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Flexible Link Analysis

M. Dawe

August 2004

Canada

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SUMMARY

An analysis was done on varying designs for flexible links to determine how the mechanical properties of the link changed depending upon slight design changes. The analysis was performed by varying the length of the small tapered section center by a value based on its diameter multiplied by 0 to 6 times. The length of the center of the link was varied depending on the length of the ends (either 0.5" or 0.25") so that the overall height of the link remained at 3.5" with 0.5" ends and 3" with 0.25" ends.

Algor's FEMPRO was used to perform bending and compression tests on the links with a one-pound load. From the deflections obtained, the stiffness of the links could be calculated in both bending and compression. From this the stiffness ratio could be found. For design purposes, the stiffness ratio had to at least greater than 5000:1 to ensure proper performance of the links in the dynamometer. Overall, all link variations obtained a ratio greater than 5000:1 excluding the shortest length link with 0x tapered section center.

In addition, a stress analysis was performed on the links using FEMPRO. For this a proper mesh on the link had to be created in CadKey and then imported in FEMPRO. Only a select few link were used in the stress analysis since the overall stress had little to no variation between different links. Overall, a stress of 43500 psi was obtained and this value did not change more than 300 to 400 psi in all the links tested.

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FLEXIBLE LINK ANALYSIS

LM-2004-19

Mark Dawe

August 2004

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An analysis was done on varying designs for flexible links to determine how the mechanical properties of the link changed depending upon slight design changes. The analysis was performed by varying the length of the small tapered section by a value based on its diameter multiplied by 0 to 6 times. The length of the center of the link was varied depending on the length of the ends (either 0.5" or 0.25") so that the overall height of the link remained at 3.5" with 0.5" ends and 3" with 0.25" ends.

In the analysis, Algor's FEMPRO was used to calculate the deflection of the flexible links when subjected to a compressive load and a bending load, both with a magnitude of one pound. With the deflections known, the stiffness of the link in both directions was calculated and then the ratio was taken. Ideally, for design purposes the ratio must be greater than 5000:1. It was found that nearly all design variations analyzed had a stiffness ratio of over 5000:1, excluding the shortest 0x link which did not obtain a ratio over 5000:1.

In addition, a stress analysis was performed on selected links using FEMPRO. CadKey was also used to create the mesh on the link necessary for the analysis to run properly. Only selected link were subjected to a stress analysis since there was little to no variation in the stress found in the tested links. Maximum stress for this analysis was always found to be approximately 43500 pounds per square inch and did not fluctuate more than 300 to 400 psi in different links.

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1.0 INTRODUCTION:

The purpose of this analysis was to look at how various mechanical properties of the flexible links changed depending upon slight differences in design. The analysis was done in two parts. The first used a beam element model of the flexible links to determine the stiffness ratio. Determining both the axial and bending stiffness of the link allowed this value to be calculated. This value is important to the design because it must be kept above 5000:1. The second part of the analysis was used to determine the stress in the link during normal operation. Both parts of the analysis together provide the required design information for the project

2.0 THE MODEL:

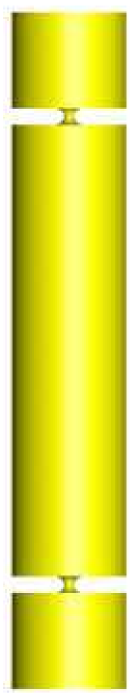

Figure 1: Model of Flexible Link

Figure 1 shows the general shape of the model used. The model itself is 3.5 inches tall with both ends measuring 0.5 inches. The height of the tapered section 0.08 inches with the diameter changing from 0.12 inches to 0.04 inches at the smallest section.

For the purpose of the analysis, the links were categorized by the ratio of the length of the center of the tapered section to the smallest diameter. For example, the tapered section of a 1x link would include a straight segment in the middle that was 0.04 inches in height, or one times the smallest diameter in height. These categories ranged from 0x to 6x inclusively with the 0x link shown above in figure 1. As the tapered section increased in size corresponding to the multiplier, the overall height of the link was kept at 3.5 inches by decreasing the height of the center segment of the link. Also the ends of the link remained at a fixed length.

3.0 ANALYTICAL PROCEDURE

With the flexible link categories defined, each category was then divided into a subcategory based on the length of the ends of the links. For the purpose of the analysis two lengths were chosen for the ends, both 0.5 and 0.25 inches. In each subcategory the analysis was conducted at three different overall lengths. These changes in overall lengths were accomplished by varying the length of the center segment so that ends and the tapered section could remain at required lengths.

In addition to changes in length, the effect of the major diameter of the links was also taking into account. The major diameter was defined as the diameter of the link excluding the two tapered sections. Therefore, at each length the major diameter of the link was varied through five steps which include; $^1/_2$", $^7/_{16}$", $^3/_8$", $^5/_{16}$" and $^1/_4$".

The first part of the analysis was to determine the axial to bending stiffness ratio of the flexible link by first determining both the bending and axial stiffness. Algor's FEMPRO was used to create a beam element model of the link. In order to accurately represent the model using beam elements, the tapered section was represented as six separate beam elements. By taking one-half of the tapered section (i.e. section from 0.12 inch diameter to 0.04 inch diameter) and then dividing it into three beam elements of equal length with diameters equal to the mean diameter of each of the three elements and then mirroring the result about the center of the tapered section, the six separate beam elements were created. The additional straight segment of the tapered section was added as another beam element that would vary according to the category of the analysis. Figure 2 below shows the model represented in beam elements with boundary conditions already applied.

Figure 2: Beam Element Model with Applied Boundary Conditions

Each of the beam elements in the tapered section were approximately 0.0133 inches in length and their diameters were the following; 0.08", 0.05" and 0.04". See figures 3 and 4 below for a representation of the model in beam element form.

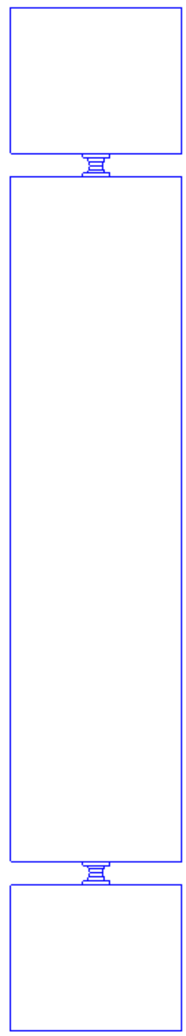

Figure 3: Representation of Beam Element Model

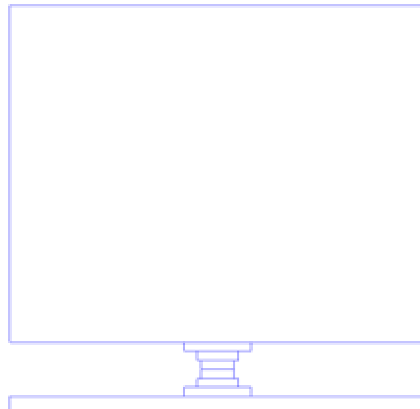

Figure 4: Close-up of Upper End and Tapered Section of the Representation of the Beam Element Model

Here is a summary of the element properties used in the beam element representation:

Sectional Properties

	Area A (in^2)	Moment of Inertia I (in^4)	Section Modulus Z (in^3)	Torsional Resistance J (in^4)	Shear Area S (in^2)
0.5" Diameter	0.1963	0.003068	0.01227	0.006136	0.1741
0.08" Diameter	0.005027	0.000002011	0.00005027	0.000004021	0.004456
0.05"Diameter	0.001963	0.000000306	0.00001227	0.000000613	0.001741
0.04" Diameter	0.001257	0.000000125	0.000006283	0.000000251	0.001114

Secondly, the boundary conditions of the model in Algor were defined and the analysis performed. One end of the model was held fixed while to the other end a nodal force of 1 pound was applied both in the horizontal and negative vertical directions. The resulting deflections were calculated by Algor and recorded in a spreadsheet. Once the deflection values were recorded, both the axial and bending stiffness were calculated by taking the inverse of the deflections. This is the case since the stiffness K equals force divided by distance (K = F/d) and the force in this case is 1 pound. Now the stiffness ratio could be calculated by dividing calculated axial stiffness of the link in compression by the bending stiffness of the link.

For the second part of the analysis, a suitable mesh had to be developed in order to ensure accurate results during the stress analysis. The model was partly created in CadKey by drawing a mesh of half of a cross-section view of the flexible link through its center as shown in Figure 5.   The mesh was constructed from a series of four-sided figures whose ratio of dimensions did not exceed 6 to 1 at any point. It is ideal that the ratio remains as close to 1 to 1 as possible. Three-sided figures were not used but could have been, provided that they were as few as possible and not located near the edge of the model. The mesh used can be seen in both Figures 5 and 6 below. Figure 6 shows a close-up of the mesh on the tapered section while Figure 5, as previously mentioned, shows the full half cross-section mesh.

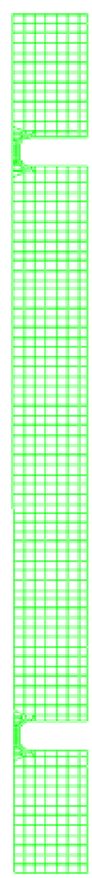

Figure 5: Meshed Half Cross-Section Drawing of a 1x Flexible Link

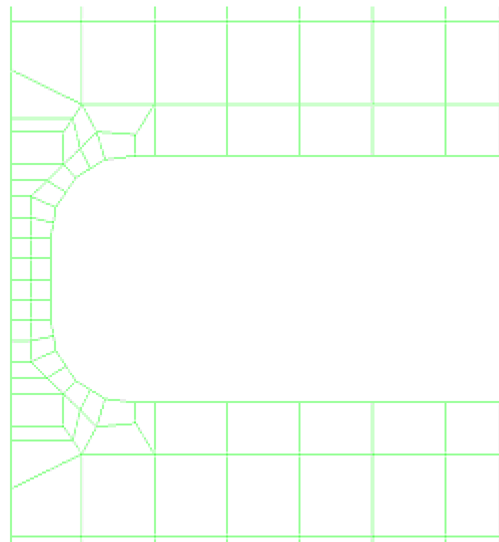

Figure 6: Close-up of Meshed Tapered Section on a 1x Flexible Link

Once this mesh model of the half cross-section was complete it was exported as an IGES file format (extension .igs) and then imported into Superdraw. In Superdraw the Quick RMS feature was used to make ten joined copies of the meshed section that were spaced 36 degrees apart rotated around the center of the flexible link. This model was then exported to FEMPRO so the stress analysis could be performed using brick elements on the model. Figure 7 shows the three-dimensional model with brick elements created in Superdraw and FEMPRO.

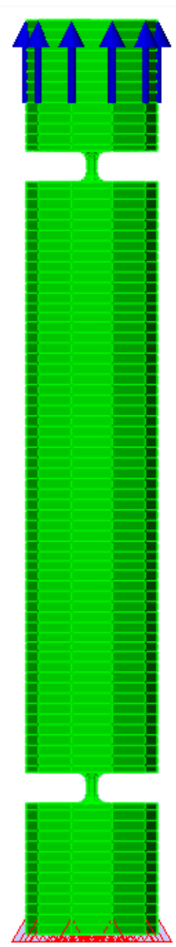

Figure 7: Three-Dimensional Brick Element Model of Flexible with Nodal Forces and Boundary Conditions

For the stress analysis it was also required to applied nodal forces and boundary conditions. As with the first part of the analysis, one end of the link was held fixed while the other was subjected to an applied load. It can be seen from Figure 7 above, that since the model is three-dimensional, the fixed boundary condition had to be applied to all nodes on one end and the 50-pound force that was to be used had to be divided among all nodes on the opposite end. In this particular case there were 71 nodes on each end, therefore a nodal force of 0.704225 pounds was applied to each of the nodes.

4.0 RESULTS

Consistent trends were observed in the stiffness ratio results (See Appendix A). There is a sharp increase in the stiffness ratio when moving from a 0x Flexible Link to a 1x. After this sharp increase, the results then continue to gradually increase from 1x to 6x until finally leveling out. For example, using the 3.5-inch long Flexible Link with 0.5-inch ends, the stiffness ratio starts at 29144 with the 0x link and then increases to 35226, 37617, 38757, 39329, 39598, and finally 39691 at the 6x link. Similar results are displayed in all other configurations.

It can also be seen that lowering the overall length of the link lowers the stiffness ratio. This is also the same behavior when the major diameters of the links are changed. Therefore, from the results it can be seen that both decreasing the diameter and length of the Flexible Link leads to a decrease in the stiffness ratio. This result also confirms the trend that develops when we look at both lengths of end segments. With the center length held constant, decreasing the length of the ends to 0.25 inches causes the stiffness ratio to drop since the overall length of the link is shortened by 0.5 inches.

Since we are looking for values of the stiffness ratio that are greater than 5000:1, the only category of results that does not qualify is the shortest link design tested. This was the 0x Flexible Link with 0.25-inch ends and an overall length of 1.41 inches. All stiffness ratios in this group were below the 5000:1 standard. In general, the shortest links (i.e. 0.25-inch ends with the lowest overall length) remained between a 5000:1 and a 6000:1 stiffness ratio. The highest of these ratios was calculated to be around 5700:1.

Looking at the second part of the analysis, we can see a similar behavior with the stresses as with the stiffness ratios. The main difference, however, is that the stresses remain at an overall stable level and do not fluctuate to any considerable degree. In the analysis, the maximum stresses calculated for the different designs were approximately 43500 psi. Since this result did not fluctuate more than around 300 to 400 psi, for the entire analysis it is reasonable to assume a max stress of 43500 psi for any design.

All analysis files are located in:

Knarr\CAD_User\Projects\891_AUV_Controlls – C Scout\M.Dawe\Flexible Link Analysis

5.0 CONCLUSION

The main purpose of this analysis was to determine the trends that occur when various aspects of the design of the Flexible Links are changes. The changed aspects in the design include the overall height, the length of the end segments, and the length of the tapered sections that varied directly according to the category of the links.

From the results we can conclude that a longer Flexible Link with a longer tapered section showed a larger stiffness ratio. However, this trend only continues up to a certain a level at which time the stiffness ratio remains pretty constantly around a single value. It is also possible to conclude that the stress experience by the various different designs does change any significant amount. Therefore, the stress can be omitted as a design factor for these Flexible Links and the dimensioning can be the focus of the design.

Appendix A:
Results

Link 0x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	2.34	1/2"	29144	103929	3.5661			43093
		7/16"	27692	98644	3.5622	1.01375E-05	0.280729	
		3/8"	25736	91469	3.5541	1.09327E-05	0.281368	
		5/16"	23093	81641	3.5353	1.22488E-05	0.282858	
		1/4"	19559	68149	3.4843	1.46737E-05	0.287002	43111
2.66	1.5	1/2"	16113	108717	6.7470	9.20E-06	0.148215	
		7/16"	15479	104339	6.7408	9.58413E-06	0.14835	
		3/8"	14601	98239	6.7282	1.01793E-05	0.148629	
		5/16"	13371	89570	6.6990	1.11644E-05	0.149277	
		1/4"	11640	77045	6.6191	1.29795E-05	0.151079	
1.91	0.75	1/2"	7614	113380	14.8910	8.819930E-06	0.0671547	
		7/16"	7393	110010	14.8800	9.090070E-06	0.0672045	
		3/8"	7080	105189	14.8574	9.506700E-06	0.0673067	
		5/16"	6624	98075	14.8051	1.019630E-05	0.0675441	
		1/4"	5948	87208	14.6621	1.146680E-05	0.0682032	

Link 0x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	2.34	1/2"	24505	106817	4.3589	9.36E-06	0.229414	43093
		7/16"	23429	102038	4.3553	9.80023E-06	0.229607	
		3/8"	21954	95453	4.3478	1.04764E-05	0.230004	
		5/16"	19915	86240	4.3304	1.15955E-05	0.230928	
		1/4"	17097	73223	4.2827	1.36570E-05	0.233497	
2.16	1.5	1/2"	12381	111979	9.0447	8.93E-06	0.110562	
		7/16"	11975	108237	9.0389	9.23900E-06	0.110633	
		3/8"	11403	102932	9.0271	9.71516E-06	0.110778	
		5/16"	10579	95208	8.9995	1.05033E-05	0.111117	
		1/4"	9373	83645	8.9240	1.19553E-05	0.112058	
1.41	0.75	1/2"	4838	116717	24.1273	8.567740E-06	0.0414469	
		7/16"	4733	114146	24.1159	8.760700E-06	0.0414664	
		3/8"	4582	110396	24.0928	9.058300E-06	0.0415061	
		5/16"	4355	104703	24.0395	9.550850E-06	0.0415982	
		1/4"	4002	95617	23.8930	1.045840E-05	0.0418532	

Link 1x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	2.26	1/2"	35226	63023	1.7891	1.59E-05	0.558937	43341
		7/16"	34162	61086	1.7881	1.63704E-05	0.55924	43344
		3/8"	32652	58321	1.7862	1.71465E-05	0.559862	
		5/16"	30455	54256	1.7815	1.84311E-05	0.561313	
		1/4"	27183	48082	1.7688	2.07980E-05	0.56535	
2.66	1.42	1/2"	19006	63672	3.3501	1.57E-05	0.298503	43345
		7/16"	18573	62193	3.3486	1.60790E-05	0.298636	
		3/8"	17947	60042	3.3455	1.66551E-05	0.298909	
		5/16"	17011	56790	3.3384	1.76087E-05	0.299546	
		1/4"	15559	51638	3.3188	1.93657E-05	0.301316	
1.91	0.67	1/2"	8850	66378	7.5007	1.506520E-05	0.133321	
		7/16"	8704	65261	7.4980	1.532300E-05	0.133369	
		3/8"	8490	63611	7.4925	1.572060E-05	0.133467	
		5/16"	8163	61055	7.4797	1.637860E-05	0.133695	
		1/4"	7636	56847	7.4445	1.759110E-05	0.134328	

Link 1x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	2.26	1/2"	29296	64041	2.1860	1.56E-05	0.457461	
		7/16"	28530	62340	2.1851	1.60410E-05	0.457648	
		3/8"	27430	59887	2.1833	1.66981E-05	0.458031	
		5/16"	25803	56225	2.1790	1.77857E-05	0.458923	
		1/4"	23316	50532	2.1673	1.97895E-05	0.461405	
2.16	1.42	1/2"	14451	65827	4.5551	1.52E-05	0.219536	
		7/16"	14179	64567	4.5537	1.54877E-05	0.219604	
		3/8"	13781	62716	4.5508	1.59448E-05	0.219743	
		5/16"	13177	59876	4.5441	1.67013E-05	0.220067	
		1/4"	12211	55263	4.5256	1.80953E-05	0.220967	
1.41	0.67	1/2"	5505	67508	12.2642	1.481300E-05	0.0815382	
		7/16"	5439	66695	12.2614	1.499360E-05	0.0815565	
		3/8"	5343	65479	12.2558	1.527210E-05	0.0815938	
		5/16"	5192	63560	12.2429	1.573320E-05	0.0816803	
		1/4"	4940	60304	12.2071	1.658260E-05	0.0819198	

Link 2x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	2.18	1/2"	37617	45191	1.2013	2.21E-05	0.8324	43438
		7/16"	36814	44211	1.2009	2.26190E-05	0.832695	
		3/8"	35648	42779	1.2000	2.33761E-05	0.833301	
		5/16"	33891	40602	1.1980	2.46292E-05	0.834714	
		1/4"	31132	37122	1.1924	2.69380E-05	0.838646	
2.66	1.34	1/2"	20180	46074	2.2831	2.17E-05	0.437999	
		7/16"	19856	45319	2.2824	2.20657E-05	0.438126	
		3/8"	19378	44203	2.2811	2.26228E-05	0.438388	
		5/16"	18645	42472	2.2779	2.35448E-05	0.438995	
		1/4"	17457	39614	2.2692	2.52438E-05	0.440686	
1.91	0.59	1/2"	9411	47560	5.0535	2.102620E-05	0.197881	
		7/16"	9175	46357	5.0524	2.157160E-05	0.197927	
		3/8"	9021	45558	5.0500	2.195020E-05	0.198021	
		5/16"	8781	44293	5.0444	2.257670E-05	0.19824	
		1/4"	8379	42139	5.0289	2.373110E-05	0.198849	

Link 2x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	2.18	1/2"	31072	45712	1.4712	2.19E-05	0.679734	
		7/16"	30504	44864	1.4708	2.22896E-05	0.679914	
		3/8"	29671	43615	1.4700	2.29277E-05	0.680284	
		5/16"	28400	41695	1.4681	2.39837E-05	0.681146	
		1/4"	26362	38566	1.4630	2.59295E-05	0.683542	
2.16	1.34	1/2"	15142	46615	3.0785	2.15E-05	0.324829	
		7/16"	14947	46006	3.0779	2.17363E-05	0.324894	
		3/8"	14658	45097	3.0767	2.21744E-05	0.325027	
		5/16"	14207	43669	3.0737	2.28994E-05	0.325336	
		1/4"	13460	41262	3.0656	2.42353E-05	0.326196	
1.41	0.59	1/2"	5692	47452	8.3365	2.107400E-05	0.119955	
		7/16"	5648	47076	8.3353	2.124220E-05	0.119972	
		3/8"	5581	46508	8.3328	2.150170E-05	0.120007	
		5/16"	5476	45597	8.3272	2.193120E-05	0.120088	
		1/4"	5295	44009	8.3117	2.272260E-05	0.120313	

Link 3x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	2.1	1/2"	38757	35225	0.9089	2.84E-05	1.10027	43442
		7/16"	38124	34641	0.9086	2.88677E-05	1.10055	
		3/8"	37194	33777	0.9081	2.96057E-05	1.10114	
		5/16"	35765	32439	0.9070	3.08272E-05	1.10252	
		1/4"	33447	30232	0.9039	3.30780E-05	1.10635	43443
2.66	1.26	1/2"	20660	35758	1.7308	2.80E-05	0.57777	
		7/16"	20410	35318	1.7304	2.83143E-05	0.577893	
		3/8"	20038	34659	1.7297	2.88524E-05	0.578146	
		5/16"	19458	33621	1.7279	2.97429E-05	0.578735	
		1/4"	18493	31864	1.7230	3.13838E-05	0.580371	
1.91	0.51	1/2"	9456	36249	3.8336	2.758720E-05	0.260852	
		7/16"	9378	35945	3.8329	2.782030E-05	0.260896	
		3/8"	9261	35486	3.8316	2.817980E-05	0.260986	
		5/16"	9077	34753	3.8285	2.877480E-05	0.261197	
		1/4"	8764	33477	3.8200	2.987110E-05	0.261781	

Link 3x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	2.1	1/2"	31859	35541	1.1156	2.81E-05	0.89641	
		7/16"	31417	35041	1.1153	2.85383E-05	0.896583	
		3/8"	30762	34297	1.1149	2.91573E-05	0.89694	
		5/16"	29745	33133	1.1139	3.01818E-05	0.897772	
		1/4"	28067	31182	1.1110	3.20695E-05	0.900086	
2.16	1.26	1/2"	15395	36084	2.3439	2.77E-05	0.426642	
		7/16"	15248	35734	2.3435	2.79849E-05	0.426704	
		3/8"	15027	35206	2.3428	2.84040E-05	0.426831	
		5/16"	14679	34367	2.3412	2.90975E-05	0.427126	
		1/4"	14089	32921	2.3367	3.03753E-05	0.427947	
1.41	0.51	1/2"	5736	36583	6.3782	2.733500E-05	0.156783	
		7/16"	5704	36376	6.3776	2.749090E-05	0.156799	
		3/8"	5655	36060	6.3763	2.773130E-05	0.156831	
		5/16"	5578	35550	6.3732	2.812930E-05	0.156908	
		1/4"	5444	34647	6.3646	2.886260E-05	0.157118	

Link 4x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	2.02	1/2"	39329	28860	0.7338	3.47E-05	1.36274	
		7/16"	38814	28477	0.7337	3.51163E-05	1.36302	
		3/8"	38052	27905	0.7334	3.58353E-05	1.36359	
		5/16"	36865	27009	0.7326	3.70253E-05	1.36493	
		1/4"	34899	25499	0.7306	3.92179E-05	1.36866	
2.66	1.18	1/2"	20869	29217	1.4000	3.42E-05	0.714263	
		7/16"	20689	28960	1.3998	3.45300E-05	0.714382	
		3/8"	20370	28505	1.3993	3.50820E-05	0.714627	
		5/16"	19899	27823	1.3982	3.59410E-05	0.715196	
		1/4"	19102	26650	1.3951	3.75237E-05	0.716781	
1.91	0.43	1/2"	9534	29570	3.1014	3.381820E-05	0.322434	
		7/16"	9465	29352	3.1010	3.406890E-05	0.322477	
		3/8"	9374	29062	3.1002	3.440940E-05	0.322564	
		5/16"	9229	28594	3.0982	3.497280E-05	0.322765	
		1/4"	8979	27769	3.0929	3.601110E-05	0.323326	

Link 4x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	2.02	1/2"	32202	29072	0.9028	3.44E-05	1.10769	
		7/16"	31847	28746	0.9026	3.47869E-05	1.10786	
		3/8"	31317	28259	0.9024	3.53869E-05	1.1082	
		5/16"	30484	27488	0.9017	3.63799E-05	1.10901	
		1/4"	29083	26172	0.8999	3.82095E-05	1.11124	
2.16	1.18	1/2"	15458	29434	1.9041	3.40E-05	0.525177	
		7/16"	15343	29211	1.9039	3.42336E-05	0.525236	
		3/8"	15169	28874	1.9035	3.46336E-05	0.525357	
		5/16"	14892	28332	1.9024	3.52956E-05	0.525639	
		1/4"	14416	27386	1.8996	3.65153E-05	0.526422	
1.41	0.43	1/2"	5722	29765	5.2023	3.359600E-05	0.192222	
		7/16"	5698	29639	5.2019	3.373950E-05	0.192237	
		3/8"	5661	29446	5.2011	3.396090E-05	0.192268	
		5/16"	5603	29132	5.1992	3.432700E-05	0.192339	
		1/4"	5501	28569	5.1938	3.500260E-05	0.192536	

Link 5x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	1.94	1/2"	39598	24443	0.6173	4.09E-05	1.62001	
		7/16"	39170	24175	0.6172	4.13650E-05	1.62028	
		3/8"	38532	23773	0.6170	4.20649E-05	1.62084	
		5/16"	37529	23136	0.6165	4.32234E-05	1.62215	
		1/4"	35843	22047	0.6151	4.53579E-05	1.62578	
2.66	1.1	1/2"	20937	24699	1.1797	4.05E-05	0.847679	
		7/16"	20773	24503	1.1795	4.08116E-05	0.847794	
		3/8"	20528	24206	1.1792	4.13116E-05	0.848031	
		5/16"	20138	23731	1.1784	4.21391E-05	0.848582	
		1/4"	19470	22902	1.1763	4.36637E-05	0.850115	
1.91	0.35	1/2"	9545	24932	2.6121	4.010920E-05	0.382831	
		7/16"	9496	24803	2.6118	4.031750E-05	0.382872	
		3/8"	9423	24607	2.6113	4.063900E-05	0.382955	
		5/16"	9306	24289	2.6100	4.117090E-05	0.383148	
		1/4"	9103	23724	2.6063	4.215110E-05	0.383685	

Link 5x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	1.94	1/2"	32312	24595	0.7612	4.07E-05	1.31378	
		7/16"	32020	24369	0.7611	4.10356E-05	1.31394	
		3/8"	31581	24029	0.7609	4.16165E-05	1.31427	
		5/16"	30886	23486	0.7604	4.25780E-05	1.31505	
		1/4"	29700	22548	0.7592	4.43495E-05	1.3172	
2.16	1.1	1/2"	15425	24854	1.6113	4.02E-05	0.620635	
		7/16"	15332	24702	1.6111	4.04822E-05	0.620692	
		3/8"	15192	24472	1.6108	4.08632E-05	0.620807	
		5/16"	14968	24100	1.6101	4.14936E-05	0.621076	
		1/4"	14578	23444	1.6082	4.26553E-05	0.621822	
1.41	0.35	1/2"	5682	25090	4.4155	3.985700E-05	0.226476	
		7/16"	5664	25007	4.4152	3.998820E-05	0.22649	
		3/8"	5636	24882	4.4147	4.019050E-05	0.226518	
		5/16"	5591	24676	4.4134	4.052550E-05	0.226584	
		1/4"	5512	24306	4.4098	4.114260E-05	0.226768	

Link 6x Analysis

1/2" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3.5	1.86	1/2"	39691	21199	0.5341	4.72E-05	1.8723	43442
		7/16"	39328	21002	0.5340	4.76136E-05	1.87256	
		3/8"	38785	20706	0.5339	4.82945E-05	1.87311	
		5/16"	37926	20234	0.5335	4.94215E-05	1.87438	
		1/4"	36466	19418	0.5325	5.14979E-05	1.87791	
2.66	1.02	1/2"	20925	21391	1.0223	4.67E-05	0.97822	
		7/16"	20789	21249	1.0221	4.70603E-05	0.978332	
		3/8"	20583	21034	1.0219	4.75412E-05	0.978561	
		5/16"	20256	20688	1.0214	4.83371E-05	0.979094	
		1/4"	19689	20079	1.0198	4.98037E-05	0.980577	
1.91	0.27	1/2"	9537	21566	2.2612	4.637010E-05	0.442243	
		7/16"	9498	21475	2.2610	4.656620E-05	0.442282	
		3/8"	9438	21336	2.2606	4.686860E-05	0.442361	
		5/16"	9343	21111	2.2596	4.736900E-05	0.442547	
		1/4"	9175	20708	2.2570	4.829110E-05	0.443061	

Link 6x Analysis

1/4" ends

Overall Length (in.)	Center Length (in.)	Diameter	Stiffness Ratio	Kcomp	Kdefl	Compression	Deflection	Max Stress
3	1.86	1/2"	32286	21313	0.6601	4.69E-05	1.51487	
		7/16"	32041	21149	0.6601	4.72842E-05	1.51503	
		3/8"	31671	20900	0.6599	4.78461E-05	1.51535	
		5/16"	31083	20502	0.6596	4.87760E-05	1.51609	
		1/4"	30069	19806	0.6587	5.04895E-05	1.51817	
2.16	1.02	1/2"	15339	21507	1.4021	4.65E-05	0.713219	
		7/16"	15263	21399	1.4020	4.67309E-05	0.713273	
		3/8"	15148	21235	1.4018	4.70928E-05	0.713382	
		5/16"	14964	20968	1.4013	4.76917E-05	0.713638	
		1/4"	14640	20494	1.3999	4.87953E-05	0.714349	
1.41	0.27	1/2"	5632	21684	3.8499	4.611800E-05	0.259744	
		7/16"	5618	21628	3.8498	4.623680E-05	0.259757	
		3/8"	5596	21542	3.8494	4.642010E-05	0.259784	
		5/16"	5561	21402	3.8484	4.672360E-05	0.259846	
		1/4"	5499	21149	3.8459	4.728260E-05	0.260017	