Shaping and Assembling Webbing

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Introduction

In this paper I present a simple method for reckoning a taper in webbing. I also present methods for cutting out and assembling trawlnet sections. Using techniques of whole number arithmetic, and by considering various "whole number properties" of webbing (or similar grid, e.g., a checkerboard), the novice should be able to cut out and assemble trawlnet sections from a traditional net plan. The methodology presented here should be applicable to most operations involving tapering of nets.

I wrote this paper to describe the web shaping process in completely numerical terms so the various associated calculations could be made with a computer. By using the principles described here, the net designer and builder can create their own algorithms and program the various personal or business microcomputers available today to perform calculations to suit their own specialized requirements.

A companion article entitled "A microcomputer program for the calculation of a trawlnet section taper" (Martin and Recksiek, 1983) illustrates such a program. Most such programs would input dimensions or tapers and output an unknown dimension or taper. For instance, a routine to calculate trawlnet belly section tapers would take the number of meshes on the "wide end," the number of meshes on the "narrow end," and the number of meshes in depth as input, and present, as output, the taper characteristics in a standard numerical shorthand.

Other potential applications of automating the calculations include development of computerized graphics routines which display web sections. An immediate and straightforward application of such graphics routines is to quickly and easily draw net plans which show every mesh. Being able to make similar displays in three dimensions is an initial step in visually portraying the response of a net section in numerically modeled flows. One can also envision an application where a computer would control a net making machine. This would permit a manufacturer to supply orders for "pre-shaped" sections.

There is a body of literature on the tapering of webbing. Exemplary works are by Garner (1981, 1973), Libert and Maucorps (1978), Nédélec (1975), and Hillier (1981). The first three use a system based on "meshes lost or gained" in which a table of cutting rates is presented. Each tabular element can be associated with certain gains or losses of meshes and the correct taper reckoned accordingly. Hillier (1981) presented a special series of tapering formulae which can be applied to most tapering problems. Hillier's method is well known and applied in the United States.

A traditional terminology exists to describe the tapering of webbing. In this paper I will use that of Hillier (1981). Figure 1 illustrates a rectangular section of webbing in which tapered cuts have been made. The terminology distinguishes between cuts according to which side of the "diagonal" they are on. Cuts above the diagonal are termed body cuts. These are said to be formed of bars (single cut strands) and points (two cut strands). Similarly, the taper below the diagonal, a jib cut, is said to be formed of bars and meshes.

Exemplary tapers are depicted in Figure 1. Body cut A to B consists of four sets of 2 bars 1 point; jib cut E to F

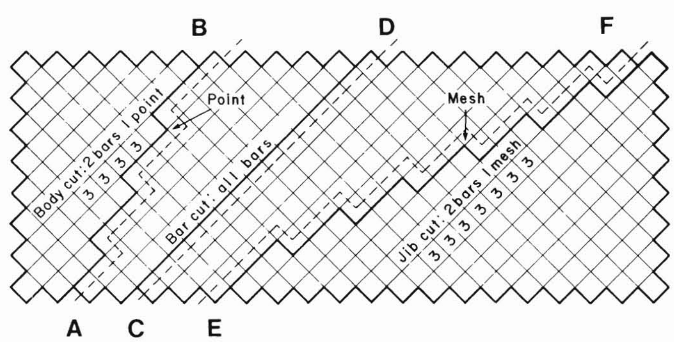

Figure 1.—Representative diagonal cuts, or tapers, in webbing. The tapered edges are drawn as heavy solid lines, with knife paths across the cut strands drawn as dashed lines. Body cut A to B forms bars and points; jib cut E to F forms bars and meshes. Note how tapers are described in traditional terms (2 bars 1 point) and as an integer sequence (3, 3, 3, 3).

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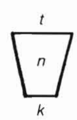
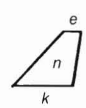
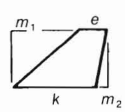
Table 1.— Summary of notation and equations used in the determination of body-cut net tapers. For explanation see text.

Text equation numbers	Equation		Explanation
(1.2), (6.6)	$T = U(S-1)+R(S)$		General tapering formula: U and R, points; S, steps/point; T, total steps.
(1.3)	Steps $= n+m-1$		Total steps across a net: n, mesh distance vertically; m, mesh distance horizontally.
(2.1)	Points $= n-m+1$		Number of points in a net taper: n, mesh distance vertically; m, mesh distance horizontally.
(6.1)	$T = P(S-1)+R$		Alternative form of the general tapering formula. P, points; S, steps/point; R, steps remainder (this expression is equivalent to $T = U(S-1)+R(S)$ by letting $P = (U+R)$.
(10.1)	$T = F\left[U'(S-1)+R'(S)\right]$		General case of $T = U(S-1)+R(S)$ where F is a common factor of U and R, and U' and R' have no common factors.
(11.1)	$t = (2m-2)+k$		Belly top formula used to determine m t, meshes across top, or wide end; k, meshes across bottom, or narrow end; m, horizontal mesh distance of taper.
(13.1)	$e = (k-n)+m$		Wing formula used to determine m e, meshes across narrow end: k, meshes across wide end; n, depth or vertical distance; m, horizontal mesh distance.
(15.1)	$e = (k-m_1)+m_2$ $m_1 > m_2$		Double-taper wing formula used to determine either m_1 or m_2: e, meshes across narrow end; k, meshes across wide end; m_1 and m_2, horizontal distances for each taper.

consists of seven sets of 2 bars 1 mesh; bar cut C to D consists of all bars.

The distinction between body cuts and jib cuts is important. The points of the body cut form sider knots, while meshes of the jib cuts form pickups. Thus the orientation of the webbing, or "run of the twine," must be considered. In this paper, the run of the twine will be assumed to be from top to bottom. (According to Libert and Maucorps (1978), page 5, the "run of the twine" is side to side. The reader should use caution in comparing references.)

I present here a method of reckoning tapers based upon arithmetic and simple algebra. This development does not exactly match the traditional twine terminology, so I will introduce a few new terms. I will, however, describe operations in traditional terms for purposes of comparison.

In the next section of this paper, Reckoning the Taper, I present new terminology and the tapering principles. Essentially, I describe the rationale behind various tapering formulae. The reader should consult Table 1 where the important equations and notations are summarized. In the next section I develop Table 1 equations (1.2) through (10.1). Table 1 equations (11.1) through (15.1) are used to calculate tapers and dimensions of webbing pieces used in building trawlnets. These are explained in subsequent sections of this article.

At this point, after reviewing Table 1, I encourage the reader to skim the Figures, particularly Figures 8-15 on pages 33-40. They should convey an impression of what the fundamental principles in the next section are leading toward and clarify the uses of some of the notations summarized in Table 1.

Reckoning the Taper

Tapering a piece of netting is analogous to stepping across a grid or checkerboard. A taper can be considered to be a pathway (really made of knife cuts) across the grid formed by the knots and strands of webbing. In Figure 2, two separate pathways from A to exemplary end meshes B and D are illustrated. To reach point B, one "steps" either "upward" or along the diagonal. To reach D, one "steps" either "sideways" or along

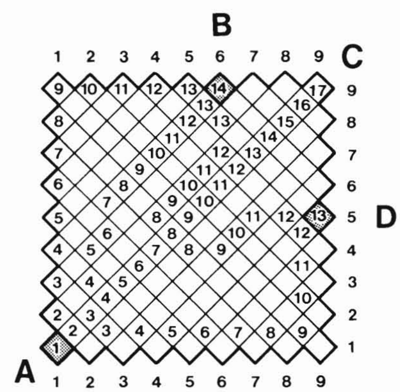


Figure 2.— Steps required to achieve tapers. Tapering webbing is analogous to stepping across a grid or checkerboard. To reach meshes B and D from starting mesh A, exactly 14 and 13 steps, respectively, are required regardless of the path. Various paths are illustrated here by numbering steps.

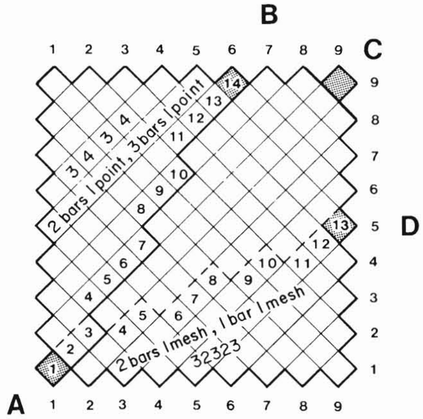


Figure 3.—Steps across webbing with tapers indicated: Body cut A to B, solid line; jib cut A to D, dashed line.

the diagonal. Note that exactly the same number of steps (14) are taken to reach point B from A. No matter how one proceeds across the grid in the direction of B (up and diagonally), 14 steps are required. Likewise, to reach D, 13 steps are required (sideways and diagonally). And, to reach C, exactly 17 steps along the diagonal are required.

Many pathways (cuts) across the grid (web) are possible. Our task is to present rules to traverse the web in as straight a path as possible. In Figure 2, the path from A to C will be perfectly straight, whereas other paths, say from A to B, will involve moving along the diagonal and moving upward.

In Figure 3, an exemplary grid is presented where steps across are subtended by darkened lines which represent finished edges of a taper. Here, the tapers lack the uniformity of those in Figure 1. For example, the taper A to B mixes cuts of 4 steps per point with cuts of 3 steps per point in a sequence 3, 4, 3, 4. This would be a body cut of 2 bars 1 point and 3 bars 1 point. Expressing the taper as a whole-number sequence, and not as a traditional mix of bars and points, is the heart of the tapering principle being presented here. Expressing the tapers as a sequence of numbers turns out to have the advantage of expressing both simple and complex tapers in an easy and straightforward manner.

Alternative tapering paths across the webbing may exist (i.e., there may be an element of choice in selecting which strands to cut to form the taper). In Figure 4, alternative paths are diagrammed. In this particular case, one could have structured the taper as 3, 4, 3, 4 or 4, 3, 4, 3. In fact, the sequences 4, 4, 3, 3 or 3, 3, 4, 4 could also have been used, but then the taper would lack "symmetry."

Referring to Figure 4, we could express the body cut A to B, 3, 4, 3, 4 as follows:

$$14 \text{ steps} = \begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix} + \begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 4 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix}. \quad (1.1)$$

That is, the sum of the integers in the sequence 3, 4, 3, 4 is equal to the total number of required steps across the web.

Equation (1.1) is an example of the fundamental tapering algorithm or rule being presented in this paper. This whole-number expression simply writes the total number of steps across the grid in the form:

$$T = U\,(S-1) + R(S) \quad (1.2)$$

where

T = total steps,
U and R = points, and
S = steps/point.

Once the taper is expressed in this form, an integer sequence which specifies the cut follows immediately. This sequence has the following general form: $(S-1)_1$, $(S-1)_2$, $(S-1)_3, \ldots$ $(S-1)_U$, S_1, S_2, $S_3, \ldots S_R$.

Although equation (1.2) is not "very compatible" with traditional twine terminology, it should be noted that $S-1$ and S are the number of strands cut in the diagonal direction below each point (for body cuts). For example, for the body cut A to B in Figure 3, note that $S = 4$ and that $S-1 = 3$. To make the taper, one would cut 3 strands along the diagonal, cut the upper right strand to form the point, cut 4 more strands along the diagonal, cut the upper right strand to make the second point, etc.

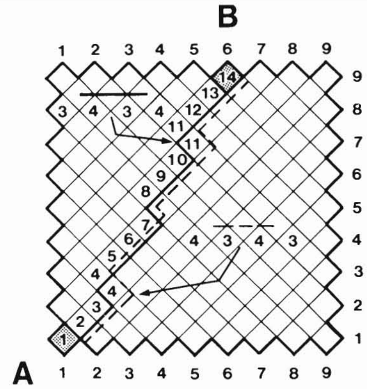


Figure 4.—Alternative tapers for the body cut A to B: 3, 4, 3, 4, solid line; 4, 3, 4, 3, dashed line. A total of 14 steps are taken regardless of which pathway or taper is used.

The total number of steps across the web to form the taper must first be known to reckon the taper. Finding the total number of steps is the first stage in what ultimately will result in the final sequence of integers given by equation (1.2). The total number of steps is a simple sum of meshes "up" and diagonally for a body cut ("sideways" and diagonally for a jib cut).

Specifically, for a body cut where points and bars are formed, in finding total steps, one needs to know a vertical distance (expressed as grid steps), n, and a horizontal distance, m, from the starting mesh (or square). The distances n and m are represented in Figure 5. Note, when examining this figure, that two situations are possible: 1) When n and m are both whole numbers, as in 5(a) and 2) when m and n are both whole numbers plus one-half, as in 5(b). Note that in the latter case a three legger must occur somewhere in the tapered piece. This characteristic is important and will be discussed in detail later.

In any event, for a body cut, total steps are given by:

$$\text{Steps} = n+m-1. \quad (1.3)$$

This equation holds for jib cuts except that the roles of m and n are reversed, i.e., m refers to the vertical distance, n to the horizontal (see Figure 5, jib cuts A to D).

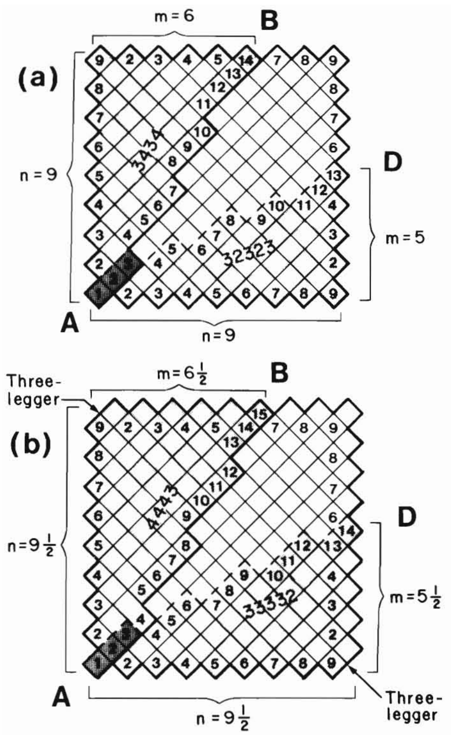


Figure 5.—(a) Illustration of mesh distances n and m. For a taper involving points, A to B, n is the vertical distance, whereas for a taper involving meshes, A to D, n is the horizontal distance. (b) Illustration of the terminal mesh (B and D) being a fractional distance in meshes from the column n (for points) or row n (for meshes). Note three-leggers in the finished pieces. Note that (a) is analogous to stepping from a black to a black square, A to B and A to D, on a checkerboard, while case (b) is analogous to stepping from a black square to a red one, A to B and A to D.

Having determined the total number of steps as a sum of mesh distances (equation (1.3)), one next determines the number of points (or meshes) which will be formed in the taper. For body cuts, this is given by the equation:

$$\text{Points} = n-m+1, \qquad (2.1)$$

and, as with equation (1.3), the roles of n and m are reversed for jib cuts. To illustrate total number of steps together with the number of points (or meshes), consider Figure 5(a). For the body cut A to B:

$$n+m-1 = 9+6-1 = 14 \text{ steps} \qquad (2.2)$$

and

$$n-m+1 = 9-6+1 = 4 \text{ points.} \qquad (2.3)$$

Observe that points occur at steps 3, 7, 10 and 14.

For the jib cut A to D:

$$n+m-1 = 9+5-1 = 13 \text{ steps} \qquad (2.4)$$

and

$$n-m+1 = 9-5+1 = 5 \text{ meshes.} \qquad (2.5)$$

Meshes occur at steps 3, 5, 8, 10 and 13.

Now consider Figure 5(b). Here, tapers A to B and A to D end at half-mesh distances. For the body cut A to B:

$$n+m-1 = 9\tfrac{1}{2}+6\tfrac{1}{2}-1 = 15 \text{ steps} \qquad (2.6)$$

and

$$n-m+1 = 9\tfrac{1}{2}-6\tfrac{1}{2}+1 = 4 \text{ points.} \qquad (2.7)$$

For the jib cut A to D:

$$n+m-1 = 9\tfrac{1}{2}+5\tfrac{1}{2}-1 = 14 \text{ steps} \qquad (2.8)$$

and

$$n-m+1 = 9\tfrac{1}{2}-5\tfrac{1}{2}+1 = 5 \text{ meshes.} \qquad (2.9)$$

Therefore, the equation

$$\frac{n+m-1}{n-m+1} = \frac{\text{steps}}{\text{points (or meshes)}} \qquad (3.1)$$

is sufficient to numerically describe tapers.

Once steps and points (assuming a body cut) are determined, one can express the taper through some simple arithmetic in the form

$$\text{total steps} = \left[\text{points}\right]\left[\frac{\text{steps}}{\text{point}}\right] + \left[\text{steps remainder}\right]. \qquad (3.2)$$

For example, in Figure 5(a), in the body cut A to B we have

$$\frac{n+m-1}{n-m+1} = \frac{14 \text{ steps}}{4 \text{ points}}. \qquad (3.3)$$

With 4 as a divisor of 14, the largest whole number quotient is 3 where 3×4 = 12. With 2 steps remainder, one can write:

$$14 \text{ steps} = \left[4 \text{ points}\right]\left[\frac{3 \text{ steps}}{\text{per point}}\right] + \left[2 \text{ steps remainder}\right]. \qquad (3.4)$$

Note that the taper, so far, consists of 4 sets of 3 steps/point with 2 steps left over. Numerical manipulation is now necessary to remove the remainder and express the taper in the form of equation (1.2). If one were to "modify" equation (3.4) so that the 2-step remainder were "absorbed" into the expression, a taper would be described. This process involves expressing the factor $n-m+1$ (4 in this example) as a sum of two numbers, one of which is the remainder. This is illustrated as follows:

$$14 \text{ steps} = \left[\begin{array}{c}4\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] + \left[\begin{array}{c}2\\ \text{steps}\end{array}\right] \qquad (3.5)$$

(fundamental expression)

$$= \left[\begin{array}{c}2\\ \text{points}\end{array}\right] + \left[\begin{array}{c}2\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] + \left[\begin{array}{c}2\\ \text{steps}\end{array}\right] \qquad (3.6)$$

(modify first term)

$$= \left[\left[\begin{array}{c}2\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] + \left[\begin{array}{c}2\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right]\right] + \left[\begin{array}{c}2\\ \text{steps}\end{array}\right] \qquad (3.7)$$

(separate terms)

$$= \left[\begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix} \right]$$

$$+ \left[\begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix} \right.$$

$$+ \left. \begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 1 \\ \text{step} \\ \text{per} \\ \text{point} \end{bmatrix} \right] \quad (3.8)$$

(Recombine terms and rewrite the remainder in the unit "points×steps/point").

Note that the last two terms share a common factor, 2 points. These therefore can be combined to write the equation in final form:

$$14 \text{ steps} = \left[\begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix} \right]$$

$$+ \left[\begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix} \right.$$

$$+ \left. \begin{bmatrix} 1 \\ \text{step} \\ \text{per} \\ \text{point} \end{bmatrix} \right] \quad (3.9)$$

$$= \begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 3 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix}$$

$$+ \begin{bmatrix} 2 \\ \text{points} \end{bmatrix} \begin{bmatrix} 4 \\ \text{steps} \\ \text{per} \\ \text{point} \end{bmatrix}. \quad (3.10)$$

This is in the form of equation (1.2). A taper sequence of 3, 3, 4, 4 is now indicated. For symmetry, one would cut the taper at 3, 4, 3, 4 or 4, 3, 4, 3. Incidentally, an algorithm for explicitly specifying the sequence will be presented later. Anyway, equation (3.10) indicates a taper of the pattern 2 bars 1 point, 3 bars 1 point repeated twice.

To illustrate reckoning a jib cut, consider A to D in Figure 5(a):

$$\frac{n+m-1}{n-m+1} = \frac{9+5-1}{9-5+1} = \frac{13 \text{ steps}}{5 \text{ meshes}} \quad (4.0)$$

or, in the form of equation (3.2),

$$13 \text{ steps} = \begin{bmatrix} 5 \\ \text{meshes} \end{bmatrix} \begin{bmatrix} 2 \\ \text{steps} \\ \text{per} \\ \text{mesh} \end{bmatrix}$$

$$+ \begin{bmatrix} 3 \\ \text{steps} \end{bmatrix}. \quad (4.1)$$

Leaving out the units for brevity, the process is as follows:

$$13 = (5)(2)+3 \quad (4.2)$$
(fundamental equation)

$$= (2+3)(2)+3 \quad (4.3)$$
(modify first term)

$$= (2)(2)+(3)(2) +3 \quad (4.4)$$
(write separate terms)

$$= (2)(2) + (3)(2)+(3)(1) \quad (4.5)$$
(recombine terms)

$$= (2)(2)+(3)(3) \quad (4.6)$$
(combine last terms to complete arithmetic).

This expression now indicates a sequence of 3, 2, 3, 2, 3 (as in Figure 5(a), A to D).

For Figure 5(b) and for the body cut A to B we have

$$\frac{n+m-1}{n-m+1} = \frac{9½+6½-1}{9½-6½+1} = \frac{15}{4} \quad (5.0)$$

and

$$15 = (4)(3)+3 \quad (5.1)$$
(fundamental equation)

$$= (1+3)(3)+3 \quad (5.2)$$
(modify first term)

$$= (1)(3)+(3)(3) +3 \quad (5.3)$$
(write separate terms)

$$= (1)(3)+(3)(3)+(3)(1) \quad (5.4)$$
(recombine terms)

$$= (1)(3)+(3)(4) \quad (5.5)$$
(complete manipulation).

This indicates a body cut of 4, 4, 4, 3 or 3, 4, 4, 4. Note again that a three-legger has been drawn in the upper left corner of the tapered piece. Note the three-legger in the jib cut piece also.

In a sense, tapering an exact mesh distance as in Figure 5(a) is akin to moving from a black square to a black square on a checkerboard. When tapering to a mesh which is a half-mesh distance away, as in Figure 5(b), one has a situation similar to moving from a black square to a red square.

The process just described can be generalized. Equations (6.1) through (6.6) show the general processes illustrated in equations (3.3) through (3.10), (4.0) through (4.6), and (5.0) through (5.5). We begin by writing total steps as:

$$T=P(S-1)+R, \quad (6.1)$$

where T = total steps,
P = points,
$S-1$ = steps/points, and
R = steps remainder.

If one rewrites equation (6.1) as

$$T = (P-R+R)(S-1)+R, \quad (6.2)$$

and letting $U = P-R$ and

$$T = (U+R)(S-1)+R, \quad (6.3)$$

then

$$T = U(S-1)+R(S-1)+R \quad (6.4)$$

$$= U(S-1)+R(S)-R(1)+R \quad (6.5)$$

$$= U(S-1)+R(S) \quad (6.6)$$

which is the same as expression (1.2) presented earlier.

Therefore, to reckon any taper, one must first express it in the form of equation (6.1). By simple substitution, one determines $U = P-R$ and writes equation (6.6) directly. For instance, for body cut A to B in Figure 5(a), from equation (2.2) and (2.3), we have:

$$14 \text{ steps} = \left[\begin{array}{c}4\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] + \left[2 \text{ steps remainder}\right] \quad (7.1)$$

which is the initial form (6.1). One now finds $U = P-R = 4-2 = 2$ points.

Therefore,

$$14 \text{ steps} = \left[\begin{array}{c}2\\ \text{points}\end{array}\right]\left[\begin{array}{c}3\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] + \begin{array}{c}2\\ \text{points}\end{array}\left[\begin{array}{c}4\\ \text{steps}\\ \text{per}\\ \text{point}\end{array}\right] \quad (7.2)$$

which is in the general form (6.6). Any taper may be expressed in this way. Basically, to determine a taper, one must know m and n. Then one can write the taper in the general form of equation (6.1), and by a simple substitution, (finding $U = P-R$) write the taper in final form (6.6).

For the sake of brevity, let us agree to describe a taper going a whole mesh distance, where m and n are both whole numbers, as "condition BB" (for black to black) and a taper going a half mesh distance, where m and n are both whole numbers plus one half, as "condition BR" (for black to red).

To further illustrate the use of general formula (6.6) in the reckoning of tapers, consider body cut A to B in Figure 6. For this cut, $n = 21$ and $m = 7$, with "condition BB,"

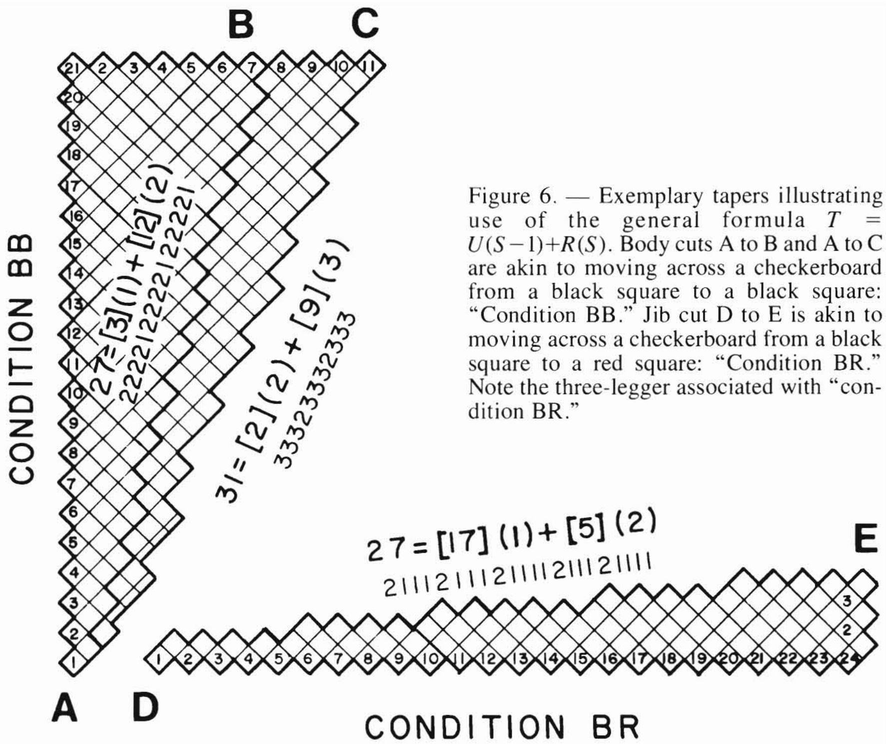


Figure 6. — Exemplary tapers illustrating use of the general formula $T = U(S-1)+R(S)$. Body cuts A to B and A to C are akin to moving across a checkerboard from a black square to a black square: "Condition BB." Jib cut D to E is akin to moving across a checkerboard from a black square to a red square: "Condition BR." Note the three-legger associated with "condition BR."

$$T = n+m-1 = 21+7-1 = 27 \text{ total steps} \quad (8.1)$$

and

$$P = n-m+1 = 21-7+1 = 15 \text{ points.} \quad (8.2)$$

From equation (6.1), we now write:

$$27 = (15)(S-1)+R. \quad (8.3)$$

The largest whole number to divide 27 by 15 is $(S-1) = 1$, so

$$27 = (15)(1)+R, \quad (8.4)$$

and $R = 12$. Since $(S-1) = 1$, $S = 2$.

$$\text{And, } U = P-R = 15-12 = 3, \quad (8.5)$$

$$\text{then } 27 = (3)(1)+(12)(2) \quad (8.6)$$

which is in the general form of equation (6.6). This expression implies a sequence 2, 2, 2, 2, 1, 2, 2, 2, 2, 1, 2, 2, 2, 2, 1 as illustrated in Figure 6. Note in expression (8.6) that there is a common factor, 3, of U and R:

$$27 = (3)(1)+(12)(2) = 3[(1)(1)+(4)(2)] \quad (8.7)$$

By finding a common factor, one can express the taper as a repeat pattern. Again in Figure 6, for the body cut A to C,

$n = 21$, $m = 11$, with "condition BB,"

$$T = n+m-1 = 21+11-1 = 31 \text{ total steps,} \quad (9.1)$$

and

$$P = n-m+1 = 21-11+1 = 11 \text{ points.} \quad (9.2)$$

From equation (6.1) we now write

$$31 = (11)(S-1)+R. \quad (9.3)$$

The largest number to divide 31 by 11 is $(S-1) = 2$, so

$$31 = (11)(2)+R \quad (9.4)$$

and, $R = 9$. Since $(S-1) = 2$, $S = 3$.

$$\text{And, } U = P-R = 11-9 = 2. \quad (9.5)$$

Then $31 = (2)(2)+(9)(3),$ (9.6)

which is the general form of equation (6.6). Note that here 2 and 9 have no common factors. The taper could be expressed as 3, 3, 3, 2, 3, 3, 3, 2, 3, 3, 3 as illustrated in Figure 6.

At this point one can express any taper in the general form of equation (6.6). As was seen in the preceeding example of Figure 6, body cut A to B, a common factor existed, 3, which simplified specifying the numerical sequence. In body cut A to C, no common factor existed.

To reckon a taper, after expressing it in the general form of equation (6.6), one looks for a common factor of U and R. One could rewrite general equation (6.6) as:

$$T = F\left[(U')(S-1)+(R')(S)\right], \quad (10.1)$$

where F is a common factor of U and R, such that $U = F \times U'$ and $R = F \times R'$.

Once the taper is expressed in this form, as it was in equation (8.7), the sequence is usually determined by inspection and written directly. If, for example, one had determined a general form expression of

$$335 = (40)(4)+(35)(5), \quad (10.2)$$

one could factor out a 5, which is a common factor of 40 and 35 so that

$$335 = 5\left[(8)(4)+(7)(5)\right], \quad (10.3)$$

which is in the form of equation (10.1) above. Therefore, there are 5 repeats of the pattern: 4, 5, 4, 5, 4, 5, 4, 5, 4, 5, 4, 5, 4, 5, 4.

When U' and R' of equation (10.1) are large numbers, it is sometimes difficult to write the sequence by inspection. Suppose one had the final expression

$$540 = 20\left[(17)(1)+(5)(2)\right]. (10.4)$$

To arrange a sequence of seventeen 1's and five 2's by inspection takes a bit of numerical juggling. However, an explicit procedure is available using ordinary graph paper. If one sets up a regular Cartesian coordinate system with U' and R' plotted as, respectively, abcissas and ordinates, the correct sequence can be specified by writing S or $S-1$ in the order by which the graph lines are crossed on the line connecting U' and R' (on their respective axes). This process is illustrated in Figure 7(a). Note that $U' = 17$ and $R' = 5$ have been plotted respectively as abcissas and ordinates, and a line $U'R'$ has been drawn between them. Note also that along the line, each time it crosses a graph line, a 1 or 2 is written depending on whether it crossed a vertical or horizontal line. In this case we have: 1, 1, 1, 1, 2, 1, 1, 1, 2, 1, 1, 1, 1, 2, 1, 1, 1, 2, 1, 1, 1, 2.

By letting $F = 1$, this sequence is illustrated in jib cut D to E in Figure 6. (I have drawn the sequence starting with a "2", that is, by reading the above sequence from right to left, so as to avoid starting the taper with four single meshes.) Note that taper D to E represents "condition BR." In Figure 7(b) another example is presented. Consider the following taper:

$$226 = 2\left[(7)(4)+(17)(5)\right]. (10.5)$$

The "graph paper technique" in this case yields two repeats of the sequence: 4, 5, 5, 4, 5, 5, 4, 5, 5, 5, 4, 5, 5, 4, 5, 5, 5, 4, 5, 5, 4, 5, 5, 5. To cut such a taper in real webbing without making a mistake somewhere would be an endurance contest at best. In practice, it would probably be advisable to modify the net plan somewhat to avoid such a complicated sequence. In any event, the graph paper technique works well enough and could easily be expressed as an algorithm suitable for inclusion in a computerized routine. (Refer to subroutine ORDER, described in Martin and Recksiek (1983).)

Cutting Out Trawlnet Sections

So far we have discussed the process of describing tapers as determined by whole-number arithmetic expressions. At this point, methods of shaping some specialized trawlnet sections will be presented. I do not intend to cover procedures for most possible net sections; rather, by detailing an approach to certain specific types, I leave it to the readers to devise their own methodology for their special needs. In particular, I will discuss the trapezoidal shapes of squares and bellies, and some quadrilateral wing shapes. All equations used in this topic area are summarized in Table 1.

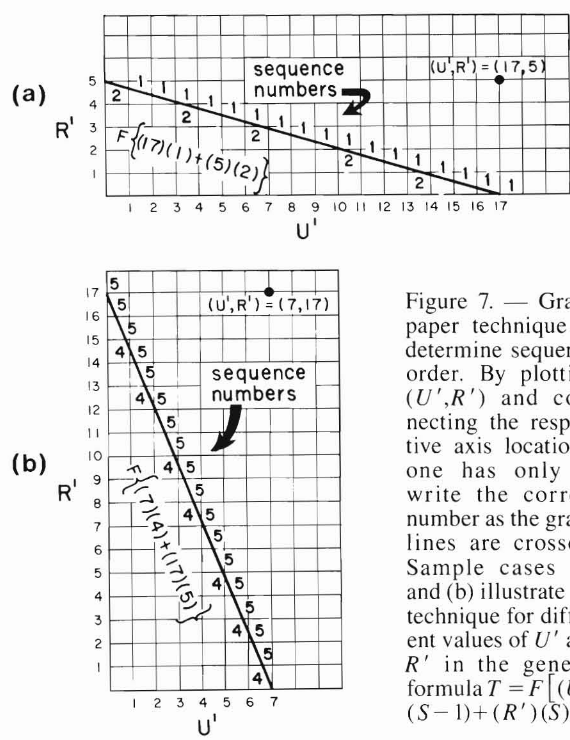


Figure 7. — Graph paper technique to determine sequence order. By plotting (U',R') and connecting the respective axis locations, one has only to write the correct number as the graph lines are crossed. Sample cases (a) and (b) illustrate the technique for different values of U' and R' in the general formula $T = F\left[(U')(S-1)+(R')(S)\right]$.

The primary motivation for this section is to aid the net planner. By being given certain section dimensions in numbers of meshes, the net planner must be able to correctly determine the taper (the number sequence). A secondary but very important motivation in this presentation is to cut the webbing so waste is minimal. Thus the ensuing discussion will continually stress procedures for making the most of the available webbing.

Squares, Bellies and Extensions

A square, belly, or extension section of a trawlnet is in the shape of a trapezoid. The cutting procedure is illustrated in Figure 8 for "condition BR" and "condition BB." Also illustrated are small trapezoids which represent the sections on a net plan.

The net plan will give us the dimension of the section in terms of meshes. Let k = meshes along the narrow end, t = meshes along the wide end, and n = meshes deep.

The basic procedure is to start with a rectangular piece of webbing, cut off a tapered piece, and sider it to the other

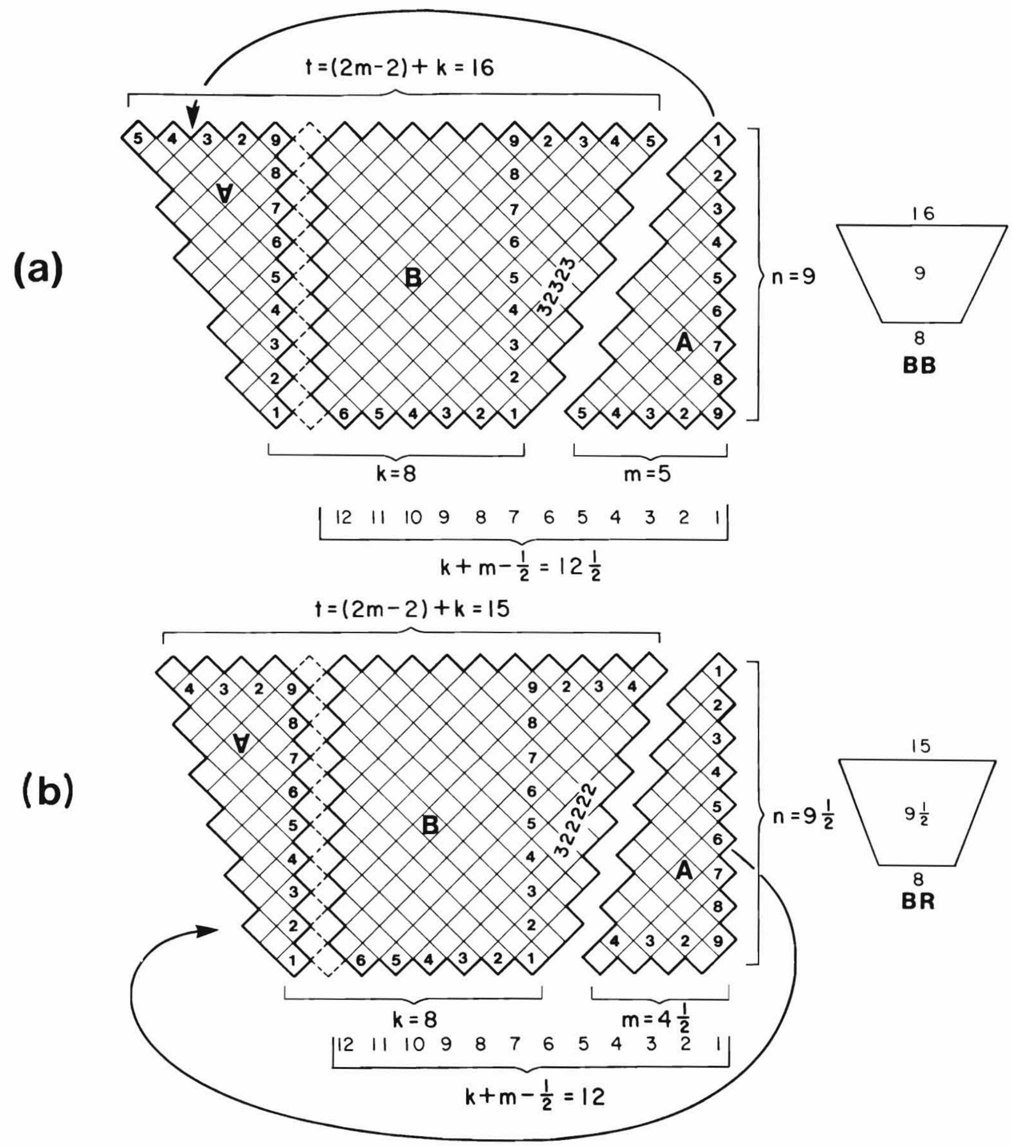


Figure 8. — Exemplary trapezoidal square, belly, or extension sections. Net plans and cutting procedure are illustrated for sections for (a) "condition BB" and for (b) "condition BR." The section dimensions are given as: t, meshes across top or wide end; k, meshes across bottom or narrow end; n, meshes deep. Arrows indicate how webbing piece A is cut away from the rectangular parent piece (yielding B) to be sidered onto the other side of B to form the finished section.

side. The arithmetic involves using k, t, and n to determine m. Both n and m are as defined previously. These are then used to find the tapering expression (6.6) as also illustrated. Once the taper is determined, it only remains to cut out two tapered pieces from a single rectangular parent piece, reorient them, and sider them back together. The process is illustrated in Figure 8.

At this point the importance of recognizing a taper as "condition BB" or "condition BR" becomes clear. In "condition BB" the net builder must cut two three-leggers into one edge of the original piece, whereas in "condition BR" piece A and piece B each have their own three-legger. Study of Figure 8 should make the distinction clear to the reader.

Let us now go through the calculations required for "condition BB" for a section having dimensions $t = 16$, $k = 8$, and $n = 9$. The process is illustrated in Figure 8(a). The first step is to determine m by a specialized "belly top" equation,

$$t = (2m-2)+k. \qquad (11.1)$$

Substituting our values into this formula we have,

$$16 = (2m-2)+8 \qquad (11.2)$$

or, $m = 5$.

Since $n = 9$,

$$\frac{T}{P} = \frac{n+m-1}{n-m+1} = \frac{9+5-1}{9-5+1} = \frac{13}{5}. \qquad (11.3)$$

In the form of equation (6.1) we have,

$$13 = (5)(2)+3. \qquad (11.4)$$

This reduces to the final form of equation (6.6) as:

$$13 = (2)(2)+(3)(3) \qquad (11.5)$$

or a sequence of 3, 2, 3, 2, 3 as shown in Figure 8(a).

One cuts the tapers, from opposite directions, to leave pieces A and B. Piece A is slid around and sidered back onto B to form the finished section. Three-leggers on the left side of the original piece of webbing permit easy sidering back together. A final point is that the original rectangular piece of webbing had dimensions $(k+m-½) = 8+5-½ = 12½$ meshes by $n = 9$ meshes. Therefore, knowledge of m is not only necessary for correct tapering but for selection of an original piece of the correct minimum size.

The calculations and methodology for Figure 8(b) "condition BR" are similar to those just described. Given that $t = 15$, $k = 8$, and $n = 9½$, substituting these values into the specialized "belly top" formula (11.1) we have,

$$15 = (2m-2)+8 \qquad (12.1)$$

or, $m = 4½$. The fact that m is not a whole number confirms that the taper represents "condition BR." So, with $m = 4½$ and $n = 9½$,

$$\frac{T}{P} = \frac{n+m-1}{n-m+1} = \frac{9½+4½-1}{9½-4½+1} = \frac{13}{6}. \qquad (12.2)$$

In the form of equation (6.1) we have,

$$13 = (6)(2)+1. \qquad (12.3)$$

This reduces to the final form of equation (6.6) as:

$$13 = (5)(2)+(1)(3) \qquad (12.4)$$

or as a sequence of 3, 2, 2, 2, 2, 2 as shown in Figure 8(b). Just like "condition BB," one cuts two tapers from opposite directions. However, each new piece has its own three-legger. These three-leggers turn out to be in a correct location for sidering the pieces back together. A starting piece is required, having dimensions $(k+m-½)$ meshes by n meshes.

At this point the reader should note that in equation (11.1), m can take either 1) a whole number value or 2) a whole number plus one-half. In these examples, illustrated in Figure 8, m took exemplary values of 5 and 4½. It turns out that for "condition BB" belly sections, n and m are both whole numbers, whereas for "condition BR" belly sections, neither n nor m are whole numbers. This consideration becomes important when following a net plan. Such a plan may specify n, t, and k. If n is fractional, m, as determined by equation (11.1) must be fractional. If n is a whole number, m must be a whole number. If these conditions are not met, the section will lack symmetry. That is, the taper on one side cannot be the same as the taper on the other side. In actual practice, one would simply calculate m from equation (11.1). If both n and m were either fractional or not fractional, the net plan would need readjustment. (Refer to Figure 1, note 4, of Martin and Recksiek (1983) where net plan belly dimensions are subjected to a test for symmetry.)

A similar situation to that just described for Figure 8 is illustrated in Figure 9. Here two identical sections are cut from one rectangular piece of webbing. The dimensions of the finished sections are the same as those illustrated in Figure 8. Note that the dimensions of the original piece are $2(m+k)-½$ meshes by n meshes.

Trawl Wings

Figure 10 illustrates the cutting out of a pair of "condition BB" wings from a single rectangular piece of webbing. The wing has one side cut all bars. Note that n is the depth, 12 in this example. Letting $e = 11$, and $k = 18$ for the respective dimensions of narrow and wide ends, m is determined by a "wing" formula:

$$e = (k-n)+m. \qquad (13.1)$$

Substituting values into this formula we have

$$11 = 18-12+m \qquad (13.2)$$

or, $m = 5$

and, therefore,

$$\frac{T}{P} = \frac{n+m-1}{n-m+1} = \frac{12+5-1}{12-5+1} = \frac{16}{8}. \qquad (13.3)$$

This reduces to the final form of equation (6.6) as: $16 = (8)(2)$ or a sequence of 2, 2, 2, 2, 2, 2, 2, 2. The rest of the operation is as illustrated in Figure 10.

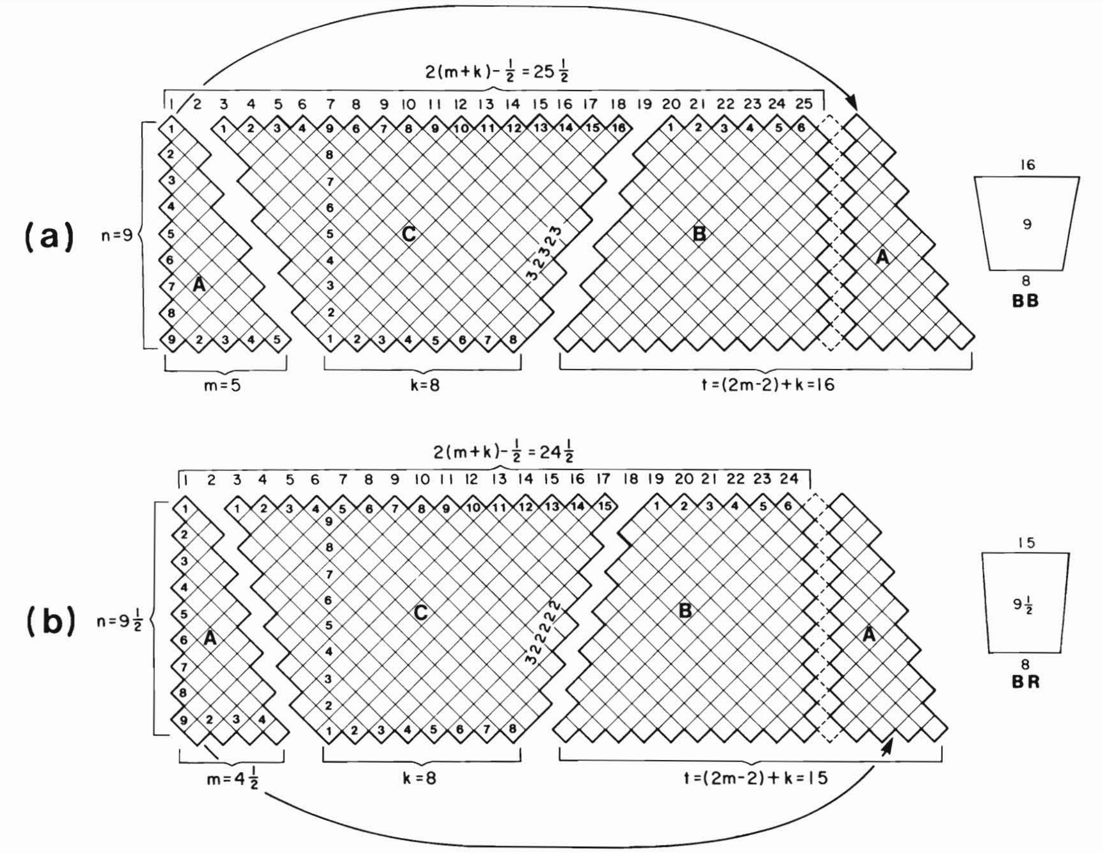


Figure 9. — Trapezoidal net sections illustrating the shaping of two finished identical pieces from the same rectangular piece of webbing. Net plans and cutting/fitting procedures are illustrated for (a) "condition BB" and for (b) "condition BR."

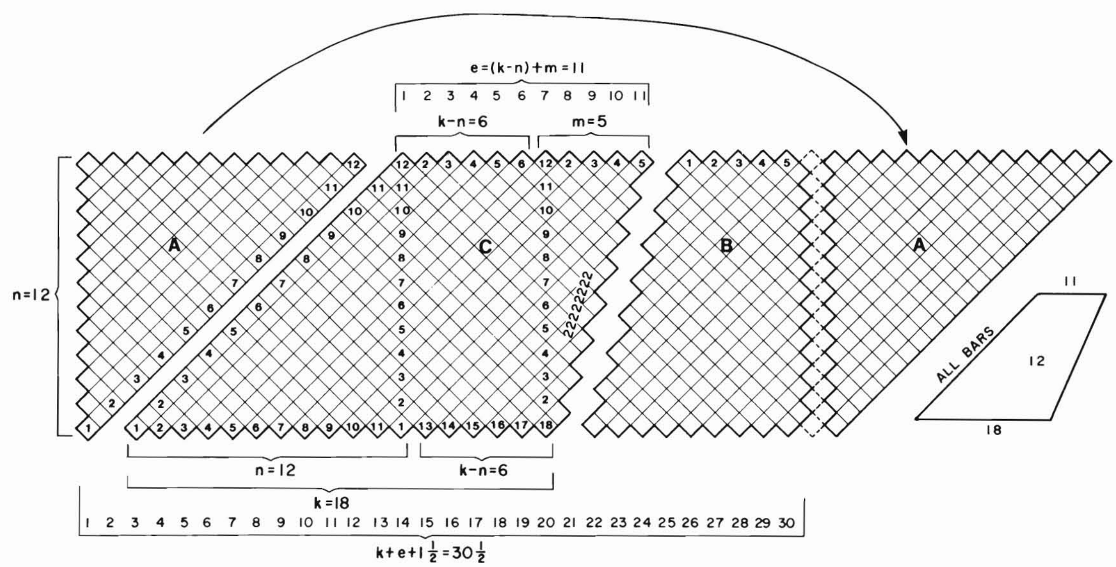
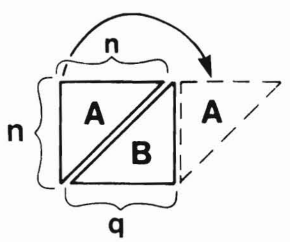


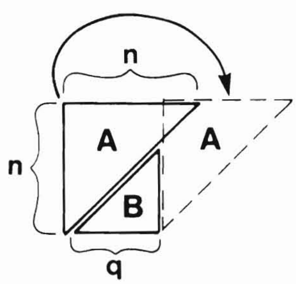
Figure 10. — Exemplary "condition BB" wing section assembly with net plan specifying wing dimensions.

The original webbing measured $(e+k+1\frac{1}{2})$ meshes by n meshes.

Practical difficulties may arise in cutting off a corner and sidering it onto the other end to form a parallelogram as was illustrated in Figure 10. There is a limit to the dimension of the top edge (or the side edge, n, which is the same) which must be considered. In the following diagram, note that piece A exactly fits back against piece B. Note too that $n = q$. This turns out to be the limit on the dimension of n for doing this kind of fit.



In the next diagram, observe that an exact fit cannot be made without waste, and $n > q$.



In Figure 11, the maximum value of n to make simple fits is illustrated. In this instance the top and bottom edges of the parallelogram are equivalent to $e+k$ ($e+k$ can be likened to q in the above diagram). For "condition BB," a simple fit can be made if $(n+1) \leq (e+k)$. Figure 11(a) illustrates this. Figure 11(b) illustrates a maximum of n for "condition BR." Here, a simple fit can be made if $(n+\frac{1}{2}) \leq (e+k)$.

In both Figures 10 and 11, observe that the bottom dimension of the original piece of webbing is given by $(e+k+1\frac{1}{2})$.

Figure 12 illustrates one possible strategy in building a pair of "condition BB" wings when $(n+1) > (e+k)$. There are certainly various means available to achieve minimal waste, and this example is but one. Note again that the parent piece has a bottom dimension of $(e+k+1\frac{1}{2})$.

Referring to Figure 12, to illustrate finding the depth from the net diagram, let us suppose that this time we are given e, k, and the taper. These are respectively, 3, 9, and "4 bars 1 point plus six sets of 3 bars 1 point." This, in our system, translates to 5, 4, 4, 4, 4, 4, 4, or,

$$29 = (6)(4)+(1)(5). \qquad (14.1)$$

This is changed to the form of equation (6.1):

$$29 = (7)(4)+1. \qquad (14.2)$$

The problem now is to find the depth, n. By expressions (1.3) and (2.1) we have a system of two equations in two unknowns which is solved by summing:

$$n+m-1 = 29 \qquad (14.3)$$
$$+n-m+1 = 7 \qquad (14.4)$$
$$2n = 36 \qquad (14.5)$$

or, $n = 18$. Note, too, that by solving expression (14.3) for m, we have $m = 12$. The piece can now be cut out and assembled.

Double tapers can also be made in wing sections. Figure 13 illustrates the forming of a double wing taper from a single rectangular piece of webbing. The net plan must specify e, k, and a taper along one edge. The problem is to reckon the second taper. To do this one uses a "double-taper wing formula" which is actually a generalization of formula (13.1):

$$e = (k-m_1)+m_2 \qquad (15.1)$$

with $m_1 > m_2$ (15.2)

where e and k are defined previously and m_1 and m_2 are horizontal mesh distances of the two tapers. The greater horizontal mesh distance, m_1, is associated with the taper closest to the diagonal. In expression (13.1), note that n plays the role of m_1 for the special case of cutting on the diagonal (all bars).

For example, in Figure 13(a) we are given $e = 7$, $k = 11$, the taper closest to the diagonal "four sets of 4B1P", or 5, 5, 5, 5, which translates to

$$20 = (4)(5). \qquad (15.3)$$

This is automatically in the form of equation (6.1) since $R = 0$, so by equations (1.3) and (2.1) we have

$$n+m_1-1 = 20 \qquad (15.4)$$
$$+n-m_1+1 = 4 \qquad (15.5)$$
$$2n = 24 \qquad (15.6)$$

or, $n = 12$. Solving equation (15.4) for m_1, we find $m_1 = 9$. Substituting values for e, k, and m_1, into equation (15.1) we have

$$7 = (11-9)+m_2 \qquad (15.7)$$

so $m_2 = 5$.

Now the wings can be shaped. Piece A is cut away and sidered back onto the parent piece. The parent piece will be, as before, $(e+k+1\frac{1}{2})$ meshes along the bottom. After A and B are sidered back together the second taper can be cut. This is reckoned in the regular way:

$$\frac{T}{P} = \frac{n+m_2-1}{n-m_2+1} = \frac{12+5-1}{12-5+1}$$
$$= \frac{16}{8} \qquad (15.8)$$

This reduces to the final form of equation (6.6) as:

$$16 = (8)(2). \qquad (15.9)$$

The tapers are now cut to form two identical wings, as in Figure 13(a). The "condition BR" example illustrated in Figure 13(b) is handled the same way. Here we are given $e = 5$, $k = 8$, and the taper closest to the diagonal "three sets of 4B1P plus 3B1P," or 5, 5, 5, 4.

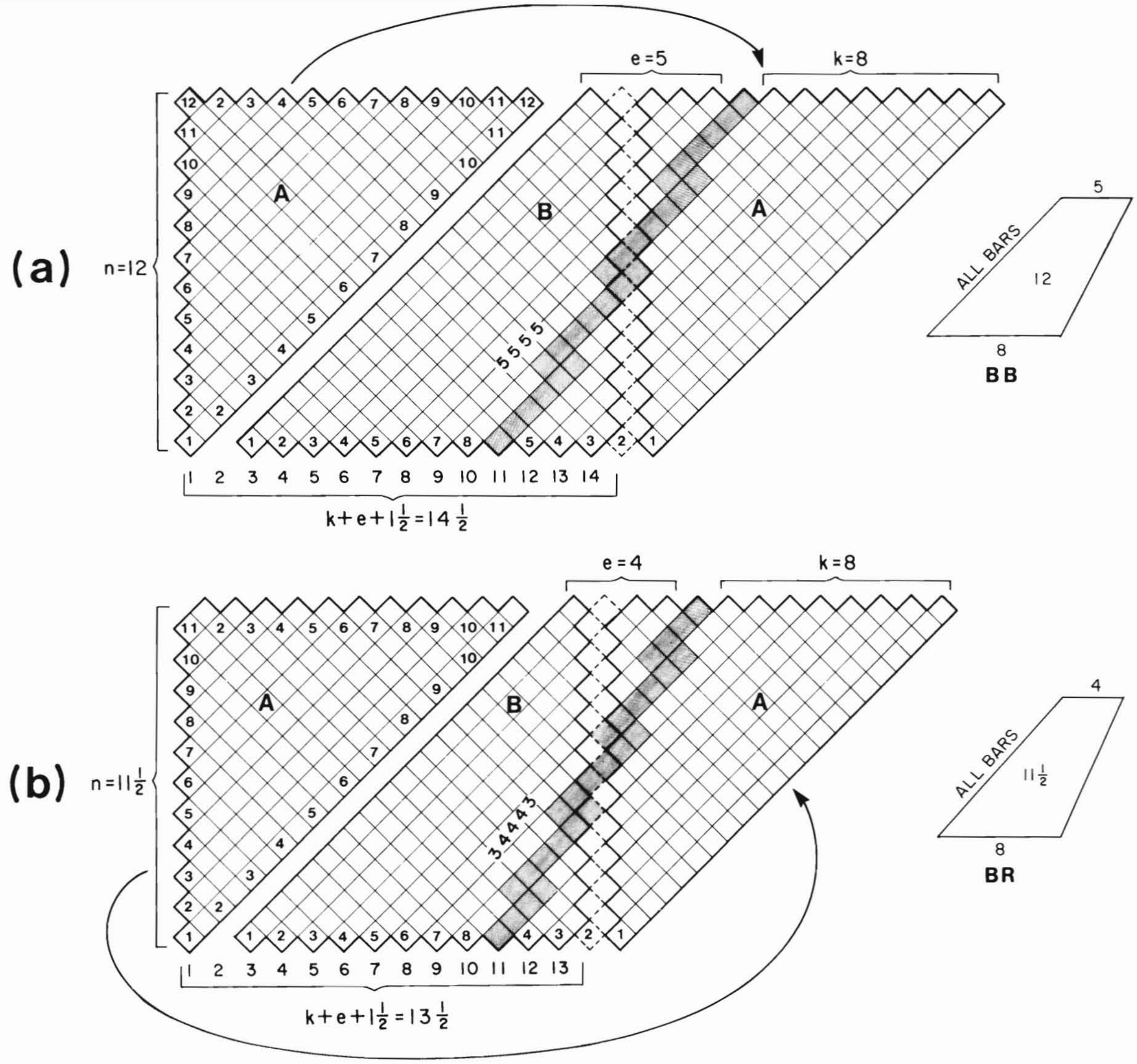
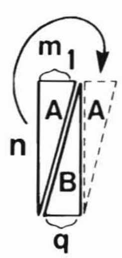


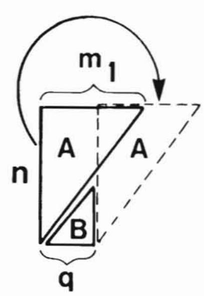
Figure 11. — Demonstration of the maximum value of n. (a) "Condition BB." In this case $(n+1) = (e+k)$. If $(n+1)$ exceeds $(e+k)$, the wing cannot be assembled this way. As with other examples, $(e+k+1½)$ meshes are required along the bottom of the parent piece. (b) "Condition BR." Here, $(n+½) = (e+k)$. If $(n+½)$ exceeds $(e+k)$, the wing cannot be assembled this way.

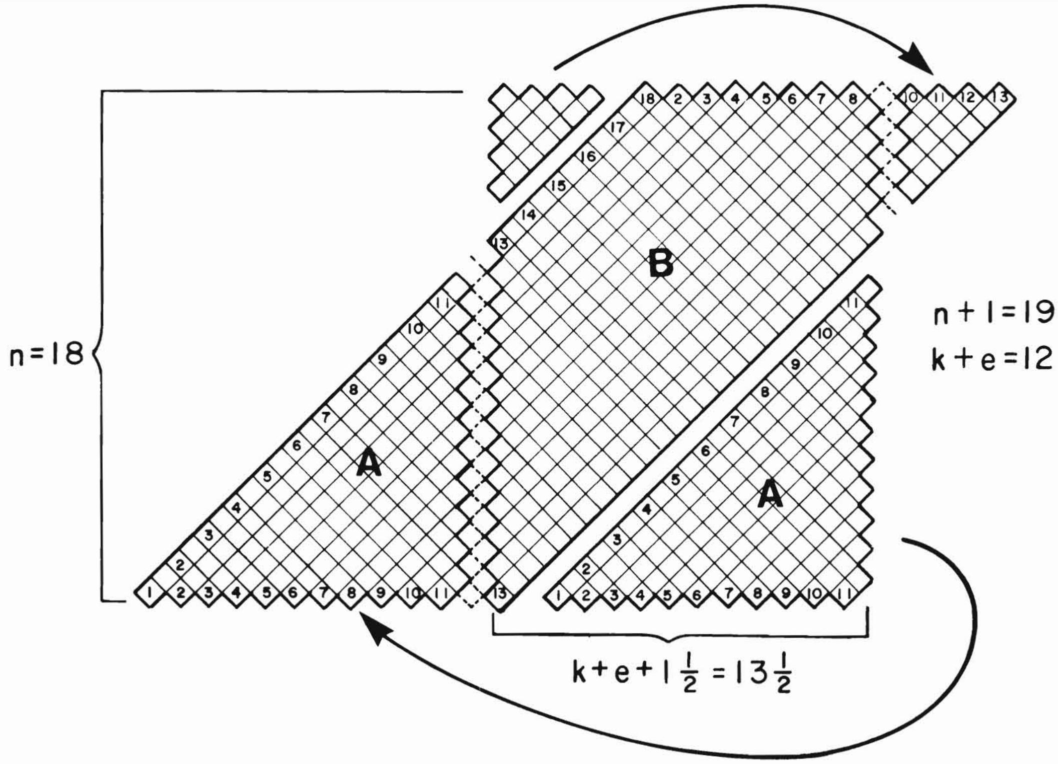
The remaining consideration is the difficulty which could be experienced when attempting to minimize waste by fitting from a single rectangular piece. In the following diagram, note that piece A fits exactly onto piece B; note also that $m_1 = q$; this turns out to be the limit on the dimension of m_1 for doing this kind of fit.



In the next diagram, $m_1 > q$ and the fit cannot be made this way without waste.

In light of previous discussions of fitting wings having one edge all bars, note that m_1 is taking the role of n in those earlier limits. The constraint, $(m_1+1) \leq (e+k)$, "condition BB," is therefore the general case and $(n+1) \leq (e+k)$ is a specific one for wings having





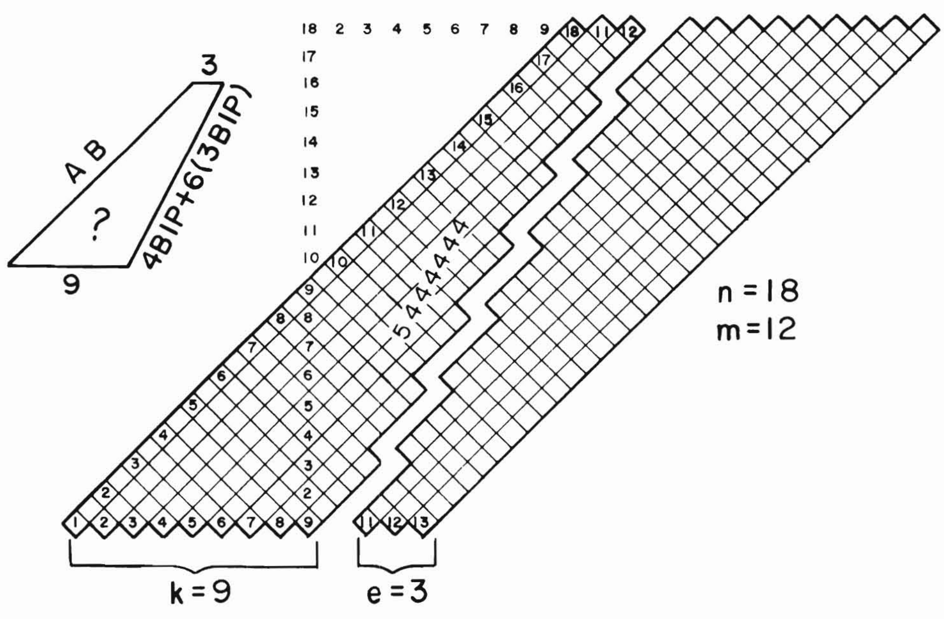


Figure 12.—Illustration of "condition BB" wing assembly when $(n+1) > (e+k)$. As with assembling wing sections using a single bar cut, $(e+k+1\frac{1}{2})$ meshes are required along the bottom. Note positions of three-leggers. Note the designation "4B1P+6(3B1P)" on the section plan. This is a shorthand for a taper of "4 bars 1 point plus six sets of 3 bars 1 point" or a tapering sequence of 5, 4, 4, 4, 4, 4, 4. For methodology of finding n knowing the taper, e, and k, see text.

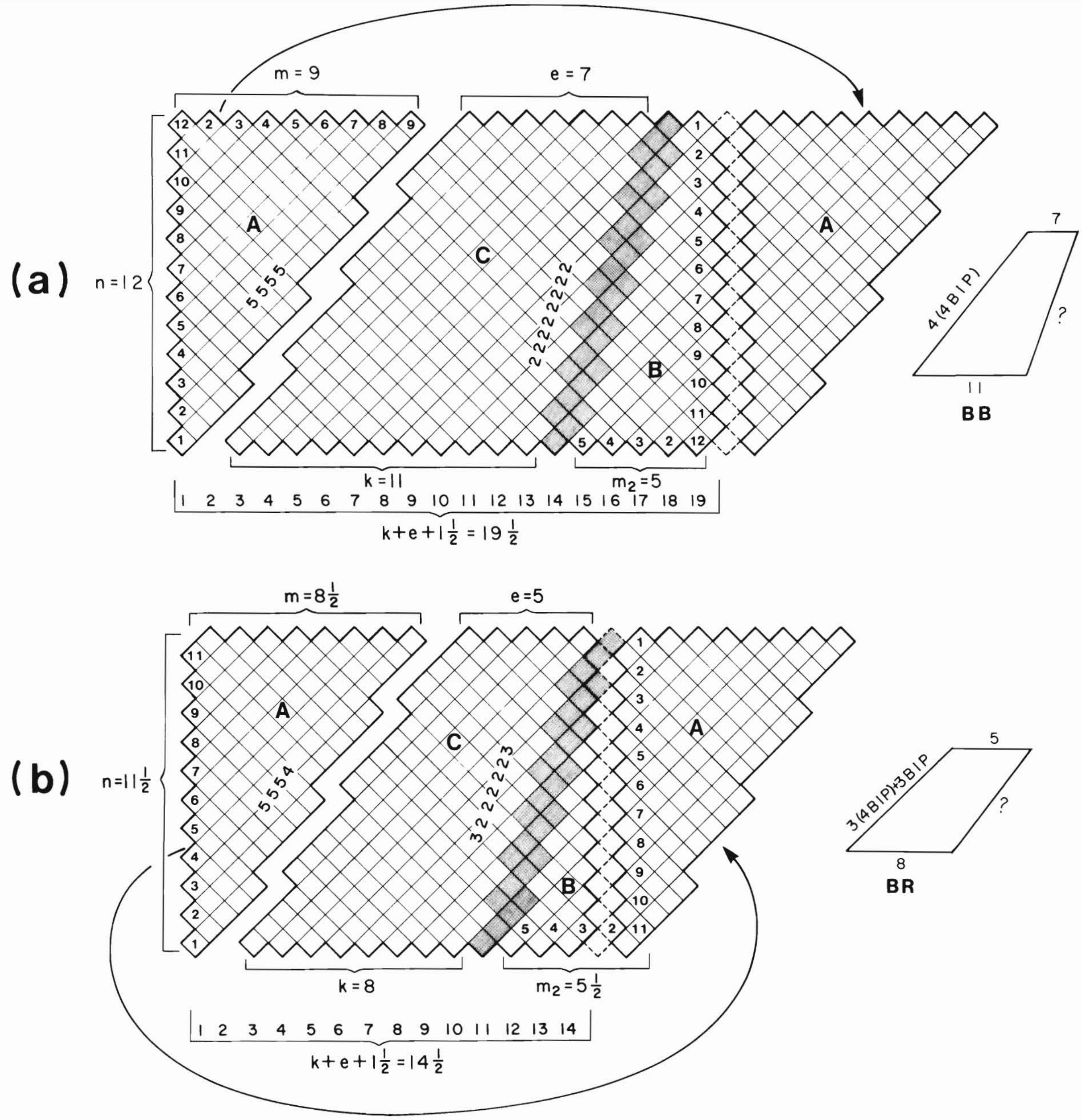


Figure 13. — Exemplary double wing tapers. In these cases the net plans give a taper along one edge. Piece A is taken off and sidered to the other side of the original piece of webbing. Then the second taper is cut across the joined piece to form pieces C and AB. Note that $(e+m_1) = (k+m_2)$. (a) Double taper, "condition BB." (b) Double taper, "condition BR."

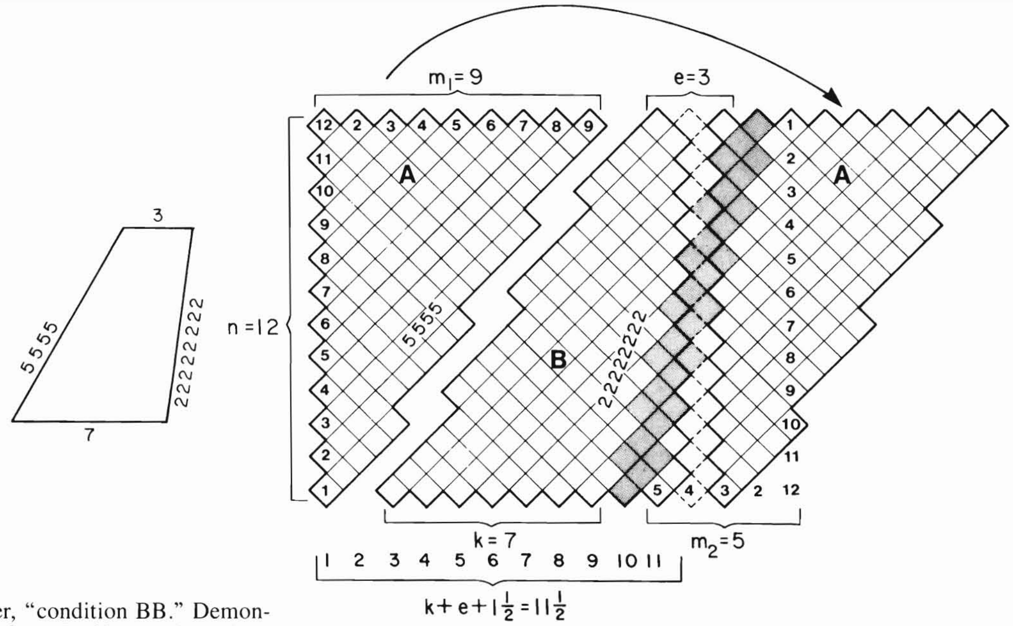


Figure 14. — Double wing taper, "condition BB." Demonstration of the maximum value of m_1. In this case $(m_1+1) = (e+k)$. If (m_1+1) exceeds $(e+k)$, the wing cannot be assembled this way. A strategy like that illustrated in Figure 12 is required. As with other examples, $(e+k+1\frac{1}{2})$ meshes are required along the bottom of the parent piece.

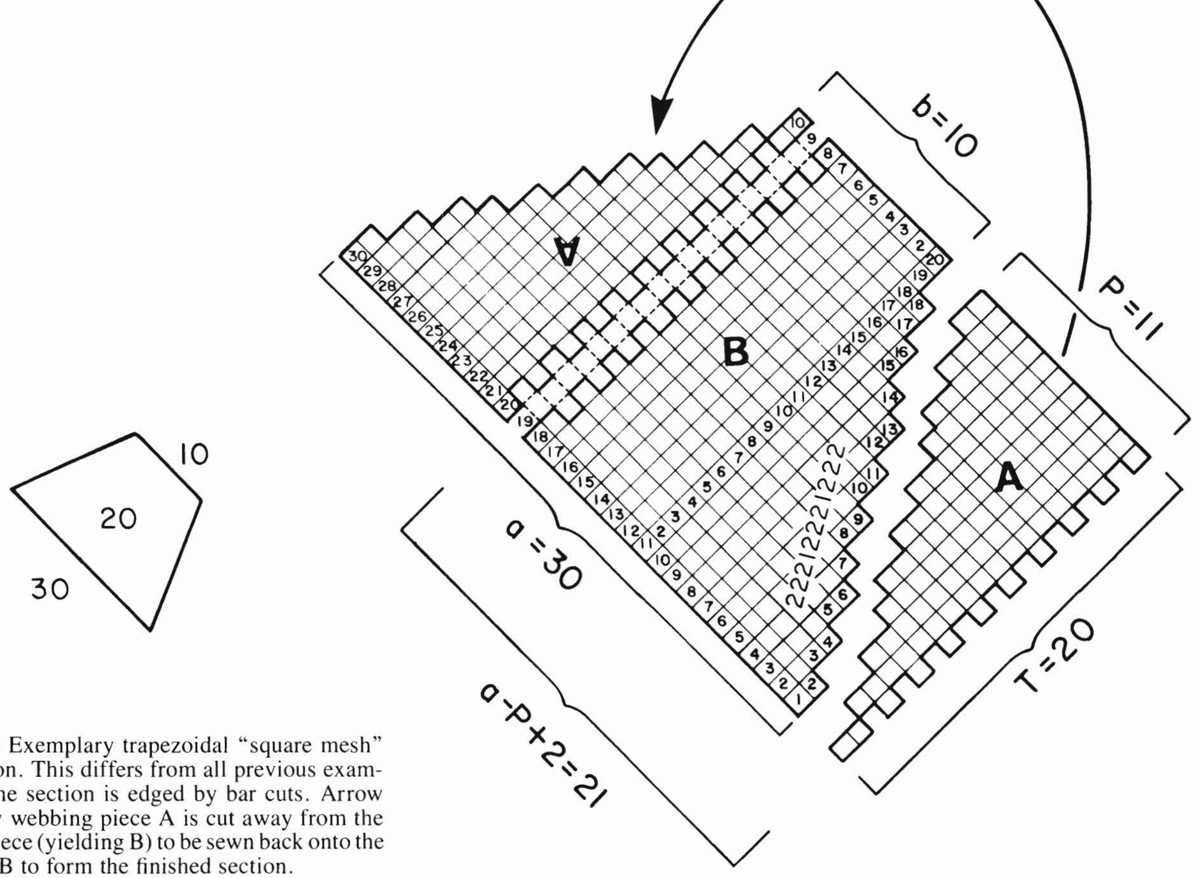


Figure 15. — Exemplary trapezoidal "square mesh" trap net section. This differs from all previous examples in that the section is edged by bar cuts. Arrow indicates how webbing piece A is cut away from the rectangular piece (yielding B) to be sewn back onto the other side of B to form the finished section.

one edge all bars. In Figure 14, "condition BB" wing tapers are presented with $(m_1+1) = (e+k) = 10$. For higher values of m_1, where $(m_1+1) > (e+k)$, the fits cannot be made as illustrated. A strategy like that illustrated in Figure 12 will be required.

Cutting Out Square Mesh Net Sections

One final consideration in applying the tapering principles presented here is that of a net section composed of "square meshes," as in a tennis net. Recent work by Robertson (1982) on square mesh codend design could be applied to net sections other than codends. Robertson's Figure 7 shows a trapezoidal upper codend section of square meshes. An example, a section from a Great Lakes trap net from Stewart and Visel[1], is pictured in Figure 15. In this case, letting $a = 30$ meshes along the wide end and $b = 10$ meshes along the narrow end, we have a shape like that of a trawl belly or extension section. The depth is given by $T = 20$ meshes. Note that the total number of steps required for the taper is equal to the depth (hence "T" as defined previously). The number of points, P, is given by a special square mesh belly formula:

[1] Stewart, L., and T. Visel. 1980. A guide to the construction of trap nets (Great Lakes Bar Type). Stationary gear workshop draft, 13 p. University of Connecticut Marine Advisory Service, Marine Science Institute, Groton, CT 06340.

$$P = (a-b)/2+1. \qquad (16.1)$$

Substituting values into this formula we have

$$P = (30-10)/2+1 = 11. \qquad (16.2)$$

In the form of equation (6.1), we have

$$20 = (11)(1)+9. \qquad (16.3)$$

This reduces to the final form of equation (6.6) as

$$20 = (2)(1)+(9)(2) \qquad (16.4)$$

or as a sequence of 2, 2, 2, 1, 2, 2, 2, 1, 2, 2, 2 as shown in Figure 15. Note that a starting piece having dimensions T meshes by $a-P+2$ meshes is required and that these dimensions are for webbing cut on the diagonal. The methodology of sewing the cut-off piece back onto the parent piece is similar to that of a belly section, the major difference being that it is done on the diagonal.

Conclusions

The cutting/assembling procedures for various net section types were each deduced by careful study of the problem at hand and applying the general tapering equations (1.3, 2.1, 6.1, 6.6, 10.1). Most tapering problems boil down to deducing m and n. The reader may wish to modify the numbering conventions and use accordingly modified equations.

Translation of the various equations into computer program algorithms is straightforward. The companion article "A microcomputer program for the calculation of a trawlnet section taper" (Martin and Recksiek, 1983), presents an example of that process for trapezoidal shapes.

Acknowledgments

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