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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 378

COMPARISON OF WEIGHTS OF 17ST AND STEEL TUBULAR STRUCTURAL MEMBERS USED IN AIRCRAFT CONSTRUCTION

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I - Introduction

Although the strong aluminum alloys have proved themselves to be very efficient in aircraft construction there is a growing competition from the high-strength steels for certain parts, especially for tubular structural members. This tendency is being reflected in research work carried on at the Bureau of Standards. In view of these facts it seems desirable to study the relative merits of these two materials strictly from a strength-weight ratio viewpoint to provide a basis for other comparisons. No attempt will be made in this discussion to include the other factors, such as cost and resistance to corrosion, which also have a bearing on the relative economy.

This study will be based largely on data given in Technical Note No. 307 of the National Advisory Committee for Aeronautics, entitled "Strength of Tubing under Combined Axial and Transverse Loading."

II - Object

The object of this study is to compare the weights of 17ST tubes and steel tubes used for structural members under various types of loading common in aircraft construction.

III - Assumptions

Any aircraft structure of tubular construction can be broken up into individual tubular members, each of which is designed principally for a certain type of loading. Ordinarily the length of these individual members and the total loads to which they are subjected are independent of the material used, and therefore in a study of relative weights of a given member designed in 17ST and steel it may be assumed that the load and length are the same for both metals. In addition to the above,

it has been assumed in this report that the yield strength of the material is more important for determining the maximum load for design purposes than the ultimate tensile strength. It has been assumed also that commercial sizes of tubes are so finely graded that almost any combination of wall thickness and diameter are available. The weights of end connections have been neglected.

IV - Tubular Tension Members

For direct tension members the following formula applies:

$$P = Af = \frac{Wf}{Lw}$$

where
- P = maximum total load on member, lb.,
- A = gross cross-sectional area, sq.in.,
- f = yield strength of material, lb./sq.in.
- W = over-all weight of member, lb.,
- L = length of member, in.,
- w = weight of material, lb./cu.in.

This formula can be rewritten as follows:

$$W = \frac{PLw}{f} .$$

As noted in Section III (p. 1), P and L are fixed by the conditions of the problem and taking this into account one arrives at the following:

$$\frac{W(17ST)}{W(Steel)} = \frac{w(17ST)}{w(Steel)} \times \frac{f(Steel)}{f(17ST)} = \frac{0.101}{0.284} \times \frac{f(Steel)}{f(17ST)} .$$

From the above expression it can be shown that any steel having a yield strength less than 2.82 times the yield strength of 17ST will make a heavier tension member when designed for the same load and length. Thus if the yield strength of 17ST is taken as 40,000 pounds per square inch in accordance with Army and Navy Specification AN 9092, 1929 issue, no steel having a yield strength less than 113,000 pounds per square inch can compete on a strict weight-strength basis.

V - Tubular Beams

In N.A.C.A. Technical Note No. 307, referred to in the introduction, bending tests on tubing of 17ST and chrome-molybdenum steel are described. These tests seem to show that the modulus of rupture (computed stress at failure) of 17ST tubular beams is limited by the tensile strength of the material, whereas the modulus of rupture of steel tubes often exceeds the tensile strength of the material by as much as 25 per cent. In spite of this, however, it would seem logical in design to assume that the yield strength of the material would be the limiting condition for computed stresses in bending, provided, of course, that there was no buckling action on the compression side. On this basis the following formula may be set up:

$$f = \frac{M}{S}$$

$$= \frac{32M}{\pi d^3 (1-k^4)}$$

where f = yield strength of material, lb./sq.in.,
M = maximum bending moment, in.-lb.
S = section modulus, in.^{3},
d = outside diameter of tube, in.,
$k = \frac{\text{inside diameter}}{\text{outside diameter}}$.

Assuming that the value of M is fixed by the design conditions and that the value of k is constant whether the tube be of steel or aluminum, it can be shown that

$$d(17ST) = \left[\frac{f(\text{Steel})}{f(17ST)}\right]^{\frac{1}{3}} \times d(\text{Steel}).$$

The over-all weight of a tubular beam may be expressed as follows:

$$W = wLA$$

$$= wL \frac{\pi}{4} d^2(1-k^2)$$

in which the terms are as defined previously. Assuming the value of L to be fixed by design conditions it follows that:

$$\frac{W(17ST)}{W(Steel)} = \frac{w(17ST)}{w(Steel)} \times \frac{d^2(17ST)}{d^2(Steel)}$$

$$= 0.355 \times \left[\frac{f(Steel)}{f(17ST)}\right]^{\frac{2}{3}}$$

From the above it can be shown that for equal over-all weight and equal beam strength, steel must have a yield strength 4.71 times that of 17ST in order to compete on a strict strength-weight basis. Assuming a 40,000 pound per square inch yield strength for 17ST, the necessary yield strength for steel would be 188,000 pounds per square inch.

The above discussion of tubular beams concerns itself only with strength, no mention being made of deflections. While a study of equal deflections is not highly important yet it may be of some interest to include it here. For equal deflections, assuming a given span length and load, the following condition must be satisfied:

$$E(17ST) \times I(17ST) = E(Steel) \times I(Steel)$$

where E = modulus of elasticity, lb./sq.in.,
I = moment of inertia, inches^4.

Assuming that the ratio of the moduli of elasticity of steel and aluminum alloys is 3 to 1 regardless of small changes in composition and assuming that k is the same for both metals, it can be shown that the condition just stated is only satisfied when

$$d(17ST) = \left[\frac{3}{1}\right]^{\frac{1}{4}} \times d(Steel)$$

$$= 1.31\ d(Steel).$$

Knowing this diameter relation, the weight ratio can be determined as follows:

$$\frac{W(17ST)}{W(Steel)} = \frac{0.101}{0.284} \times \frac{d^2(17ST)}{d^2(Steel)} = 0.615.$$

From this it follows that if the yield strength is not exceeded, an aluminum tubular beam can always be made about 39 per cent lighter than a steel tubular beam for the same span, load, and deflection.

VI - Tubular Compression Members

A study of the relation of steel and aluminum from a strength-weight standpoint for columns in general becomes quite involved owing to the complicated relation between strength and slenderness ratio. In the Euler range where the same formula applies for steel and aluminum the problem is simple enough. For columns which are too stiff to fall in this range the investigation must be conducted by plotting a series of separately determined points.

The relations in the Euler range will be studied first. In this range the strength of columns may be found from the following formula:

$$\frac{P}{A} = \frac{c\pi^2 E}{\left(\frac{L}{r}\right)^2}$$

where P = maximum axially applied column load, lb.,
r = least radius of gyration of column, in.,
c = a constant depending on end conditions of the column,
A, E, & L = same as defined previously.

Writing A and r in terms of d and k it is possible to rewrite the above formula in the following form:

$$P = c\,\frac{\pi^3 d^4 E(1-k^4)}{64L^2}$$

where d and k are the same as previously defined. Assuming that P and L are fixed by design conditions and that k is the same for 17ST and steel one arrives at the following relation of diameters:

$$\frac{d(17ST)}{d(Steel)} = \left[\frac{E(Steel)}{E(17ST)}\right]^{\frac{1}{4}}$$

$$= 1.31.$$

It will be recognized that this is the same relation of diameters as determined previously for tubular beams of equal deflection and hence it follows that the same weight relation holds true, namely:

$$\frac{W(17ST)}{W(Steel)} = 0.615.$$

In the Euler range of columns, then, an aluminum tube can always be designed for the same length and axial load as a given steel tube and still be about 39 per cent lighter.

It has already been pointed out that outside the Euler range of columns the weight relation of steel and aluminum members becomes quite complicated. By means of trial and error methods, however, it is possible to determine this relation for a number of points in a range in which test data are available. This has been done using the results of tests reported in N.A.C.A. Technical Note No. 307. The results of this study are to be found plotted in Figure 1 for a considerable range of slenderness ratios. Three different steels were studied in preparing this figure. The first two, Steel A and Steel B, were heat-treated chrome-molybdenum steels for which data were taken from the N.A.C.A. bulletin previously referred to, while the third, Steel C, represents an ordinary mild steel having a yield strength equal to that of 17ST. Steel C was not used in the N.A.C.A. investigation but was included on this figure simply for comparative purposes.

It will be noted that all values were plotted against the L/r ratio for 17ST. The L/r ratios for the three steels are indicated below the 17ST scale and will be found to differ considerably from it. This simply means, of course, that for a given length and load it is necessary to have a smaller L/r ratio for a 17ST column than it is for a corresponding steel column. It is interesting to note that the scales for steel run irregularly compared to the scale for 17ST.

At the right hand edge of the figure all three curves become tangent to the horizontal straight line at 61.5 per cent, as would be expected from the study of the Euler range of columns given above. The curve for Steel C dips below this line immediately, reaching a minimum value of about 37 per cent at $L/r = 0$. The curves for the other two steels lie above the horizontal straight line and the one for Steel A actually goes above 100 per cent and shows a considerable saving in weight over 17ST. All three curves have been carried up to $L/r = 0$ even though actual test data were not available in the case of Steels A and B for values of L/r less than 30. It was possible to extrapolate from the test data with reasonable accuracy, however, and while the results may not be exactly correct they at least indicate the trend of the relation. It may be safely concluded from Figure 1 that for a given load and length, 17ST tubular columns may be designed lighter than steel columns for all values of L/r greater than 40 (60 for steel) regardless of the strength of the steel. The above study is based on the results of tests of columns having round ends and it can be

assumed that the same relation would hold for other end conditions especially in the Euler range where their validity has already been demonstrated. Test results are not available, however, for other end conditions.

VII - Tubular Members Under Combined Bending and Compression

Figure 2 shows the ratio of weights of tubular members of 17ST and heat-treated chrome-molybdenum steel under combined bending and compression. The assumptions upon which this study was based are indicated at the bottom of the figure. The values used in plotting the curves were determined from data given in Figures 4 and 5 of N.A.C.A. Technical Note No. 307. Since these data are based on average results for the three steels tested, it may be assumed that the steel represented in Figure 2 has a yield strength of about 116,000 pounds per square inch which puts it about midway between Steels A and B in Figure 1. The value of k (ratio of inside to outside diameter) was assumed to be 0.96 for both 17ST and steel. It was not considered wise in this case to extrapolate the data as was done in Figure 1 for columns in compression only, since there was no background of tests to indicate the trend of the results.

In order to show the effect of varying the ratio of transverse load to axial load, P_t to P, two values of m were selected as shown in Figure 2. It should be understood that m itself is not the ratio of P_t to P but is defined as follows:

$$m = \frac{P_t}{P_T}$$

where P_T = transverse load which would cause bending failure when the axial load is zero.

Since P_T is different for a steel tube and a 17ST tube it follows that m would also be different when P_t is kept constant. The m values shown in Figure 2 were selected for 17ST to give a reasonable relation of P_t to P without regard for the corresponding m values for the steel. The resulting ratio P/P_t was approximately 8 for $m = 20$ per cent and approximately 3 for $m = 40$ per cent.

Comparing Figure 2 with Figure 1, it is clear that the addition of transverse or bending loads to a column does not greatly affect the weight ratio of 17ST to steel in the range

for which values are given. In fact it seems reasonable from studying the shape of the curves in Figure 2 that there is a tendency to approach the 61 per cent line in the Euler range in the same manner as was found in the case of Figure 1.

VIII - The Effect of Local Buckling

It has been assumed throughout the discussion above that the strength of the tubular members was not affected by local failures, that is, that the ratio of outside diameter of tube to thickness of wall, d/t, was so chosen that local failures could not occur. It often happens in aircraft construction that in the effort to reduce weight to a minimum, the d/t ratio is made so large that if the members are tested to destruction they are found to fail locally by wall crumpling. The strength of such members is always less than would be indicated by the formulas which apply to members of smaller d/t ratio. In general it may be said that the lightest member for a given loading condition results from choosing the d/t ratio that is just on the border line of local failure.

The relations of the variables involved in a study of local buckling are not very well understood although considerable work is being done by various investigators on this problem. There is some evidence that the limit of local buckling occurs in aluminum tubes at a smaller d/t ratio than in steel tubes. Naturally this fact would alter results obtained in the foregoing discussion of weight ratios since it could no longer be assumed that k (ratio of inside diameter to outside diameter) was the same for 17ST and steel in all cases.

It should be pointed out in this connection, however, that the wall thickness of a tube is often determined by the stiffness required for handling the tube in the shop or field rather than by theoretical requirements. For this reason it is highly probable that in many cases the advantage of the greater resistance of steel to local failure under compressive forces could not be fully realized.

In order to study the effect of d/t ratio on the relative weight of 17ST and steel tubular members it has been assumed that the limiting d/t ratios for 17ST and steel are as follows:

$$\frac{d}{t}(17ST) = 50$$

$$\frac{d}{t}(Steel) = 100.$$

These ratios of d/t may also be expressed in terms of the k ratio previously used in this report as follows:

$$k(17ST) = 0.96$$

$$k(Steel) = 0.98.$$

It is believed that the above figures favor steel to some extent, that is, if the limiting d/t ratio for 17ST is 50 the corresponding d/t ratio for steel would not be as great as 100. The above values will be satisfactory for the present investigation, however, and will be used below to study the changes which they cause on the ratio of weights of 17ST and steel for the various loading conditions.

Tubular tension members.- A study of Section IV of this report will show that the value of k does not affect the relative weights of direct tension members in 17ST and steel. In other words, provided the strength of the material is constant, the thickness of the wall of the tube has no effect on the maximum stress which the tube can carry in direct tension and therefore the conclusions drawn from Section IV above apply just as well here.

Tubular beams.- A study of Section V above shows that the value of k affects the study at several points. Thus we find that the ratio of diameters comes out as follows:

$$\frac{d(17ST)}{d(Steel)} = \left[\frac{f(Steel)}{f(17ST)}\right]^{\frac{1}{3}} \times \left[\frac{1 - k^4(Steel)}{1 - k^4(17ST)}\right]^{\frac{1}{3}}$$

$$= \left[\frac{f(Steel)}{f(17ST)}\right]^{\frac{1}{3}} \times 0.802.$$

The ratio of weights of the two materials becomes

$$\frac{W(17ST)}{W(Steel)} = \frac{w(17ST)}{w(Steel)} \times \frac{d^2(17ST)}{d^2(Steel)} \times \frac{1-k^2(17ST)}{1-k^2(Steel)}$$

$$= 0.453 \times \left[\frac{f(Steel)}{f(17ST)}\right]^{\frac{2}{3}}.$$

From the above relation it follows that for equal weights the yield strength of steel must be 3.27 times that of 17ST. Assuming the yield strength of 17ST to be 40,000 pounds per square inch, the yield strength of steel would have to be at least 131,000 pounds per square inch if the steel is to com-

pete on a weight basis. It will be found that this comparison is much more favorable to steel than the one previously found in Section V as would be expected.

For equal deflections in tubular beams it is found that the ratio of diameters is as follows:

$$\frac{d(17ST)}{d(Steel)} = \left[\frac{E(Steel)}{E(17ST)}\right]^{\frac{1}{4}} \times \left[\frac{1-k^4(Steel)}{1-k^4(17ST)}\right]^{\frac{1}{4}}$$

$$= 1.115.$$

From this it follows that the ratio of weights for equal deflections is

$$\frac{W(17ST)}{W(Steel)} = 0.876.$$

These figures show that, if the yield strength is not exceeded, aluminum tubular beams can always be made 12 per cent lighter than steel tubular beams of the same span length and deflection. A comparison of this statement with the corresponding one made in Section V will show that here again the new k ratios have been decidedly in favor of steel but have not overcome the weight-saving advantage of aluminum.

Tubular compression members.- The effect of the new k values on the ratio of weights of 17ST and steel tubular compression members will now be studied. In the Euler range of columns it can be shown that the following relation holds:

$$\frac{d(17ST)}{d(Steel)} = \left[\frac{E(Steel)}{E(17ST)}\right]^{\frac{1}{4}} \times \left[\frac{1-k^4(Steel)}{1-k^4(17ST)}\right]^{\frac{1}{4}}$$

$$= 1.115.$$

This expression is identical with the one given above for equal deflections of tubular beams and therefore it follows that the ratio of weights will also be identical:

$$\frac{W(17ST)}{W(Steel)} = 0.876.$$

Figure 3 has been drawn in the same manner as Figure 1 except that the new values of k for 17ST and steel were used. It will be noted that the curves in this figure start at the same point as in Figure 1 for L/r values of 0 but are higher throughout the rest of the range of L/r values becoming tan-

gent to the 87 per cent line in the Euler range. It is obvious that the new k values have been very favorable to steel but have not resulted in 17ST entirely losing its weight advantage. It may be said from a study of Figure 3 that for L/r values of 60 or more (70 in the case of steel), 17ST members can always be made lighter than steel.

IX - The Effect of Keeping Outside Diameters Equal

So far in this report the outside diameters of the tubes have been allowed to vary as necessary in order to satisfy certain conditions as to the ratio of inside to outside diameters. In general this has resulted in 17ST being used very efficiently because it has allowed the 17ST member to have a larger outside diameter than that of the corresponding steel member of equal strength. It should be appreciated, however, that there are cases in which the outside diameter of the 17ST tube cannot be larger than that of the corresponding steel tube if the comparison of weights is to be entirely fair. For example, exposed tubular aircraft members will offer wind resistance in proportion to their diameters and this fact places a premium on small diameters especially in high speed planes. For this reason it seems wise to study briefly the effect of designing not only for equal load and length but also for equal outside diameters. This will be done in the following paragraphs.

Direct tension members.- As previously noted under Section VIII the relative dimensions of the tubes do not enter the problem of comparing weights of direct tension members designed for equal load and length and hence the conclusions drawn in Section IV apply equally well here.

Tubular beams.- If a 17ST tubular beam and a steel tubular beam of equal outside diameter are designed to carry the same load on the same span length, their inside diameters will vary according to their yield strengths. If the yield strengths of the two materials are equal the inside diameters of the two tubes, of course, will be equal. If the yield strength of the steel is greater than that of the 17ST the inside diameter of the steel tube will be somewhat greater than that of the 17ST tube, but the difference will not be directly proportional to the difference in yield strength.

These relations can be shown by the expression below which follows from the work in Section V if d(17ST) is assumed equal to d(Steel):

$$\frac{f(17ST)}{f(Steel)} = \frac{1-k^4(Steel)}{1-k^4(17ST)} .$$

It can also be shown from the work in Section V that for equal outside diameters the ratio of weights is as follows:

$$\frac{W(17ST)}{W(Steel)} = \frac{w(17ST)}{w(Steel)} \times \frac{1-k^2(17ST)}{1-k^2(Steel)} .$$

Knowing these relations it has been possible to prepare Figure 4 which shows graphically the weight relations of 17ST and three different steels. The abscissas for this figure have been handled in much the same manner as those for preceding figures, that is, the plotting was done on the basis of the values for 17ST, and the corresponding values for the steels are indicated below the main scale. It is important to note that for Steels A and B the k values (ratio of inside to outside diameter) do not start with zero at the left side as do those for 17ST and Steel C. This means that there are some sizes of tubes which if made of a steel having higher properties than 17ST cannot be matched in beam strength by any 17ST tube of equal outside diameter regardless of weight. In other words the solid rod becomes the limiting condition beyond which the wall thickness cannot be increased. Since most aircraft tubing falls in the range, $k = 0.90$ to 0.98, however, it is unnecessary to consider those impossible cases.

It will be noted in Figure 4 that the curve for Steel A lies entirely above the equal weight line which shows that under the restriction of equal outside diameters Steel A will always make a lighter tubular beam than 17ST. It can be shown that any steel having a yield strength higher than 113,000 pounds per square inch is similar to Steel A in this respect. Comparing the above findings with those of Section V it is evident that placing a restriction on the outside diameter of the 17ST tubular beams has been favorable to steel.

Comparing tubular beams of equal outside diameter designed for equal deflections under a given load on a given span one finds that 17ST cannot compete with steel regardless of strength. The curve representing the ratio of weights in this case coincides with the curve for Steel D in Figure 4.

Tubular compression members.- In the Euler range the weight relation of 17ST and steel tubular columns of equal outside diameter is exactly the same as that for beams of equal deflection, and can be represented by the same curve. This means that if outside diameters are held equal, slender 17ST tubular columns will always be heavier than steel columns of equal length and strength regardless of the properties of the steel used.

For tubular columns which are too short and stiff to fall in the Euler range the relation of weights of 17ST and steel is complicated by the fact that both slenderness ratio and k ratio are variables which affect the results. In order to plot the values shown in Figure 5 the problem was simplified by selecting an average value for the k ratio for steel, k(steel) = 0.94. This made it possible to show the trend of the weight relation for various slenderness ratios. If a higher k ratio had been selected for the steel the curves would all have been lowered slightly and vice versa. In other words, the thinner the wall of a steel tube the better chance 17ST has to compete on a weight basis for a given outside diameter.

It will be noted in Figure 5 that the curves for Steels A and B become tangent to and follow the 128 per cent line toward the right side of the sheet. It can be shown that the curve for Steel C does the same if continued beyond the limits of the sheet. This 128 per cent line represents the weight relation in the Euler range of columns and may be checked by studying the dotted curve in Figure 4. This curve has an ordinate of 1.28 at the point where its k value is 0.94.

Comparing Figure 5 with Figure 1 it is clear that holding the outside diameter of a 17ST tube the same as that used in the corresponding steel tube has again been favorable to the steel. It has resulted in Steel A being lighter for all slenderness ratios and has almost put Steel B in the same class.

X - Summary

The preceding sections of this report show the relation of weights of tubular structural members built of 17ST and various steels for a number of types of loading. It has been demonstrated that 17ST makes a considerably lighter member than steel in many cases but it is difficult to summarize the findings because of the many variables involved. Therefore it seems well to restrict the following discussion to a comparison of 17ST with one typical high strength steel. The steel selected will be called Steel E and will be one which will meet the U. S. Army Air Service Specifications No. 10231-B (June 21, 1926) for Alloy Steel Tubes.* These specifications call for a minimum tensile strength of 95,000 pounds per square inch but state no yield strength. Assuming 97 per cent for the ratio of yield strength to tensile strength* one arrives at a yield strength of say 92,000 pounds per square inch for Steel E. The 17ST

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*N.A.C.A. Technical Note No. 307.

tubing will be assumed to have a 40,000 pound per square inch yield strength in compliance with Army Navy Specifications A N 9092 (1929 issue). Therefore the assumed ratio of yield strengths will be as follows:

$$\frac{\text{Yield strength Steel E}}{\text{Yield strength 17ST}} = \frac{92{,}000 \text{ lb./sq.in.}}{40{,}000 \text{ lb./sq.in.}} = 2.3.$$

Tubular Tension Members, Equal Strength

17St is about 18 per cent lighter than Steel E.

Tubular Beams, Equal Strength

17ST is about 38 per cent lighter than Steel E if the k ratio of the 17ST tube can be equal to that for the steel tube. The outside diameter of the 17ST tube will be 32 per cent greater than that of the steel tube.

17ST is about 21 per cent lighter than Steel E if the k ratio of the 17ST tube must be smaller than that for steel in the ratio 0.96 to 0.98. The outside diameter of the 17ST tube will be about 6 per cent greater than that of the steel tube.

If the outside diameter of the 17ST tube cannot be larger than that of the steel tube, 17ST will be lighter than Steel E only when the k ratio of the steel is greater than about 0.90. Even in the most favorable circumstances (k for steel greater than 0.98) 17ST can be only about 20 per cent lighter.

Tubular Beams, Equal Deflection

17ST is about 39 per cent lighter than Steel E if the k ratio of the 17ST tube can be equal to that for the steel tube. The outside diameter of the 17ST tube will be 31 per cent greater than that of the steel tube.

17ST is about 12 per cent lighter than Steel E if the k ratio of the 17ST tube must be smaller than that for the steel tube in the ratio of 0.96 to 0.98. The outside diameter of the 17ST tube will be about 12 per cent greater than that of the steel tube.

If the outside diameter of the 17ST tube cannot be larger than that for the steel tube the former will be heavier by at least 6 per cent.

The statements above for beams of equal deflection are not restricted to a comparison of 17ST with Steel E but apply equally well for any other steel having a modulus of elasticity of about 30,000,000 pounds per square inch.

Tubular Columns, Equal Strength, Euler Range

The statements made in the first three paragraphs for beams of equal deflection can be made equally well.

Tubular Columns, Equal Strength, Outside Euler Range

When short stiff columns are considered, the relation of weights becomes complicated and reference should be made to Figures 1, 3, and 5. The curve for Steel E in each case would lie just below that for Steel B and would become tangent to the horizontal line at about the same point. In general it may be said that if the outside diameter of the 17ST tube may be made larger than that of the steel tube, 17ST is lighter than Steel E by about 5 to 39 per cent depending upon the restrictions placed on the k ratio. Even when the outside diameter of the 17ST tube cannot be larger than that of the steel tube, 17ST is lighter than Steel E if the steel tube has an L/r ratio of 40 or less.

XI - Conclusions

The following conclusions are based on the studies presented in this report:

1. A steel tubular structural member designed for any ratio of d/t (outside diameter to wall thickness) can be equalled in strength by a 17ST tubular member having the same d/t ratio at a substantial saving in weight as indicated below.

   a) If the yield strength of the steel is equal to that of 17ST, the 17ST tube will be from 38 to 64 per cent lighter.

   b) If the yield strength of the steel is about equal to 97 per cent of the minimum tensile strength for alloy steels stated in the U. S. Army Air Service Specifications No. 10231-B, say 92,000 pounds per square inch, the 17ST tube will be from 10 to 40 per cent lighter.

c) If the yield strength of the steel is raised to about 115,000 pounds per square inch the 17ST tube begins to lose its weight-saving advantage for tension members and short columns but retains some advantage for beams and long columns.

d) Regardless of the other properties of the steel, if the modulus of elasticity remains about 30,000,000 pounds per square inch the 17ST tube will always be 39 per cent lighter than the steel tube for long columns and for beams designed for a given deflection.

2. Under the conditions stated for the first conclusion the 17ST tube will have a larger outside diameter than the steel tube in the four cases as indicated below:

a) If the yield strength of the steel is equal to that of 17ST the diameter of the 17ST tube will be from 0 to 31 per cent larger than that of the steel tube.

b) If the yield strength of steel is 92,000 pounds per square inch the diameter of the 17ST tube will be from 31 to 58 per cent larger.

c) If the yield strength of steel is 115,000 pounds per square inch the diameter of the 17ST tube will be from 31 to 72 per cent larger.

d) For long columns and for beams designed for a given deflection the diameter of the 17ST tube will be 31 per cent larger.

3. If it is specified that the outside diameter of the 17ST tube cannot be larger than that of the steel tube, 17ST loses much of its weight-saving advantage for columns and beams. In long columns and in beams designed for a given deflection, steel tubes will be lighter regardless of the yield strength of the steel. In short columns and in beams designed for strength the 17ST tube will be considerably lighter if the steel has a yield strength about equal to that of 17ST but will lose this advantage rapidly as the yield strength is raised. If the steel has a yield strength of more than 115,000 pounds per square inch the steel tube will be lighter than the 17ST tube for all loading conditions.

4. If the d/t ratio for a 17ST tube must be kept smaller than that for a steel tube because of the likelihood

of local compression failure, 17 ST loses some of its weight-saving advantage in short columns and in beams designed for strength but not as much as indicated above for the condition of equal outside diameters.

5. For most tubular structural members 17ST should be able to compete easily on a weight basis with any steel having a yield strength less than 90,000 pounds per square inch. In some cases it should be able to compete with steels having yield strengths as high as 115,000 pounds per square inch.

XII - Recommendation

It is recommended that this investigation be continued to study more thoroughly the effect of variations in ratio of inside to outside diameter. This can only be done when more complete data are available on the subject of local buckling of steel and aluminum tubular members in compression.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., March 27, 1931.

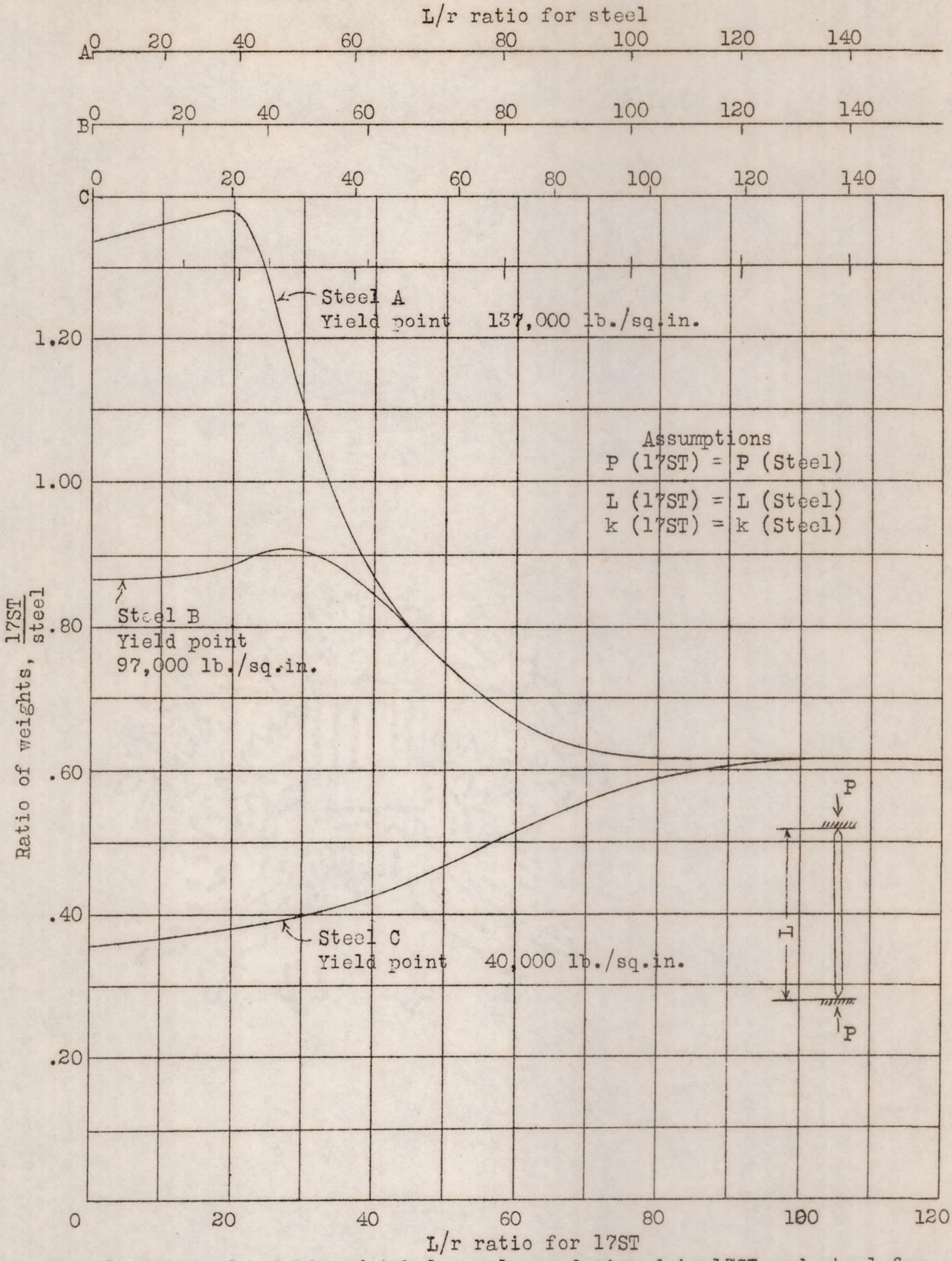
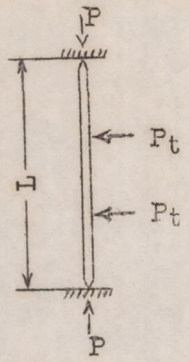


Fig. 1 Ratio of weights of tubular columns designed in 17ST and steel for equal load and length.

Assumptions

P (17ST) = P (Steel)
L (17ST) = L (Steel)
P_t (17ST) = P_t (Steel)
k (17ST) = k (Steel)
P_t = m x Load required to cause bending failure of 17ST tube when P = 0.



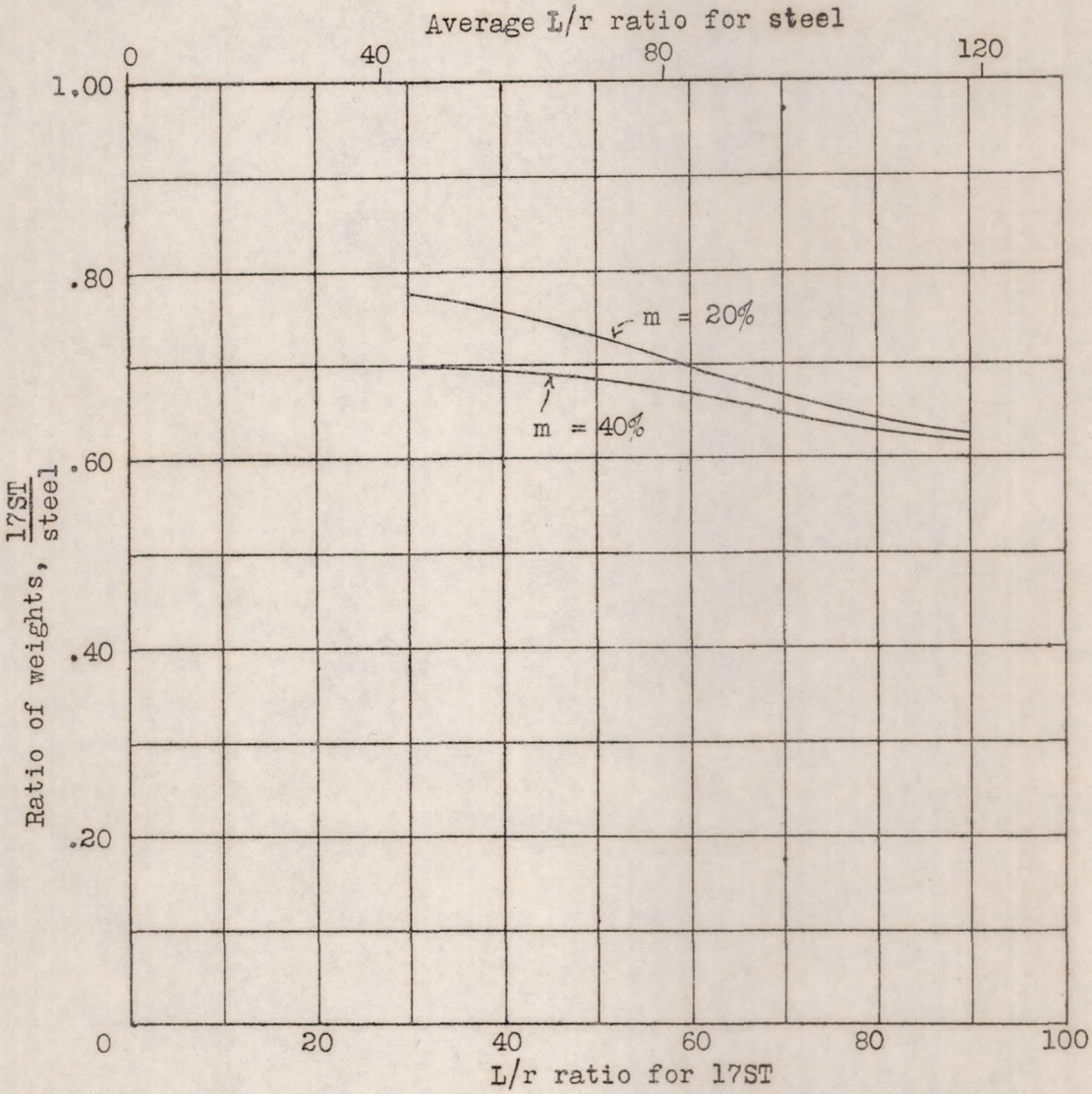


Fig. 2 Ratio of weights of tubular columns under combined bending and compression.

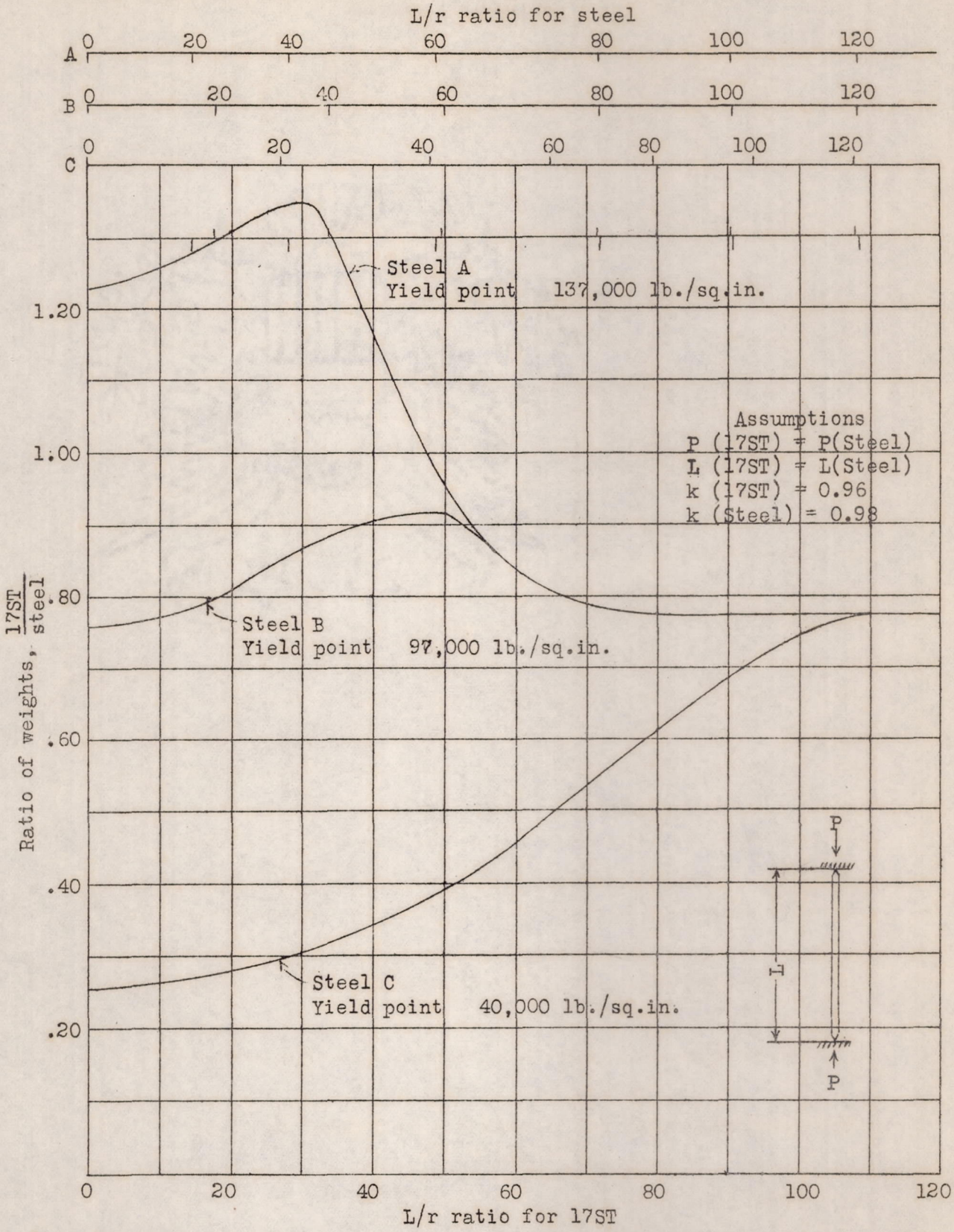


Fig. 3 Ratio of weights of tubular columns designed in 17ST and steel for equal load and length.

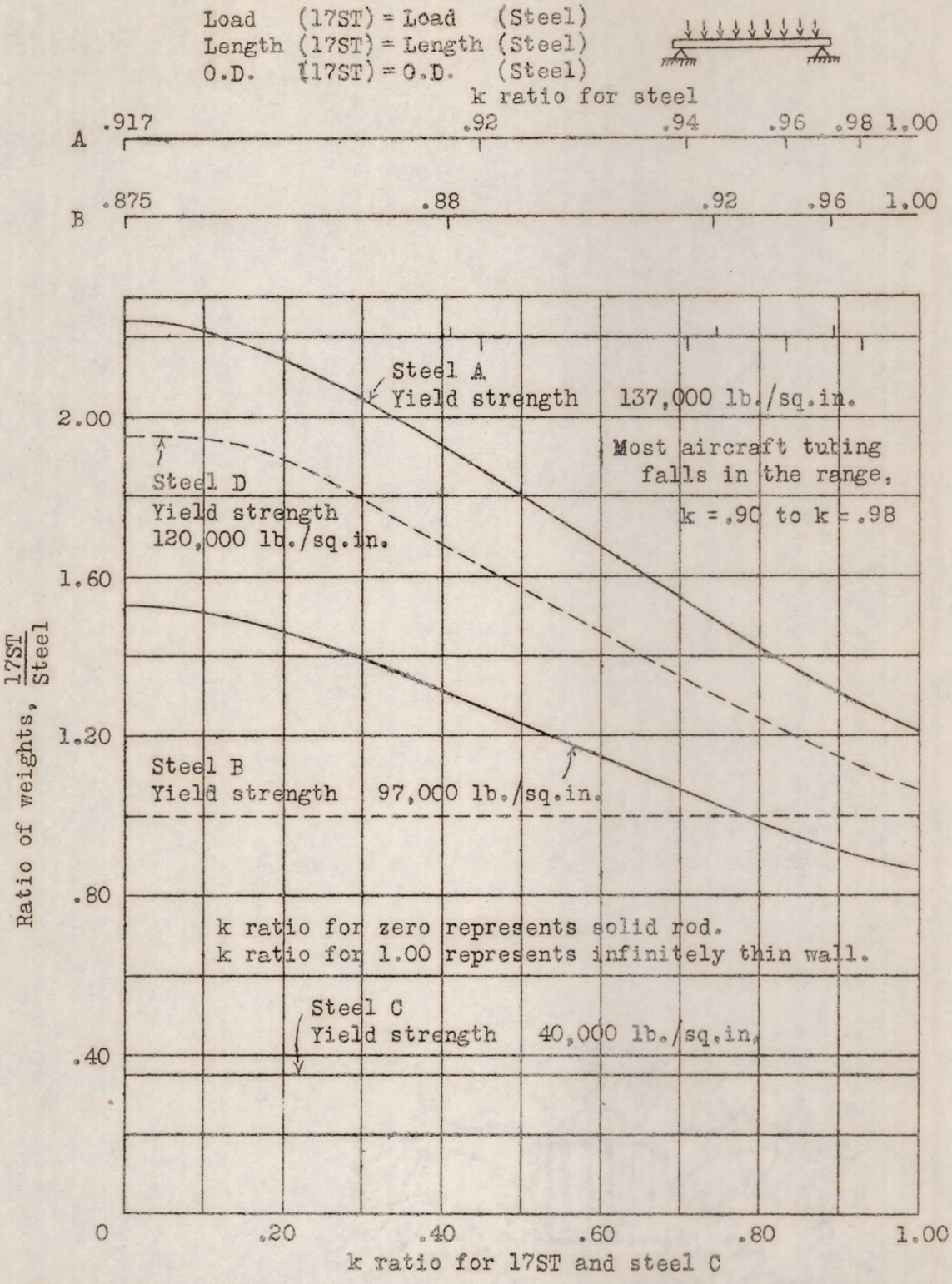


Fig. 4 Ratio of weights of tubular beams designed in 17ST and steel for equal load and length.

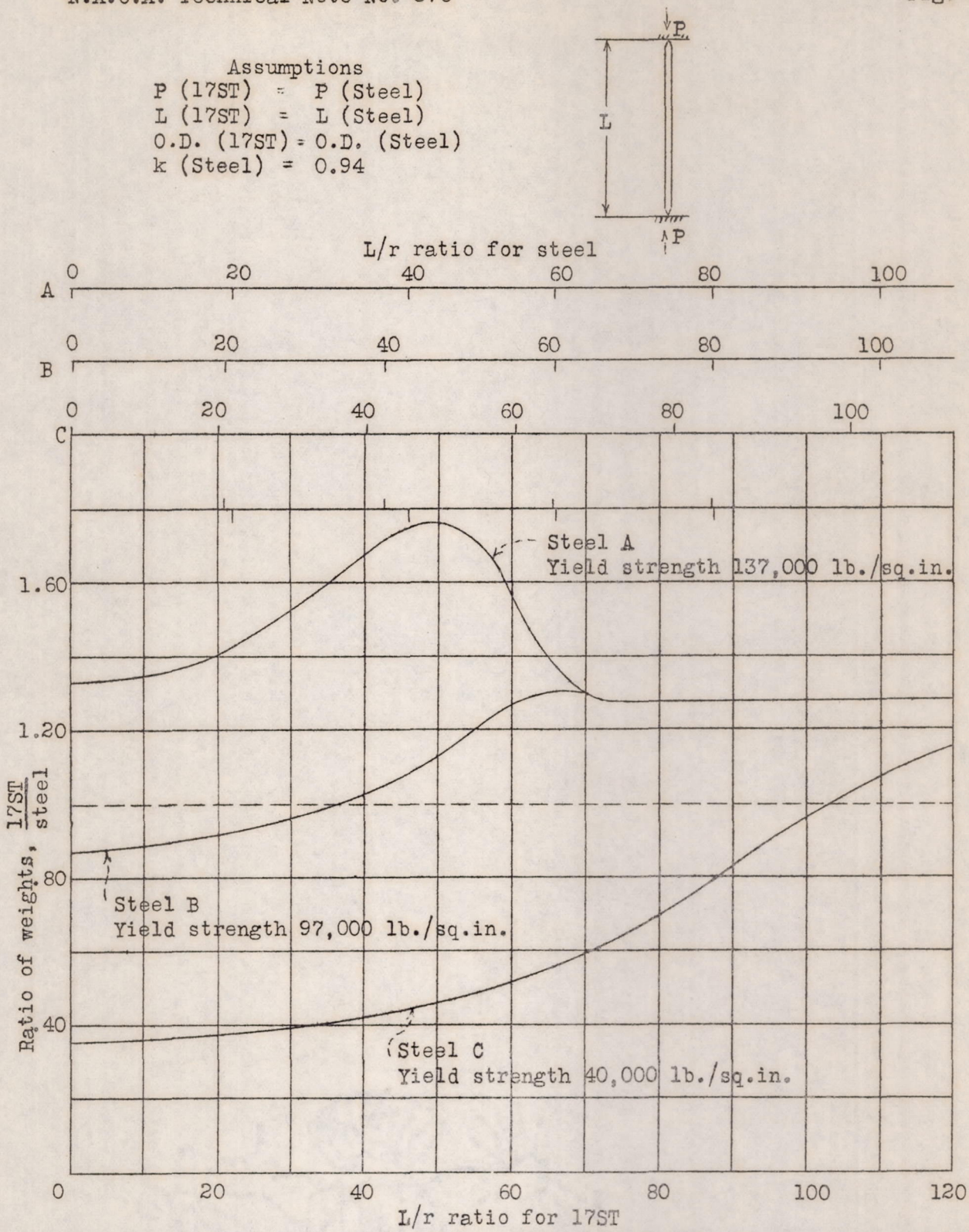


Fig. 5 Ratio for weights of tubular columns designed in 17ST and steel for equal load and length.