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ALGEBRA AND AIR REFUELING

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As boom operators, one could argue that our most important task (other than maintaining safety) during air refueling is keeping the receiver inside of the air refueling envelope. After all, if we can't maintain contact, we can't offload fuel.

To assist us, Boeing designed the pilot director light system and also provided us with position indicators that allow us to know a receiver's exact location in the envelope. During EMCON 2 operations, we rely solely on the pilot director lights to provide information to the receiver pilot. At other times, for example during training, we use EMCON 1 procedures. During EMCON I, the pilot director lights, along with other visual references that receiver pilots use during closure and contact will still be the pilot's primary means of position information, however, sometimes it becomes necessary to give verbal corrections. In some cases verbal corrections can be the most effective method of insuring the receiver stays within the prescribed envelope, especially for those receiver pilots who have not developed an effective scanning system that inputs all reference information and identifies trends in motion, or for those receivers that have different limits than those displayed by the pilot director lights (such as fighters, KC-10's, etc.).

We know that the air refueling manual tells us that we have to "inform the receiver of corrections necessary to stay within the air refueling envelope unless radio silence is being utilized" and that "direction will precede distance," but when to give a correction has sometimes been a matter of debate. It's often a "rate of motion" matter. At other times it's not as simple to determine when a correction is necessary. Rate of motion is usually easy; if the movement looks too excessive, then it probably is. When rate is not a concern, should you begin giving corrections at 2, 4, or 6 degrees?

If we look at the pilot director light system, the lights will not indicate a change until the receiver has moved more than a foot in telescoping or more than four degrees in elevation (from the optimum of 0 deg. azimuth; 30 deg. elevation; and 12 ft. extension. See T.O. 1-1C-1-3, page 1-8, fig. 1-3). This fact, combined with the point that four degrees is about halfway to the limit, makes sense as a reasonable place to give a correction.

Armed with some free time and an interest in finding out just how large a given displacement was for a given amount of degrees, I used some basic math to derive the formula "d=2*pi*r*angle/360 " and to determine the values. As an example, let's see how big of a movement a receiver actually makes to change elevation (or azimuth) two degrees while at 12 ft. extension, given: pi=3.14; r=27.7 ft. (length of the boom) +12 ft. (extension of the boom)=39.7 ft.;angle=2 deg.; then:

d = 2*pi*40*2/360 = 1.4 ft. of movement

A 4 degree movement at the same extension would be 2.8 ft., a 6 degree movement would be 4.2 ft., and an 8 degree movement would be 5.5 ft. (see table 1).

What's the whole point of this? Merely to point out that corrections in azimuth or elevation of small amounts (such as two degrees) are almost pointless because the magnitude of the movement is less than one and a half feet! Imagine trying to move a 380,000 lb. airplane with sluggish controls a foot and a half! This supports the argument that 4 degrees is a good place to begin giving corrections.

One last item that it is important to discuss is the interrelationship of movement when dealing with an angular system like the boom. You should realize that a linear movement along one axis will also cause movement along another axis. Most receiver pilots know this, and are quite proficient in moving in arcs (see figure 1). A good example of how this can become dangerous is the classic "receiver low and close in the envelope" scenario. Imagine you've got a B-52 at 39 degrees elevation and 9 ft. extension. What would be the best correction to give? Some booms with less experience will invariably see the receiver as very low in the envelope and give an "up" correction. Experienced booms will realize that an improperly made correction (one in which the receiver moves only up) will compress the boom and may even cause metal to meet metal. In this case, the receiver would have compressed the boom into about five feet extension! Giving a "back 3" correction would have changed the elevation to 36 degrees, again, assuming the receiver moved in one direction only. In case you're interested, the size of the air refueling envelope is about 12 ft. by 12 ft. at the inner limit, 12 ft. long, 14 ft. by 14 ft. at 12 ft. extension, and 16 ft. by 16 ft. at the aft limit (see figure 2).

During your next air refueling, think about the verbal corrections you give. Be sure the corrections are necessary, timely, and also realize that they may not have the exact effect you thought they would.

FORMULAE:

1. To find the actual displacement for a given change in degrees azimuth or elevation for a given length :

Where: **Length** = extension (telescoping) + 27.7 (length of boom)
pi = 3.14
angle = degrees of change (in azimuth or elevation)
d = the actual displacement in feet that would be moved for the given

$$d = \frac{2(pi)(L)(angle)}{360} \quad \text{or} \quad d = \sin(angle)(L)$$

Based on: C=2(pi)r, d=%C or d=angle/360 OPP = sin(ang)HYP

2. To find the the change in telescoping (compression or extension) of the boom for a given change in azimuth or elevation :

Where: **Lo** = origninal length; extension (telescoping) + 27.7 (length of boom)
a = original angle
b = new angle
Length = new total length (to find extension, subtract 27.7)

$$\textbf{Length} = \frac{\textbf{(cos a) (Lo)}}{\textbf{cos b}}$$

Based on : ADJ = cos(ang) HYP and $\text{HYP} = \frac{\text{ADJ}}{\cos(\text{ang})}$ *Substituting*, $\text{HYP} = \frac{\cos(\text{ang.orig})(\text{HYP})}{\cos(\text{ang new})}$

3. To find the elevation or azimuth change for a given change in extension (telescoping) :

Where: **Lo** = original length (length of boom; 27.7; + telescoping)
Ln = new length (extension of boom + 27.7)
a = the original angle
b = the new angle

$$\textbf{sin b} = \frac{\textbf{sin(angle original) (Lo)}}{\textbf{Ln}}$$

Based on: OPP = sin(ang)HYP and sin(ang) = OPP / HYP

Substituting, sin (ang x) = sin(orig. ang.)HYPold / HYPnew

Table 1.

TABLE OF DISPLACEMENT
(FEET EXTENSION vs. DEGREES AZIMUTH OR ELEVATION)

Extension (ft.)

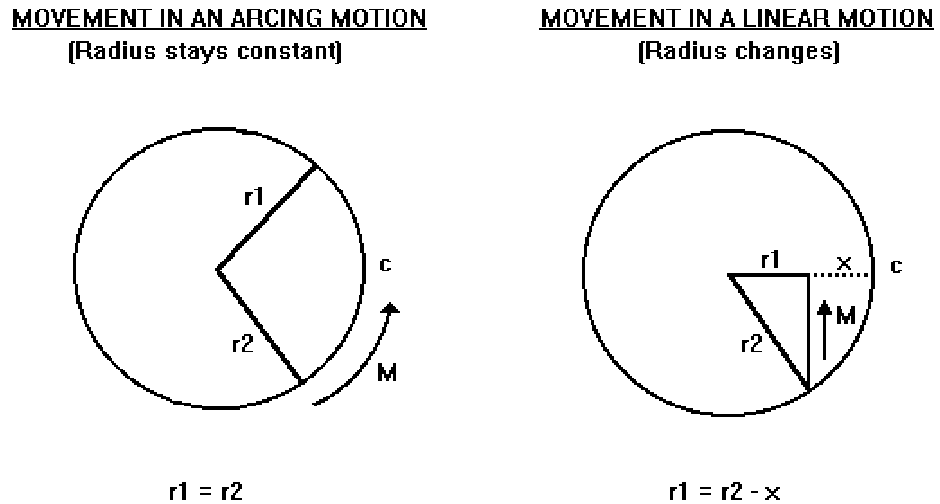
DEGREES AZIMUTH OR ELEVATION	6	7	8	9	10	11	12	13	14	15	16	17	18
1	.5	.6	.6	.6	.7	.7	.7	.7	.7	.7	.8	.8	.8
2	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.5	1.5	1.5	1.6	1.6
3	1.8	1.8	1.9	1.9	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4
4	2.4	2.4	2.5	2.6	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.1	3.2
5	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.6	3.7	3.8	3.9	4.0
6	3.5	3.6	3.7	3.8	3.9	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8
7	4.1	4.2	4.4	4.5	4.6	4.7	4.9	5.0	5.1	5.2	5.3	5.5	5.6
8	4.7	4.8	5.0	5.1	5.3	5.4	5.5	5.7	5.8	6.0	6.1	6.2	6.4
9	5.3	5.4	5.6	5.8	5.9	6.1	6.2	6.4	6.6	6.7	6.9	7.0	7.2
10	5.9	6.1	6.2	6.4	6.6	6.8	6.9	7.1	7.3	7.5	7.6	7.8	8.0
*************************************AZIMUTH LIMIT**													
11	6.5	6.7	6.9	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8
12	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.2	9.3	9.5
13	7.6	7.9	8.1	8.3	8.6	8.8	9.0	9.2	9.5	9.6	9.9	10.1	10.4
14	8.2	8.5	8.7	9.0	9.2	9.5	9.7	9.9	10.2	10.4	10.7	10.9	11.2
15	8.8	9.1	9.3	9.6	9.9	10.1	10.4	10.7	10.9	11.2	11.4	11.7	12.0
16	9.4	9.7	10.0	10.2	10.5	10.8	11.1	11.4	11.6	11.9	12.2	12.5	12.8
17	10.0	10.3	10.6	10.9	11.2	11.5	11.8	12.1	12.4	12.7	13.0	13.3	13.6
18	10.6	10.9	11.2	11.5	11.8	12.2	12.5	12.8	13.1	13.4	13.7	14.0	14.4
19	11.2	11.5	11.8	12.2	12.5	12.8	13.2	13.5	13.8	14.2	14.5	14.8	15.2
20	11.8	12.1	12.5	12.8	13.2	13.5	13.9	14.2	14.6	14.9	15.3	15.6	16.0
***********************************ELEVATION LIMIT**************************************													

Example: For a 6 degree change in azimuth (or elevation) at 12 ft. extension, the actual displacement is 4.2 ft.

Tenth' s of a Foot to Inches Scale:

.1 Foot = 1.2 Inches
.2 = 2.4
.3 = 3.6
.4 = 4.8
.5 = 6.0
.6 = 7.2
.7 = 8.4
.8 = 9.6
.9 = 10.8

FIGURE 1, Explanation of movement.



In the first example above, a movement upward is made in an arcing motion and the radius stays the same. In the second example, an upwards movement is made in a direct motion and the radius changes.

FIGURE 2, The Air Refueling Envelope.