A. Stein
SEI Team

FEA Results: BSC ISI Spring, 0-1

large displacement flag enabled in SolidWorks Simulation

Spring material: Maraging 300

Ex	189.6	GPa	Young's Modulus
Gxy	80	GPa	Shear Modulus
nu	0.3		Poisson's Ratio

Z axis: in-plane, parallel to Spring's long axis
Y axis: out-of-plane

force applied to "Dummy Flexure Mount" mated to top of Spring tip, concentric with the Flexure's axis
Dummy Flexure Mount material… custom very-high-stiffness

Ex	6.89E+04	GPa	Young's Modulus
Gxy	2.28E+04	GPa	Shear Modulus
nu	0.33		Poisson's Ratio

Study Name **"Equ Flex"**

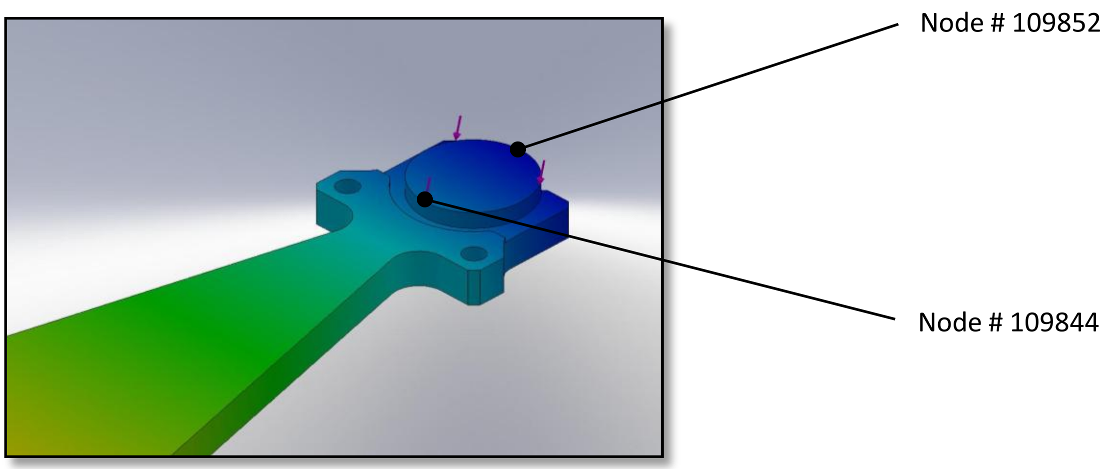
Force	**2750**	lb	*this is the expected load per 0-1 Spring*
Angle of Force, from Tip normal	13.18	deg	*this value taken from geometry of ASI's curved Spring model*
mesh size	0.175	in	

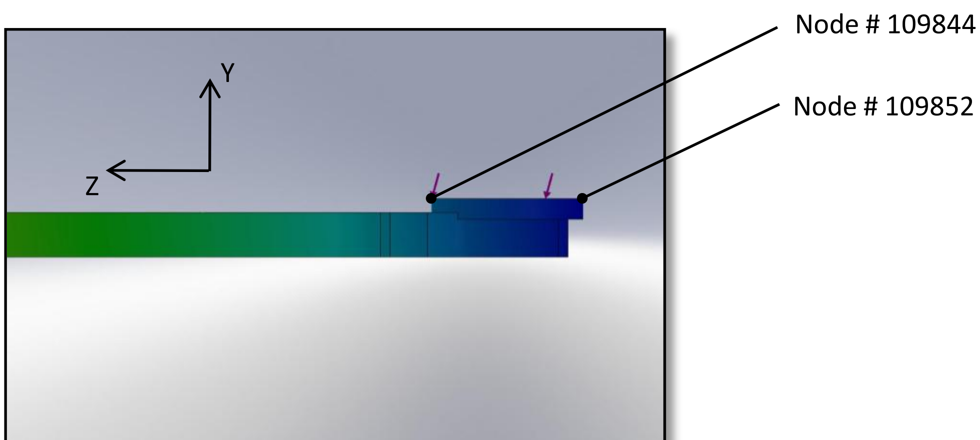
results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
109844	-16.188		-1.983	5.435E-02		-
109852	-17.813		-2.369	1.007E-01		13.74

resultant displacement **2.18** in *referenced to undeformed shape*

Displacements are recorded at two points on the infinitely stiff "dummy flexure mount." Typical location of these points (or "nodes") are shown in the following two SolidWorks Simulation screen captures. Knowing the distance between the nodes and the displacements predicted there, we can estimate the angle of the Spring tip when the given load is applied.





A. Stein
SEI Team

Study Name **"Equ+ Flex"**

Force	**2800**	lb	**50 lbs more** than the equilibrium load
Angle of Force, from Tip normal	13.18	deg	
mesh size	0.175	in	

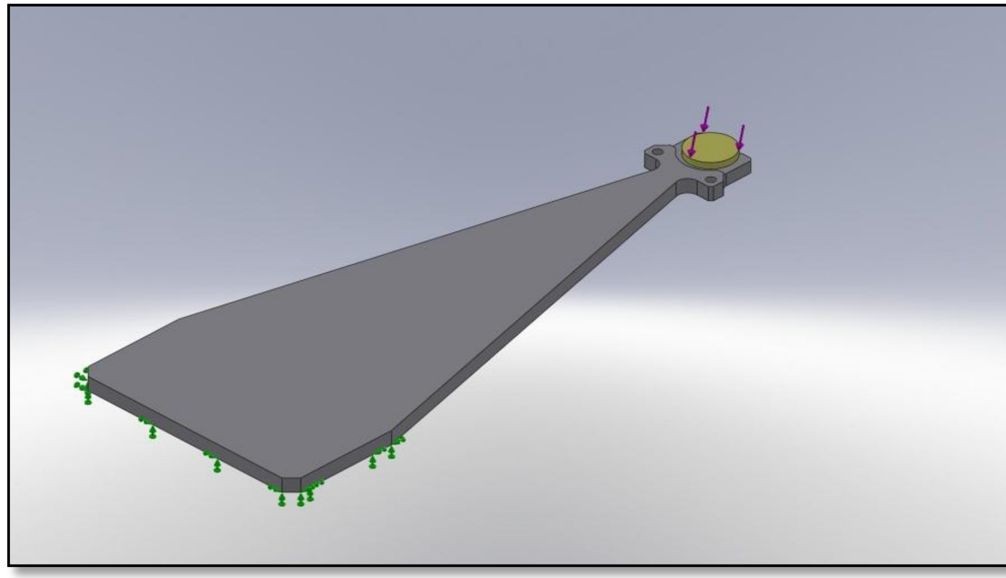
results:

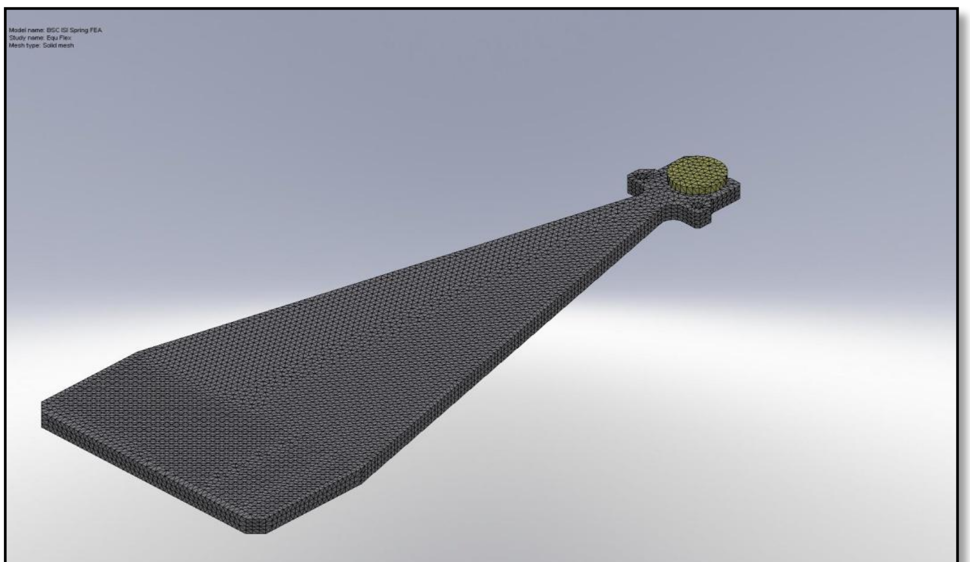
Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
109844	-16.188		-2.020	5.837E-02		-
109852	-17.813		-2.412	1.064E-01		13.96

resultant displacement **0.0403** in — *referenced to "Equ Flex" deformed shape*

linear stiffness, near equilibrium	1241	lb/in	*1.24 lb per .001"*
	4.448	N/lb	***Per Blade*** *- for stiffness of entire Stage, multiply by 3x*
	3.94E-05	in/um	
	0.217	**N/um**	

0-1 Spring:
FEA Setup

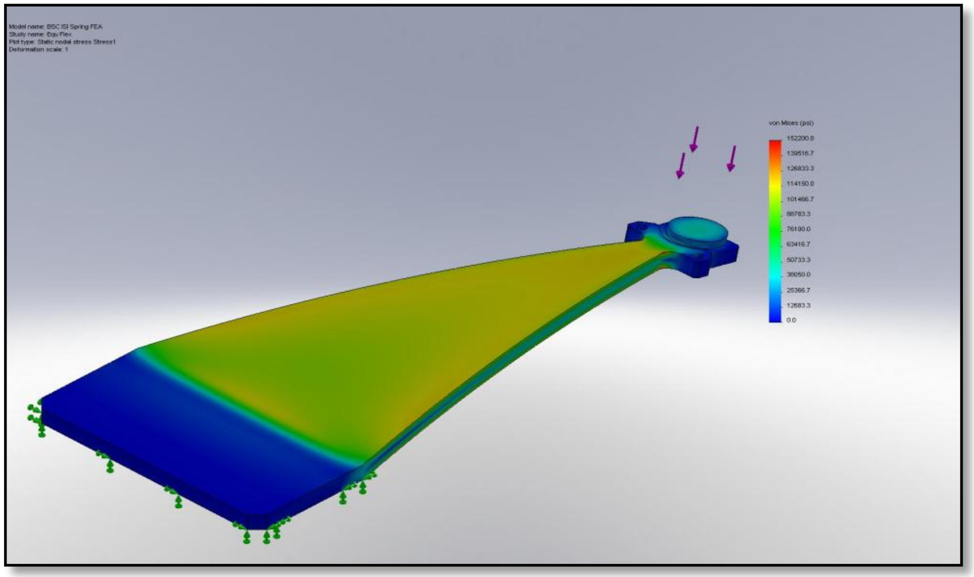




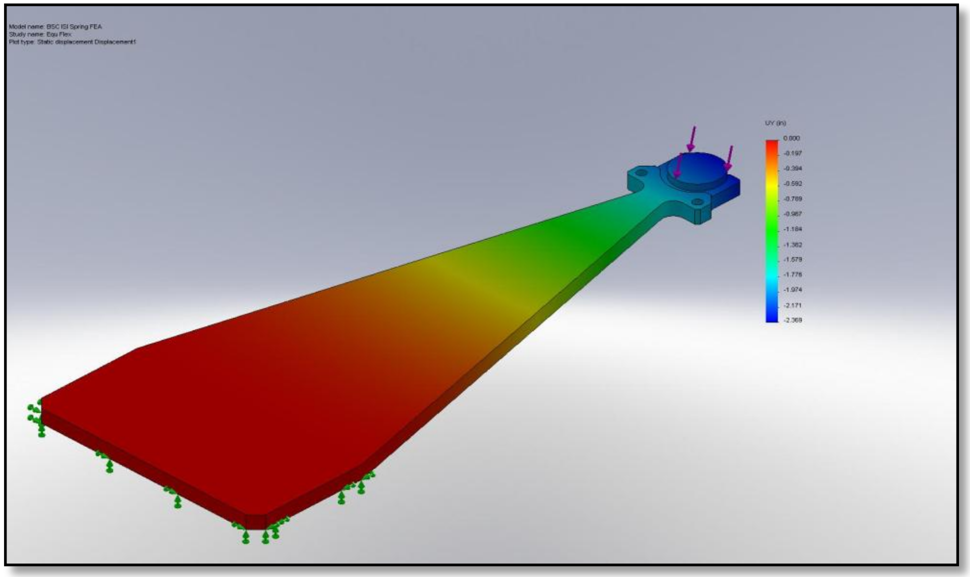
0-1 Spring:
After Meshing

A. Stein
SEI Team

0-1 Spring:
"Equ Flex" Stress



max value	152200 psi
min value	0 psi



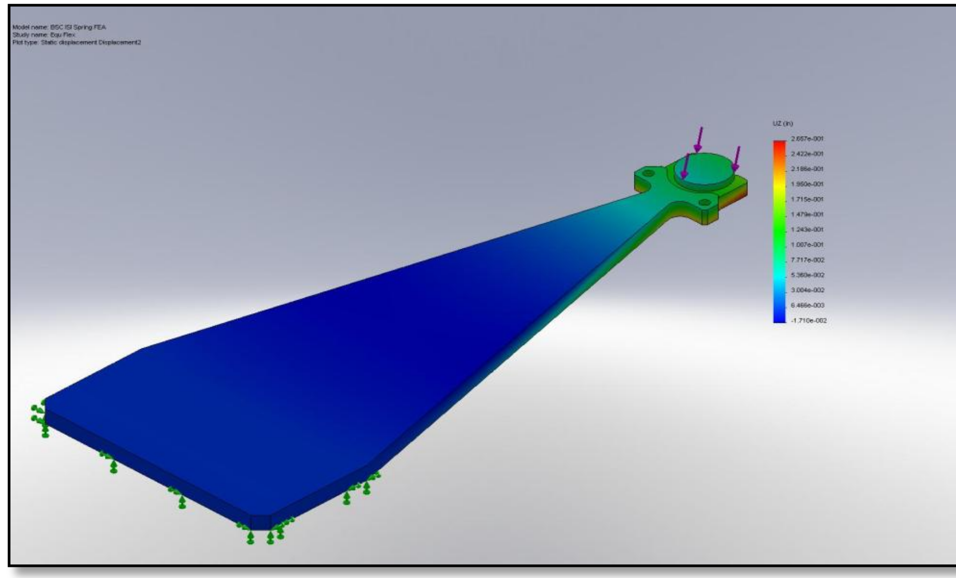
0-1 Spring:
"Equ Flex" ΔY Results

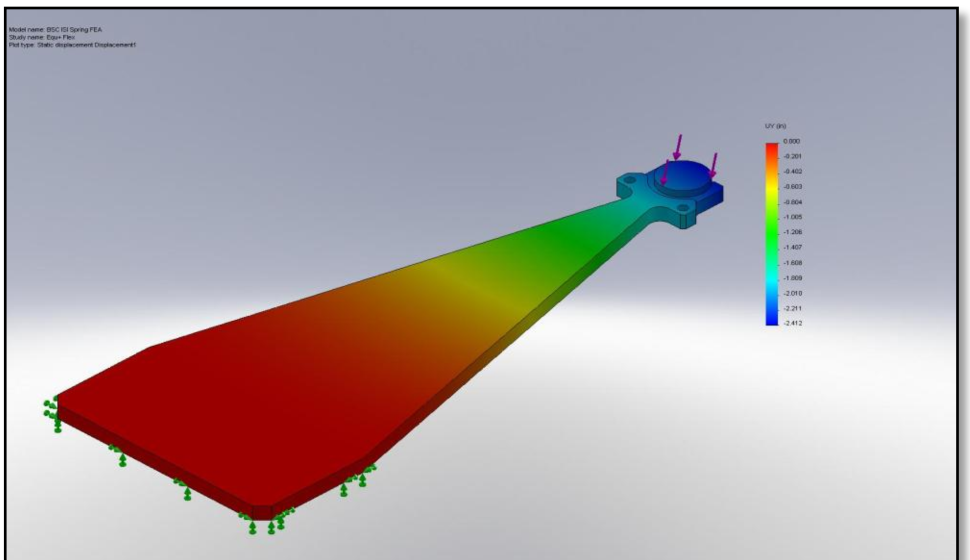
max value	0 in
min value	-2.369 in

A. Stein
SEI Team

0-1 Spring:
"Equ Flex" ΔZ Results

max value	2.657E-01 in
min value	-1.710E-02 in





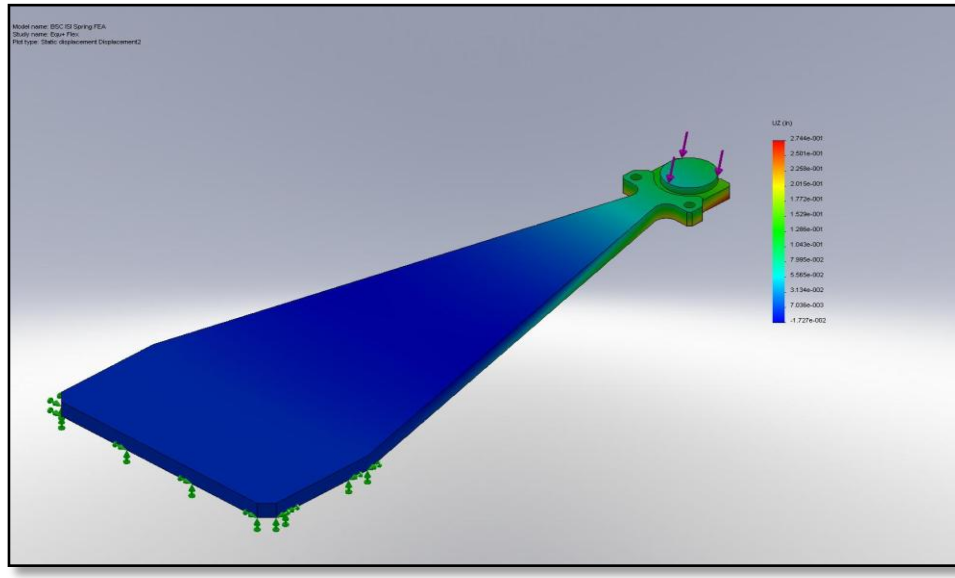
0-1 Spring:
"Equ+ Flex" ΔY Results

max value	0 in
min value	-2.412 in

A. Stein
SEI Team

0-1 Spring: "Equ+ Flex" ΔZ Results

max value	2.744E-01	in
min value	-1.727E-02	in



Re-running the "Equ Flex" study for the 0-1 Spring, this time using the slightly larger angle for the force line, as evaluated in the initial study above:

Study Name **"Equ Flex"**

Force	**2750**	lb	*this is the expected load per 0-1 Spring*
Angle of Force, from Tip normal	13.74	deg	
mesh size	0.175	in	

results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
111011	-16.188		-1.981	5.410E-02		-
111019	-17.813		-2.366	1.003E-01		13.71

resultant displacement **2.17** in *referenced to undeformed shape*

conclusion: *no significant effect from re-aligning force line to equilibrium tip angle.*

Re-running the "Equ Flex" study for the 0-1 Spring, again. We now use the tip angle evaluated in the above study, and the "correct" value for the Maraging 300's Shear Modulus (Gxy). Also, the mesh density is slightly higher than in all the previous 0-1 Spring FEAs:

Study Name **"Equ Flex"**

Force	**2750**	lb
Angle of Force, from Tip normal	13.71	deg
mesh size	0.150	in

Maraging 300 properties:

Ex	189.6	GPa
Gxy	73	GPa
nu	0.3	

results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
176382	-16.188		-1.982	5.423E-02		-
176402	-17.813		-2.367	1.005E-01		13.71

resultant displacement **2.18** in *referenced to undeformed shape*

conclusion: *There is almost no difference between these results and the results listed directly above it. Sensitivity to mesh size and value of Gxy appear to be low enough to give good confidence in the results.*

A. Stein
SEI Team

Re-running the "Equ+ Flex" study for the 0-1 Spring, to re-evaluate the Spring's stiffness. We now use the tip angle evaluated in the initial "Equ+ Flex" study, and the correct value for the Maraging 300's Shear Modulus (Gxy):

Study Name	**"Equ+ Flex"**	
Force	**2800**	lb
Angle of Force, from Tip normal	13.90	deg
mesh size	0.175	in

Maraging 300 properties:

Ex	189.6	GPa
Gxy	73	GPa
nu	0.3	

results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
111011	-16.188		-2.017	5.805E-02		-
111019	-17.813		-2.408	1.059E-01		13.92

resultant displacement **0.0383** in — *referenced to "Equ Flex" deformed shape*

linear stiffness, near equilibrium	1306	lb/in	*1.31 lb per .001"*
	4.448	N/lb	
	3.94E-05	in/um	***Per Blade*** *- for stiffness of entire Stage, multiply by 3x*
	0.229	**N/um**	

conclusion: *We see a small change in the evaluated stiffness.*

New study named "Equ- Flex," using a force 50 lbs less than the nominal Spring load:

Study Name **"Equ- Flex"**

Force	**2700**	lb
Angle of Force, from Tip normal	13.45	deg
mesh size	0.175	in

Maraging 300 properties:

Ex	189.6	GPa
Gxy	73	GPa
nu	0.3	

results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
111011	-16.188		-1.946	5.031E-02		-
111019	-17.813		-2.324	9.489E-02		13.45

resultant displacement **0.0398** in

referenced to "Equ Flex" deformed shape

linear stiffness, near equilibrium	1257	lb/in	*1.26 lb per .001"*
	4.448	N/lb	
	3.94E-05	in/um	***Per Blade*** *- for stiffness of entire Stage, multiply by 3x*
	0.220	**N/um**	

conclusion: *The stiffness calculated in this direction (subtracting from, rather than adding to the nominal force) is very similar to that calculated directly above, adding to our confidence in the previous results.*

A. Stein
SEI Team

FEA Results: BSC ISI Spring, 1-2

large displacement flag enabled in SolidWorks Simulation

Spring material: Maraging 300

Ex	189.6	GPa	Young's Modulus
Gxy	80	GPa	Shear Modulus
nu	0.3		Poisson's Ratio

Z axis: in-plane, parallel to Spring's long axis
Y axis: out-of-plane

force applied to "Dummy Flexure Mount" mated to top of Spring tip, concentric with the Flexure's axis
Dummy Flexure Mount material... custom very-high-stiffness

Ex	6.89E+04	GPa	Young's Modulus
Gxy	2.28E+04	GPa	Shear Modulus
nu	0.33		Poisson's Ratio

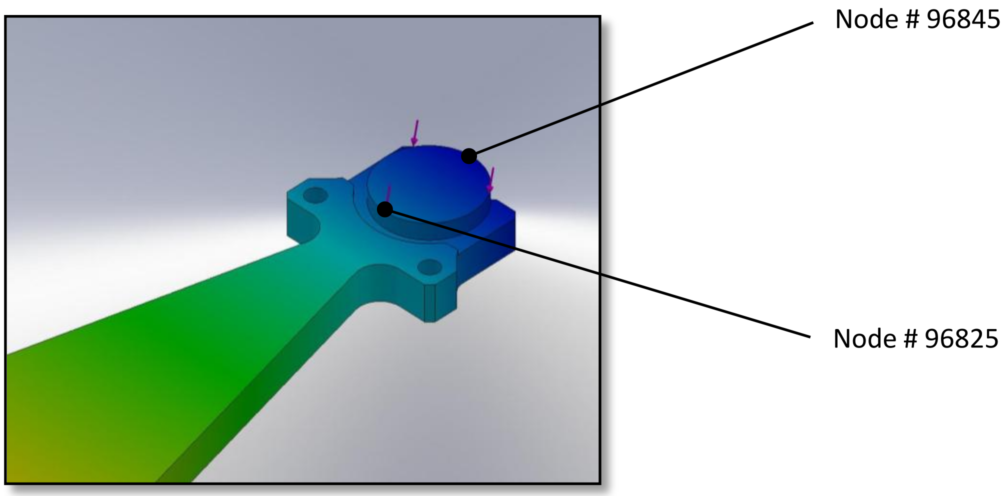
Study Name	**"Equ Flex"**		
Force	**2080**	lb	*this is the expected load per 1-2 Spring*
Angle of Force, from Tip	11.04	deg	*this value taken from geometry of ASI's curved Spring model*
mesh size	0.15	in	

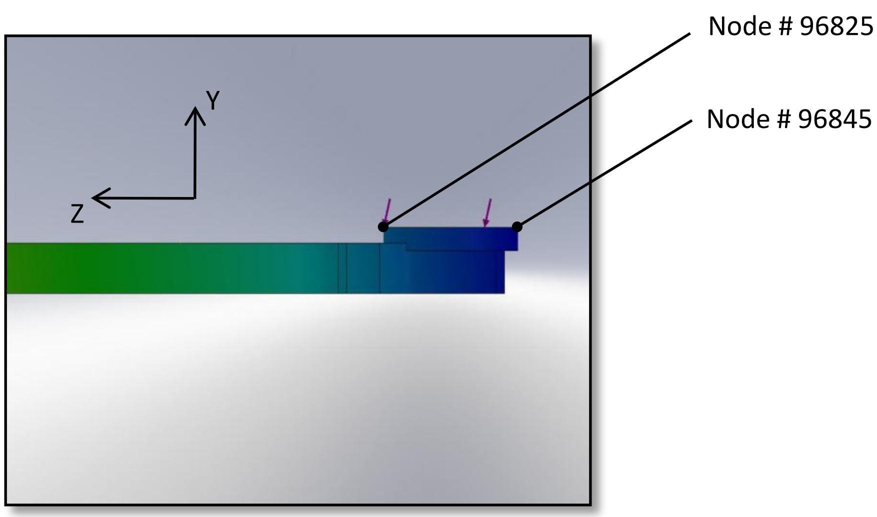
results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
96825	-11.938		-1.227	1.408E-03		-
96845	-13.563		-1.547	3.324E-02		11.36

resultant displacement **1.39** in *referenced to undeformed shape*

Displacements are recorded at two points on the infinitely stiff "dummy flexure mount." Typical location of these points (or "nodes") are shown in the following two SolidWorks Simulation screen captures. Knowing the distance between the nodes and the displacements predicted there, we can estimate the angle of the Spring tip when the given load is applied.





Study Name **"Equ+ Flex"**

Force	**2130**	lb	**50 lbs more** than the equilibrium load
Angle of Force, from Tip	11.04	deg	
mesh size	0.15	in	

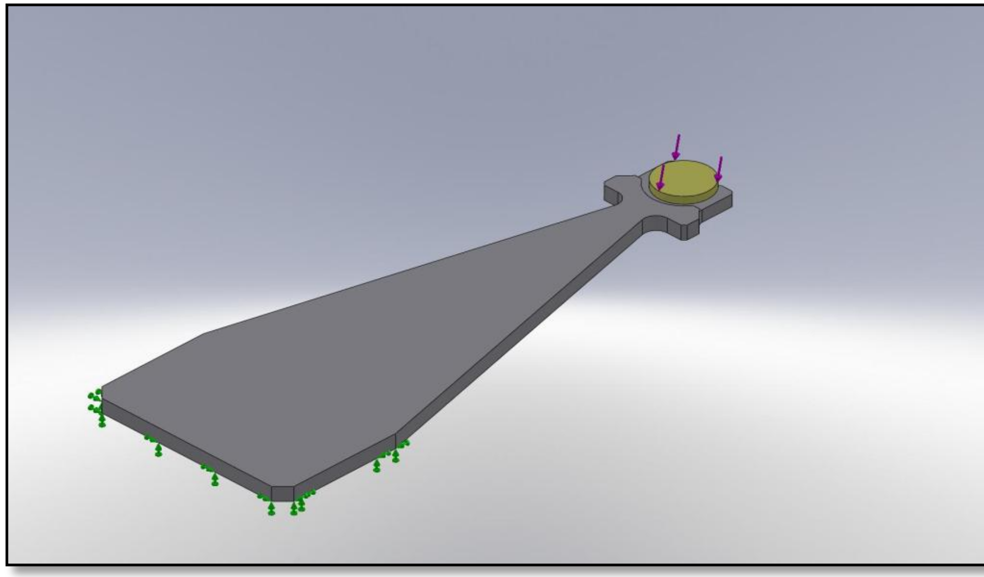
results:

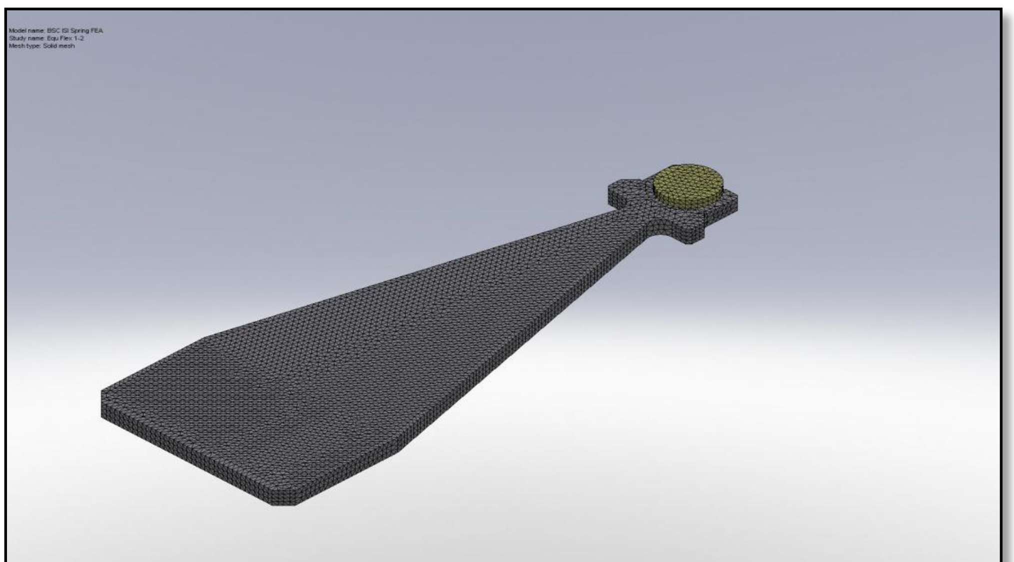
Node Number	Node Position		Displacement (in)			Tip Angle (Deg)
#	Z		ΔY	ΔZ		
96825	-11.938		-1.257	3.509E-03		-
96845	-13.563		-1.585	3.691E-02		11.64

resultant displacement **0.0341** in — *referenced to "Equ Flex" deformed shape*

linear stiffness, near equilibrium	1465	lb/in	*1.47 lb per .001"*
	4.448	N/lb	***Per Blade*** *- for stiffness of entire Stage, multiply by 3x*
	3.94E-05	in/um	
	0.257	**N/um**	

1-2 Spring:
FEA Setup



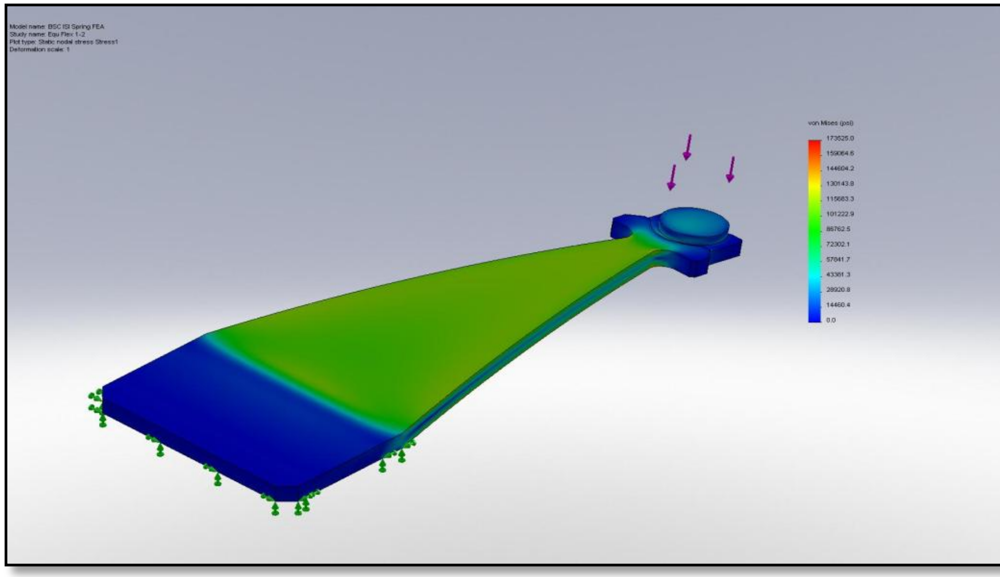


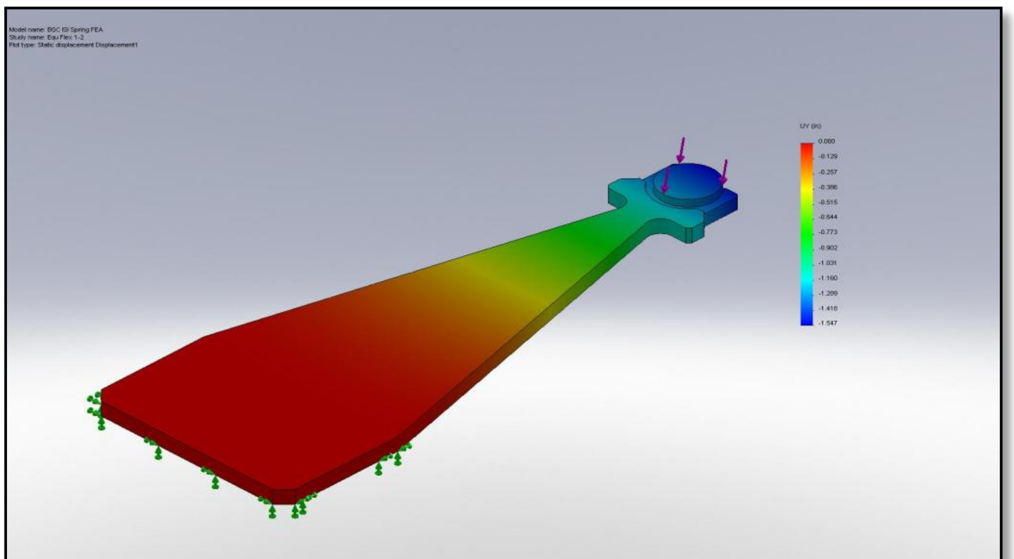
1-2 Spring:
After Meshing

A. Stein
SEI Team

1-2 Spring:
"Equ Flex" Stress Results

max value	173525 psi
min value	0 psi



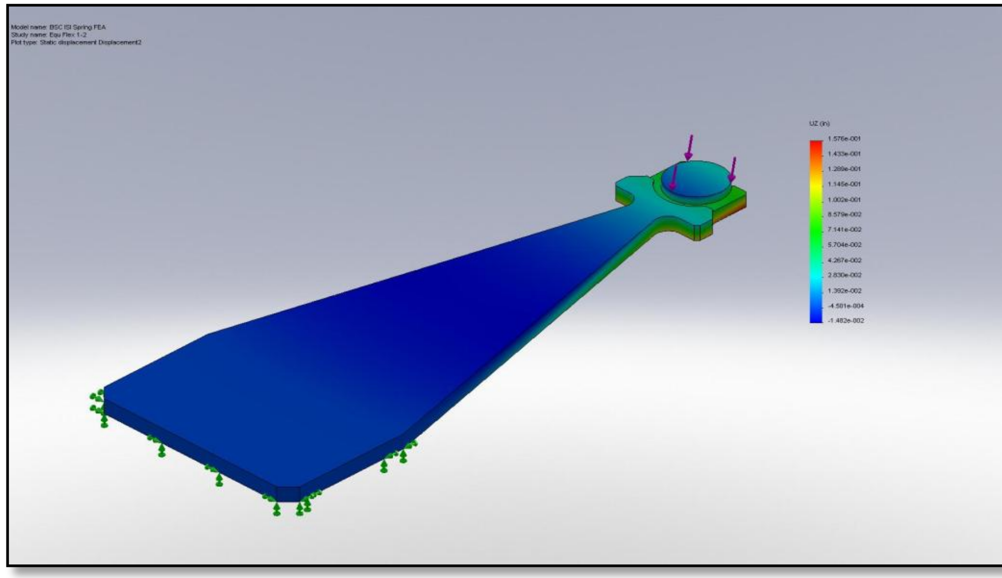


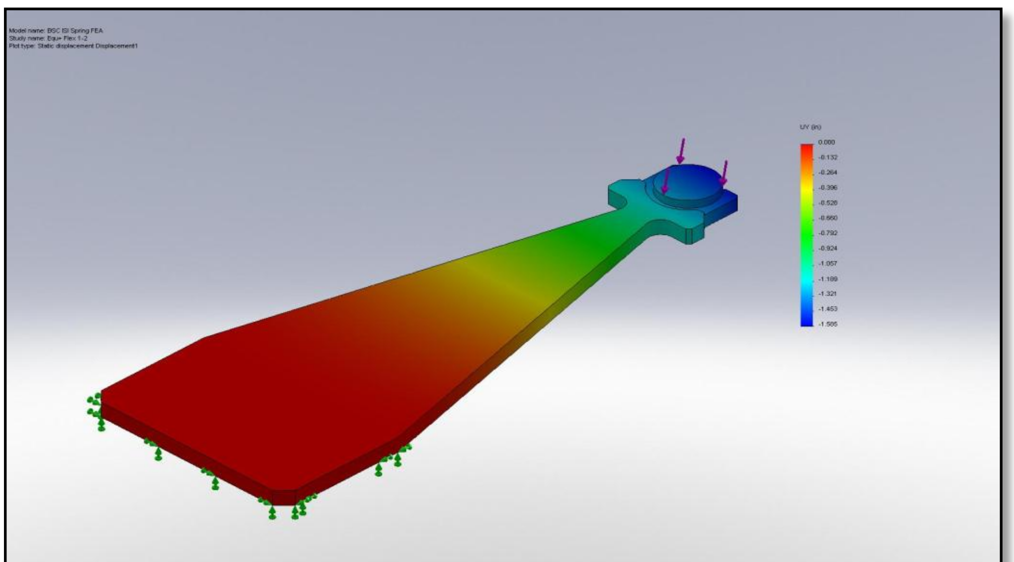
1-2 Spring:
"Equ Flex" ΔY Results

max value	0 in
min value	-1.547 in

1-2 Spring:
"Equ Flex" ΔZ Results

max value	1.576E-01 in
min value	-1.482E-02 in





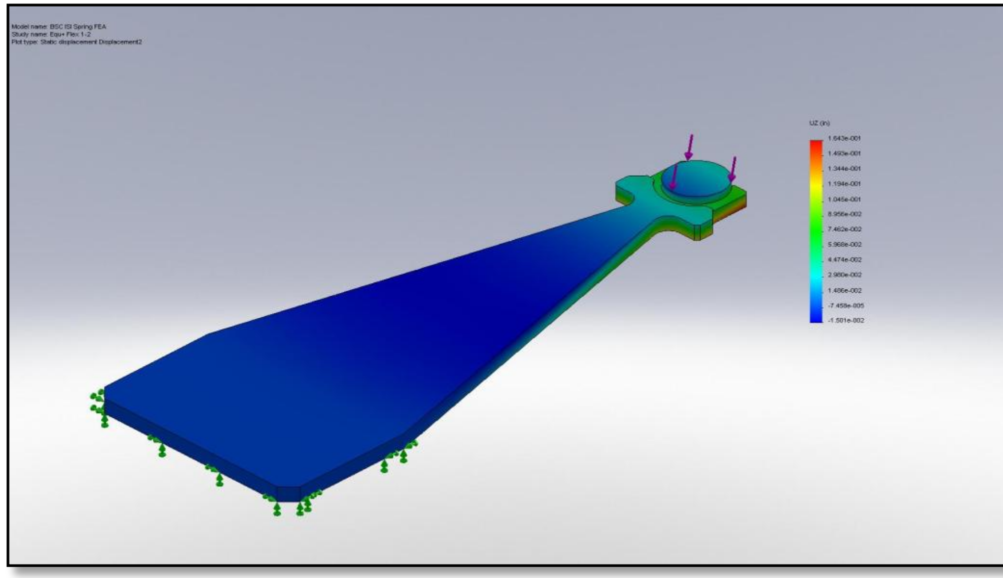
1-2 Spring:
"Equ+ Flex" ΔY Results

max value	0 in
min value	-1.585 in

A. Stein
SEI Team

1-2 Spring: "Equ+ Flex" ΔZ Results

max value	1.643E-01 in
min value	-1.501E-02 in



A. Stein
SEI Team

Re-running the "Equ Flex" study for the 1-2 Spring, this time using the correct value for the Shear Modulus (Gxy) and the slightly larger angle for the force line, as evaluated in the initial study above:

Study Name **"Equ Flex"**

Force	**2080**	lb
Angle of Force, from Tip normal	11.36	deg
mesh size	0.15	in

Maraging 300 material properties:

Ex	189.6	GPa
Gxy	73	GPa
nu	0.3	

results:

Node Number	**Node Position**		**Displacement (in)**			**Tip Angle (Deg)**
#	Z		ΔY	ΔZ		
96825	-11.938		-1.227	1.367E-03		-
96845	-13.563		-1.546	3.315E-02		11.32

resultant displacement **1.39** in *referenced to undeformed shape*

conclusion: *the minor "corrections" to the model result in almost no change to the results, which is a welcome result.*