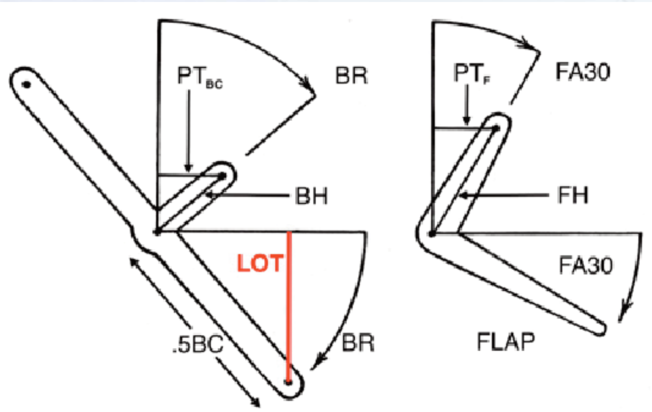
Flight Control System Thoughts

by Hube Start
MAAC 1335

The flight control system in a control line airplane utilizes forces, angles, and lengths in a way that can be fairly accurately designed and modified to suit your personal flying style, and the abilities of both plane and pilot. The obvious need to maintain adequate control throughout the PA pattern can be largely insured by properly sizing these components.

The normal 3G level flight tension along the control lines is considerably reduced while overhead. When turning the upper right corner of the hourglass, for instance, the less pull you have to exert on the down line, the crisper the turn without compromising line tension. This article will explain the process of maximizing this ability through the use of one basic equation to integrate the various elements.



$$\frac{4LOT}{BC} = \frac{FH}{BH} = \frac{\sin BR}{\sin FA}$$

LOT	Lead-Out Travel
PT	Pushrod translation
BC	Bellcrank width
BR	Bellcrank rotation angle
BH	Bellcrank horn
FA	Flap angle
FH	Flap horn
FA30	Flap angle 30º

The LOT equation shown above gives the relationship between the six basic variables of the flight control system. It gives the fundamental geometric relationship only, and doesn't address other variables, such as bellcrank positioning, pushrod angles, etc., that others have documented over time. Lead-Out Travel (LOT) is the extent of motion of either leadout from neutral at a flap angle of 30º.

Control surfaces are often made to move much more than this, but 30º was chosen as a standard to compare LOT values between different setups. The equation has three elements, with any two used at a time to solve for the various values. The reference is to a flap angle, but if there are no flaps, use EA instead for elevator angle. Elevators are ignored in the calculations, since a 1:1 flap/elevator ratio is common and gives identical deflection. The 1:1 ratio, of course, is often later adjusted as part of flight trimming.

Modern PA designs with somewhat further aft CG's, longer tails, slightly smaller control surfaces, and increased tail volumes are capable of performing the pattern with control surface deflections of 15 - 20º for rounds, and 20 - 25º for squares. With optimized layout and balance, this allows for designing and building in a structural maximum of around 30 - 35º of up or down control surface deflection. It can be seen from the use of the equation that these lower structural deflection maximums allow for higher values of LOT (mechanical advantage).

There have been articles in various media over the years to describe the "Netzeband Wall," and how it can be limiting to effective flight control. They showed how pulling on either line during flight to move the control surfaces against air loads can use up the available centrifugal force on one line only, leaving the other line slack.

They also indicate how, under certain conditions, a heavier airframe could outperform a lighter one, and how an increase in mechanical advantage against air loads could help keep the Netzeband Wall at bay. This article will re-visit the LOT concept published 20 years ago, and show as well how to approximate a starting point for line spacing at the handle.

Good mechanical advantage is obtained by using a smaller force acting over a greater distance to do the same work as a greater force acting over a shorter distance. For control line flying, this allows for the lines to move back and forth through a greater distance, with less force acting on each line, so that the centrifugal force available during maneuvers is shared more equally by each line.

Moving the flaps up or down to a reference angle of 30º should result in at least 1 to $1^3/_4$ inches of movement of either leadout from neutral where they exit the wingtip. This can be determined as well from the LOT equation when any three of the other variables are known.

Mechanical advantage in operating the controls is directly related to LOT and is increased by these three items: a wider bellcrank (BC), a shorter bellcrank horn (BH), and a taller flap horn (FH). Think of the basic flight control system as consisting of this central group of three variables: BC, BH and FH. To maximize mechanical advantage is to essentially have the bellcrank rotate as much as possible, and the control surfaces to deflect as little as possible.

The use of too high an LOT can sometimes pose a problem. This can be seen in the case of a 4-inch bellcrank using an LOT of 2 inches. As a result, the bellcrank must rotate fully 90º to move the flaps to only 30º. For a 4-inch bellcrank, a more practical limit for LOT of about 1.8 inches provides a more workable bellcrank rotation angle of 80º, giving a fairly ample flap angle of 33º. Similarly, when using a 3-inch bellcrank, the practical limit of LOT drops to about 1.4 inches for the same angles of 80 and 33.

Note that the lengths of the horns that attach on each end of the flap to elevator pushrod have no effect on LOT. Keep them both the same length if using a 1:1 ratio, and as long as reasonably possible in order to reduce both pushrod load and bearing wear.

The 4-inch bellcrank is a special case, in that the FH/BH ratio always has the same numerical value as the desired LOT, simplifying the calculation. For example, if you choose to build in a particular LOT of 1.5 inches, and will be using a 4-inch bellcrank, then FH should be made $1^1/_8$ inches if BH is ¾ inch, or ¾ inch if BH is ½ inch, or any other combination of different lengths you choose for this pair of horns. It is only the ratio of FH/BH that matters, and not their actual lengths.

The following shows one use of the

LOT equation when analyzing the control system. You may have a 4-inch bellcrank which is able to rotate 60º from neutral before encountering structure, and the BH happens to be 7/8 inch. To have good mechanical advantage, you decide to build in an LOT of say 1.5 inches. With this data then, you'll be able to make the

flap horn FH to the proper length. By using the equation: 4LOT/BC = FH/BH, 4 x 1.5/4 = FH/(7/8), and FH solves for 1.3125 inches or 1 5/16 inches. Also from the equation, FH/BH = sinBR/sinFA. This shows that FA solves for an ample 35.3º from neutral.

By inserting different values for the six variables in the equation, you'll discover that different combinations can provide the same LOT. You may also find that a large bellcrank doesn't necessarily produce a higher LOT. For example, a 3-inch bellcrank with BH = 5/8 inch and FH = 1 1/8 inches yields an LOT of 1.35 inches. A 4-inch bellcrank, however, with BH = .9 inch and FH = 1 inch drops the LOT to 1.11 inches. This, however, is not to suggest that a 3-inch bellcrank is preferable, since in combination with a higher FH/BH ratio, the 4-inch bellcrank is more often a better choice.

Line spacing LS at the handle may also be pre-set before further adjustments are made to it during flight trimming. In this calculation, two approximations are made. One is the flap angle FA required for the square corner, and the other is the preferred handle angle HA that would comfortably give that angle. A square corner has been shown to require about 20° - 25º in a

Angle / sin	Angle / sin	Angle / sin
30 .500	48 .743	66 .914
32 .530	50 .766	68 .927
34 .559	52 .788	70 .940
36 .588	54 .809	72 .951
38 .616	56 .829	74 .961
40 .643	58 .848	76 .970
42 .669	60 .866	78 .978
44 .695	62 .883	80 .985
46 .719	64 .899	82 .990

proper setup, say 23º for the calculation, and a handle angle of 35º is fairly nominal. The equation then for line spacing is as follows: LS = BC x FH/BH x sinFA/sinHA. Inserting the data from the example above, LS = 4 x 1.31/.875 x sin23/sin35 = 4.1 inches. In this case, a 4-inch handle makes a good starting point. Note that adjustments made at the handle have no effect on LOT. Closer handle line spacing simply reduces sensitivity and over-controlling by requiring the hand to turn through a greater angle for a given control surface deflection.

Finally, maintain a record of the LOT equation. Higher values of LOT, generally between 1 inch to 1.75 inches, will provide better mechanical advantage with less individual line pull for a given control surface deflection. You'll find that higher bellcrank angles of 70 or 80º are not generally required for optimum results. For example, a 4-inch bellcrank at only 60º rotation will easily get the flaps to 35º with a good LOT of 1.5 inches. Decide how much mechanical advantage you would like by first choosing a value for LOT, then use the equation to accurately lay out your control system to give you that result. SN

Extra items and derivations:

1. LOT Equation: $PT_{BC} = PT_F$ = BH x sinBR = FH x sinFA30
Since sinBR = LOT/.5BC, and sinFA30 = .5, then FH/BH = LOT/.5BC/.5 = 4LOT/BC

2. Line Spacing: since LOT = .5BC x sinBR = .5LS x sinHA, and sinBR = FH/BH x sinFA
then **LS = BC x FH/BH x sinFA/sinHA.**

3. Airplane Velocity: from $V = 2\prod R/T$, V_{FPS} **= 6.28R/T** or V_{MPH} **= 4.28R/T**

4. Line Pull: since $V = 2\prod R/T$ and m = W/32.2 x 16
then $F = mV^2/R = W4\prod^2 R^2/(16 \times 32.2 \times T^2 R)$, F_{LBS} **= .077WR/T²**

5. 3G Lap Time: T^2 = **.4R** Bill Netzeband pointed out the importance of 3G flight based on lap time T and radius R, where adequate centrifugal force at the handle should be 3 times the weight of the airplane. R = official line length + 2 ft. arm extension. Note that airplane weight is not a factor. Cf. SN Mar/Apr05 p.50

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