TESTS OF SMALL LAMINATED & SOLID SPRUCE BEAMS FOR AEROPLANES

BY

SYDNEY V. JAMES

ARMOUR INSTITUTE OF TECHNOLOGY

1911

T
691.1
J 23

Illinois Institute
of Technology
Libraries

AT 227
James, Sydney V.
Comparative tests of small
 laminated and solid spruce

COMPARATIVE TESTS OF SMALL LAMINATED AND SOLID SPRUCE BEAMS FOR AEROPLANE CONSTRUCTION

A THESIS

PRESENTBD BY

SYDNEY V. JAMES

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

MECHANICAL ENGINEER

HAVING FULFILLED THE REQUIRED CONDITIONS
PREPARATORY TO MAKING SUCH PRESENTATION

May 4, 1911.

Sydney V. James.

ILLINOIS INSTITUTE OF TECHNOLOGY
PAUL V. GALVIN LIBRARY
35 WEST 33RD STREET
CHICAGO, IL 60616

O.K.
G.F. Gebhardt 5/17/11
H.M. Raymond
L.C. Monin.

969
J23

Contents.

-----0------

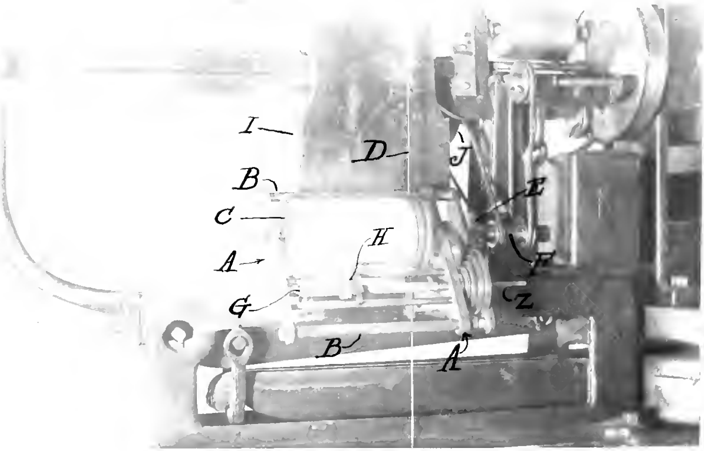

Fig. 1.

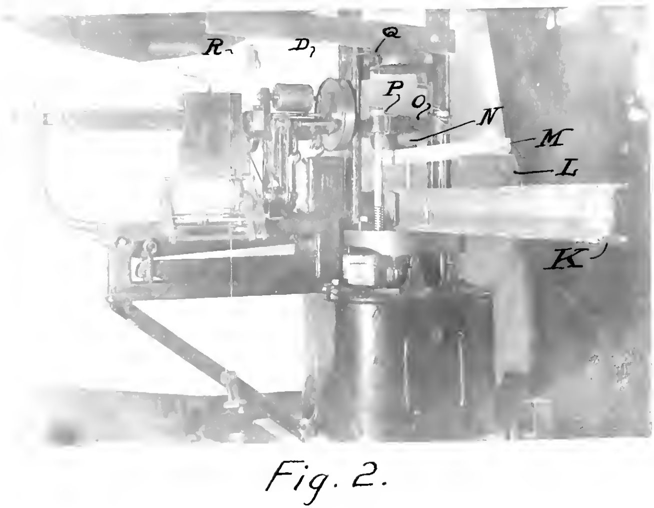

Fig. 2.

COMPARATIVE TESTS OF SMALL LAMINATED AND SOLID SPRUCE BEAMS FOR AEROPLANE CONSTRUCTION.

OBJECT- In taking up the investigation of the above, the object in view was to make a series of tests of small wooden beams, both laminated and solid, to determine a working value for the strength of the spruce in small sizes, and also to determine what, if any, advantage there is in making such beams of laminated construction. By "laminated beam" is meant in this case a beam built up of horizontal layers of wood glued together to form a unit or single beam.

As to the working strength of spruce such as is used in aeroplane construction, very little reliable data is available, especially so with regard to the transverse strength. Most of the tests made to determine such figures have been made with specimens of large size, suitable for use in ordinary building construction, hence such specimens contain knots, shakes, and other defects such as occur in the ordinary run of lumber. The aeroplane is such a highly specialized structure, one in which unnecessary weight and size of parts must be reduced to a minimum, that the low allowable strength such as determined by these tests on large specimens gives too much weight. As the beams used in an aeroplane are all of small section, and therefore perfect wood may be selected for them, the strength of the small

specimens must be determined in order to be able to get the benefit of the full strength of the material. This is the main reason for undertaking tests on small specimens.

Another phase of the design of aeroplanes has been the use of a laminated construction for these parts, especially in the places where a curved beam is to be used. In this manner a curved beam may be bent in a form and the laminations glued up while in the form, thus preserving the required curve after the drying of the glue. This method makes a remarkably stiff beam, and one which is readily built. Beams built in this way are used for such parts as the ribs for the aeroplane carrying surfaces, the skids which rub on the ground upon landing, the laminated propellers, and even the long members of the main girder-like frame-work.

The writer has thought it would be of value to determine whether or not such laminated beams are stiffer, i.e., have a smaller deflection for a given load than a beam made of single piece of wood of the same size.

APPARATUS - A schedule of the tests was laid out and it was soon seen that a large number of beams would have to be tested in order to get representative results. This caused the writer to devise an instrument for autographically recording the results of the tests and its use involved a great saving both of time and labor as well as insuring a uniformity of reliability for the results. The instrument was attached to the 10,000 pound Olsen Wire-Testing Machine in the Mechanical Laboratory of the Armour Institute of

Technology and is shown in the photograph, Fig. 1.

It consists of a pair of bracket plates A,A with connecting rods B,B attached by tap screws to the bed of the testing machine. This frame carries a wooden drum "C", 3 inches in diameter, mounted on conical pivots and capable of receiving a recording paper by means of a brass clip. This drum has a recess turned in its surface at one end to take a cord "D" which communicates a motion of rotation to the drum. At one end of the frame of the instrument is a set of stepped change gears. The upper set "E" receives motion from a gear mounted on the countershaft "F" of the testing machine and transmits its motion to the lower set mounted on the axis of the screw "G". The latter carries a block and pencil "H" so that as the screw turns it carries the pencil along parallel to its axis. The motion of the pencil, it will be seen, is directly proportional to the rate of application of the load on the specimen, since running out the counterpoise "I" on the beam arm also runs the pencil along the screw. This motion is obtained from the handwheel "J" which runs the counterweight.

The deflection of the specimen is communicated to the drum cord "D" by pulleys, hence the rotation of the drum is proportional to the deflection. Therefore, the diagram drawn by the pencil on the drum will be a "stress-strain" diagram if the counterpoise is carefully managed, so as to keep the beam balanced at all times.

Fig. 2 shows the general arrangement of the

apparatus. A steel I-beam "K" was laid on the platform of the testing machine and a pair of the supports (one of which is seen at "L") were spaced 36 inches apart on the beam, 18 inches each side of the center. The specimen to be tested "M" was laid upon the knife-edges and a cast iron block "N" placed under the draw-head "O" of the testing machine to apply the load to the specimen. This block was in the form of a half cylinder, the flat side of which rested against the draw-head and its axis was at right angles to the center line of the test beam.

The drum cord "D" was attached to the draw-head at "P" and passed over a pulley "Q" to the enlarging motion pulley "R". This multiplied the deflection about two and one half times, thus giving a large rotation of the drum and consequently a longer diagram.

The load was applied by hand and the draw-head moved down at a uniform rate determined by giving the hand crank which operated it one revolution per second as indicated by a metronome.

All beams were tested with a span of 36 inches and the test continued until the specimen failed. The diagrams given by the recording instrument were measured and having previously determined the exact values of one inch of ordinate and abscissa the results were converted into their proper values. The change gears of the instrument were used to give a higher load ordinate on the diagram for the smaller sizes of beam. Each gear change was effected by the sliding key pin "Z" shown in Fig. 1 at the lower set of gears on the

instrument. Each set of gears was calibrated and its constant determined.

SCHEDULE OF TEST BEAMS -

The specimens were grouped as indicated below. The dimensions here given are nominal. Exact sizes are given later.

Series "A" all beams 2" deep X $1\frac{3}{8}$" wide.

1. $\frac{1}{2}$" laminations -
   3 beams - a, b, c.
2. $\frac{1}{4}$" laminations -
   3 beams - a, b, c.
3. solid beams
   3 beams - a, b, c.

Series "B" all beams have $\frac{1}{4}$" laminations and are $1\frac{3}{8}$" wide.

1. 3 laminations - 3 beams a, b, c.
2. 5 " - 3 " a, b, c.
3. 7 " - 3 " a, b, c.
4. solid - $\frac{3}{4}$" deep - equivalent to 3-$\frac{1}{4}$" laminations.
   2 beams - a, b.
5. solid - $1\frac{1}{4}$" deep - equivalent to 5-$\frac{1}{4}$" laminations.
   3 beams a, b, c.
6. solid - $1\frac{3}{4}$" deep - equivalent to 7 - $\frac{1}{4}$" laminations.
   3 beams a, b, c.

Series "C" all beams $1\frac{1}{2}$" deep.

I. Beams having 3 - $\frac{1}{2}$" laminations.
   1. $1\frac{1}{2}$" wide, 3 beams - a, b, c.
   2. 2" wide, 3 " - a, b, c.
   3. $2\frac{1}{2}$" wide, 3 " - a, b, c.

II. Beams having 6 - $\frac{1}{4}$" laminations.

1. $1\frac{1}{2}$" wide, 3 beams - a, b, c.
2. 2" wide, 3 " - a, b, c.
3. $2\frac{1}{2}$" wide, 2 " - a, b.

III. Beams of solid section.

1. $1\frac{1}{2}$" wide, 3 beams - a, b, c.
2. 2" wide, 3 " - a, b, c.
3. $2\frac{1}{2}$" wide, 3 " - a, b, c.

CALCULATIONS - Calculations are all based on the two principle formulae in the mechanics of a rectangular solid section beam supported at the ends and loaded in the middle by a single force. These are - (1) Formula for bending moment,

(2) Formula for deflection

$$(1) \quad R\frac{I}{e} = \frac{Pl}{4}$$

where "R" is the stress in pounds per sq. in. at the outer fibre;"I"is the moment of inertia of the section; "e" is the distance from the neutral axis to the outer fibre in inches; "P" is the load in pounds; "l" is the span or distance between knife-edges in inches.

$$(2) \quad d = \frac{Pl^3}{48EI}$$

where "d" is the deflection of center in inches; "P" is same as above; "E" is the modulus of elasticity in pounds per square inch; and "I" and "l" are the same as above.

Sample diagrams drawn by the "stress-strainograph" are included with the data on p. 16 and the system of numbering such as "Bla" means Series "B", sub-heading 1, specimen a. Measurements of the ordinate and abscissa at the

elastic limit and at the maximum were made as indicated and averaged for the three beams of approximately the same dimensions in each group. Moments of inertia were calculated and averaged, and the value of "R" in Formula (1) was calculated both for the elastic limit and for the maximum condition.

Solving Formula (2) for "E" we have

$$E = \frac{Pl^3}{48dI}$$

All the items on the right hand side are known for the elastic limit and the value for "E" was calculated in each case for the average P, d, I in the groups of a, b, c beams, Page 15 shows the results of the average calculations both for the fibre stress at elastic limit and the fibre stress at the maximum (Modulus of Rupture) as well as the Modulus of Elasticity.

On pages 16 - 18 are shown a few sample records as made by the recording instrument. These show the nature of the work done by this instrument as well as the way in which measurements of the loads and deflections were taken. An average line was drawn smoothing out irregularities and the measurements taken from this line. The irregularities in the line as drawn by the instrument are due to the lack of sensitiveness on the part of the operator in keeping the beam of the machine exactly balanced. If care is taken, however, during this operation, the average line drawn through this diagram should be closely representative of the condition during the test.

CALIBRATION DATA -

With gear No.1 - 1" of ordinate = 162.4 lbs.

" " " 2 - 1" " " = 304.0 lbs.

" " " 3 - 1" " " = 540.0 lbs.

Diam. large Pulley on Enlarging gear = 3.313"

" small " " "" " = 1.375"

" cord " " " = 0.0625"

Radius to center of cord - large pulley =

$$3.313 + \frac{0.0625}{2} = 3.344"$$

Radius to center of cord - small pulley =

$$1.375 + \frac{0.0625}{2} = 1.407"$$

Ratio of Enlargement for drum motion =

$$\frac{3.344}{1.407} = 2.375$$

Hence 1" abscissa on diagram = $\frac{1}{2.375}$ = 0.421"

actual deflection of test specimen. 1" abscissa also represents 41.6 seconds of time of application of the load.

DISCUSSION OF RESULTS - It will be best to first consider the results obtained in these tests in comparison with those obtained by tests of full size specimens. Lanza in his "Applied Mechanics" beginning at p. 677 gives a long series of tests on large beams having spans of from 10 to 30 feet and having a cross-sectional areas of from 20 to 70 or more square inches. He recommends from these tests that with the usual run of lumber from any one yard a modulus of rupture of 3000 pounds per square inch is all that may safely be allowed; with selected lumber from any one yard, 4000 pounds

per square inch; with carefully selected lumber from several yards only retaining the best, 5000 pounds per square inch. The value of the modulus of elasticity was about 1,330,000. These figures on the usual building lumber are much lower than can be used for aeroplane designing for the results obtained in the writer's tests show an average of about 11,250 pounds per square inch for the modulus of rupture and 1,703,000 for the modulus of elasticity.

The figures taken at the elastic limit show an average of 8450 for the modulus of rupture and even this is twice as high as that used in ordinary building construction. Using a factor of safety of 4 the outside fibre stress could be allowed as high as 2120 pounds per square inch.

As to the time of application of the load, it is known that for a structure which is loaded continuously a low value of modulus of elasticity should be used. Lanza recommends that a value of about one half of that obtained by short time tests is all that can safely be used. The usual loading of aeroplane framing is light, and the heavy loads come on suddenly for a short time, therefore it would seem that the maximum value can be used - or in other words, that obtained by short time tests.

The results obtained for comparison of laminated and solid beams show no great advantage in favor of the laminated construction as far as increased stiffness is

concerned. In fact for beams having a depth much greater than the width, the modulus of elasticity was less, indicating that solid beams are stiffer than laminated ones, with this relation of depth to width. This is illustrated by Series "A" of the present tests.

The results of this series also indicate that a large number of laminations is better than a small number. Beams in A2 showed a modulus of elasticity 10 percent higher than those in A1. This effect resulted from the larger number of laminations in the case of the beams in A2. It was shown by some tests not recorded here, that if the number of laminations was increased to 16 in beams of the same size as those used in Series "A", that the longitudinal shear in the glued joints caused failure before the full strength of the wood could be developed.

Series "B" showed that beams having a width greater than the depth were stiffer in the laminated construction than solid. The remarkably high modulus of elasticity of the laminated beams indicates this clearly. This series further indicates an increase in modulus of elasticity of about 10 percent due to doubling the depth of the beam by adding laminations of the same thickness. The laminated beams in this series average about 35 to 40 percent stiffer than the solid ones, but this may have been due to exceptionally good quality of wood in the laminated ones. No indications upon examination of the beams were present to show this, however. The modulus of rupture was slightly better for the laminated beams of this series than for the solid

ones.

Series "C" indicates nothing remarkable in favor of either the solid or the laminated beams.

To sum up the above it might be stated that on the whole, a straight laminated beam is not a decided improvement over the solid one of the same dimensions from the point of view of strength or stiffness. At least such is the result of the present tests. A large number of tests are required in an investigation of this kind and it may be that on account of the variability of wood representative figures can not be obtained on as few tests as the writer has carried out. But in view of the fact that the aeroplane frame is made only of the best grades of wood, it may safely be designed on some such basis as the above results would indicate. The full strength of the lumber in small perfect specimens is the correct basis to use in such cases and it seems that the tests here described have shown that a modulus of rupture of 11,350 pounds per square inch, and a modulus of elasticity of 1,703,000 pounds per square inch, may be considered as ultimate maximum values. The factor of safety, whatever it may be taken, will divide these figures to obtain the working values not to be exceeded.

---------------o---------------

Mark on Beam	Gear No.	Width, b (inches)	Depth, h (inches)	Deflections, inches E. L. Ind.	Deflections, inches E. L. Actual	Deflections, inches Max. Ind.	Deflections, inches Max. Actual	Values of P {inches / pounds} E. L. Ind. (inches)	Values of P E. L. Actual (pounds)	Values of P Max. Ind. (inches)	Values of P Max. Actual (pounds)	Time of Test, sec.	Remarks.
A1a	3	$1\frac{3}{8}$	$1\frac{15}{16}$	1.37	0.577	3.14	1.32	1.47	794	2.37	1280	130.5	Failed by tension – outer fibre
A1b	3	"	$1\frac{7}{8}$	0.93	0.391	2.3	0.968	1.92	497	1.5	810	95.6	" " " – " "
A1c	3	"	$1\frac{15}{16}$	1.18	0.497	2.14	0.901	0.74	400	1.02	551	89.0	" " " – " "
A2a	3	"	2	1.2	0.505	2.92	1.23	1.2	648	2.03	1096	121.5	" " crushing
A2b	3	"	2	1.1	0.463	2.76	1.16	1.18	637	1.98	1070	115	" " long. shear lower lam.
A2c	3	"	2	0.8	0.337	1.78	0.749	1.06	573	1.60	865	74	" " comp. & tension.
A3a	3	"	2	1.03	0.434	2.58	1.085	1.32	713	2.02	1090	107.3	" " " " " .
A3b	3	"	$1\frac{7}{8}$	1.18	0.497	2.59	1.05	1.3	702	1.96	1059	107.8	" " " " " .
A3c	3	"	$1\frac{15}{16}$	1.18	0.497	2.8	1.18	1.42	767	2.13	1150	116.5	" " " " " .
B1a	1	"	$\frac{3}{4}$	2.5	1.053	3.6	1.515	0.67	109	0.85	138	150	" " " " " .
B1b	1	"	"	3.19	1.34	4.98	2.10	1.04	169	1.27	206	207	" " " " " .
B1c	1	"	"	4.03	1.7	6.24	2.62	1.03	168	1.25	203	260	" " " " " .
B2a	1	$1\frac{5}{16}$	$1\frac{1}{4}$	1.23	0.518	3.48	1.465	1.83	297	3.16	514	145	" " " " " .
B2b	1	$1\frac{1}{4}$	$1\frac{1}{4}$	1.1	0.463	2.52	1.06	1.9	309	3.03	492	105	" " " " " .
B2c	1	$1\frac{3}{8}$	$1\frac{1}{4}$	2.0	0.843	3.69	1.65	2.3	373	3.1	504	153.5	" " tension.
B3a	2	$1\frac{9}{32}$	$1\frac{25}{32}$	0.43	0.181	2.5	1.05	1.12	319	2.83	860	104	" " "
B3b	2	$1\frac{5}{16}$	$1\frac{13}{16}$	0.42	0.177	0.88	0.37	1.4	426	2.17	660	37	" " "
B3c	2	"	$1\frac{3}{4}$	1.5	0.632	2.8	1.18	2.4	730	3.3	1003	116.5	" " shear – long. next to bot. lam.
B4a	1	$1\frac{5}{16}$	$\frac{3}{4}$	3.11	1.31	3.69	1.55	0.76	123	0.85	138	154	" " tension & compression
B4b	1	"	"	3.8	1.60	6.11	2.57	0.85	138	1.1	179	255	" " " " "
B5a	2	$1\frac{3}{8}$	$1\frac{1}{4}$	2.0	0.842	3.08	1.296	1.28	389	1.65	502	128	" " " " "
B5b	2	"	"	–	–	–	–	–	–	–	–	—	" " tension, bad grain.

Mark on Beam	Gear No	Width, b (inches)	Depth, h (inches)	Deflections, inches: E. L. Ind.	Deflections, inches: E. L. Actual	Deflections, inches: Max. Ind.	Deflections, inches: Max. Actual	Values of P {inches, pounds: E. L. Ind. inches	Values of P: E. L. Actual pounds	Values of P: Max. Ind. inches	Values of P: Max. Actual pounds	Time of Test, sec.	Remarks.
B5c	2	1 3/8	1 1/4	2.41	1.015	3.23	1.36	1.0	304	1.22	371	134	Failed by tension.
B6a	2	1 3/8	1 11/16	1.92	0.808	3.12	1.324	1.77	538	2.24	681	130	" " " & comp
B6b	1	"	1 3/8	1.78	0.749	3.62	1.525	3.24	526	4.43	720	150.5	" " " " "
B6c	1	"	"	1.56	0.657	2.13	0.897	2.75	446	3.38	550	89.7	" " " " "
CI1a	2	"	1 1/2	1.75	0.737	2.92	1.296	1.37	417	1.92	584	121.5	" " " " "
CI1b	2	"	"	1.37	0.577	2.22	0.935	1.12	341	1.65	502	92.5	" " " " "
CI1c	2	"	"	1.40	0.589	3.02	1.27	1.39	423	2.0	608	125	" " " " "
CI2a	2	2 7/8	1 7/16	2.33	0.980	3.40	1.43	1.8	548	2.31	704	142	" " " " "
CI2b	2	"	"	1.46	0.615	3.22	1.36	1.53	466	2.42	736	134	" " sudden break
CI2c	2	"	"	1.73	0.728	3.41	1.44	1.75	532	2.9	882	142	" " tension.
CI3a	2	2 3/8	1 3/8	2.04	0.859	3.56	1.50	1.7	517	2.41	704	148	" " sudden break
CI3b	2	"	1 3/8	1.36	0.572	2.04	0.86	1.23	374	1.48	450	85	" " " " bottom
CI3c	2	2 5/16	1 7/16	1.8	0.758	2.68	1.13	1.8	548	2.33	708	112	" " " complete break
CII1a	2	1 3/8	1 9/16	1.38	0.581	3.0	1.26	1.56	474	2.15	654	125	" " tension
CII1b	2	"	1 7/16	1.57	0.661	3.53	1.49	1.27	386	1.82	553	147	" " sudden tension break
CII1c	2	"	1 3/8	1.5	0.632	3.16	1.33	1.25	380	1.72	523	132	" " " " "
CII2a	2	1 7/8	1 3/8	1.76	0.731	3.48	1.47	2.06	626	2.82	858	145	" " tension
CII2b	2	"	"	1.46	0.665	2.48	1.003	1.58	389	2.28	693	103	" " "
CII2c	2	"	"	1.65	0.695	2.87	1.21	1.9	578	2.50	760	119	" " "
CII3a	2	2 5/16	1 7/16	1.84	0.774	3.08	1.296	2.14	651	3.02	918	126	" " "
CII3b	2	"	1 5/16	1.55	0.653	2.4	1.010	1.82	550	2.45	745	100	" " "

Mark on Beam.	Gear No.	Width, b (inches)	Depth, h (inches)	Deflections, inches				Values of P, {inches / pounds}				Time of Test, sec	Remarks.
				E. L.		Max.		E. L.		Max			
				Ind.	Actual	Ind.	Actual	Ind. inches	Actual pounds	Ind. inches	Actual pounds		
CIII 1 a	2	$1\frac{1}{2}$	$1\frac{3}{8}$	1.95	0.821	4.17	1.760	1.82	554	2.7	821	174	Failed by tension & comp.
CIII 1 b	2	"	"	1.88	0.791	3.34	1.406	1.48	450	2.02	615	139	" " tension & 2 comp.
CIII 1 c	2	"	"	1.81	0.762	3.08	1.296	1.28	389	1.77	538	128	" " " & 1 comp.
CIII 2 a	2	$1\frac{7}{8}$	"	1.61	0.677	3.15	1.325	1.85	563	2.53	770	131	" " " .
CIII 2 b	2	$1\frac{15}{16}$	"	1.42	0.597	3.51	1.477	1.68	511	2.63	800	146	" " " .
CIII 2 c	2	"	"	1.45	0.610	3.60	1.515	1.76	535	2.81	855	149.7	" " " .
CIII 3 a	2	$1\frac{3}{8}$	$1\frac{7}{16}$	1.96	0.825	2.72	1.145	2.5	760	3.03	921	113	" " " – suddenly.
CIII 3 b	2	"	$1\frac{1}{2}$	1.75	0.737	3.75	1.58	1.96	596	3.08	937	156	" " sudden break.
CIII 3 c	2	"	$1\frac{1}{2}$	1.63	0.686	3.54	1.49	2.63	770	3.87	1177	147	" " tension & comp.

Table of Average Results.

Mark of Beam Group.	Deflection, in.		Load P, lbs.		Fibre Stress, lbs/in.² (in outer fibre)		Modulus of Elasticity.
	Elas. Lim.	Max.	Elas. Lim.	Max.	Elas. Lim.	Max.	
A 1	0.488	1.063	564	880	6190	9650	1,367,000.
A 2	0.435	1.046	619	1010	6075	9910	1,505,000.
A 3	0.476	1.105	727	1033	7950	11280	1,775,000.
B 1	1.37	2.078	148.5	182	10350	12700	2,175,000.
B 2	0.608	1.358	326	503	8580	13240	2,430,000.
B 3	0.330	0.866	491	841	6420	10970	2,350,000.
B 4	1.455	2.06	130	158.5	9510	11600	1,875,000.
B 5	0.928	1.328	346	436	8690	10950	1,615,000.
B 6	0.738	1.249	503	650	8740	11280	1,857,000.
C I 1	0.634	1.500	394	565	11460	16150	1,560,000.
C I 2	0.774	1.410	515	774	4680	7040	907,500.
C I 3	0.729	1.163	479	620	5620	7270	1,195,000.
C II 1	0.625	1.360	413	577	7650	10680	1,785,000.
C II 2	0.680	1.226	531	770	8100	11740	1,868,000.
C II 3	0.714	1.153	600	831	7410	10260	1,623,000.
C III 1	0.791	1.487	464	658	8820	12500	1,750,000.
C III 2	0.628	1.439	536	808	7980	12030	1,623,000.
C III 3	0.749	1.405	709	1011	7340	10470	1,425,000.

Date: 4/4/11

A2b

E.L. 1.18"

Max. 1.98"

1.1"   2.76"

Date: 4/5/11

B2c

E.L. 2.3"

Max. 3.1"

2.0"   3.69"

Date: 4/5/11

CIII 2b

E.L. 1.68"

Max. 2.63

1.42"   3.51"

Date: 4/5/11

CIII 2a

	E.L.	Max.
	1.85"	2.53"
	1.61"	3.15"

Date: 4/4/11

A 1 a

	E.L.	Max.
	1.47"	2.37"
	1.37"	3.14"

Date: 4/5/11

C I 2 b

	E.L.	Max.
	1.46"	2.42"
	1.46"	3.22"

Date: 4/5/11
B3C

Max.

E.L.

2.4"

3.3"

1.5"

2.8"

Date: 4/5/11
CIII 2 C

Max.

E.L.

1.76

2.81"

1.45"

3.6"

References.

Trautwine-"Engineer's Pocket-Book"

Kent-"Mech. Engineer's Pocket-Book".

Lanza-"Applied Mechanics".

Church-"Mechanics of Engineering".