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Flying Tactics, Flying Rules and Race Performance

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With closely called flying fouls and a Sporting Code which is open to interpretation in a few areas as regards flying technique, flying style and the Judges' interpretation of it, can have a major effect on the outcome of team race competition. Now the FAI Sporting Code for Aeromodels is far superior to the AMA rule book in this area so one doesn't want to advocate anything as silly as adopting the AMA rules, but, as good as the FAI rules are, there is still room for improvement.

The rules can be divided into two categories, written and unwritten. For example, the World Championships were run for about ten years using an unwritten rule that three flying fouls were required before disqualification. There was nothing in the rule book all that time to even hint at this procedure; all the sporting code did was enumerate the causes for disqualification implying that once was enough.

Just plain change won't make things better, of course. To make things better one has to first have a concept of what better means. I think that "better" in this case can mean, for instance, a reduction in the ability of the pilot to improve race performance through towing the racer and blocking others. It also means making uniform flying standards easier to enforce. In addition, judges and pilots should be equally aware of the relation of flying technique on race performance. The minute one side is substantially smarter than the other races can be decided by gamesmanship.

In writing this article (or series) then, I have two purposes. The first one being to improve the rules, or at least the way they are interpreted. The second being to help competitors overcome the effects of blocking and make the most out of what they have. It may not make for easy reading all the way through, but how many things that are really worthwhile are easy? (On the other hand, how many things that were hard were worthwhile?

Section I : Flying Alone

Before one can talk about flying in competition, the speed when flying alone as it is affected by the way the flying is done, has to be pretty well understood. To this end I will try to show in the first section how pilot action is connected to the speed the racer is timed at. This section will end up with a method of estimating just how much speed is gained or lost by any flying technique.

Assume that there is a pilot in the center flying inside the three meter radius flying circle and someone on the outside with a stopwatch timing him. Time for ten laps please, no old eight and four lap bad habits held over from AMA racing (my apologies to Dunkin and Wright!). The person on the outside computes the speed from the ten lap times. This is only an apparent speed as, for example, if the plane is flown arm extended the distance covered is more than one kilometer per ten laps. The formula used for speed calculation assumes the standard one kilometer distance for ten laps that an FAI speed plane flies when in the pylon.

Since everyone has electronic calculators these days, the formula are given below. Although rounded off, they provide more accuracy than you need even if you are timing with a millisecond timing error.

speed in kilometers/hour = 3600/T

speed in miles/hour= 2237/T

T, in the formula above, is the time in seconds to fly ten laps. The reason for using this as the speed is that it is the only one we can measure easily and it is the only thing that really counts.

Now that this person is assumed to be out there flying, let us perform some experiments to determine the relation between speed and technique.

The easiest effects to understand are those that occur when the plane is flying a circular path no "yo yo" (e.g., pulling the arm in to suddenly reduce the flying circle radius) and no wind. If the pilot is leading or holding back on the airplane, he does so continually, not just for a fraction of a lap. The handle and the airplane will both move in a circle at a steady rate. In short, what is called "steady state operation" is established. Under these conditions there are two kinds of effects; those due to changed flying radius and those attributable to power added (subtracted) by leading (holding back) on the plane.

>For discussion purposes, say that the speed achieved when flown from an FAI pylon is the standard. Compared to flying from a speed pylon, if the plane is flown according to the new team racing rules (center of rotation, handle,, plane all in a line), the line length is effectively increased. Except for a tiny increase in line drag, the true air speed will not change. The speed (based on time per lap) goes down because the aircraft flies further than one hundred meters per lap. If the pilot's hand moves in a one-foot (0.3 meter) radius circle, for example, and the handle is between the airplane and the center of rotation, there is about a 2% decrease in timed speed (see Figure 1). If the pilot gets way "behind .the plane" the lines pass over the left shoulder (center of rotation between the handle and plane) and the effect is reversed (see Figure 2). Most of us thought this latter position is where Herb Stockton flies; Herb was probably just getting set up to pass.

Table I Approximate Dimensions for Figures I and 2

Data Given in English and (Metric) Units

Figure	1	2
Line length	52.22 (15.92)	52.22 (15.92)
Handle path radius	1.0 (.30)	1.0 (.30)
Aircraft flight radius	53. 22 (16. 22)	51.22 (15. 62)
Apparent gain in speed for Figure 4 a 100 mi/hr racer	-2.0 (-3.2)	+2.0 (+3.2)
Change in Ten lap time time	+.43	-.43

Note from Figure 2 that shortening the radius means the pilot must lean toward the plane while he flies and the lines will come off his left shoulder. Increasing the radius just reverses things. Note that the net change is .86 seconds in the time to fly ten laps and neither pilot is "whipping".

The discussion above illustrated apparent speed change by changing flying radius without whipping. Before discussing the most general case, two more special cases will be discussed. These two cases will be maintaining the same flying radius (approximately), but changing speed by leading or lagging, one might call it the "pure whipping case". The first one, shown in Figure 3, is the natural flying posture most beginners and sport fliers assume without being instructed. The pilot walks around in a circle with the lines perpendicular to his shoulders. In Figure 4, the pilot walks backward as you might right after a pass in AMA competition or, as some stunt fliers do, between maneuvers to get high maneuver entry speeds. By calculation for an example world class racer, the speed lost is five mi/hr in Figure 3. In Figure 4 the speed gained is six mi/hr. The reason the gain is more than the loss is the feedback; the pilot whips, the airplane speed increases, increasing the line tension that further increases the effect of whipping.

Table II summarizes the four positions discussed so far and how to detect them. In each case a line drawn from the center of rotation will go right through the shoulders of the pilot. This will not be the case in intermediate positions.

Table II
Four Basic Flying Positions and Identifying Features

Increased flying radius, no lead (see Figure 1)

- pilot leans away from airplane
- shoulders parallel to lines, right shoulder closest to aircraft
- pilot and plane face the same way
- pilot seems to walk straight ahead

Decreased flying radius, no lead (see Figure 2)

- pilot leans toward airplane
- shoulders parallel to lines, left shoulder closest to plane
- pilot faces in the opposite direction to the aircraft
- pilot seems to walk straight ahead

Little change in flying radius pilot lags plane (see Figure 3)

- pilot faces airplane
- shoulders at right angles to lines, left shoulder toward center of rotation
- pilot seems to walk straight ahead

Little change In flying radius, pilot leads plane (see Figure 4)

- pilot faces plane
- shoulders at right angles to lines, right shoulder toward center of rotation
- pilot walks backward

There are a lot of flying stances other than the four just discussed, of course, and all involve leading or lagging the airplane. That is the handle will be ahead of behind a line drawn through the center of rotation and the airplane. If the handle is s ahead of the line (displaced in the direction of flight) then the pilot is leading the plane, commonly called "whipping", and if the handle is behind then the pilot is lagging, for which condition there is no slang word equivalent. For those of you who would like to coin a word, here is the place it could be called whoaing or maybe dewhipping or...

On an FAI team racer the line tension is from 10 to 15 pounds (44 to 67 Newtons) for most planes. With a little lead the line tension is pointed slightly forward and this is an added thrust force. This force causes a power input to the plane. The faster and heavier the plane the more added power for a given lead; the more horsepower that's taken away for a given lag, too.

To help fix ideas, a specific example will be given. Consider a world class racer capable of flying at 100 mi/hr (161 km/hr) in a pylon, and with a mass, equivalent to a weight of 1.00 Ibm. (454 gm). In an FAI speed pylon the line tension would be about 12. 8 lbs (56.9 Newtons). Assume the pilot flies with the handle 2.0 feet (0.61 meters) from the center of rotation and leads the plane by .5 feet (1.5 meters). The power input to the plane from the line is 0.165 horsepower (123 watts). Considering that the thrust power from the engine is about 0.4 horsepower (298 watts) (this includes propeller efficiency), this is a substantial increase. The top view in Figure 5 shows what is meant. Clearly the racer will loose some speed because. It is flying in a larger radius circle, but it will also gain because the airplane will fly faster due to the extra power.

The whole problem is then to find out exactly what the net effect is, considering both effects. As it turns out, in this example there is a net loss of about one mi/hr.

I have done a lot of calculation, but to explain what was done without going through a bunch of formulae (I can send them. to you if you want) the assumptions and explanations are as follows: The position of the handle relative to the center of rotation and airplane are given. The problem is to calculate the resulting change in apparent speed (or lap time) for any given airplane. First, the effective flight circle radius from geometry is computed. The centrifugal force is then related to the line tension and the line tension plus the lead (lag) of the lines relative to the airplane show how much extra thrust is being applied. Assuming that the engine thrust power was constant ' the resulting increase in air speed is computed. This, in effect, assumes that the power required is proportional to the cube of the flying speed. Once the "flying speed is known and the effective flight circle radius is also known, the time for ten laps and the apparent speed can be computed. I've done all this for many cases and the results are shown in Figure 6. Calculations are done for the assumed world-class racer described above. To use Figure 6 just imagine the center of rotation is as marked, the plane way off the paper in the direction indicated. Then imagine the handle position somewhere in relation to these and read the gain or loss in speed off the graph. The positions shown in the figures are marked on this graph by a small dot and the corresponding figure number next to it.

The next section will describe unsteady or "yo yo" effects and wind effects and then take up flying tactics.

From Figure 6 you can see that the "normal" flying position is somewhere between point I and point 4 and the flier is losing a little speed compared to what he could do flying from a pylon. To make up for the speed lost by flying in a larger radius in a pylon the pilot must lead the plane. As can also be visualized in Figures 5 and 6, "position 5" flying (which isn't whipping much) requires that peculiar crab like walk pilots do while looking over their shoulder. Getting on the other side of the center of rotation over toward position 2 really helps a lot. If you want an excellent example of something close to this position see the picture of Peterson of Denmark on the way to a 3:56.7 time on page 584 of the October 1976, Aeromodeller. It's worth 1000 extra rpm. You might argue that the rulebook outlaws position 2, but the jury has to call it.

In the first part of the article, flying alone in steady state conditions was discussed. The end of the flying alone section will consider unsteady effects, namely; acceleration, wind, change of flying radius, pull ups and high flying.

Wind has an effect on speed as does acceleration and deceleration. For the world class racer used in previous examples (I pound weight, 0.4 thrust horsepower, 100 mi/hr when flown from a pylon), assuming that the racer accelerates to its terminal velocity while being flown from a pylon, it takes about 0.7 seconds to go from 90 to 95 and 0.7 seconds to go from 95 to 97.5 and so on. In other words, when flying near terminal velocity it takes 0.7 seconds to get half the way to steady state speed from whatever speed you start, and that goes whether you're slowing down or speeding up. Now, of course, this slow creep up to racing speed is not good and most pilots will give a little tug or pull the flying radius in right at the end to hurry the process up. When flying speed is disturbed in a race it always takes time to build it back up again, which is the reason to avoid sharp pull ups that will drag the speed down.

Wind generally has (in small doses) little effect on average speed. When the plane flies dead into the wind the airspeed is higher than normal as inertia is still carrying it, but its ground speed is low. Around 18 degrees after coming full into the wind the airplane is going the slowest in terms of ground speed and 180 degrees around from that, the fastest (see Figure 7).

Wind does, however, offer a good opportunity to make whipping more effective. When the ground speed is the highest the line tension is the highest and the whipping most effective. The best place, therefore, is around either side of the 18 degrees from downwind position. This is where a pass should be made. Going into the wind is the time to shorten the flying radius. Speed and line tension are low so whipping isn't as effective and no one can get away with leading the airplane around over the whole lap anyway.

The foregoing suggests a pattern seen once in a while. The pilot (especially in a two up situation) flies in "position 2" apparently way behind the plane and going like stink. Just before the plane has the wind square on its tail, the pilot starts his pass raising his hand over his head and pivoting to his left on his right foot and taking a few backward steps while completing the pass. By this time the plane is going like a bomb about 5 or 10 mi/hr over speed for whipping.

Joe Turkey, whom he just passed flying in "position 4", is losing 5 mi/hr so he's wondering where the hot dog's 10 15 mi/hr speed advantage came from. About now, the faster plane is coming into the wind, the jury is scowling and thinking of calling a foul when the pilot stops the whip, turns around and starts flying lines off the left shoulder again. In two more laps he will be ready for another pass at this rate.

The foregoing discussion briefly touched on the effect of acceleration and wind. The next to last effect to be considered is the "yo yo". Since angular momentum is conserved, if the flying radius is shortened very rapidly, the speed has to go up. The time per lap goes down even faster than the speed increase would indicate as the flying radius is also shortened. Of course, the speed immediately begins to die down to the steady state speed, but for a second or so it helps, possibly just long enough to make a pass. The instantaneous apparent speed goes up as the square of the ratio of the old and new flying radii. For example the effect helps after takeoff as the pilot spirals inward toward the center. If the example racer is doing 90.0 mi./hr airspeed at a 55 foot flying radius the apparent speed is 85.4. By suddenly pulling the radius in to 53 feet it jumps up to about 92.0. The biggest increase in speed is when the airplane is going fast, so this spiraling into the center should not be done right after takeoff. Probably the best place is right at the end of the first lap, the pilot taking advantage of the "hand off the chest for two laps after takeoff" rule.

Another way this effect was used was when the arm could be extended during a pass. After drawing even with his opponent, the pilot would pull his arm in and take a step backward to help things along. This same phenomenon is used in Sunday flying to great effect when doing loops downwind. After the engine quits, the pilot can whip and pull in on the bottom of the loop and then coast up to the top, putting enough energy in to keep the plane flying for long periods.

In all of the discussion to here, not enough sufficient attention has been paid to the subject of the load put on the engine and the setting. If the mechanic has tuned the engine to run its best at a given speed and load, and the pilot then changes the conditions for which the setting is best, things can get worse rapidly. Flying in positions I and 2 does not change the load on the engine perceptibly, even though there is a slight change in line drag. Leading the airplane, coming into the wind, and having the flying radius reduced suddenly, all unload the engine and the reverse loads it up. In addition to these causes, increasing the g loading on the plane will increase its drag and also load up the engine. With light airplanes all of these loading up effects are minimized and the high aspect ratios employed on most team racers helps to reduce the drag increase effects.

Now those "g" loading effects will be touched on in a moment, but the worst effect is that from the pilot lagging the plane, perhaps because of being stuck behind a skillful, slower opponent, perhaps because of inexperience or lack of knowledge. This continual lap after lap running at lower airspeed leads to overheating and, if the engine doesn't cook up and stop, it may not restart easily and the airplane will eventually slow down and lose its speed advantage, thus nullifying a superior airplane. The only way to fight back is to lead the plane and run the risk of being fouled out or to adjust the engine before the race for a loaded up condition, which requires a richer, and under compressed setting and must give up laps and speed. To this, add the fact that a common mistake is to tune the airplane to run best while leading more (or lagging less) than normal flying circumstances will permit. In the 1970's this is a recognized mistake, even though it doesn't make for good practice times, and it is not made nearly so often as it was in the previous decade. As one can see, the pilot must make every effort to pass at the first opportunity. This will unload the engine and cool it down and, more importantly, establish in the jury's mind his superior speed and right to pass. If the pilot gets blocked for five laps or so and then in desperation decides to tow a little and pass, the jury will think his plane is matched in speed and he is "applying physical effort" to pass when he could not do so fairly.

Returning to the effect of "g loading", note that high flying demands far more lift from the wings than just the weight of the airplane. Continuous high flying requires wind lift to support some of the centrifugal force, for which see Figure 8. Assuming the 100 mi/hr pylon speed racer and the handle circling in a one foot radius circle about the center of rotation ("center spot" as the FAI Sporting Code calls it), the following calculations should illustrate the problem:

Handle against the chest held 4.50 feet (1.4 m) above ground level, airplane flown continuously at the minimum/maximum normal flying height 2 m to 3 m (6.56 feet - 9.84 feet), the wing lift must be 1.5 to 2.3 times the weight. Only if the plane could be flown at 4.5 feet (1.4 m) altitude would the lift equal the weight, and this is against the rules.

Handle above head at 6.00 feet (1.8m) above ground level and airplane flying at the maximum height permitted during passing 6 m (19.69 feet), the lift must be 4.41 times weight. Very few people realize that flying at a constant altitude like this puts such a load on the airplane. No wonder wings flex!

This additional lift will certainly reduce the airspeed of the aircraft since the drag must be higher. However, since the flying radius is shortened, the effective speed or timed speed may not go down at all; for most high aspect ratio racers just the opposite may occur and high flying may pay off if you can get away with it.

Flying within the altitude limits of the rules, and that is flying at a constant three meters altitude compared with two meters, shortens the radius less than one tenth of one percent. The increased load for pulling a continuous 2.3 g's can hardly be worth it, so the best position is down low. Few juries foul pilots for flying below the two meter limit and "its done all the time" so this encourages a lot of really low flying. Normal flying isn't the problem. The question is, when passing   passing two at a time for instance   how high should one fly? The best solution is to time a few laps while flying high (six meters) and, if the speed is timed as increasing, then consider using the maximum height allowed during a pass. This reduces radius about 3.5 percent. Also, the dive down to normal height or lower after the pass will help gain speed when passing the fastest people.

SECTION II :
Flying With Others

So far, all of the things affecting speed that the pilot can contribute to have been discussed, but mainly as if the pilot were out there flying all by himself. In competition, the presence of others in the circle won't change these facts, but it will change what the pilot has the opportunity to accomplish. The discussion of these problems is necessarily much more qualitative. It is impossible to estimate the speed loss due to getting your lines caught in the competition's hair, for instance.

Flying with other people presents a number of problems, not the least of which is passing, even when you have the faster airplane. The Soviet Union proposed a "hand off the chest for three laps" rule to provide a longer time in which to pass. Just how much faster you have to fly to pass while obeying the flying rules is an interesting thing. Consider two cases; (both airplanes flying at a constant speed), the faster airplane having to gain (a) 1/8 of a lap and (b) 1/4 of a lap while covering no more than two laps. The tables below show the fastest opponent you can pass.

Fastest Opponent Passed In Two Laps

Your speed	90.0	100.0	110.0
Gain 1/8 lap	84.4	93.8	103.1
Gain 1/4 lap	76.8	87.5	96.3

Fastest Opponent Passed In Three Laps

Your speed	90.0	100.0	110.0
Gain 1/8 lap	86.3	95.8	105.4
Gain 1/4 lap	82.5	91.7	100.8

As is plain to see, under present conditions and a strict interpretation of the rules you have to have a terrific speed margin to do any good. A 100 mi/hr racer can't even squeak by a 94 mi/hr racer in two laps. As we will soon see, blocking makes it even worse. Getting into the semis may depend on being lucky enough not to have to fly against a good slow team. That is, one that won't retire, will fly for the best possible race outcome, and makes rapid pits. The Russian proposal will help some, as you can see from the table above.

Even if you have the speed advantage necessary to pass, the presence of another pilot in the circle can take it away. Taking the simplest case first, one big problem is presented when one pilot occupies the center, just twirling around on his heels. He is probably some gorilla who should be a defensive lineman in the NFL and who can also lean back with an alarming spinal curvature. Worst of all, he can't speak English so you can't tell him how you feel. Since the British rule proposal isn't formal yet, you can't fly with your lines over his shoulder unless you are taller than he is so, for practical purposes, the space he blocks out space that your lines can't pass through and space you can't occupy is approximately a rectangle two feet by one foot.

Suppose he has a 95 mi/hr plane and you have a 100 mi/hr plane (when flying from a pylon, as usual). From our simpleminded catch up analysis above you won't gain 1/8 of a lap on him in two laps even if you both fly at your normal speeds undisturbed. Still, with five miles per hour on him you have to try a pass and hope you don't get fouled, maybe you can get it done in less than 1/8 of a lap. In this case the jury is not faulting him for standing. The blocker's profile is shaded in and his lines are shown in Figure 9. Your plane is always toward the top of the page in Figure 9. There are four plates showing the conditions 1/2 lap, 1/4 lap, 1/8 lap and even with him. Half a lap apart he has you pushed out a little so you do 97 and he does 94 because of increased flying radius. In all the other plates his effective speed is 94. Note how yours is brought down the closer you get. The flying speed differences are calculated from Figure 6.

By the time you get close enough to pass he has forced you into a large walking circle and the entire speed differential is lost. Clearly, if the jury doesn't call him he will ruin your time and improve his own and this kind of conduct is the jury's first duty to stop. From the standpoint of jury psychology, what is crucial (as pointed out earlier) is to get behind him and whip if possible to pass him right away and establish in the jury's mind your superior speed and right to pass. If you get fouled on the first attempt you can always cool it and take your lumps later.

In summary, my opinion on flying and officiation races (written in 1977) is as follows:

Low flying should be penalized instead of overlooked. It is dangerous to the mechanics; it encourages sloppy and uncontrolled flying. It makes legal high flying while passing look way too high, and winking at low flying encourages the jury to pick and choose which rules they will and won't enforce.

To discourage blocking and make radius shortening more difficult, the pilots should be required to keep the lines pointing to their right from parallel to their shoulder line to 45º ahead. If due north is straight ahead (perpendicular to the shoulder line), then the lines should be from northeast to due east.

Rules should make it explicit that while passing the handle should be raised vertically from the normal flying position and not extended outward from the body.

Landing and taking off should allow arm extended, but only while the pilot is stooped over for others to pass. When the pilot stands erect he should have to hold his hand on the chest.

A one half meter diameter circle should be painted solid in the center of the pilot's circle. The jury to judge whether or not the pilots are occupying the center should use this. Pilots should not occupy this circle for more than a fraction of a lap except when passing. Clearly, lines should never extend across this circle. This area might be marked with slight protrusions so the pilot could feel when he stepped on it.

Finally, there are a few other points to add:

One factor is difficult to legislate and that is pilot height. Some nations (e.g. Bulgaria) seem to have exceptionally short pilots while others (e.g. Sweden) have many tall ones. Even if organizers were required to match heights to some extent in the heats it wouldn't help in the semis and finals. Perhaps there's nothing for it. Tell them to grow more or learn to pit.

The rule changes above are designed to reduce the pilot's ability to block, make it easier to pass, stop the line shortening which is used so effectively, and make the pilots concentrate on smooth flying. Most of all, they are designed to provide better criteria for the jury to use in calling fouls.

One point should be added. The jury deserves to be free from intimidation and also deserves some special recognition. We, all of us, have sworn at, berated, demeaned and scorned officials and can't understand why they aren't better. What's the incentive for the jury? It would be good if the jury were to be honored, if some care would be made in their selection, and if they could be encouraged to be very strict. Perhaps team trials and nationals would be a good place to place this emphasis.

The jury should be permitted a warm up heat, if possible, to let the competitors see how they will call races and demonstrate they way they have elected to communicate fouls to the contestants. The Sporting Code calls out a panel of three for the jury. Besides supporting them perhaps someday we could send one to the world champs.

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Figure 2

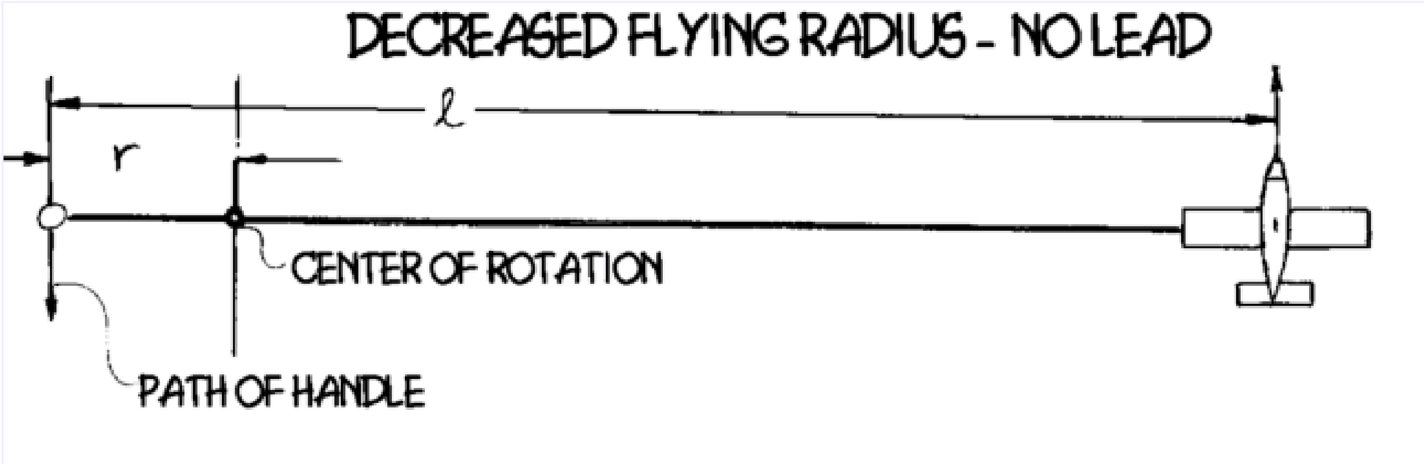

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Figure 9

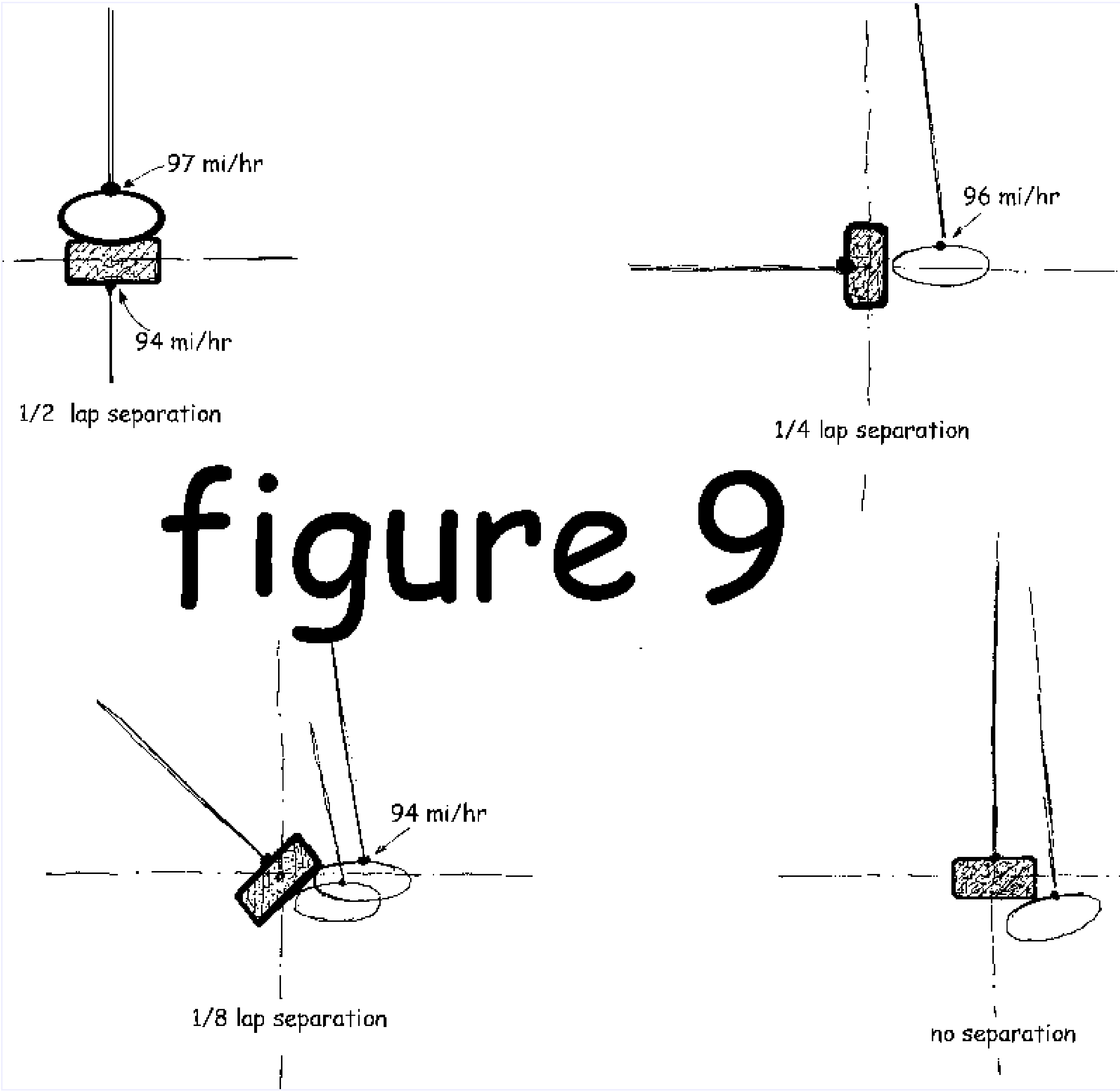

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Figure 7

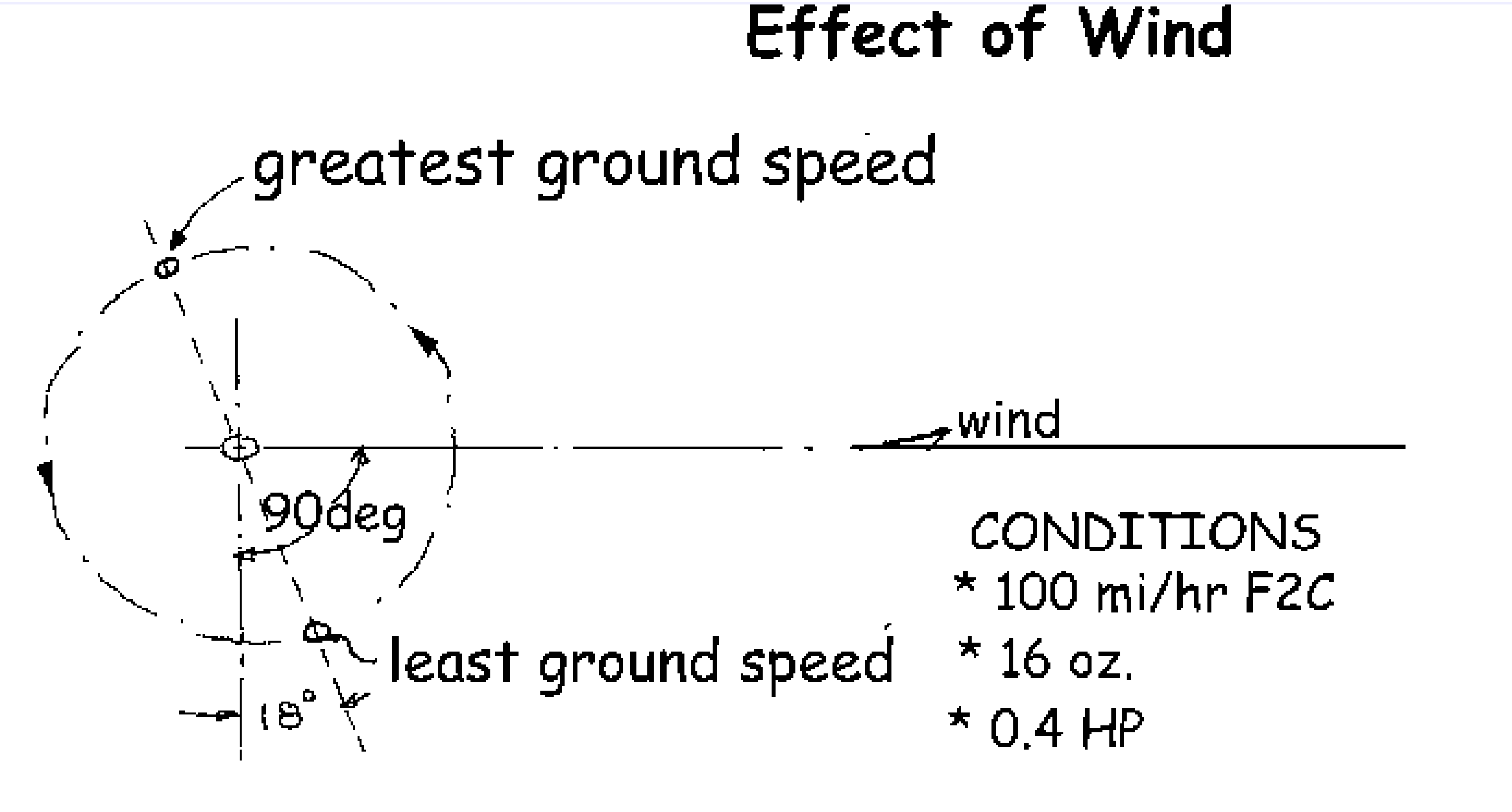

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Figure 8

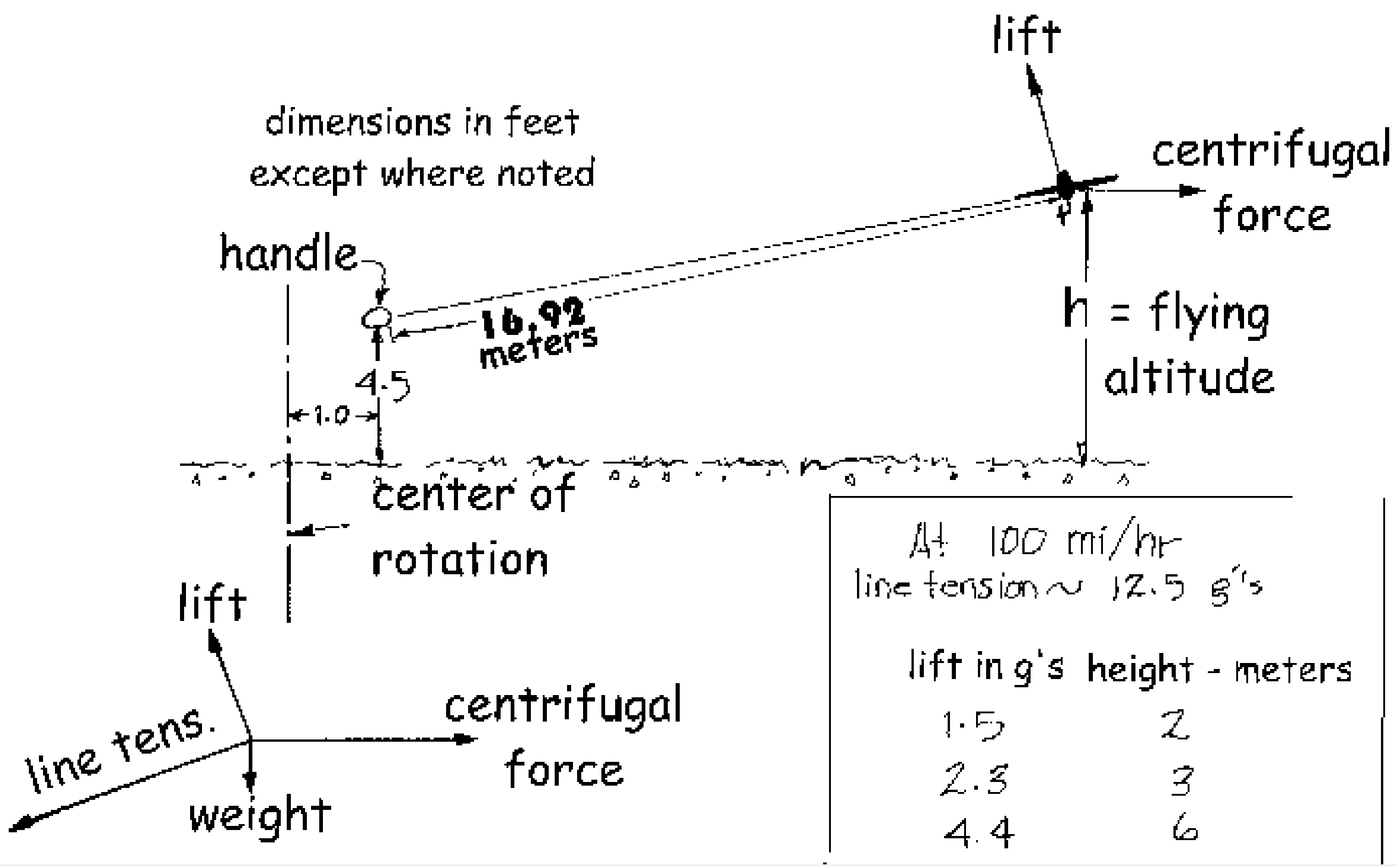

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Figure 6

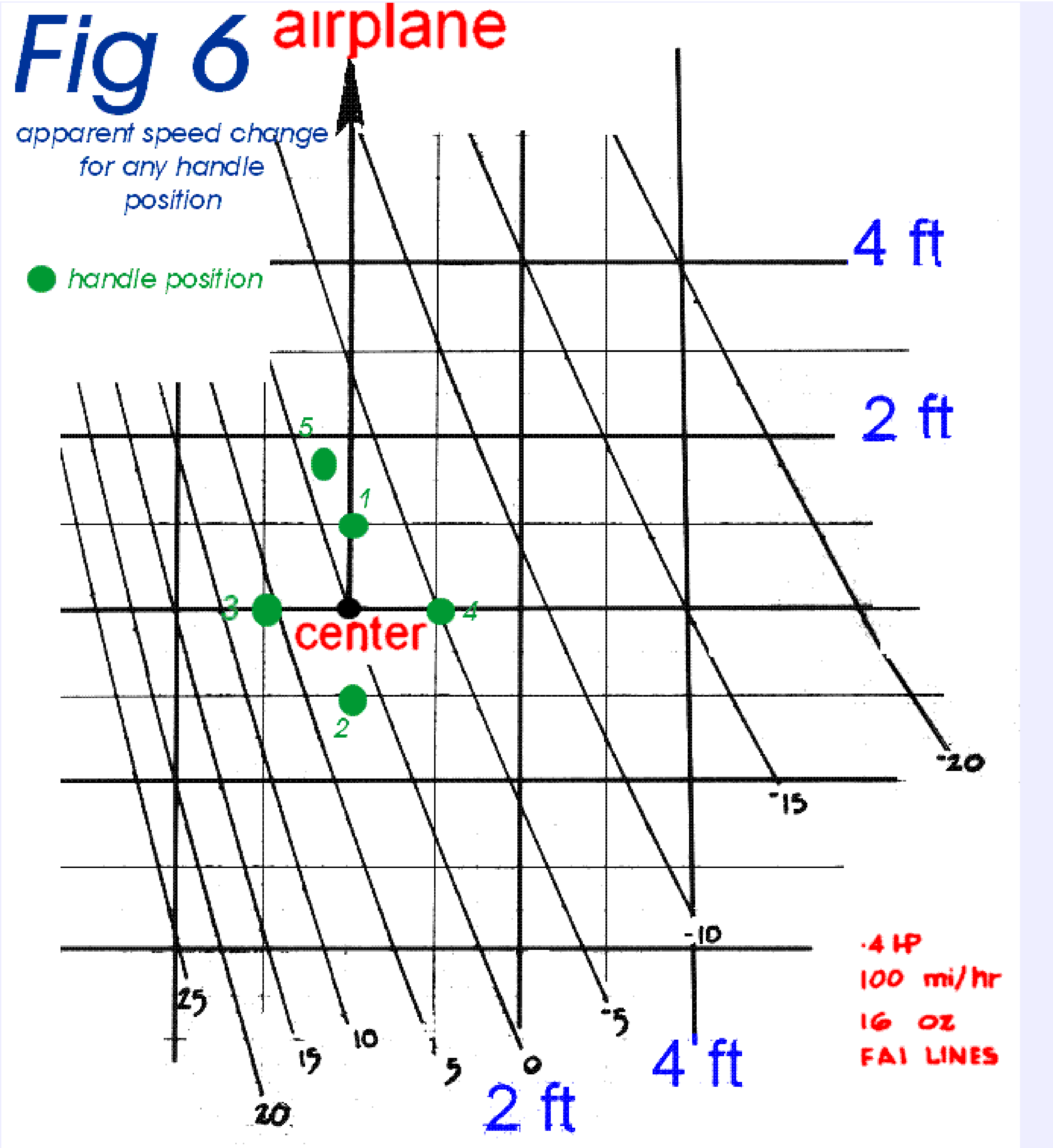

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Figure 5

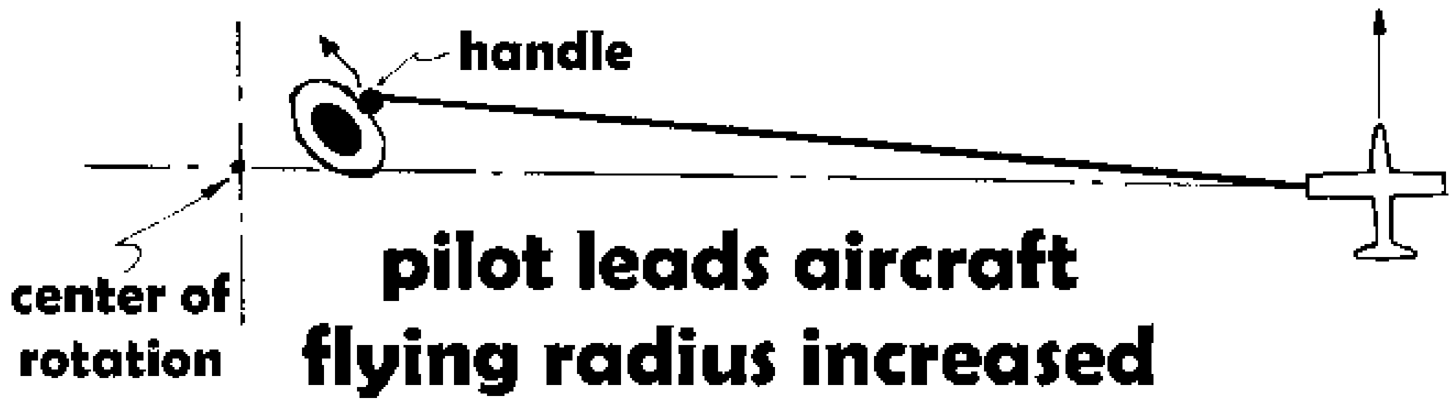

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Figure 4

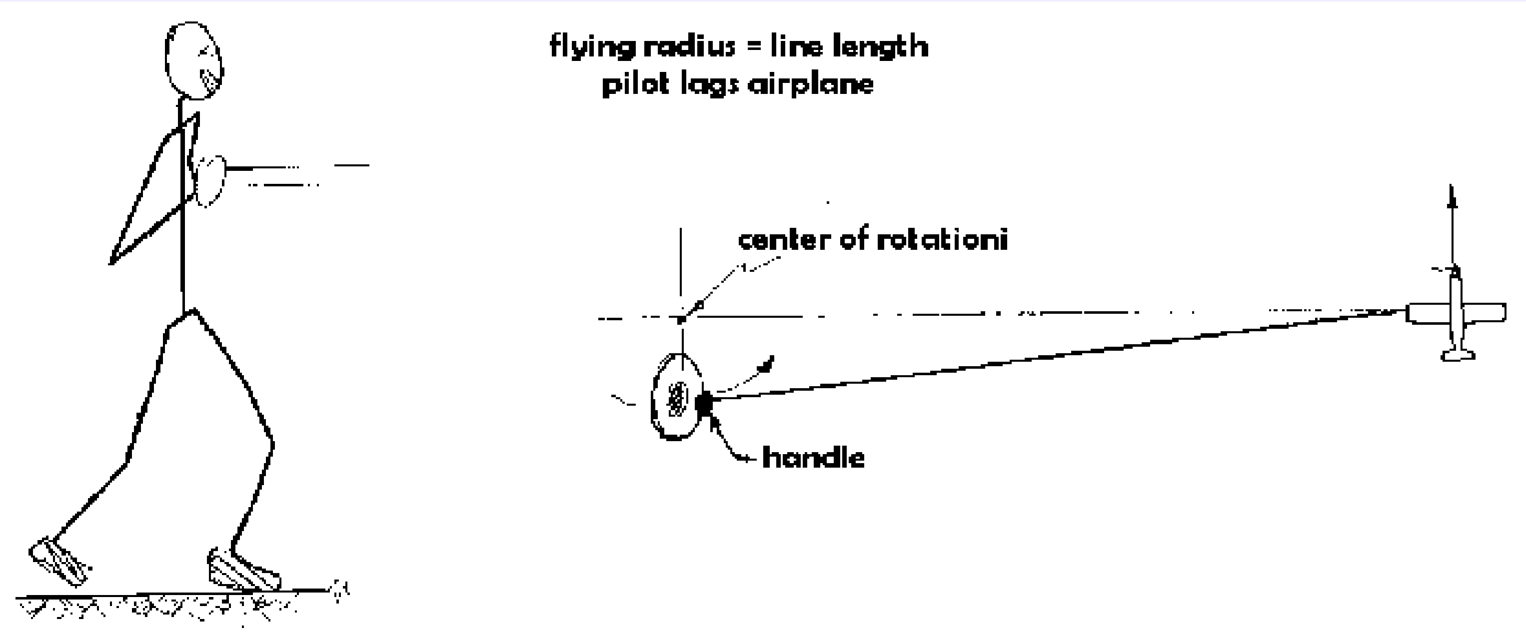

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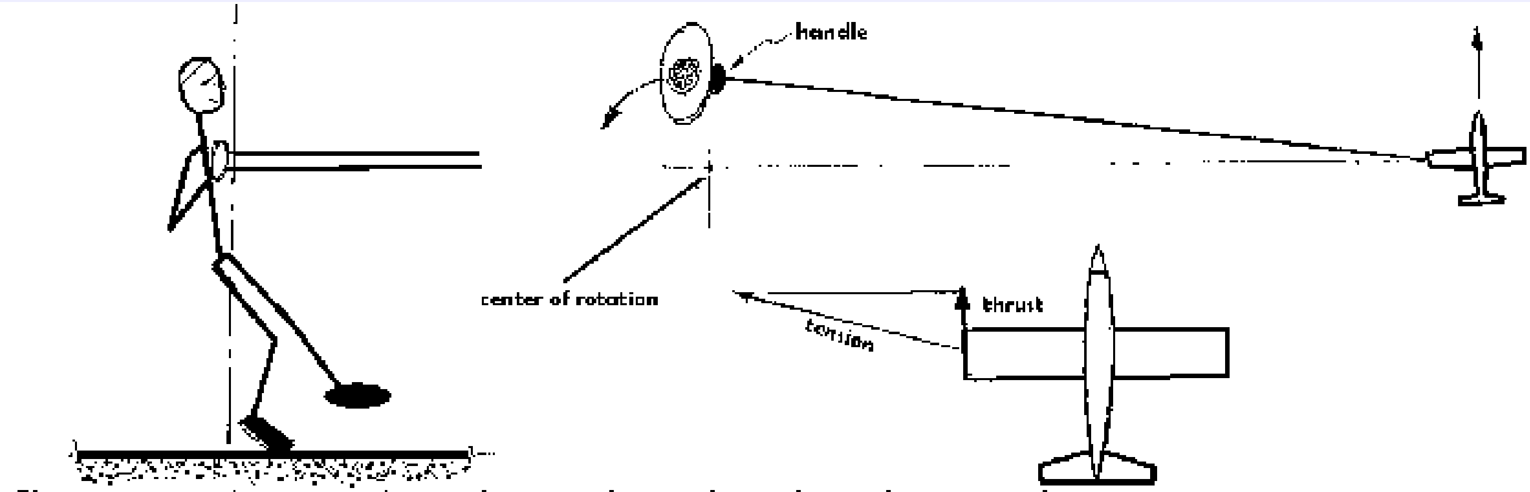
Figure 3



flying radius = line length; pilot leads airplane

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Figure 1