Review of Analysis of Observed and Measured In-Flight Turns Suggests Superior Control of 9/11 WTC Aircraft

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Abstract

Video footage depicts United Airlines Flight 175 (UA 175) impacting World Trade Center tower 2 (WTC 2) on September 11, 2001 in New York City via a trajectory comprised of two separate banked turns. The second turn was apparently not required to generate impact. The first turn, which maintains a constant angle of bank (AoB), is evident at 1.2 miles before impact.[1] Although human control of UA 175's observed maneuvers cannot be ruled out, the precise coordination of variables such as the selections of a correct bank angle and turn start time for the first turn apparently pose challenges to the unaided human control hypothesis. The observed turn stability favors the use of autopilot operation, either functioning in a conventional course control mode or in Control Wheel Steering (CWS) mode. The probability that either of these two control systems were used is discussed. Flight deck images of United and American airlines 757s and 767s suggest that such CWS functions may have been disabled circa 2001. Constant radius turns utilizing plotted waypoints during commercial aviation operations are routinely supported by augmented GPS navigation service and related commercial Flight Management Systems (FMS) available circa 2001.[2] As will be demonstrated, the implementation of UA 175's observed 1.2 mile constant radius arc, seconds earlier or later than observed, would apparently result in UA 175 missing WTC 2. Estimates of the likely effect of crosswinds on the approach to WTC 2 are also provided. It is noted that a projected impact via the first observed banked turn would have occurred under crosswind conditions capable of generating between 122 and 134 approximate total feet of lateral displacement from the calculated final position of the aircraft if not affected by such crosswinds. Aircraft distances and other calculations are based on reported aircraft speed for UA 175 of 799 feet per second at impact and measured times to impact [3]. The observed speeds of both attack aircraft were extreme by comparison to the typical speeds of similarly descending aircraft. While creating significantly less response time for possible human hijacker pilot course corrections during final target approaches that would demand superior control surface operation, a general vector analysis considering the final course and speed for each aircraft suggests that the unusually high speeds observed would generate greater accuracy of the aircraft while enroute to their targets, as a result of smaller course deflection angles and ground track displacements, created by existing and potential crosswinds.

Keywords: Bank Angle, Constant Radius Turn, Vector, Ground Track, Radius-to-Fix Turn, Autopilot, Control Wheel Steering

UA 175's Nearly Mile Long Banked Constant Radius Turn

Fig. 1: UA 175 Eight Seconds and Approximately 1.2 Miles Before Impact

Fig. 2: UA 175 Seven Seconds and Approximately 1.05 Miles Before Impact

Fig. 3: UA 175 Six Seconds and Approximately 0.9 Miles Before Impact

Fig 4: UA 175 Five Seconds and Approximately 0.75 Miles Before Impact

Fig. 5: UA 175 Four Seconds and Approximately 0.6 Miles Before Impact

Fig. 6: UA 175 Three Seconds and Approximately 0.45 Miles Before Impact

Introduction

It can be shown that UA 175's stable next-to-final 20 degree banked turn toward WTC 2 alone without correction, would apparently have led to the impact of the plane with the south face of the tower. At approximately 2.5 seconds prior to its impact, UA 175 banks an additional 18 degrees to its left, apparently generating an estimated lateral movement of just 19 feet closer to the center of the south face of the tower.[4] This approximate measure of 18 degrees of bank is arrived at by subtracting the approximately 20 degree observed bank angle of UA 175 while enroute to WTC 2 during 2.5 of its final eight seconds of flight, from the 38 degree angle of impact.

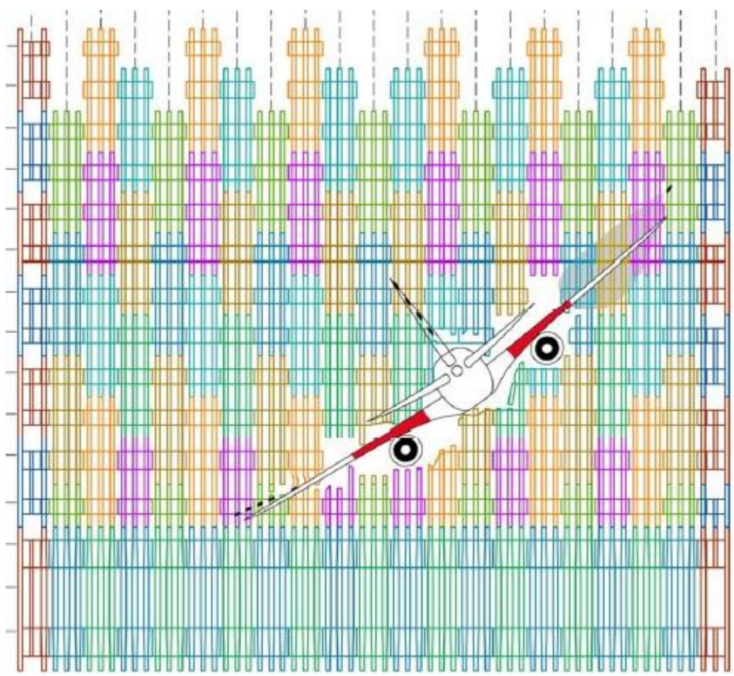

Fig. 7: UA 175's 38 Degree Angle of Impact with WTC 2

Figs. 8 and 9: UA 175 at Moment of Impact with WTC 2

There appear to be three possible explanations for the observed final 18 degree roll of UA 175 prior to impact with WTC 2: 1.) the roll was the final component of an executed flight plan under augmented GPS-guided autopilot control; 2.) the roll was a correction of a crosswind induced tracking error of the observed 20 degree mile-long banked turn via a flight plan under augmented GPS-guided autopilot control. 3.) the roll was a correction by a human pilot to centralize an impact with WTC 2.

The first and third explanations are complicated by the apparent fact that the final 18 degree roll was not required to generate impact. The second explanation is complicated by the likelihood that a crosswind induced error correction would be performed more subtly or incrementally by an autopilot system. The first explanation is also potentially complicated by possible bank angle/rate of turn limits imposed by FMS configurations that may restrict 38 degree banks under autopilot control without modification. A possible rationale for a final 18 degree roll under autopilot control would be to create an impression of active human control.

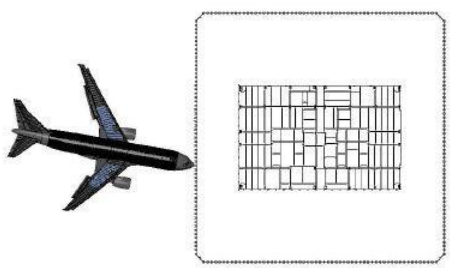

Fig. 10: UA 175's Impact Approximately 23 Feet Right of Center of WTC 2 Via 20 Degree AoB + 18 Degree Roll

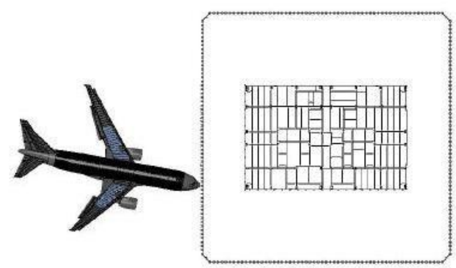

Fig. 11: UA 175's Estimated Impact Point Approximately 44 Feet Right of Center of WTC 2, Via 1.2 Mile Long 20 Degree AoB

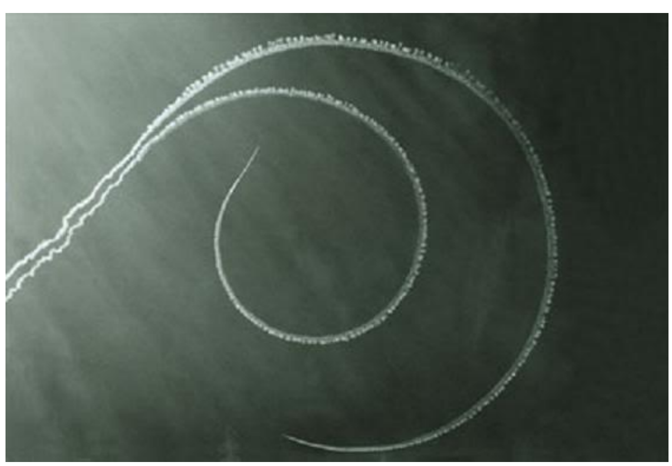

Fig 12: Increasing Separation Between Two Differing Rates of Turn Beginning at Common Point

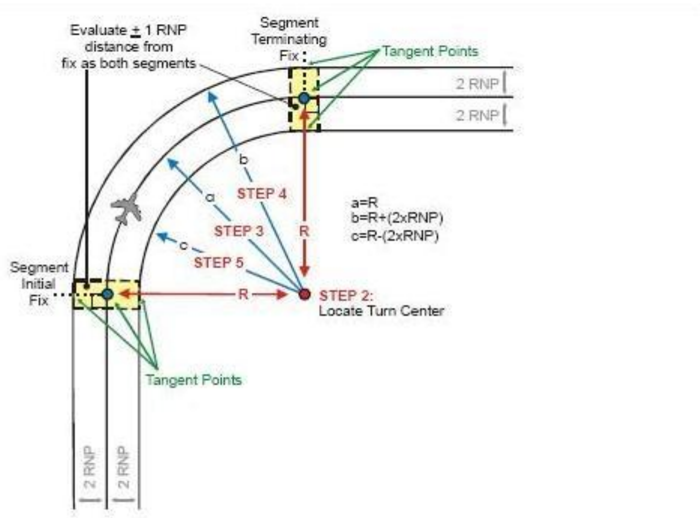

Fig.13: Augmented GPS, Autopilot Controlled Constant Radius-To-Fix Turn

Turn Separation Distances

Estimates for aircraft turn radius and turn circumference are derived from the following calculations:

Aircraft turn radiuses (R) are provided by: R = True Airspeed²/32.16Tan(Angle of Bank).

Aircraft turn circumferences (C) are provided by: C = 2(Pi)R.

The proportions of each constant radius turn completed are provided by: Turn arc time = Speed x Time/Circumference of Turn.

Turn proportions are then multiplied by 360 degrees to determine the number of degrees of each turn completed:

UA 175's Final Turn Radius (Aircraft A) = 799²/32.16Tan(29 degrees) = 35,813 feet. This 29 degree AoB is an approximated average for a span of 20-38 degrees during the 2.5 seconds prior to impact with WTC 2 [38-20=18; 18/2=9; 20+9=29].

UA 175's Final Turn Angle: [(799f/s)2.5/225,020] x 360 = 3.196 degrees of turn.

UA 175's Next-to-Final Turn Radius (Aircraft B) = 799²/32.16Tan(20 degrees) = 54,541 feet. This 20 degree AoB is based on observed approximations.

UA 175's Next-to-Final Turn Angle: [(799f/s)2.5/342,691] x 360 = 2.098 degrees of turn.

Angles of turn completed and turn radiuses are then utilized in order to obtain ordered pairs for use in a Cartesian coordinate system:

X(for Turns A and B) = R - [R x Cos (Degrees of Turn)]
Y(for Turns A and B) = R x Sin (Degrees of Turn)

Aircraft Turn A (final turn):

Xa = 35,813- (35,813 x Cos (3.196)) = 55.701
Ya = 35,813 x Sin (3.196) = 1,996.639

Aircraft Turn B (next-to-final turn):

Xb = 54,541 - [54,541 x Cos (2.098)] = 36.560
Yb = 54,541 x Sin 2.098 = 1,996.681

Individual aircraft X and Y components are combined:

X-separation = Xa - Xb
Y-separation = Ya - Yb

X-separation = 55.701 – 36.560 = 19.141
Y-separation = 1,996.639 – 1,996.681 = -.042

The approximate final distance between UA 175's next-to-final turn and its final turn at impact with WTC 2, is obtained by Pythagorean's theorem:

$[(X\text{-separation}^2) + (Y\text{-separation}^2)] = 19.141^2 + -.042^2 = 366.379^{1/2} = 19.141$ feet.

Adding or subtracting a mere 5 degrees of bank angle with respect to UA 175's observed stable 20 degrees of banking next-to-final turn apparent from a distance of 1.2 miles prior to impact with WTC 2, results in displacements of 98.8 feet and 105.2 feet respectively to the left and right of the observed ground track and the aircraft substantially missing the tower's center by a distance greater than half its wingspan, under the ideal circumstance of a course causing the plane to impact the tower's center.

In fact, the type of descending constant radius turn observed during UA 175's next-to-final banked turn, is specifically described as being supported by augmented GPS service activated one year prior to September 11, 2001 and related Boeing 767 Flight Management Systems (FMS), during its research and development period in 1998:

> "The Wide Area Augmentation System (WAAS) ... allows pilots to fly ... approaches that cannot necessarily be flown with current instrumentation ... Complex curved approaches, including approaches turning to a short (less than one mile) final ... Pathways were constructed from ... climbing, or descending constant radius arcs ... Autopilots could use WAAS position and velocity to fly curved trajectories."[5]

<u>Turn Separation Between 15 and 20 Degrees of Bank</u>

Aircraft Turn A: 15 degrees: (r: 74,086); [(799)8/465,496] x 360 = 4.943

Aircraft Turn B: 20 degrees: (r: 54,540); [(799)8/342,685] x 360 = 6.715

Aircraft Turn A:

Xa (15 deg.) = 74,086 - [74,086 x Cos (4.943)] = 275.532
Ya (15 deg.) = 74,086 x Sin 4.943 = 6,383.594

Aircraft Turn B:

Xb (20 deg.) = 54,540 - [54,540 x Cos (6.715)] = 374.140
Yb (20 deg.) = 54,540 x Sin 6.715 = 6,377.402

X-separation = Xa - Xb
Y-separation = Ya - Yb

X-separation = 275.532 - 374.140 = -98.608
Y-separation = 6,383.594 - 6,377.402= 6.192

Separation = square root of $[(X\text{-separation}^2) + (Y\text{-separation}^2)]$

$(-98.608)^2 + (6.192)^2 = 9{,}752.595^{1/2} =$ **98.802 feet**

<u>Turn Separation Between 20 and 25 Degrees of Bank</u>

Aircraft Turn A: 20 degrees: (r: 54,540); [(799)8/342,685] x 360 = 6.714

Aircraft Turn B: 25 degrees: (r: 42,571); [(799)8/267,481] x 360 = 8.602

Aircraft Turn A:

Xa (20 deg.) = 54,540 - [54,540 x Cos (6.715)] = 374.140
Ya (20 deg.) = 54,540 x Sin 6.715 = 6,377.402

Aircraft Turn B:

Xb (25 deg.) = 42,571 - [42,571 x Cos (8.602)] = 478.874
Yb (25 deg.) = 42,571 x Sin 8.602 = 6,367.338

X-separation = Xa - Xb
Y-separation = Ya - Yb

X-separation = 374.140– 478.874 = -104.734
Y-separation = 6,377.402- 6,367.338 = 10.06

Separation = square root of $[(X\text{-separation}^2) + (Y\text{-separation}^2)]$

$(-104.734)^2 + (10.06)^2 = 11{,}075.630^{1/2} =$ **105.216 feet**

Fig. 14: Largely Indiscernible Difference Between 15 and 20 Degrees of Bank

Fig. 15: Largely Indiscernible Difference Between 20 and 25 Degrees of Bank

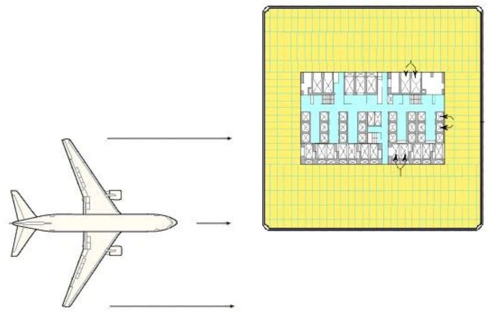

Fig. 16: UA 175 Wide Right of WTC 2's Center by 98.8 Feet with 15 Degree AoB

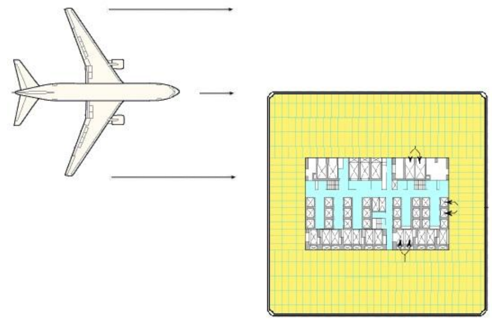

Fig. 17: UA 175 Wide Left of WTC 2's Center by 105.2 Feet with 25 Degree AoB

20 Degree Bank Angle Initiation Time

Using as a reference UA 175's required 2.5 seconds to bank an additional 18 degrees beyond the 20 degree bank angle observed just prior to impact with WTC 2, it is estimated that UA 175 may have required 2.7 seconds to achieve the initial bank of 20 degrees while out of view behind the tower. Therefore, UA 175 may have started its 20 degree precisely banked turn toward WTC 2 from a distance of approximately 1.6 miles, only 1.2 miles of which was observed.

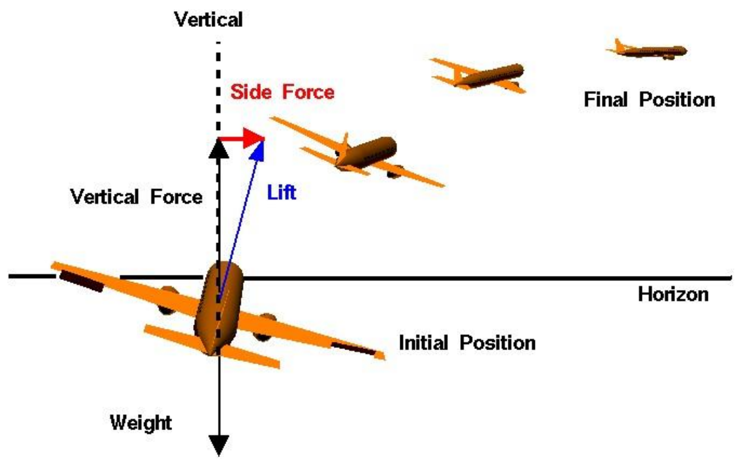

Fig. 18: Aircraft Banked Turn Illustration; Initiation Through Completion

UA 175's Turn Timing

Based on observations, it is known that UA 175 was traveling an apparently wings-level and descending trajectory at a rate of possibly greater than the recorded 799f/s at impact before beginning its observed next-to-final stable 20 degree banked turn toward WTC 2. To have begun this turn toward the tower seconds sooner or later than observed would necessarily result in a shift of this arc short of or beyond the tower at a rate of at least 799f/s and result in UA 175 missing the 208 foot wide WTC 2. Interception of a target via a constant radius turn requires a precise coordination of two variables: 1.) the selection of a turn with a particular bank angle. 2.) the selection of a correct start time for the turn with the selected bank angle. Once again, the observed mile long-plus 20 degree banked turn of UA 175 would apparently have generated impact with WTC 2 without the final 18 degree roll. The 20 degree banked turn also seems to contain no other corrective movements. It is noteworthy that UA 175's projected successful impact with WTC 2 while maintaining its original 20 degree banked turn, would have occurred under crosswind conditions capable of generating between 122 and 134 feet of lateral drift during the aircraft's 8 second observable period of flight, were it linear in nature. The 8 second observable period of flight spanned 6.7 degrees of circular flight, between 38 and 44.7 degrees of orientation. The 122 and 134 foot drift estimates are based the aircraft bearings of 38 and 44.7 degrees respectively. The formula utilized and incorporating these bearings can be viewed on pages 11 and 12.

Fig. 19: UA 175's Apparently Wings-Level Descent Prior to its Observed 20 Degree Stable Banked Turn

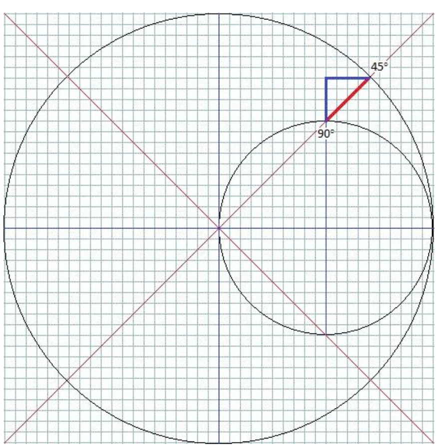

Fig. 20: Graphed Relationship Between Turns of Different Radiuses; Turn Separation Distance Determined by Pythagorean's Theorem

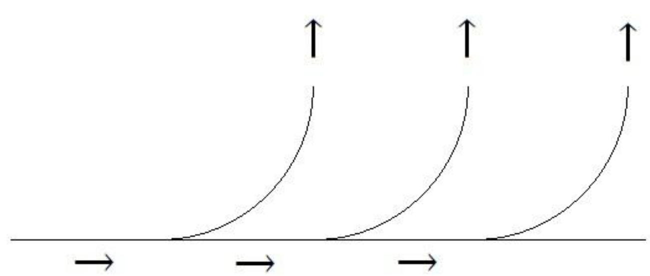

Fig. 21: Identical Turn Arcs Originating from and Arriving at Different Locations

American Airline's 11 Descending Banked Turn

Based on observations and impact angle measurements, it can be determined that American Airlines flight 11 also approached WTC 1 via a descending turn prior to its impact with WTC 1, as with the case of UA 175.

Fig. 22: AA 11's Descending and Banked Approach Toward WTC 1

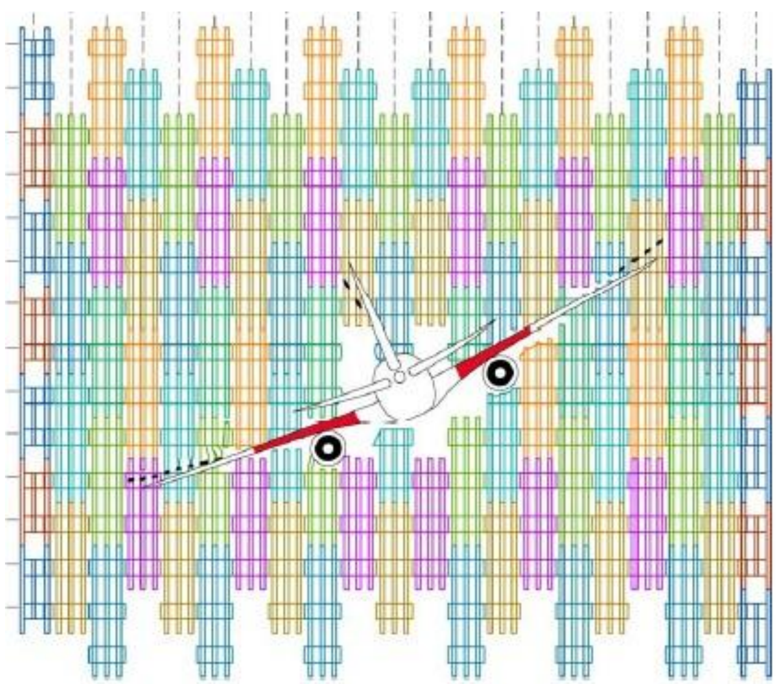

Fig. 23: AA 11's 27 Degree Impact Angle with WTC 1

Higher Speeds Limit Lateral Drift and Deflection Angles

For the morning of September 11, 2001, wind speed and direction for the altitude of the aircraft impacts with each WTC tower were reported to be between 11 mph and 22mph, from the direction of true north.[6] For this analysis, the average estimate of 16.5mph (24.2 f/s) is used. Wind speeds near coastlines like those on Manhattan at the Hudson River and Upper New York Bay, can often be double those recorded inland. Wind directions near such coastlines are also known to be less predictable than inland winds.[7] The north faces of each WTC tower were oriented 29 degrees clockwise from true north. [8] The impact of AA 11 with WTC 1 was perpendicular to its north face. The impact of UA 175 was approximately 9 degrees clockwise of perpendicular to its south face. Comparison of observed higher and hypothesized lower aircraft speeds demonstrates that the greater observed speed of UA 175 reduced potential wind induced drift angles and drift distances while enroute toward WTC 2.

At its time of impact with WTC 1, AA 11 is estimated to have been traveling at a speed of 683 feet per second (466 mph).[9] At its time of impact with WTC 2, UA 175 is estimated to have been traveling at a speed of 799 feet per second (545 mph).[10] Analysis of adjusted hypothetical speeds for AA 11 and UA 175 (185 mph) is based on recommended wide-body commercial aviation aircraft landing approach speed.[11] Lateral displacement per 1,000 feet traveled for UA 175 while traveling at 799 f/s is just 19.15 feet ([1,000/799f/s] x 15.3f/s = 19.15). However, displacement per 1,000 feet traveled for UA 175 if traveling at 272 f/s is 55.15 feet ([1,000/272f/s] x 15f/s = 55.15). Lateral displacement per 1,000 feet traveled for AA 11 while traveling at 683 f/s is just 17.42 feet ([1,000/683f/s] x 11.9f/s = 17.42). However, displacement per 1,000 feet traveled for AA 11 if traveling at 272 f/s is 43.4 feet ([1,000/272f/s] x 11.8f/s = 43.38).

Vector Calculations for American Airlines Flight 11

P (plane): approximate compass bearing 209° (traveling approximately southwest) at 662 f/s (446 mph air speed); W (wind): traveling south at 24.2 f/s (16.5 mph).

Plane and wind vector components represented by ordered pairs:

P = [662 f/s cos(241°), 662 f/s sin(241°)] = -320.9, -579

W = [24.2 f/s cos(270°), 24.2 f/s sin(270°)] = 0, -24.2

-320.9 + 0 = -320.9

-579 + (-24.2) = -603.2

Resolved components substituted into Pythagoreans theorem for resultant speed:

||P + W|| = 320.9² + 603.2² = 466, 827 $^{1/2}$ = **683.2 f/s** (466 mph ground speed)

Resolved components substituted for resultant bearing:

$\tan^{-1}$(603.2/320.9) = 62°; (90° - 62°) + 180° = 208°

Drift angle = 209° - 208° = **1°**

Ground track displacement = 1°tan(683f/s) = **11.9f/s**

Vector Calculations for Adjusted Speed for American Airlines Flight 11

P (plane): approximate compass bearing 209° (traveling approximately southwest) at 272 f/s (185 mph air speed); W (wind): traveling south at 24.2 f/s (16.5 mph).

Plane and wind vector components represented by ordered pairs:

P = [272 f/s cos(241°), 272 f/s sin(241°)] = -131.9, -237.9

W = [24.2 f/s cos(270°), 24.2 f/s sin(270°)] = 0, -24.2

-131.9 + 0 = -131.9

-237.9 + (-24.2) = -262.1

Resolved components substituted into Pythagoreans theorem for resultant speed:

||P + W|| = 131.9² + 262.1² = 86,094 $^{1/2}$ = 293.4 f/s (205 mph ground speed)

Resolved components substituted for resultant bearing:

$\tan^{-1}$(262.1/131.9) = 63.3°; (90° - 63.3°) + 180° = 206.7°

Drift angle = 209° - 206.7° = **2.3°**

Ground track displacement = 2.3°tan(293.4 f/s) = **11.8 f/s**

Vector Calculations for United Airlines Flight 175

P (plane): approximate compass bearing 38° (traveling approximately northeast) at 818 f/s (561 mph air speed); W (wind): traveling south at 24.2 f/s (16.5 mph).

Plane and wind vector components represented by ordered pairs:

P = [818 f/s cos(52°), 818 f/s sin(52°)] = 503.6, 644.6

W = [24.2 f/s cos(270°), 24.2 f/s sin(270°)] = 0, -24.2

503.6 + 0 = 503.6

644.6 + (-24.2) = 620.4

Resolved components substituted into Pythagoreans theorem for resultant speed:

$\|P + W\| = 503.6^2 + 620.4^2 = 638{,}509^{1/2}$ = **799 f/s** (545 mph ground speed)

Resolved components substituted for resultant bearing:

$\tan^{-1}(620.4/503.6) = 50.9°$; (90° - 50.9°) = 39.1°

Drift angle = 39.1° - 38° = **1.1°**

Ground track displacement = 1.1°tan(799 f/s) = **15.3f/s**

Vector Calculations for Adjusted Speed for United Airlines Flight 175

P (plane): approximate compass bearing 38° (traveling approximately northeast) at speed 272 f/s (185 mph air speed); W (wind): traveling south at 24.2 f/s (16.5 mph).

Plane and wind vector components represented by ordered pairs:

P = [272 f/s cos(52°), 272 f/s sin(52°)] = 167.4, 214.3

W = [24.2 f/s cos(270°), 24.2 f/s sin(270°)] = 0, -24.2

167.4 + 0 = 167.4

214.3 + (-24.2) = 190.1

Resolved components substituted into Pythagoreans theorem for resultant speed:

$\|P + W\| = 167.4^2 + 190.1^2 = 64{,}160^{1/2}$ = 253.3 f/s (168 mph ground speed)

Resolved components substituted for resultant bearing:

$\tan^{-1}(190.1/167.4) = 48.6°$; (90° - 48.6°) = 41.4°

Drift angle = 41.4° - 38° = **3.4°**

Ground track displacement = 3.4°tan(253.3 f/s) = **15 f/s**

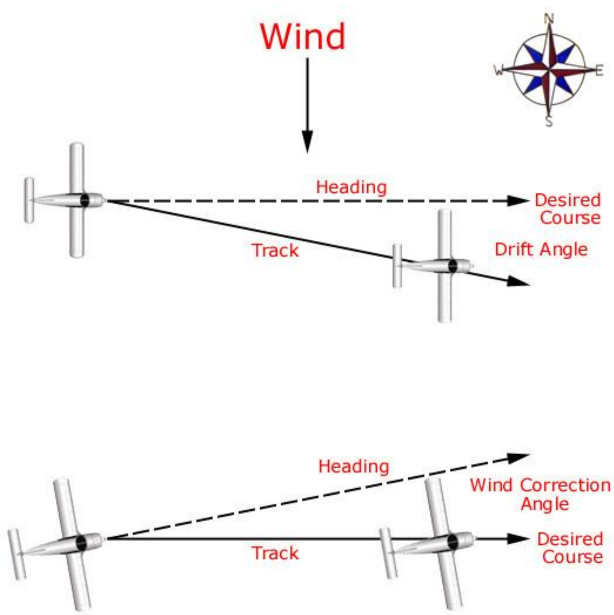

Fig. 24: Wind Induced Aircraft Drift Angles

As demonstrated, the extraordinarily high aircraft speeds of the aircraft that impacted the WTC towers would help to preserve their courses based on distances traveled while enroute to their targets by minimizing the deflection angles and ground track displacements created by present crosswinds and potential wind shear.

Achieving a desired course under crosswind conditions that can deflect an aircraft from a desired destination requires consideration of the relationship between an aircraft's direction and speed, with respect to a wind's direction and speed.

Such relationships are represented trigonometrically by a "wind triangle", which is typically calculated by aircraft Flight Management Systems:

> "On aircraft equipped with advanced navigation equipment, the wind triangle is often solved within the flight management system, (FMS) using inputs from the air data computer (ADC), inertial navigation system (INS), global positioning system (GPS), and other instruments, (VOR), (DME), (ADF)."[12]

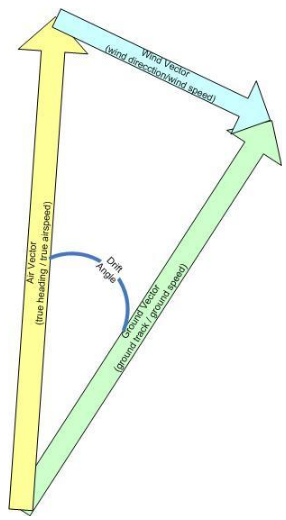

Fig. 25: Relationship Between Wind, Aircraft Heading and Aircraft Ground Track Vector Components

Discussion

Although human control of UA 175 cannot be ruled out, small margins for error are evident in the number of available degrees of bank that could generate impact with WTC 2 via a constant radius turn from approximately 1.5 miles distant. An error of 5 degrees of bank left or right seems largely indiscernible to an observer, but would generate substantial distances from a given target. To achieve impact via a mile-long plus constant radius banked turn, within an acceptable margin of error would seem to be a substantial challenge to a reportedly inexperienced pilot without aid. The CWS function would apparently provide an in-flight automated stability that would permit a pilot to apply greater attention to the course of an aircraft and consider whether additional maneuvers would be required.

In contrast to the observed controlled flight of UA 175 during the seconds before its impact with WTC 2, it has been posited that National Transportation Safety Board (NTSB) Flight Data Recorder (FDR) data indicates inexperienced human control of American Airlines flight 77 (AA 77), in the form of repeated and erratic changes in aircraft altitude, attitude, speed and direction and that therefore human control of the other 3 aircraft destroyed on September 11, 2001 must be considered. Discrepancies surrounding the authenticity and quality of this FDR data are public knowledge however, including the absence of published inventory control serial numbers for the FDR of AA 77 and a discrepancy of 5 hours between the reported recovery time of AA 77's alleged FDR and the time stamp contained within its data download file[13][14].

The CWS feature described earlier as being capable of maintaining the stable 20 degree bank angle observed during UA 175's mile-plus long approach toward WTC 2 was apparently a standard feature of Boeing 767-200s circa 2001[15]. However, photographic flight deck evidence suggests the CWS feature within American Airlines and United Airlines 767s was disabled circa 2001[16][17]. Any CWS disabling would be readily reversible. Because CWS is a component of autopilot function, possible bank angle limitations preventing 38 degree bank angles under autopilot control may also similarly restrict the CWS function. Adjustable autopilot bank angle limitations are possibly one aspect of modifiable aircraft performance related FMS default settings, contained in easily loadable system software:

> "Many newer airplanes, such as the Boeing … 767, feature loadable systems whose functionality may be changed or updated using onboard loadable software. This feature allows operators to change the configuration of loadable systems without physically modifying or replacing hardware components. In addition, software often can be loaded just in the time required to turn an airplane around for the next flight. Some of the databases used by software loadable LRUs (line replaceable units) are: Flight management computer (FMC) navigation database (NDB); FMC performance defaults database."[18]

Given the limited open source references to the technology at issue, further study of this aspect of aircraft performance is required.

When considering the probability of conventional autopilot and CWS control of UA 175, there appear to be factors which weigh against both and apparently neither method can be ruled out definitively. The final sharp turn weighs against standard autopilot control without autopilot modification. The uniformity and accuracy of the initial bank capable of generating impact weighs against CWS facilitated human control, as it indicates that the initial bank angle set was very nearly correct. The low probability of such a fortunate initial selection must be considered.

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