Eights On Pylons – An Analysis of a Ground Reference Maneuver

Running Title: Eights On Pylons

by

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Abstract

The Eights-On-Pylons ground reference flight maneuver is often considered to be one of the more difficult maneuvers to fly. An applicant for a Commercial Airplane pilot certificate is required to demonstrate proficiency in the execution of the maneuver during a Federal Aviation Administration (FAA) certification flight test. Basic Eights-On-Pylon concepts are reviewed and a quantitative model analysis is carried out. The computer simulations illustrate the intrinsic symmetries of the maneuver flight paths and associated ground tracks. For varying wind speeds, the ground tracks are found to most closely resemble non-concentric circles. Results for calm, 10, and 20 knot winds are presented and common errors are discussed.

Introduction

Eights On Pylons, or Pylon Eights, is a ground reference flight maneuver. Its training objective is to develop the student's multitasking skills. The airplane is to be maneuvered accurately and smoothly while the pilot's attention is divided between outside visual and instrument references. Furthermore, situational awareness is to be maintained while scanning for other airborne traffic as well as obstructions on the ground. Eights On Pylons is unlike other ground reference maneuvers and its intricacies may seem less intuitive.

While power generally is kept constant, the airplane's bank, pitch, altitude, and ground track turn radius typically vary continuously throughout the performance of the maneuver. Based on assumed prevailing winds, the maneuver is conveniently entered flying a downwind heading at an initially estimated altitude. The flight path's altitude depends upon the ground speed of the airplane and varies continuously upon entering the maneuver. The rate of altitude change is
proportional to the change of the airplane's ground speed, assuring continual alignment of the airplane's lateral axis with a fixed spot (the pylon) on the ground. Flown at proper altitude, i.e., the pivotal altitude, the airplane's lateral axis may be imagined to pivot on the pylon as the turn around the pylon is completed.

The maneuver is described in the literature. The Flight Training Handbook (FTH, 1984), published by the Federal Aviation Administration (FAA), has been an invaluable tool for students learning, and instructors teaching, basic flight maneuvers for many years. For non-zero wind speeds, the Handbook suggests that the Eights-On-Pylons maneuver ground tracks are geometrically asymmetric with respect to the line joining the pylons. In addition, the ground tracks include extended straight-and-level flight segments, which appear to require substantial fractions of the total time to complete the maneuver. While Kershner (Kershner, 1994) has called attention to the symmetries of the maneuver, he presents egg-shaped ground tracks for moderate to high wind conditions. In this work, we further investigate the maneuver's intrinsic symmetries and the dependence of the ground tracks on prevailing winds. Moreover, procedural requirements are explored for controlling the airplane and meeting the straight-and-level flight time restrictions set forth by the FAA for pilot certification.

It is often difficult to evaluate results of an actual, possibly less-than-perfect flight performance. In order to examine the effects of pitch, bank, and power on the outcome of the maneuver while limiting airborne frustrations, a simple computer model was developed. It was built on the aerodynamics of an airfoil. The model integrates the equations of motion and tracks all
basic dynamic and kinetic flight variables. Its parameters were chosen to simulate flight characteristics of a complex trainer airplane, such as a Piper Arrow or a Cessna 172RG.

When the maneuver is flown properly, the airplane’s lateral axis may be imagined to pivot on a central pylon. The lateral axis of the airplane, however, is not visible and it is of little use to the pilot while monitoring the progress of the maneuver. The pilot requires sensible visual cues to continuously gauge altitude and bank deviations as well as the need for corrective control inputs to maintain the desired flight path.

The maneuver is flown using a visual reference line that parallels the lateral axis of the airplane. This sighting reference line presents an adequate approximation to the lateral axis and provides the required lateral and vertical visual reference throughout execution of the maneuver. It is very important to take some time to determine the reference line. Indifference with respect to the reference line is otherwise frequently followed by multiple minutes of aeronautical misery during practice of the maneuver.

A Point of Reference

Knowledge of the somewhat spurious sighting reference line is an important and often overlooked prerequisite for mastery of the maneuver. While the lateral axis of the airplane is unique, the reference line is not. Its location depends upon the distance of the pilot’s eyes from the center of gravity (CG) of the airplane. The vertical and longitudinal distances of the reference line from the CG of the airplane are affected by the physique of the pilot and the height of the seat, as well as its relative forward or aft position in the airplane. While the
distance of the pilot's eyes from the CG varies with the seat position and the pilot's physique, each pilot's individual reference line is easily determined during straight and level flight.

Flying straight and level, the sighting reference line extends from the pilot's eyes to one point on the horizon. The point on the horizon is determined by looking out the side window at a right (90°) angle to the longitudinal axis of the airplane. Weather and topography permitting, the horizon is often well defined while some precision guessing may be required when estimating a right angle to the longitudinal axis of the airplane.

It is useful to define a point of visual reference that relates the perceived location of the reference line to the wing tip of the specific airplane flown. As the reference line extends outward from the pilot's eyes to the horizon, the reference point is just one point on that line somewhere in the neighborhood of the wing tip, as illustrated in Figure 1. The location of the imaginary reference point relative to the wing tip should be committed to memory because its apparent position relative to a landmark on the ground (the pylon) later will determine the required bank angle and the need for pitch adjustments when performing the maneuver. It is important to note that the reference point appears some vertical distance above (below) the wing tip and usually lies within the longitudinal bounds of the wing tip when flying a low-wing (high-wing) airplane as illustrated in Figure 1.

An Altitude to Pivot

Flying straight and level, the reference point, by definition, appears to the pilot as virtually stationary on the distant horizon. During turning flight with the wings banked, the reference
point seems to describe a curved path on the ground somewhere between the horizon and the airplane's ground track as illustrated in Figure 2. The steeper the airplane is banked, the closer to the airplane the reference point appears to describe its path on the ground. Furthermore, the reference point may seem to follow the movement of the airplane or to run in opposite direction, depending on the altitude of the airplane above ground level. When flying at lower altitudes and assuming negligible winds and a constant bank angle, the reference point usually appears to follow the motion of the airplane on the ground somewhere between the plane's circular ground track and the center of the circle it describes. At higher altitudes and under otherwise unchanged conditions, the reference point may be seen to move in the direction opposite the motion of the airplane, somewhere beyond the center of the circle. If flown at an intermediate altitude, the reference point will appear to remain stationary on a fixed spot on the ground, the pylon. In that case, the reference line of sight extending from the pilot's eyes to the reference point and down to the pylon circumscribes a cone standing on its tip and extending upward from the pylon on the ground. Flown at such altitude, the reference line seems to pivot on the pylon as the turn continues. It comes as no surprise that the associated altitude is referred to as pivotal altitude.

The force acting on an airplane in flight is often viewed as the sum of four basic force components. All opposing force components are required to be equal in magnitude to cancel one another, if the airplane is to maintain linear and unaccelerated flight. For an airplane of mass $M$ that is subject to a drag force $D$ and propelled by thrust $T$ with banked airfoils generating lift $L$ in turning and vertically unaccelerated flight, the sum of the vertical force components vanishes, i.e.
\[ L \cos(\beta) \cos(\gamma) + T \sin(\alpha) + D \sin(-\gamma) - Mg = 0, \]  \hspace{1cm} (1)

where \( \beta \) is the bank angle and \( g \) denotes the acceleration in the earth’s gravitational field. The pitch angle \( \alpha \) and the flight path angle \( \gamma \) are defined relative to a horizontal plane and assume positive (negative) values for angles above (below) the plane.

The horizontal component of lift provides the radial force required to maintain turning flight. If the turn is coordinated, the resulting rotational motion around the pylon is described by

\[ L \sin(\beta) \cos(\gamma) - M \frac{v_G^2}{r} = 0, \]  \hspace{1cm} (2)

where \( v_G \) is the airplane’s ground speed and \( r \) denotes the radius of the turn. Minimal manipulation and dividing Equation (2) by Equation (1) yields

\[ \tan(\beta) = \frac{M v_G^2}{r (Mg - T \sin(\alpha) - D \sin(-\gamma))}. \]  \hspace{1cm} (3)

For an airplane turning at any pivotal altitude \( A_p \), the trigonometric identity

\[ \tan(\beta) = \frac{A_p}{r} \]  \hspace{1cm} (4)

holds true relating bank angle \( \beta \) and turn radius \( r \) in a coordinated turn. Equating Equations (3) and (4), the pivotal altitude can be deduced as

\[ A_p = \frac{M v_G^2}{Mg - T \sin(\alpha) - D \sin(-\gamma)}. \]  \hspace{1cm} (5)

The pivotal altitude is often approximated assuming level flight \((\gamma = 0)\) and vanishing pitch angle \((\alpha = 0)\). For this simplified case, Equation (5) reduces to the frequently cited expression for pivotal altitude
\[ A_p = \frac{v_G^2}{g}, \]  

where \( g \) is the acceleration due to gravity. Thus, pivotal altitude mainly depends upon the airplane's speed with respect to the ground. This is because a greater ground speed requires a greater rate of turn to circle around the stationary pylon. If alignment of the reference point and the pylon is to be maintained by an airplane at some distance from the pylon, a greater rate of turn calls for a steeper bank angle, which in turn necessitates flight at a higher altitude.

The pivotal altitude is easily calculated in units of feet above ground level (AGL) for a given ground speed in units of knots (kt) if 11.3 \( \text{kt}^2/\text{ft} \) is used for the acceleration \( g \) in the gravitational field of the earth. Pivotal altitudes for a few typical speeds are shown in Table 1.

**Flying The Eight**

Getting ready for the maneuver involves positioning the airplane for a downwind entry at pivotal altitude. As pivotal altitude mainly depends upon the aircraft's ground speed, the direction and speed of the prevailing winds should be estimated prior to flight. Interpolation of surface weather observations and the winds aloft forecast may provide useful ballpark figures. For example, a 100 kt maneuver airspeed and a 10 kt wind would result in a ground speed of 110 kt and a pivotal altitude of 1070 ft AGL during a downwind entry. Backing up the weather data by actual observations in the practice area (blowing smoke, dust etc.) may increase the pilot's confidence that the maneuver is entered on the preferred downwind heading. The trueairspeed should not exceed the design maneuvering speed for the weight of the airplane.
While establishing flight at pivotal altitude, the Before-Maneuver checklist is completed and the pilot searches for a pair of suitable pylons. Two cross roads or other easily recognizable landmarks will do the trick. The pylons should stand out from the ground clutter in an unobstructed and uncongested area. They typically are 1/2 - 5/8 miles apart, and the line joining the pylons (the base line) should make a right angle to the wind direction at pivotal altitude. It is useful to keep in mind that a longer pylon separation distance prolongs possibly painstaking Eights-On-Pylons practice.

Once the pylons are spotted, emergency landing areas are identified as part of “plan B” if engine trouble should be encountered during execution of the maneuver. The probability of a simulated engine failure often is reported to increase during a certification check ride if no suitable emergency landing sites are pointed out by the Commercial Pilot applicant.

Clearing turns may serve to change the heading for a downwind entry perpendicular to the base line halfway between the pylons. Before reaching the base line, the airplane should be trimmed for level flight. A vigilant scan for traffic in the area should be maintained throughout execution of the maneuver. Once the area is checked in the direction of the first turn, the pilot is ready to roll.

Upon crossing the base line, the airplane is rolled swiftly toward the first pylon. The maneuver is flown by visual references and with minimal reference to the instruments. While rudder pressures counteract adverse aileron yaw and maintain coordination as the aircraft rolls, sparing to no rudder control inputs are required once established in the turns.
Upon entering the maneuver, the degree of relative visual misalignment of the reference point and the pylon indicates to the pilot the need for pitch and bank corrections. Whereas the degree of their longitudinal misalignment is used to gauge the need for pitch corrections, the proper bank angle is deduced from their vertical alignment.

The appropriate bank angle is attained if the reference point and the pylon appear vertically aligned. For an airplane entering the maneuver downwind at an airspeed of 100 kt, the resulting initial bank angle is illustrated in Figure 3. While the bank angle is seen to mainly depend upon the pylon separation distance, it also is a function of wind speed. The speed of the prevailing winds should therefore be taken into consideration to find a pair suitably separated pylons. While the bank and pitch requirements of the maneuver often are manageable around pylons half a mile apart in light winds, a wider separation distance may be more appropriate on a windy day.

**Simulation Results**

**The Ideal Scenario.** As the airplane turns, its ground speed will vary (mainly due to the instantaneous head wind or tail wind components it encounters) and altitude adjustments become necessary. A reference point that appears to fall behind the pylon indicates the need to descend to a lower pivotal altitude. Conversely, if the reference point seems ahead of the pylon, the airplane’s altitude is below pivotal altitude and a pitch-up correction is required to climb to pivotal altitude. For idealized conditions in which the airplane maintains constant airspeed, Figure 4 illustrates simulated ground tracks for calm, 10, and 20 kt winds. Figure 5
shows bank, pitch and altitude for this ideal scenario in which the airspeed remains unchanged by continually re-positioning the airplane at pivotal altitude and keeping the pitch angle fixed. Figure 6 depicts both ground tracks and flight paths associated with calm, 10, and 20 kt winds. It is noteworthy that an Eights-On-Pylon ground track is found to most closely resemble a pair of circles. If the wind is calm, the centers of the circles are co-located with the pylons. For increasing wind speeds, the radii of the circles increase and the centers of the circles are found to lie non-concentrically outward from the pylons on the line defined by the pylons. The circular ground tracks can be seen to result from the interplay between: 1) maintaining a heading perpendicular to the radius of the turn and 2) constant drifting of the airplane relative to the ground owing to the prevailing wind. While the former is due to sustaining appropriately banked flight at the associated instantaneous pivotal altitude, the latter simultaneously yields gradual changes in the airplane’s the ground speed.

**A More Realistic Scenario.** At a given airspeed, the horizontal alignment of the reference point and the pylon can be seen as an exquisite altitude deviation sensor. Timely and smooth pitch adjustments ideally result in maintaining a steadily varying pivotal altitude. When pitch and altitude control are less than perfect, reflecting more realistic conditions, the flight paths and associated ground tracks may differ considerably from those shown in Figure 6. The results of such more realistic flight performance are illustrated in Figures 7, 8, and 9. They were obtained by allowing small altitude deviations to occur before gentle pitch adjustments were made. Furthermore, the airspeed is not kept constant. It is free to vary throughout the maneuver which results from pitch changes required to approximately maintain pivotal altitude. This
simulation may be seen as more closely describing the performance expected from an actual airplane and an experienced human manipulator of the flight controls.

**Discussion of Common Errors**

During execution of the Eights-On-Pylons maneuver, any changes in altitude generally require simultaneous changes in bank angle to maintain vertical alignment of the reference point and the pylon. While suitably swift and positive aileron pressures are adequate to make bank angle adjustments, smooth pitch control inputs are called for throughout the maneuver. This is because any significant pitch change affects the airplane's true airspeed and in turn its ground speed. If, for instance, the reference point appears to the pilot to lag behind the pylon, a pitch correction is indicated to descend to the actual lower pivotal altitude. Reducing the pitch angle, however, may lead to increasing airspeed. The associated higher ground speed entails a higher pivotal altitude and reduces the extend to which an altitude correction is needed to descend to the now raised pivotal altitude. In this example, inadvertently descending below the pivotal altitude is likely to occur if the correcting pitch change is too great, as illustrated in Figure 10. Pitch corrections should therefore be made with reserve and smoothness to maintain the airplane’s delicate balance between altitude and airspeed and to avoid the need for oscillatory pitch changes or “chasing of the pivotal altitude”.

Such “chasing of the pivotal altitude” is often set in motion by delaying proper maneuver entry. If rolling the airplane is commenced at some distance beyond the point abeam the pylons or if the roll rate is insufficient, the resulting misalignment of the pylon and the reference point erroneously indicates a need to climb to an altitude above pivotal altitude. If vertical alignment
of the reference point and the pylon is maintained, the ensuing increased bank angle is likely to bring about their longitudinal alignment, but only for a brief moment. The steeper than appropriate bank angle will cause the airplane to change heading more quickly. The airplane turns upwind more quickly and the associated ground speed reduction lowers the pivotal altitude and further increases the airplane's excess in altitude above pivotal altitude. This will be indicated by the reference point swiftly falling behind the pylon. Excessive pitch control inputs may then sufficiently disturb the airplane's delicate altitude-airspeed balance to initiate often-aggravating pivotal altitude oscillations.

If the location of the reference point is properly determined and alignment of the reference point and the pylon is maintained throughout the maneuver, the resulting ground track is shown in Figure 11 (a) for the case of no wind. However, the vertical distance the reference point appears either above (low-wing) or below (high-wing) the wing tip is often underestimated. If vertical alignment of the reference point and the pylon is not maintained and the reference point is confused with some point closer to the wing tip or the wing tip itself, the resulting ground track may differ significantly. In a high-wing airplane, the resulting higher bank angles provide increased rates of turn, yielding typical ground tracks qualitatively illustrated in Figure 11 (b). Similarly, in a low-wing airplane, the associated lesser bank angles result in decreased rates of turn and typically produce ground tracks similar to those shown in Figure 11 (c). It is important to note that such continual vertical misalignment also leads to an increasing longitudinal misalignment of the reference point and the pylon because a heading perpendicular to the radius of the turn cannot be maintained. The scenario depicted in Figure 11 (b) will cause the reference point to fall behind the pylon, erroneously indicating a need to
descend, often significantly below pivotal altitude. If the flight path is lowered below pivotal altitude, the associated reduction of the bank angle may inadvertently result in lessening the falsely ensuing decrease of the distance from the pylon. The scenario illustrated in Figure 11 (c) will cause the reference point to move ahead of the pylon, erroneously indicating a need to climb above pivotal altitude. If the flight path is raised above pivotal altitude, the associated increase of the bank angle may inadvertently result in lessening the falsely ensuing increase of the distance from the pylon. The exact outcome of the maneuver will mainly depend upon the severity of the two errors: the degree of vertical misalignment and the erroneous descent below or climb above pivotal altitude to inappropriately restore longitudinal alignment of the reference point and the pylon. Although it may appear as if the detrimental effects of establishing the wrong bank angle can be compensated for by maintaining flight at the wrong altitude, the two wrongs cannot make the maneuver right, and it is clear that ground track alone cannot adequately serve to evaluate an actual flight performance. The qualitative effects of bank and altitude on the outcome of the maneuver are summarized in Table 2.

The Practical Test Standards (PTS) (PTS, 1997), published by the Federal Aviation Administration, specify the standards for satisfactory performance of the Eights-On-Pylons maneuver for commercial pilot certification. Approximately three to five seconds of straight-and-level flight between the two 360 degree turns are designated by the PTS to check the area. A few seconds of straight and level flight may indeed be helpful if the second pylon is not selected prior to maneuver entry or if there is a need to amend a previously selected pylon. On the other hand, if no amendment is required, it appears advantageous if the airplane is rolled continuously for quickest possible alignment of the reference point and the second pylon
while checking the area. The results of the computer simulations presented here seem to indicate that there is no intrinsic need for extended straight and level flight between the turns. Minimizing the time of straight-and-level flight may further enhance proper aircraft control. If visual alignment of the reference point and the second pylon is attempted soon, altitude deviations can be noted early and flight at pivotal altitude can be restored without delay.

Summary

Execution of the Eights-On-Pylons maneuver calls for timeliness, exactness, and smoothness when controlling pitch and bank of the airplane with control inputs mainly based on indications from outside visual references. Unlike other ground reference maneuvers, it provides superbly delicate visual feedback that allows the pilot to delineate minute bank and pitch deviations. Successful performance of the maneuver is found to result in ground tracks that most closely resemble non-concentric circles. If the wind is calm, the centers of the circles are co-located with the pylons. For increasing wind speeds, the centers lie outward from the pylons on the line defined by the pylons.

The maneuver teaches hand-eye coordination, and mastery of the maneuver relies upon improved motor skills similar to those that pave the way for successful flight solely with reference to instruments. During instrument training, the task of maintaining linear flight along the descending glide slope of a precision approach may be put in a different aeronautical perspective by the Eights-On-Pylons maneuver that not only requires exact bank control but also that essentially circular flight is maintained at continually varying pivotal altitude. As long as flight is not fully automated from take-off to touch-down and precise manual control of an
airplane is important, the Eights-On-Pylons maneuver is uniquely suited to help develop valuable flying skills for years to come.

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References


Figure 1
Figure 2
Figure 3

Maneuver Entry Bank Angle (deg) vs. Pylon Separation Distance (NM)

- No Wind
- Wind 10 kts
- Wind 20 kts
Eights On Pylons
Figure 6
Figure 8
Figure 9
Figure 10
Eights On Pylons

Figure 11