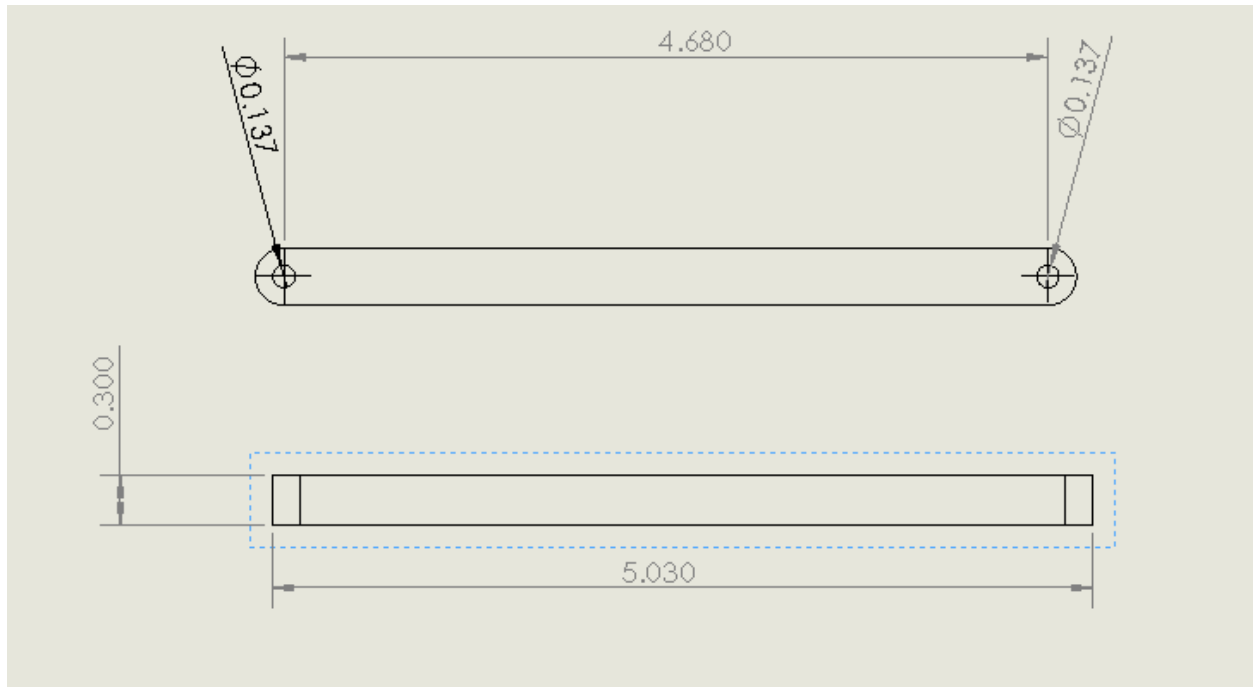*Figure 1 - Drawing of Member OA*

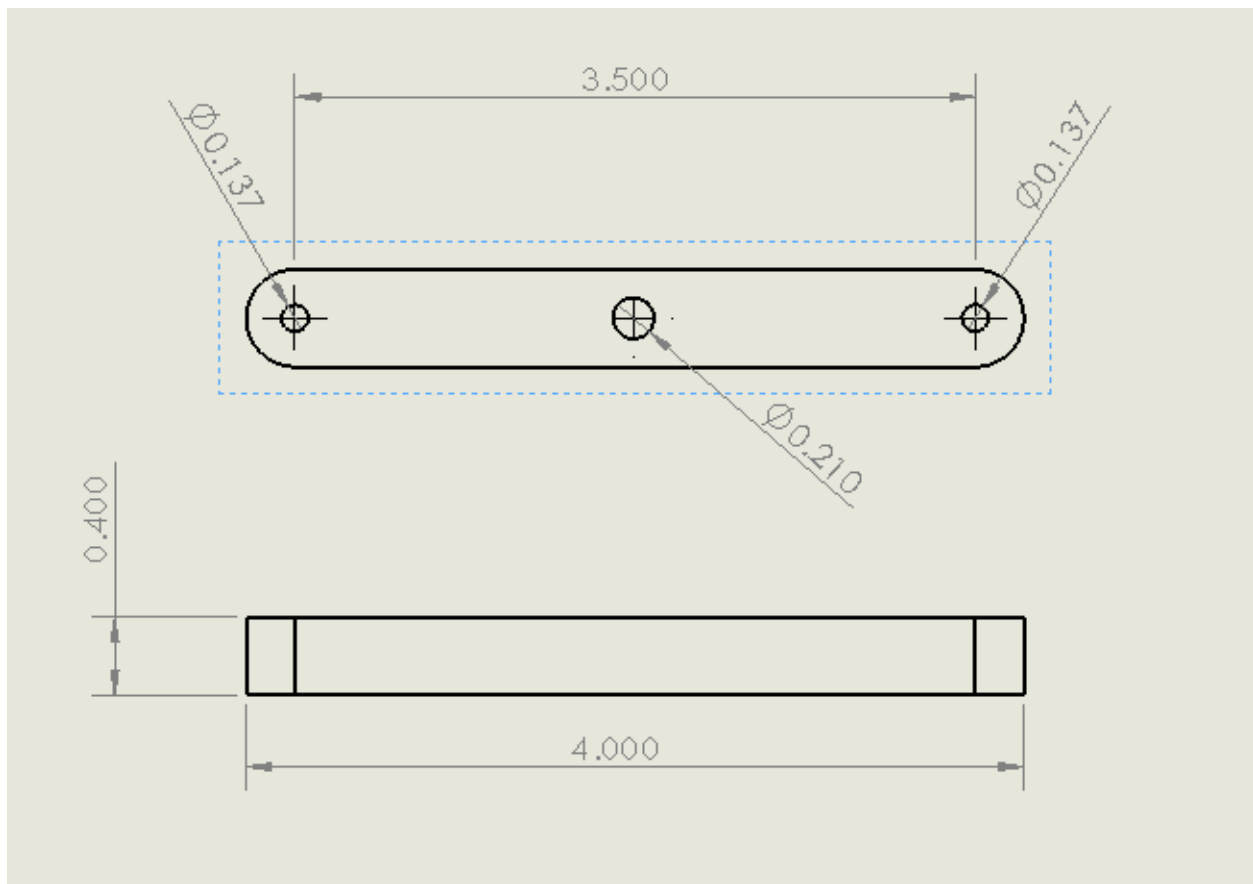*Figure 2 - Drawing of Member AB*
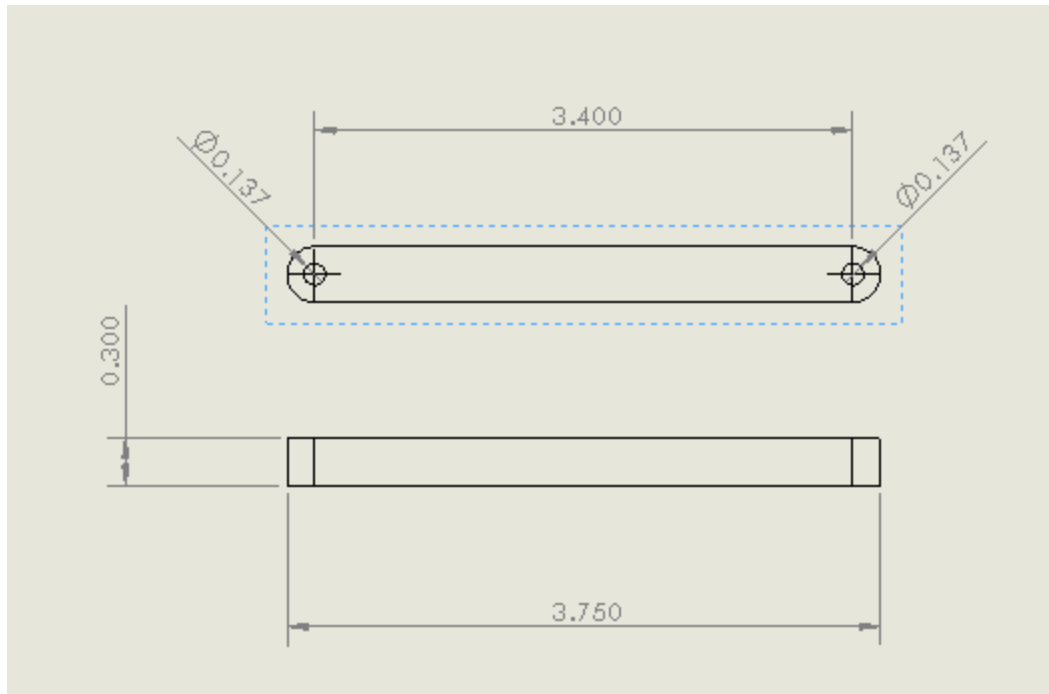

Figure 3 - Drawing of Member BD

Figure 4 - Drawing of Member DE
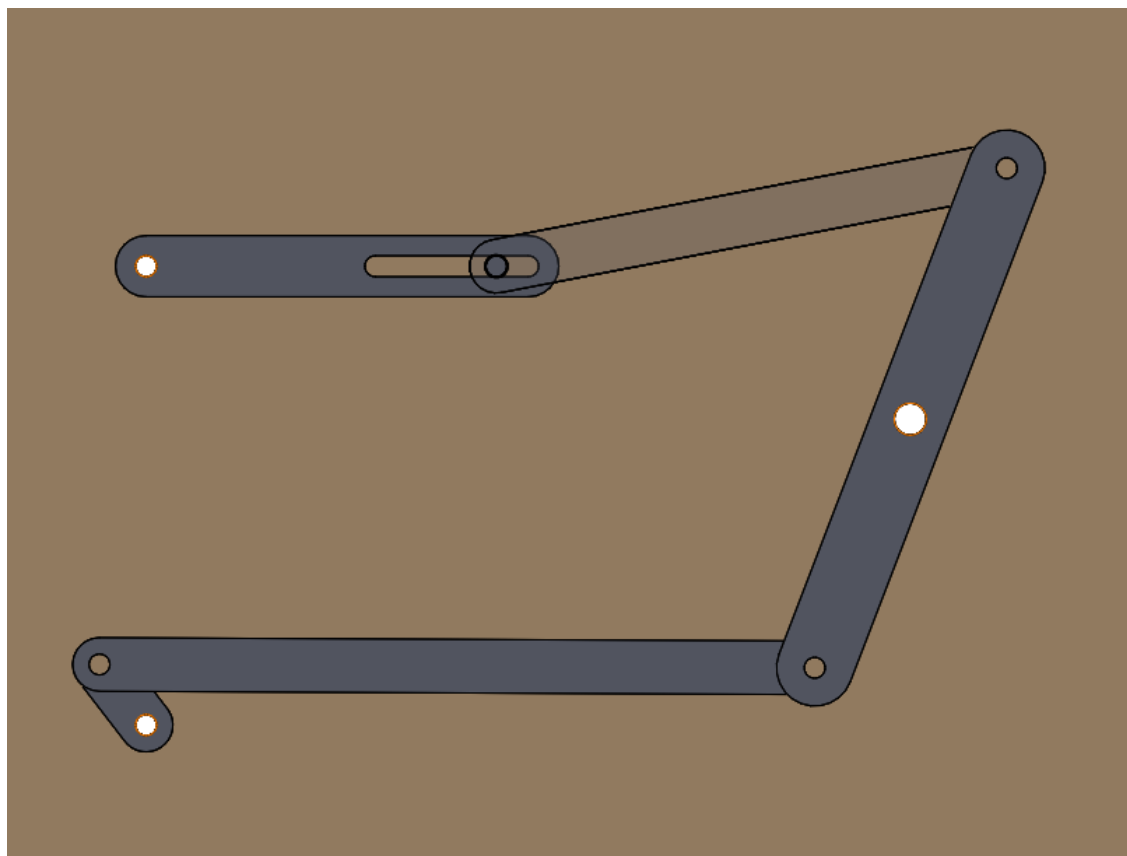
Figure 5 - 2D Figure of Full Assembly
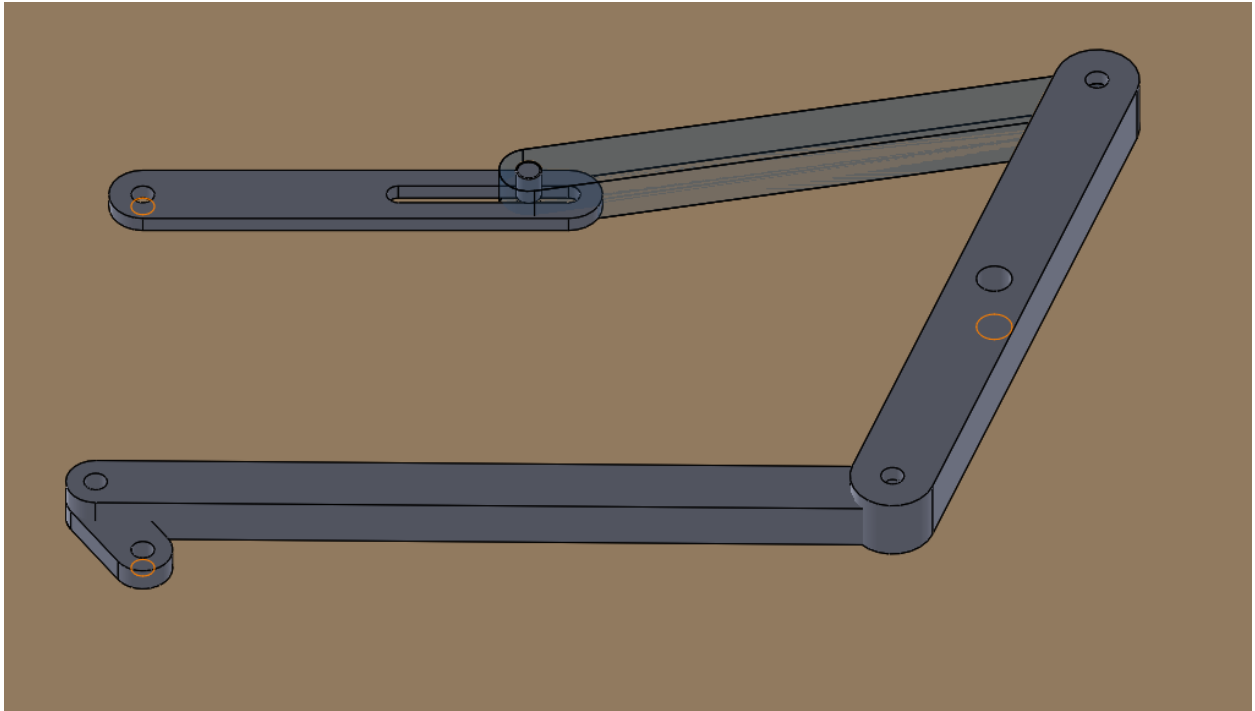
Figure 6 - 3D Figure of Full Assembly

Appendix

MATLAB Code

```matlab
clear all; close all; clc

%Plastic Properties Given

Mod_El=230000; %Modulus of Elasticity E = 230000psi
Sig_y=2500; %Yeild Strength Sig_y = 2500psi
Sig_uts=3000; %Ultamate Tensile Strength Sig_uts = 3000psi
Density=0.0376; %Density = 0.0376lb/in^3

%Extra Definitions
w=50; %Omega = 50rpm
theta=(0:1:360).*(pi/180); %Singular Rotation
k=1; %lbf/in

%Lengths Determined
r_AB = 4.68;
r_BD = 3.5;
r_DE = 3.4;

%Lengths Defined
r_OA = 0.5;
r_EF = 2.5;

%Geometry of Each Segment
    %Base = b
    %Height = h

%Base
dimb = .35;
dimh = .30;

b_AB=dimb;
b_DE=dimb;
b_EF=dimb;
%Height

h_AB=dimh;
h_EF=dimh;
h_DE=dimh;

% member BD 3
dim2b = .5;
dim2h = .4;
h_BD=dim2h;
b_BD=dim2b;
```

```matlab
%Member OA
dim3b = .35;
dim3h = .15;
b_OA=dim3b;
h_OA=dim3h;


%Dimentions [In Inches]
Width=dimh/2;
Width2=dim2h/2;
Width3=dim3h/2;
Thickness=0.125;
Area=[b_OA*h_OA,b_AB*h_AB,b_BD*h_BD,b_EF*h_EF];

%Y values for Bending Calculations
y_OA=h_OA/2;
y_AB=h_AB/2;
y_BD=h_BD/2;
y_DE=h_DE/2;


%Inertia Calculations
I_OA=(b_OA*(h_OA^3))/12;
I_AB=(b_AB*(h_AB^3))/12;
I_BD=(b_BD*(h_BD^3))/12;
I_DE=(b_DE*(h_DE^3))/12;
    %Inertia Matrix
I=[I_OA,I_AB,I_BD,I_DE];

%Moment Table from Deliverable 1 Solution
    %Values in lb*in
Mmax_OA=0.56;
Mmin_AB=0.00;
Mmax_BD=2.67;
Mmin_DE=0.00;
Mmin_OA=0.54;
Mmax_AB=0.00;
Mmin_BD=0.72;
Mmax_DE=0.00;

Mmin_Bending=[Mmin_OA,Mmin_AB,Mmin_BD,Mmin_DE];
Mmax_Bending=[Mmax_OA,Mmax_AB,Mmax_BD,Mmax_DE];

Min_Bending_Stress=zeros(1,4);
Max_Bending_Stress=zeros(1,4);
for i=1:4
    if i == 3
        Min_Bending_Stress(i)=(Mmin_Bending(i)*(Width2/2)/I(i));
        Max_Bending_Stress(i)=(Mmax_Bending(i)*(Width2/2)/I(i));
```

```matlab
    end

    Min_Bending_Stress(i)=(Mmin_Bending(i)*(Width/2)/I(i));
    Max_Bending_Stress(i)=(Mmax_Bending(i)*(Width/2)/I(i));
end

%Axial Forces Table from Deliverable 1 Solution
    %Values in lb
Ax_Mmax_OA=0.4;
Ax_Mmax_AB=1.49;
Ax_Mmin_BD=0.06;
Ax_Mmax_DE=1.50;
Ax_Mmin_OA=0.39;
Ax_Mmin_AB=0.53;
Ax_Mmax_BD=0.36;
Ax_Mmin_DE=0.54;

% %Maxiumum Compression Table from Deliverable 1 Solution
%     %Values in lb
% CMax_OA=-1.49;
% CMax_AB=-1.49;
% CMax_BD=-0.46; %Located in BC Region
% CMax_DE=-1.5;

%Maxiumum Force in each Pin Table from Deliverable 1 Solutions
    %Values in lb
FMax_A=1.49;
FMax_B=1.49;
FMax_C=2.97;
FMax_D=1.5;
FMax_E=1.5;
F = [FMax_A,FMax_B,FMax_C,FMax_D,FMax_E]
%Bending Calculations
    %Bending values calulated by (M*y)/I
    %Maximum
Bending_Max_OA=(Mmax_OA*y_OA)/I_OA;
Bending_Max_AB=(Mmax_AB*y_AB)/I_AB;
Bending_Max_BD=(Mmax_BD*y_BD)/I_BD;
Bending_Max_DE=(Mmax_DE*y_DE)/I_DE;
    %Minimum
Bending_Min_OA=(Mmin_OA*y_OA)/I_OA;
Bending_Min_AB=(Mmin_AB*y_AB)/I_AB;
Bending_Min_BD=(Mmin_BD*y_BD)/I_BD;
Bending_Min_DE=(Mmin_DE*y_DE)/I_DE;
    %Bending Stress Matrix
%Max_Bending_Stress=[Bending_Max_OA,Bending_Max_AB,Bending_Max_BD,Bending_Max_DE];
%Min_Bending_Stress=[Bending_Min_OA,Bending_Min_AB,Bending_Min_BD,Bending_Min_DE];

%Axial Calculations
    %Axial Stress Matrix
```

```matlab
Max_Axial=[Ax_Mmax_OA,Ax_Mmax_AB,Ax_Mmax_BD,Ax_Mmax_DE];
Min_Axial=[Ax_Mmin_OA,Ax_Mmin_AB,Ax_Mmin_BD,Ax_Mmin_DE];

Max_Axial_Stress=Max_Axial./Area;
Min_Axial_Stress=Min_Axial./Area;

%Combined Stress Calculations
    Max_Comb_Stress=zeros(1,4);
    Min_Comb_Stress=zeros(1,4);
for i=1:4
    Max_Comb_Stress(i)=Max_Bending_Stress(i)+Max_Axial_Stress(i);
    Min_Comb_Stress(i)=Min_Bending_Stress(i)+Min_Axial_Stress(i);
end

%Mean and Alternating Stress
Mean_Stress=(Max_Comb_Stress+Min_Comb_Stress)./2;
Alt_Stress=(Max_Comb_Stress-Min_Comb_Stress)./2;

%Buckling & Deflection
L=[r_OA,r_AB,r_BD,r_DE];
Buckling = (pi^2*Mod_El*I)./(L.^2);

Max_Deflection=L./360;
Actual_Deflection=(Mmax_Bending.*(L.^2))./(9*sqrt(3)*Mod_El.*I);

%Fatigue
Sf_prime=Sig_uts/2;
Cload=1;
Csize=1;
a_surf=4.511;
b_surf=-0.265;
Csurf=a_surf*Sig_uts^b_surf;
Creliab=0.814;
Ctemp=1;
Sf=Cload*Csize*Csurf*Ctemp*Creliab*Sf_prime;

%Factor of Safety Calculations
    %Fatigue
FOS_Fatigue_N1=(Sf*Sig_uts)./((Alt_Stress.*Sig_uts)+(Mean_Stress.*Sf));

    %Yeild
FOS_Yeild_Tension=Sig_y./abs(Alt_Stress - Mean_Stress);
FOS_Yeild_N_2=Sf./Alt_Stress;

FOS_Yeild_N_4=Sig_y./(Alt_Stress + Mean_Stress);

    %Deflection
FOS_Deflection=Max_Deflection./Actual_Deflection;

    %Buckling
```

```matlab
FOS_Buckling=Buckling./Max_Axial_Stress;

%Shear Calculations

%Pin Values and Calculations
    %Diameter = d [Values in Inches]
d_A=0.137795;
d_B=0.137795;
d_C=0.21;
d_D=0.137795;
d_E=0.137795;
Length=0.19685;
d = [d_A,d_B,d_C,d_D,d_E]

%Shear Stress Calculations per Pin
Shear_Stress_A=sqrt(3)*FMax_A/(pi*d_A^2)/4;
Shear_Stress_B=sqrt(3)*FMax_B/(pi*d_B^2)/4;
Shear_Stress_C=sqrt(3)*FMax_C/(pi*d_C^2)/4;
Shear_Stress_D=sqrt(3)*FMax_D/(pi*d_D^2)/4;
Shear_Stress_E=sqrt(3)*FMax_E/(pi*d_E^2)/4;
%Shear Stress Array
Shear_Stress=[Shear_Stress_A,Shear_Stress_B,Shear_Stress_C,Shear_Stress_D,Shear_Stress
_E];

%Bearing Stress Calculations per Pin
Bearing_Stress_A=FMax_A/((pi*d_A*Length)/4);
Bearing_Stress_B=FMax_B/((pi*d_B*Length)/4);
Bearing_Stress_C=FMax_C/((pi*d_C*Length)/4);
Bearing_Stress_D=FMax_D/((pi*d_D*Length)/4);
Bearing_Stress_E=FMax_E/((pi*d_E*Length)/4);
%Bearing Stress Array
Bearing_Stress=[Bearing_Stress_A,Bearing_Stress_B,Bearing_Stress_C,Bearing_Stress_D,Be
aring_Stress_E];

%Factor of Safety Pin Calculations
FOS_Shear=Sig_y./Shear_Stress;
FOS_Bearing=Sig_y./Bearing_Stress;

%Tearout Calculations
Tearout_Stress_OA=sqrt(3)*Max_Axial(1)/(2*b_OA*h_OA);
Tearout_Stress_AB=sqrt(3)*Max_Axial(2)/(2*b_AB*h_AB);
Tearout_Stress_BD=sqrt(3)*Max_Axial(3)/(2*b_BD*h_BD);
Tearout_Stress_DE=sqrt(3)*Max_Axial(4)/(2*b_DE*h_DE);
%Tearout Array
Tearout_Stress=[Tearout_Stress_OA,Tearout_Stress_AB,Tearout_Stress_BD,Tearout_Stress_D
E];

%Factor of Safety for Tearout
FOS_Tearout=Sig_y./Tearout_Stress;
```

```matlab
% Creating FOS Table
t = table(FOS_Fatigue_N1',FOS_Yeild_Tension',FOS_Yeild_N_2'...
    ,FOS_Yeild_N_4',FOS_Deflection',FOS_Buckling',FOS_Tearout');

t2 = table(FOS_Bearing',FOS_Shear');
```