



NATIONAL TRANSPORTATION SAFETY BOARD

**Office of Aviation Safety
Western Pacific Region**

WAKE VORTEX STUDY

**NTSB Accident: WPR16FA086
Accident Date: March 21, 2016**

Report Author: Michael Huhn

This document contains 15 embedded images

A. ACCIDENT

Location: Hawthorne, California
Date: March 21, 2016
Aircraft: Airborne XT912, N670EM, Serial # XT912-0214
NTSB IIC: Michael Huhn

B. ACCIDENT SUMMARY

On March 21, 2016 about 1201 Pacific daylight time, an Airborne XT912 weigh shift control (WSC) special light sport aircraft, N670EM, was destroyed when it impacted a fence and a roadway shortly after takeoff from Hawthorne Municipal Airport (HHR), Hawthorne, California. The student pilot received fatal injuries. The instructional flight was operated under the provisions of Title 14 Code of Federal Regulations Part 91. Visual meteorological conditions prevailed, and no flight plan was filed for the flight.

C. INVESTIGATION SUMMARY

The wreckage was examined in detail, and no evidence consistent with in-flight structural failure or engine malfunction was observed. Although it was not reported by any of the HHR air traffic control tower (ATCT) controllers, investigation review of air traffic control (ATC) radar data indicated that a de Havilland Canada DHC-6 was estimated to have landed on the same runway about 40 seconds prior to the HHR ATCT controller's issuance of a takeoff clearance for N670EM. The presence of the DHC-6 was not discovered by the investigation until about 7 weeks after the accident.

The possibility that N670EM encountered the wake of the landing DHC-6, and that that encounter resulted in an airborne loss of control and the accident, was investigated. The study was limited by the lack of definitive positional and temporal data for the two aircraft, and the lack of fine-resolution meteorological data. However, there was sufficient information to enable an assessment of the potential for such a wake encounter, as well as quantify the potential effects of the wake on N670EM.

The DHC-6 is a twin-engine turboprop airplane with a 65 ft span high wing, and a maximum gross weight of about 12,000 lbs. N670EM was a pusher-configuration 'trike' (engine & pilot carriage suspended from a tube and fabric sail-type wing) with an 80 hp engine, a maximum gross weight of 992 lbs, and a wingspan of 32.8 ft.

The NASA Langley Aircraft Vortex Spacing System Predictor Algorithm (APA) was used to determine potential wake vortex location and strength values. The results indicated that the meteorological conditions, in combination with the relative times and flight paths of the two aircraft, allowed for the possibility of a wake encounter by N670EM. Specifically, the results indicate that the location of the DHC-6 left vortex between 60 and 80 seconds after that airplane overflew the threshold could have been in the proper location to be encountered by N670EM.

In addition, the residual vortex circulation strength would have been of sufficient magnitude to upset or even completely overpower (by exceeding the available roll control) N670EM. Depending on the location of the vortex core along N670EM's wing span, the vortex-induced rolling moments generally exceeded the N670EM roll capability provided by normal control inputs, and could have been approximately quadruple the N670EM roll capability for vortex core locations near the N670EM wing centerline.

D. ANALYSIS INPUTS

1.0 General

There was no ATC tracking radar that sensed or recorded aircraft ground operations at HHR, and the radar detection 'floor' for the airspace around HHR was several hundred feet above the airport elevation. Therefore, there was no quantitative position, altitude, or speed data for the final descent of the DHC-6, the climb of N670EM, or their respective ground operations. Consequently, the flight profiles and relative timing of the two aircraft operations had to be developed using witness accounts and recorded ATC communications.

2.0 Witness Reports

None of the ATCT personnel or other ground-based persons who witnessed the accident reported the presence of the DHC-6, and several witnesses explicitly stated that they did not see any other aircraft that could have potentially interfered with the departure of N670EM. Eyewitness estimates from several persons, including the accident pilot's flight instructor, of the altitude of N670EM when it began the right roll and descent, ranged from 40 feet to 200 feet above ground level.

Once the presence of the DHC-6 was identified (via archived radar tracking data) by the investigation, the flight crew members of the DHC-6 were telephonically interviewed separately by the investigation. Both crew members reported that they witnessed the accident as they were taxiing to their parking area after they exited the runway after landing. Their taxi route to parking began with a 180 degree left turn as they exited the runway; the taxi route was back along the taxiway/ramp that paralleled the south side of runway 25. After witnessing the accident, the DHC-6 crew discussed with one another the possibility that N670EM encountered their wake, but they did not reach out to any investigative or other relevant agencies regarding the accident.

As part of their NTSB interviews, the DHC-6 crew provided information as able regarding their landing weight, descent profile, approach and landing speeds, and approximate touchdown point. Most of the two crew member's recollections and comments were in concurrence. However, due to the length of time that elapsed between the accident and the interview, the crew was unable to be very specific about their exact touchdown point.

3.0 DHC-6 Trajectory

Based on the crew member reports, a presumed still-air approach/landing trajectory for the DHC-6 was developed. The developed trajectory included two segments:

- a) A steady speed descent down the VASI glide path until the airplane crossed the eastern end of the paved runway surface (referred to in this analysis as the 'fence'), and
- b) A constant rate of descent flight path from the 'fence' to the touchdown point

The touchdown point was selected as the longitudinal center of the painted runway "touchdown aim point" markings (dual solid white boxes), which was about 1,100 feet from the runway threshold, and about 1,585 feet from the 'fence'.

The speed for the steady state VASI descent segment was 75 knots (kts) or 127 feet per second (fps). The touchdown speed was 65 kts (110 fps). The airplane was presumed to decelerate linearly (constant deceleration rate) from 75 kts to 65 kts. These speeds and fixed points were then used to calculate the trajectory in terms of time and position (altitude, location along runway). Still-air conditions were assumed for all calculations.

These values are based on flight crew recollections, and represent the best possible estimate of the DHC-6 trajectory. However, the number of variables, and the uncertainty associated with each, allow for significant variations between this derived trajectory and the actual trajectory. Such variations include but are not limited to approach path speed, approach path angle, and touchdown speed, timing, and location. It is conceivable that altitudes can readily vary by 50 feet, speeds by 10 kts, and touchdown location by several hundred feet.

4.0 N670EM Trajectory

The takeoff roll and initial climb still-air trajectory of the accident aircraft was developed from the witness reports, HHR layout, and the POH-provided values. The beginning of the takeoff roll was selected as 30 feet from the east pavement end of runway 25; this point was beyond (west of) the yellow runway arrow markings, within the white-marked portion prior to (east of) the displaced threshold.

Using the POH takeoff distance of 810 feet to 50 feet altitude, the initial climb flight path angle of 10 degrees, and a climbout speed of 50 kts, the N670EM takeoff ground and air distances were calculated. These were calculated to be 527 feet (ground run), and 283 feet (air run).

While these values are based on published POH performance, and represent the best possible estimate of the N670EM trajectory, the number of variables, and the uncertainty associated with each, allow for significant variations between this derived trajectory and the actual trajectory. Such variations include, but are not limited to, ground roll start location, ground roll distance, ground roll duration, climb speed, and climb angle. In view of these uncertainties, it is conceivable that altitudes can easily vary by 50 feet, speeds by 5 kts, and liftoff location by a few hundred feet.

5.0 Trajectory Relative Location

In addition to the uncertainties associated with each of the individual trajectory profiles, the spatial location of those trajectories relative to the runway and each other was subject to the same lack of precision. Therefore, the derived relative locations are a best estimate only, and each trajectory could differ by 50 feet vertically and several hundred feet longitudinally.

A plan view of the departure end of the runway and the locations of items relevant to the accident is shown in Figure 1.

A profile view of the estimated flight paths of the DHC-6 and N670EM is depicted in Figure 2.



Figure 1 – Overview of HHR East End (Taxiways A, B, & C, plus other features, noted)

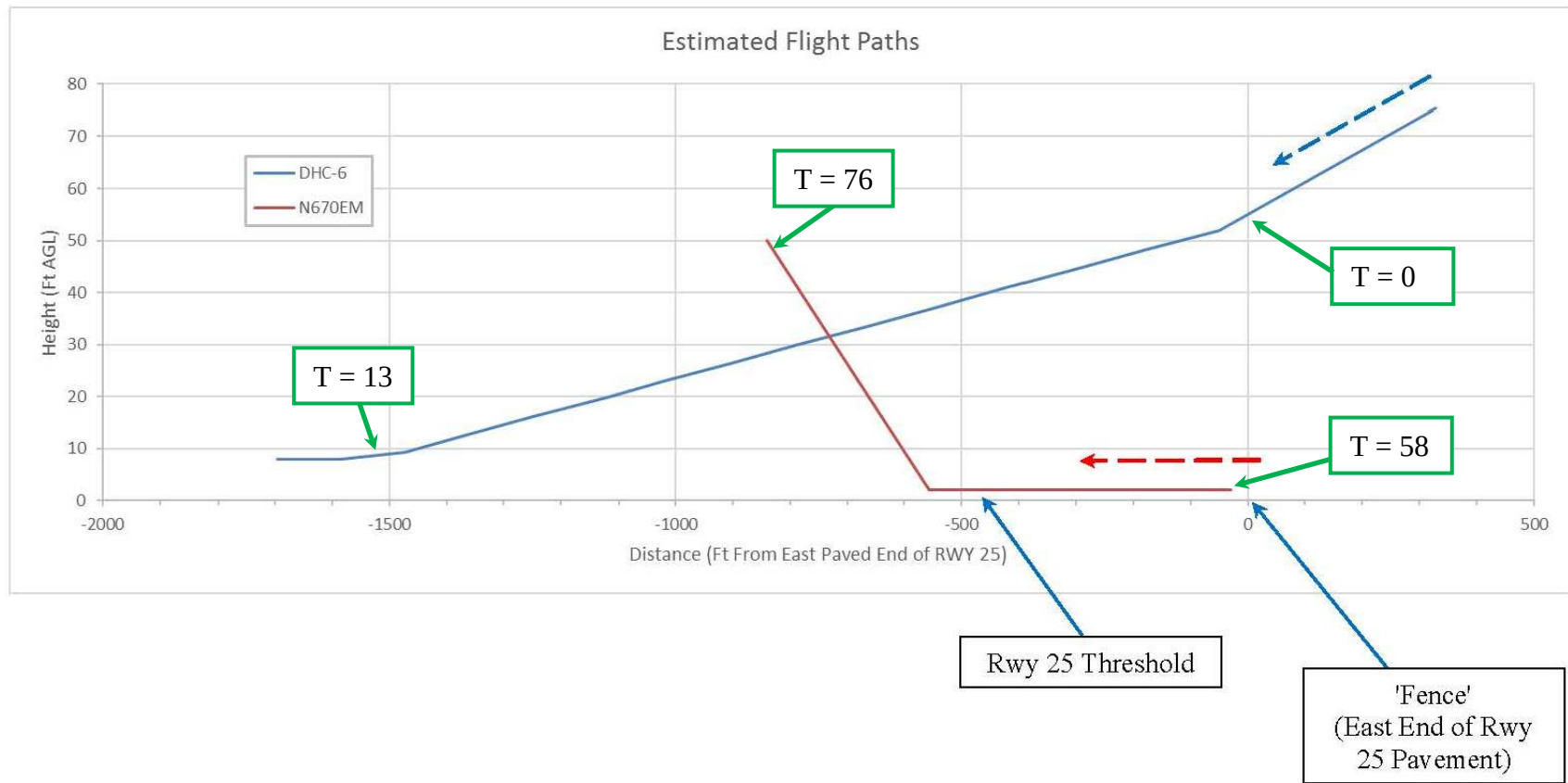


Figure 2 - Profile View of Two Flight Paths (Dashed arrows depict travel directions, "T" = time, sec)

6.0 Trajectory Relative Timing

Once the two trajectories were developed both spatially (geometrically relative to the runway), and temporally on an individual basis, they had to be correlated in time relative to one another. This was accomplished primarily using the ATCT audio recording. The DHC-6 touchdown time was estimated based on the communications content and timing, and the known time of the N670EM takeoff clearance issuance was 40 seconds after that estimated DHC-6 touchdown time.

As was the case for the trajectory relative locations, the relative timing of the two trajectories was derived with the best available information, which was extremely limited and imprecise. Therefore, the derived relative timing is a "best estimate" only. The assumptions used to derive the relative timing included the following:

- a) The ATCT controller did not query the DHC-6 crew about their parking location until after the DHC-6 landed
- b) The ATCT controller did not clear N670EM until the DHC-6 exited the runway
- c) A 5-second line-up time was added to the takeoff clearance time to determine the initiation of the N670EM takeoff roll

Presuming that the ATCT did not query the DHC-6 about parking until after touchdown, the 40 second time interval between the DHC-6 estimated landing time and the N670EM takeoff clearance could be as short as 30 seconds. Although less likely, it is possible that the ATCT controller made the parking query before the DHC-6 landed, which would further reduce the interval. Conversely, a delay between when the DHC-6 landed and when the ATCT controller inquired about parking location would add to the 40 second estimate.

Comparison of the developed trajectories of the two aircraft in time and space indicated that N670EM climbed through the DHC-6 descent trajectory at a point about 32 feet above the ground, about 740 feet from the 'fence' (see Fig 2 and Appendix 1), and about 67 seconds after the DHC-6 descended through that same geometric location.

7.0 Meteorological Conditions

The HHR METAR data was used to provide the temperature and baseline wind conditions. Those METAR input parameter values included a temperature of 66° F (7° F above standard atmosphere) and the initial wind speed of 0 kts (calm). Due to the known behavior for the left and right vortices to translate away from the runway (or more accurately, flight path) centerline under zero crosswind conditions, slight crosswind component inputs had to be introduced into the vortex modeling to enable a vortex to be located above the runway.

HHR runway elevation was 65 feet MSL. To simplify the analysis, the runway elevation was presumed to be 0 ft MSL (sea level), and all MSL elevations were therefore also AGL altitudes.

NOTE- See Appendix 1 for the most complete list of input parameters, data, and assumptions.

E. WAKE VORTEX & MODELING PROGRAM INFORMATION

1.0 General

According to the FAA Aeronautical Information Manual (AIM), "Every aircraft generates a wake while in flight. ...[This wake is primarily] a pair of counter-rotating vortices trailing from the wing tips." The AIM explains the vortex origin as follows: "Lift is generated by the creation of a pressure differential over the wing surface. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers the roll up of the airflow aft of the wing resulting in swirling air masses trailing downstream of the wing tips. After the roll up is completed, the wake consists of two counter-rotating cylindrical vortices. Most of the energy is within a few feet of the center of each vortex, but pilots should avoid a region within about 100 feet of the vortex core."

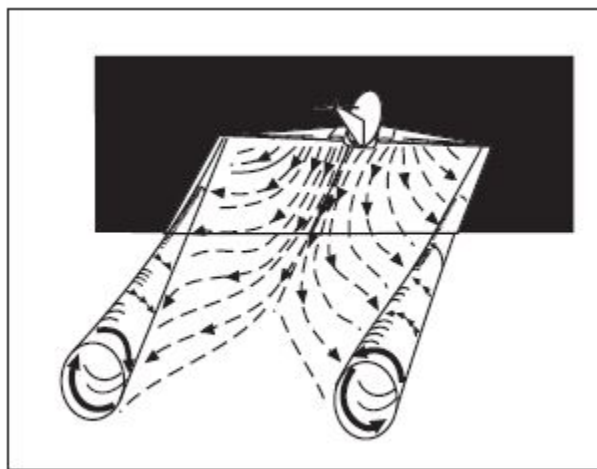


Figure 3 - Vortex Illustration

2.0 Effect of Wake Vortices on Trailing Aircraft

In addition to the AIM, wake vortices are discussed in FAA Advisory Circular (AC) 90-23G ("Aircraft Wake Turbulence"), Chapters 4 and 13 of the FAA Pilot's Handbook of Aeronautical Knowledge (PHAK, FAA-H8083-25), and the NTSB Aircraft Performance Study for NTSB Accident # CEN13TA113, and that information is partially summarized here. The AIM states that the "vortices from larger aircraft pose problems to encountering aircraft. For instance, the wake of these aircraft can impose rolling moments exceeding the roll-control authority of the encountering aircraft." As described in the CEN13TA113 Study, wake vortices produce forces and moments on a trailing aircraft by inducing velocities in the air surrounding them, which change the local angles of attack and sideslip on the encountering aircraft surfaces.

The magnitude and distribution of those changes over the aircraft depend on the magnitude of the velocities induced by the vortices, which in turn depend on the vortices' strength, the speed of the trailing airplane, and the position and orientation of the aircraft relative to the vortex cores.

The worst-case scenario is the wake encounter geometry that produces the maximum rolling moment on a trailing aircraft; this geometry corresponds to an encounter in which the rotational axis of one of the vortices is parallel to the longitudinal axis of the encountering aircraft, and located in the plane of the wing at mid-span. In such a worst-case situation, the vortex will induce upward velocities on one wing and downward velocities on the other, causing a distribution of equal and opposite angle of attack and lift changes along each wing, resulting in a rolling moment. The capability of an aircraft to counteract the roll imposed by the wake vortex primarily depends on the roll-control authority of the encountering aircraft.

In this accident case, because N670EM rolled right wing down (RWD), the affecting vortex circulation was initially presumed to be clockwise (as viewed in the direction of flight). That rotational direction, because the DHC-6 and N670EM were traveling in the same direction, would be associated with the left wingtip vortex of the DHC-6, and for these reasons, the modeling and analysis was limited to the left wing vortex. However, once the models were run and analyzed, it became apparent that, depending on the spanwise location of the vortex core encounter, the left vortex could induce either a RWD or left wing down (LWD) rolling moment, and the same holds true for the right vortex.

3.0 Vortex Characteristics and Behavior

As described in the CEN13TA113 Study, the initial circulation of a vortex is a function of air density and the generating airplane's weight, airspeed, and wingspan. Over time, viscous effects cause the circulation of the vortex to decay, decreasing the velocities induced by the vortex.

The vortex pair formed in the wake of an airplane induce a velocity field that causes the vortex system to sink over time. This motion is affected by the ground, and near the ground the velocity field induced by the vortex pair system causes the separation between the vortices to grow, moving them away from one another. In addition, research indicates that sinking vortices will rebound (bounce) off the ground before sinking again. Vortex interaction with the ground accelerates the vortex decay, causing vortices to fade more quickly in ground effect than when in free air.

Finally, vortices will be transported laterally by wind. A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex.

Vortex strength is calculated from its circulation characteristics; "Gamma" (symbol ' Γ ') is the term assigned to the parameter of vortex circulation, and the units are feet squared per second. Vortex tangential velocity at any radius ' r ' from the vortex core can be calculated by the expression $\Gamma / 2\pi r$ (for further details, see the CEN13TA113 Study).

4.0 NASA Vortex Predictor Algorithm ('APA')

A NASA-developed vortex predictor algorithm, known as APA, is a numerical tool used to model the behavior of aircraft trailing vortices that are subject to atmospheric effects and

interaction with the ground. The APA model accounts for vortex evolution in three distinct phases, as required: out of ground effect, near ground effect, and in ground effect. APA-required input data are the initial height, separation distance, and descent speed of the vortices, and vertical profiles of crosswind, temperature, and eddy dissipation rate in the atmosphere. (For eddy dissipation rate discussion, see p 11 of the CEN13TA113 Study. For this analysis, the default value of .0002, which is between smooth air (0.00001) and slightly turbulent air (0.001), was used). Output parameters from the model are circulation, height, and lateral position for each primary vortex as a function of time.

NOTE - Technical documentation for the APA algorithm can be found in:
Robins, R.E., and Delisi, D.P. NWRA AVOSS Wake Vortex Prediction Algorithm Version 3.1.1. NASA Langley Research Center, June 2002. Report number NASA/CR-2002-211746.

In this Study, APA was used (per the methods described in detail in the CEN13TA113 Study) to calculate the position and strength of the DHC-6 wake vortices. For a given DHC-6 position and condition, the APA model first calculates the initial strength of the two vortices as they are formed at the DHC-6 wingtips, and then calculates their movement and decay as a function of time. The initial height of the vortices is assumed to be the altitude of the DHC-6 at the starting time of each individual APA run; this altitude was determined from the airplane's approach and landing trajectory (Figs 1 and 2). The initial descent speed of the vortices is a function of the initial circulation, which in turn depends on the DHC-6 weight, airspeed, and wingspan, as well as the air density.

The time interval between each set of calculations, as well as the overall time duration of the APA run (ie, how long the strength and location of each vortex will be calculated for) is user-specified. For example, for a single vortex initiation time/location point, the user can specify that APA calculate the vortex strength and location every 5 seconds for a period of 2 minutes. This would yield a set of 24 vortex data subsets. Each such set of vortex position and strength data subsets (in this example case 24) is referred to as a "snapshot." Vortex position data refers to the height and lateral location of the vortex axis or core.

In order to derive a picture of the entire wake position in space, and the vortex strength as a function of position at a given time, APA is run multiple times in order to calculate the development of the wake from several longitudinally arrayed starting points along the flight path of the DHC-6. Thus, for the example case above, if one wanted to look at the vortex behavior at five different locations along a generating airplane's trajectory, five snapshots would be required, and a total of 120 (5 x 24) data subsets would be generated. Then, the APA results are surveyed and culled for the wake height, lateral position, and strength values at the snapshot times of interest. These 'times of interest' would be those which correspond to the longitudinal geographic locations of interest, which in this case would be where N670EM appeared to lose control (encountered the vortex). The collected results provide the desired details of the wake position, as well as the circulation values along the length of the wake, at the sampled times.

F. WAKE VORTEX PROGRAM RESULTS

1.0 APA Program Timing and Wind Selections

Because neither the trajectories nor their relative times were known with certainty, the APA runs had to be of sufficient duration to ensure temporal capture of the event, and with enough snapshots to provide the longitudinal spatial resolution necessary to evaluate the possibility of a vortex encounter by N670EM. A run duration of 90 seconds, with snapshots every 5 seconds, was used. The 5 second snapshot interval, with the DHC-6 traveling at an average speed of about 115 fps, provided a longitudinal spatial resolution (vortex locations along the flight path or runway) of about 575 feet. These input and run parameters resulted in strength and position datasets for 18 longitudinal positions along the DHC-6 landing trajectory, and the two output longitudinal locations of 545 ft and 1,135 ft from the 'fence' bracketed the estimated N670EM loss of control location. In the rest of this report, these two vortex locations are referred to as the "545' and 1,135' vortices."

For each calculation subset of vortex strength, lateral position, and height, an interval of 5 seconds was also used.

This study presumed that both the DHC-6 and N670EM tracked the runway centerline for their respective landing and takeoff. Because the N670EM roll direction suggested that it was affected by the left DHC-6 vortex, and the DHC-6 vortices would migrate away from the runway centerline once they contact the ground, a mechanism to align the DHC-6 left vortex with the runway centerline had to be identified. Because vortices can be laterally translated by wind, a series of direct (perpendicular to the runway) left crosswind cases were run to determine their effect on vortex lateral travel. Initially, three wind cases (0, 2, and 4 kts) were run, but those results indicated that a 2kt wind laterally displaced the vortices too much, and a 1kt wind case was then run.

2.0 Vortex Location Results

The datasets for the 545' and 1,135' vortices for the three wind cases (0, 1, & 2 kts) were separated from the APA full output sets and examined in greater detail. Time histories of altitude and lateral location were plotted separately for each wind case, and annotated with selected DHC-6 and N670EM events.

The output data (Figs 4 through 6) showed that both the 545' and 1,135' vortices initially descended, and then bounced to altitudes higher than their formation altitudes. The 545' vortex formed at an altitude of about 37 feet, and then bounced to an altitude of about 52 feet by 75 seconds after its formation. Similarly, the 1,135' vortex formed at an altitude of about 18 feet, and bounced to an altitude of about 38 feet by 70 seconds after its formation. Crosswinds had negligible effect on the altitude behavior of the vortices.

Superimposing the N670EM climb trajectory on the altitude plots revealed that it was possible for the aircraft and vortex altitudes to intersect with regard to time. As calculated, the results

demonstrated that the vortices and N670EM could both end up at the same altitude at the same time, even if the vortex initially formed at a lower altitude.

Although not depicted directly on the altitude traces, the vortex and trajectory longitudinal positions with respect to time did not intersect for this specific calculation set. The data shows that, for this specific case, the N670EM longitudinal location is situated approximately midway between (~300 feet either direction) the 545' and 1,135' vortices at the common altitude-time points. Because this 300 foot difference is within the trajectory input data uncertainty range (particularly for the DHC-6), the calculations demonstrate the possibility for the vortices and N670EM to be concurrently collocated in altitude and longitudinal (along the runway) position.

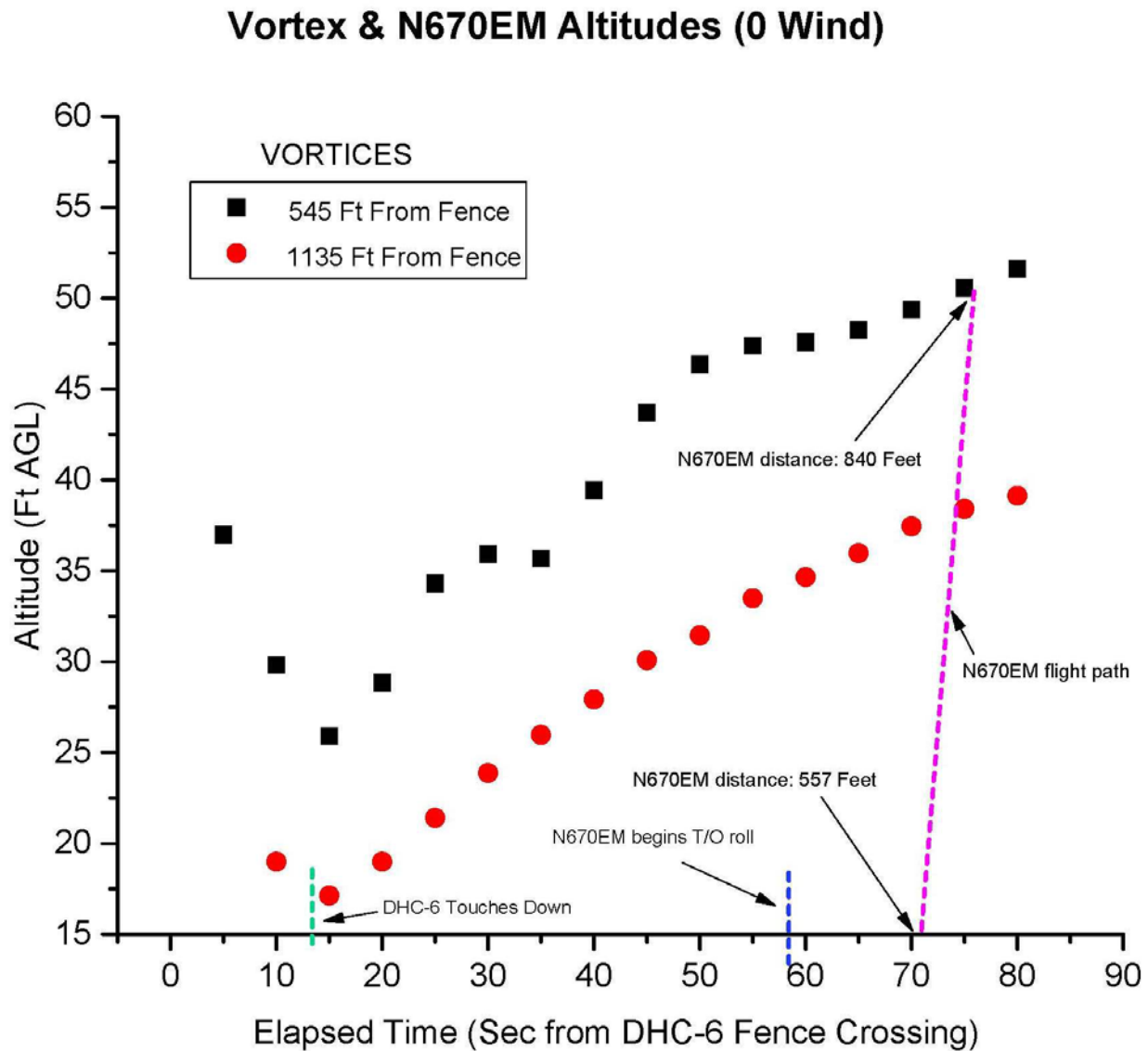


Figure 4 – Vortex Heights

Vortex & N670EM Altitudes (1kt X-Wind)

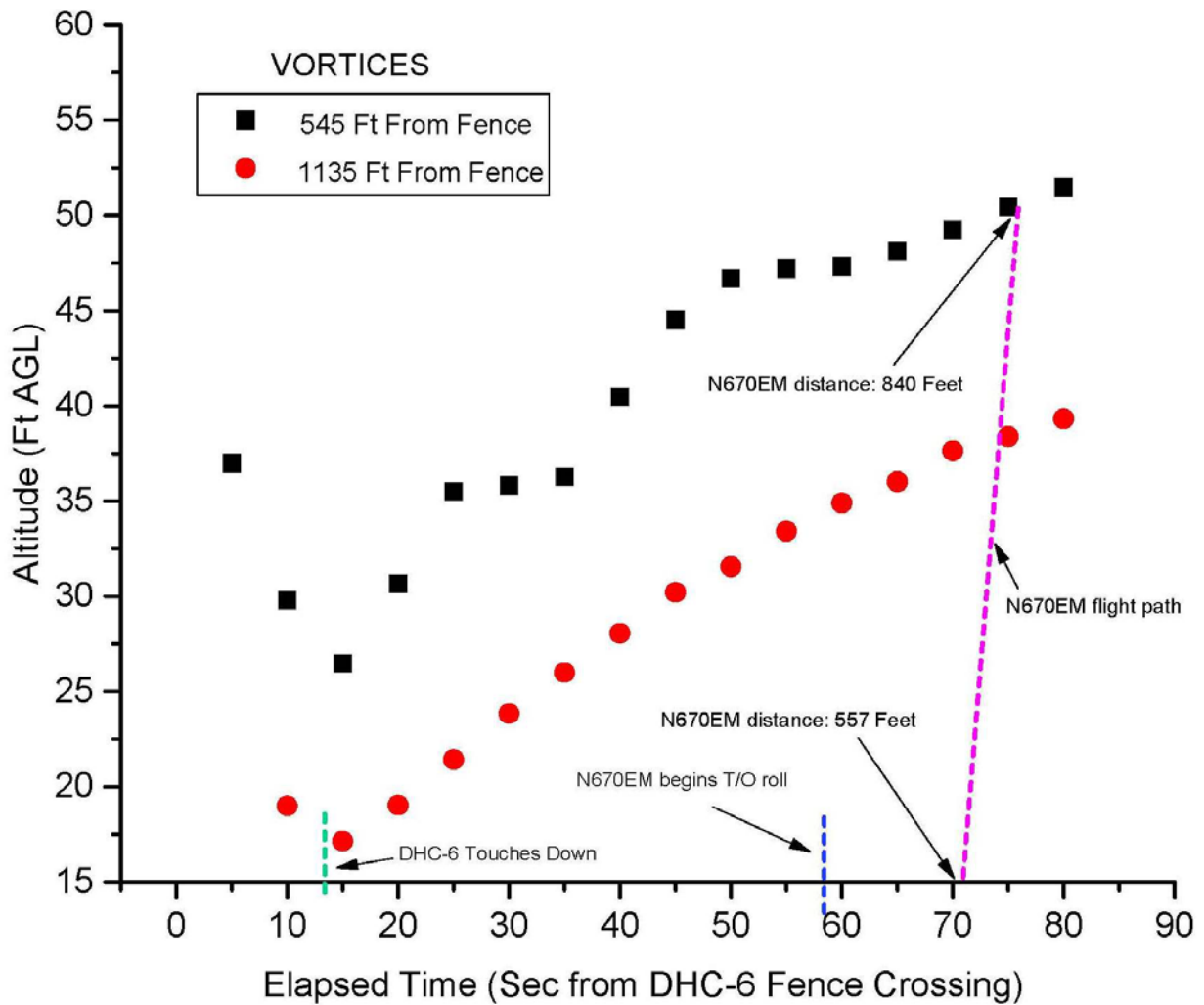


Figure 5 – Vortex Heights

Vortex & N670EM Altitudes (2kt Wind)

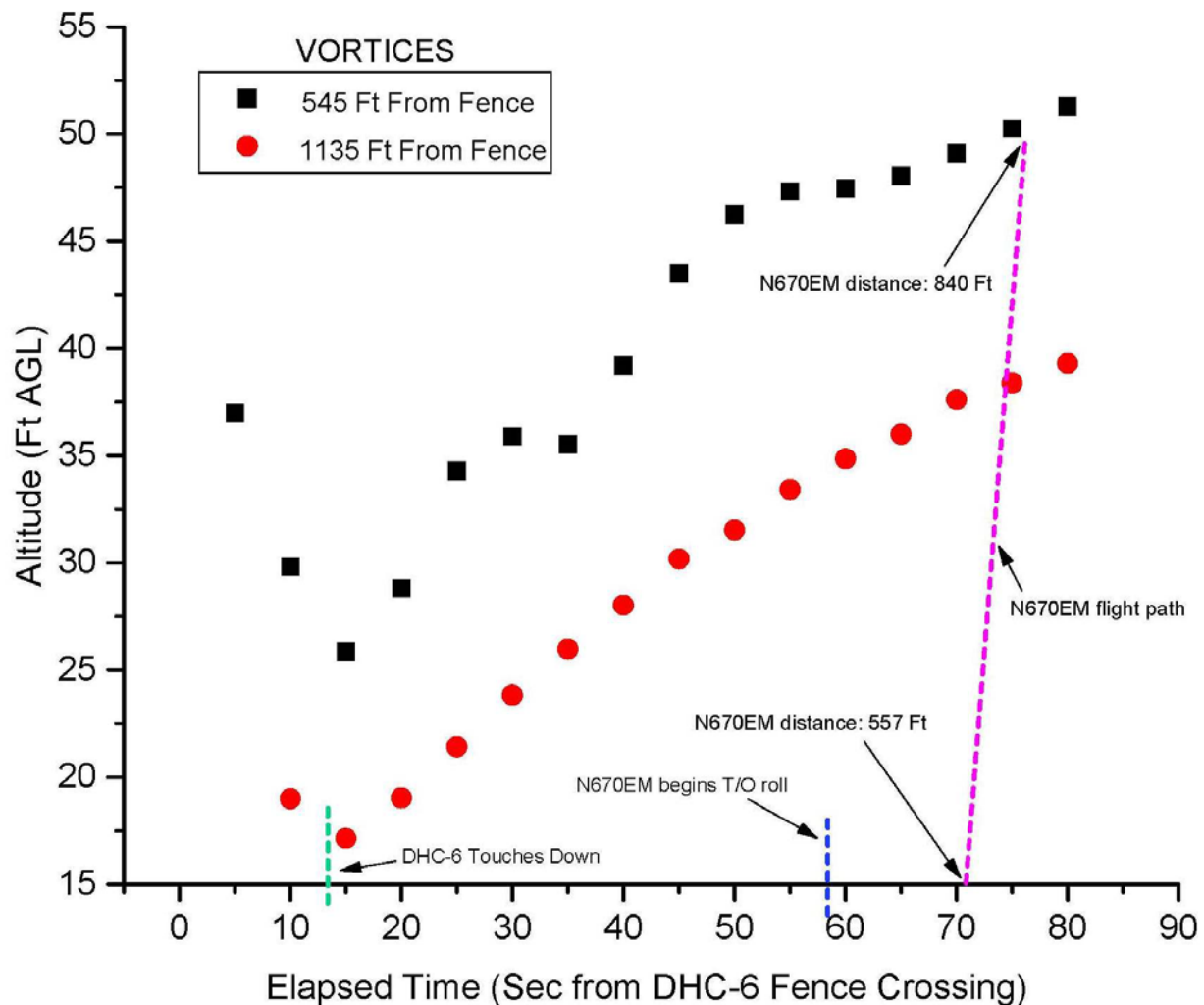


Figure 6 – Vortex Heights

As noted previously, direct left crosswinds caused the left vortex to migrate to the right, which brought the vortex over, and then beyond, the runway centerline (Figs 7 through 9). Using the estimated trajectory set and timing, the 2kt direct crosswind (Fig 8) displaced the left 1,135' vortex to a location about 55 feet right of the centerline when N670EM was lifting off, and displaced the 545' vortex about 100 feet right of the centerline. By the time the N670EM trajectory reached 50 ft altitude, the 1,135' vortex was about 100 ft right of centerline, and the 545' vortex was about 150 ft right of centerline.

Using the same estimated trajectory set and timing, the 1kt direct crosswind (Fig 9) displaced the left 1,135' vortex to a location about 10 feet left of the centerline when N670EM was lifting off, and displaced the 545' vortex about 25 feet right of the centerline. By the time the N670EM trajectory reached 50 ft altitude, the 1,135' vortex was situated approximately on the centerline, and the 545' vortex was about 50 ft right of centerline.

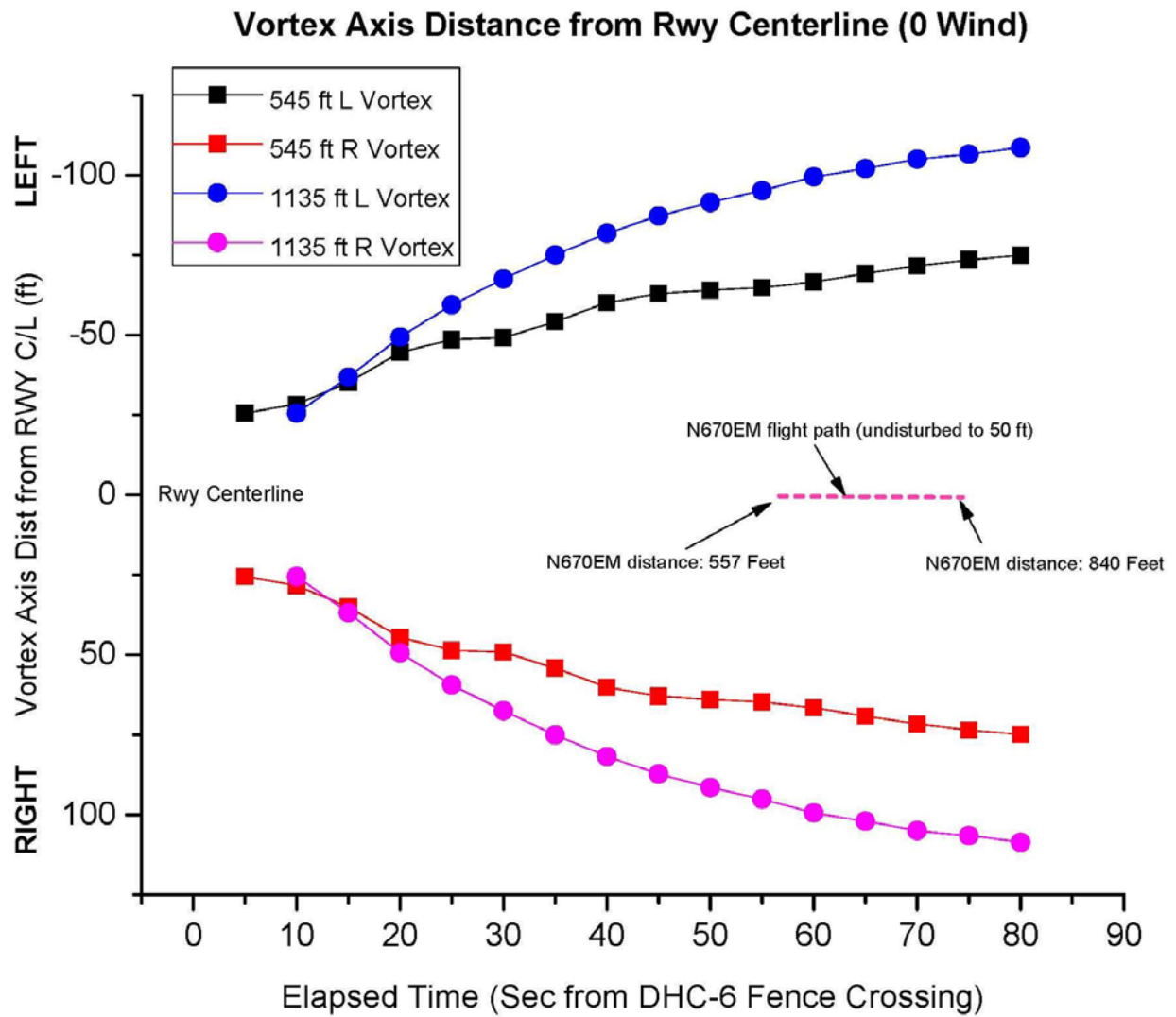


Figure 7 – Vortex Lateral Locations

Vortex Axis Distance from Rwy Centerline (2 kt X-Wind)

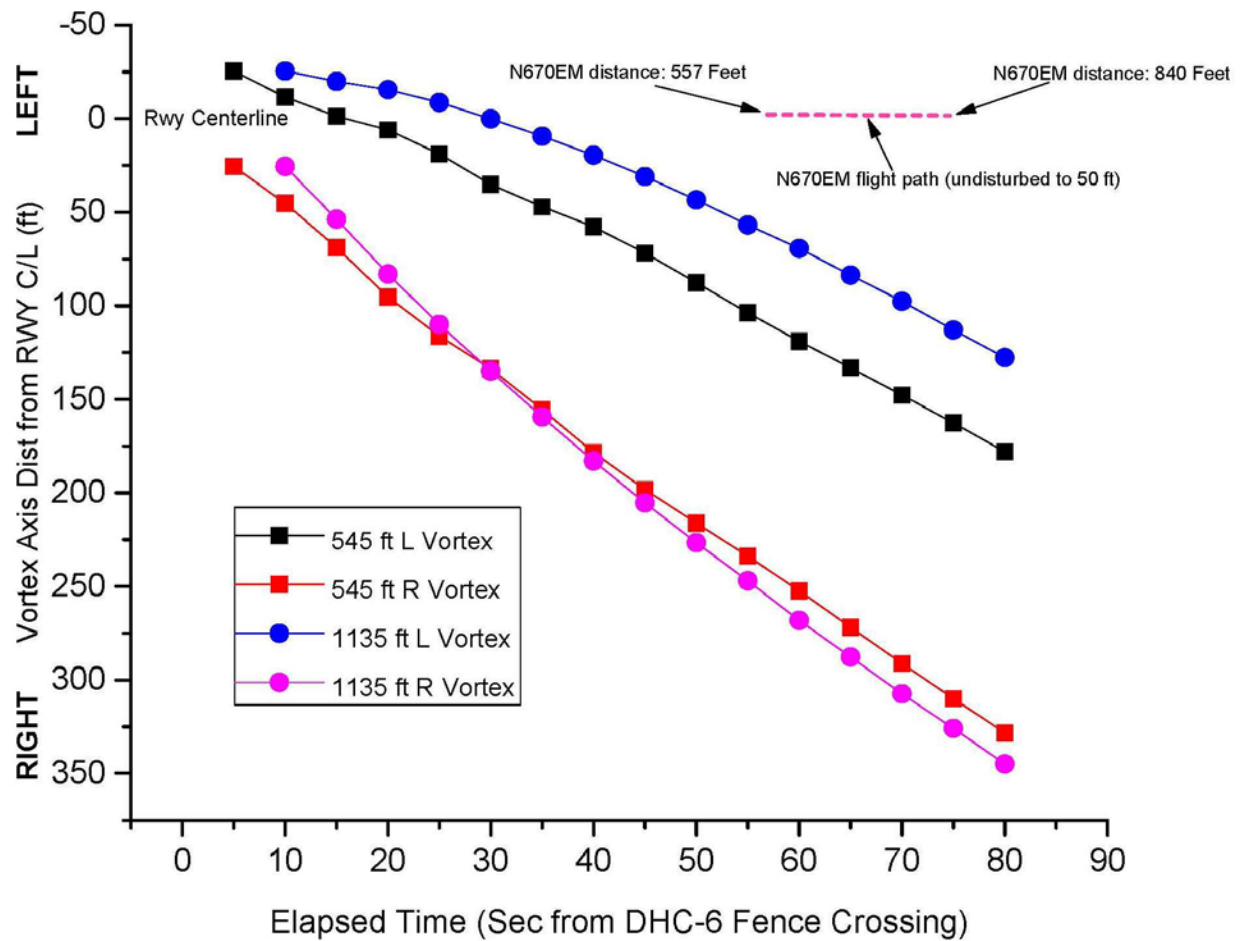


Figure 8 – Vortex Lateral Locations

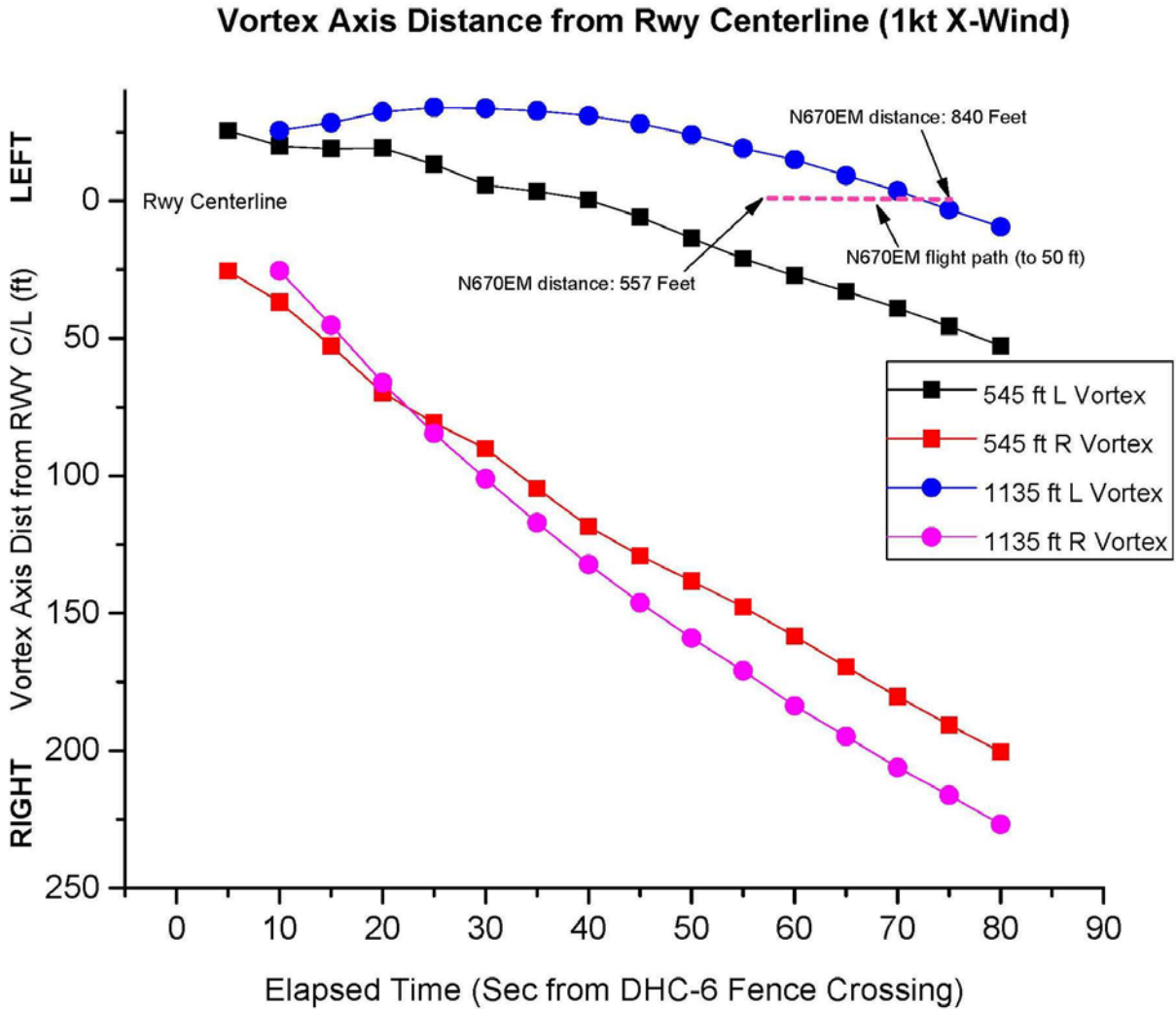


Figure 9 – Vortex Lateral Locations

3.0 Vortex Strength Estimates

For each of the 18 snapshots (longitudinal position/time points as specified above) the wake modeling program output also included vortex strength time history data (in 5 second increments) in terms of Gamma (Γ), the vortex circulation term.

3.1 Vortex Circulation Speed Estimates

Review of the previously-presented altitude data and trajectory comparisons indicated that, with allowances for the uncertainties, the N670EM vortex encounter likely occurred during the time window from 60 to 80 seconds after the DHC-6 crossed the fence. The vortex Γ results from the two vortex distance cases (545' and 1,135'), with the three wind cases for each, were run at three time points (60, 70, & 80 seconds) for vortex radii of 10, 20, 30, 40 and 50 ft to calculate vortex speed in fps. The results were plotted (Figs 10 through 12) as vortex speed vs. vortex radius for the two vortices and three time points, for each of the three wind cases (0, 1, and 2 kts).

The vortex speeds decayed with time and increasing radius from the vortex core, and the speeds of the 545' vortex were less than those of the 1,135' vortex at the same time points, because the 545' vortex was older. The results indicated that, for the times examined, the wind effects on vortex strength were negligible.

Specifically, the maximum speed calculated was about 5 fps, which was for the 1,135' vortex 10 ft radius at T= 60 seconds. That speed decreased to about 2.5 fps at T= 80 seconds. The 1,135' vortex speed at T= 60 seconds for the N670EM semi-span of 16.4 ft (i.e., vortex core coincident with N670EM centerline) was about 3.5 fps, and decayed to about 1.8 fps at T= 80 seconds.

The 545' vortex speed was about 4.5 fps at a radius of 10 feet for T= 60 seconds, and decreased to about 2.2 fps at T= 80 seconds. The 545' vortex speed at T= 60 seconds for the N670EM semi-span was about 3.2 fps, and decayed to about 1.5 fps at T= 80 seconds.

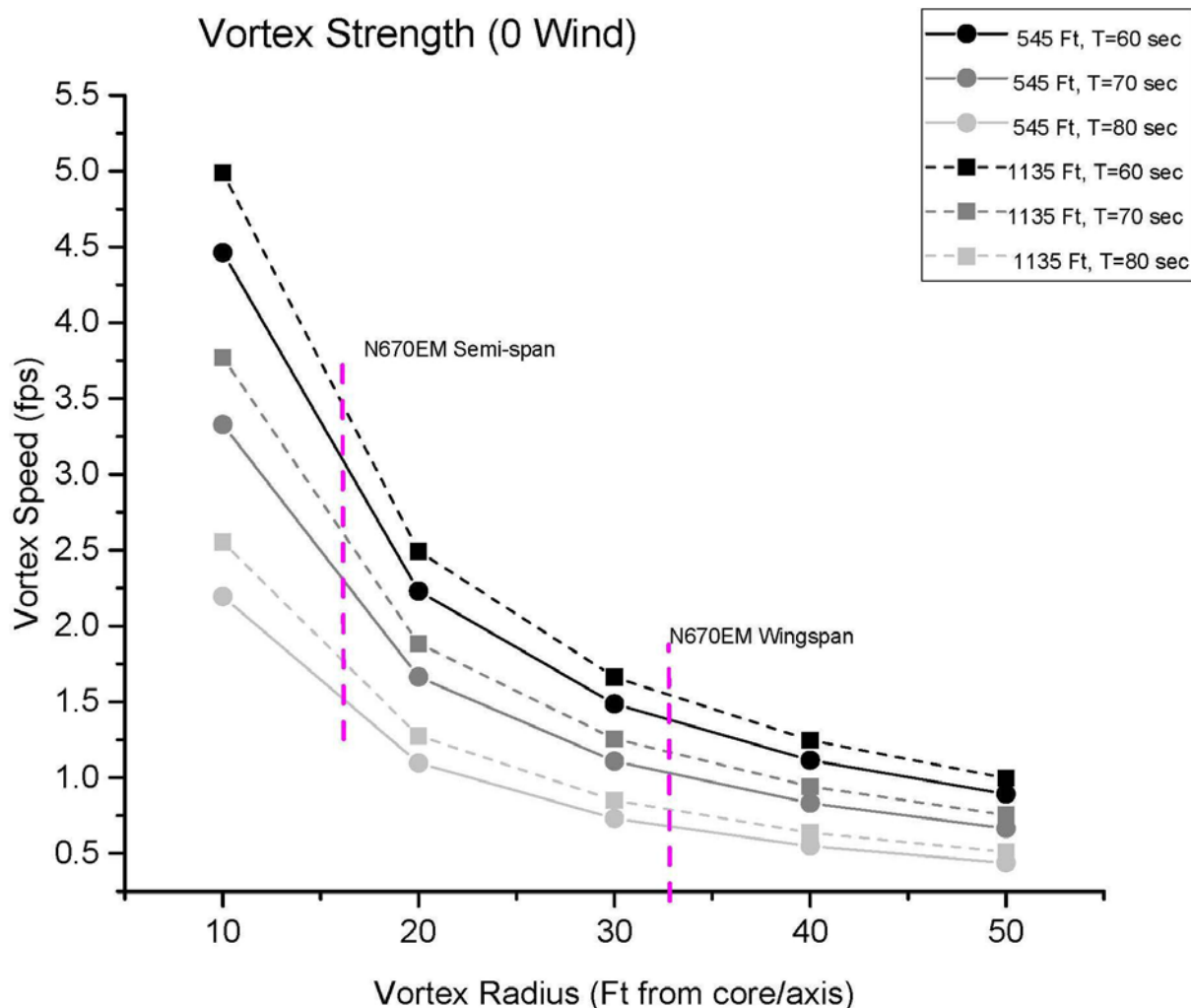


Figure 10 – Vortex Speed vs Radius

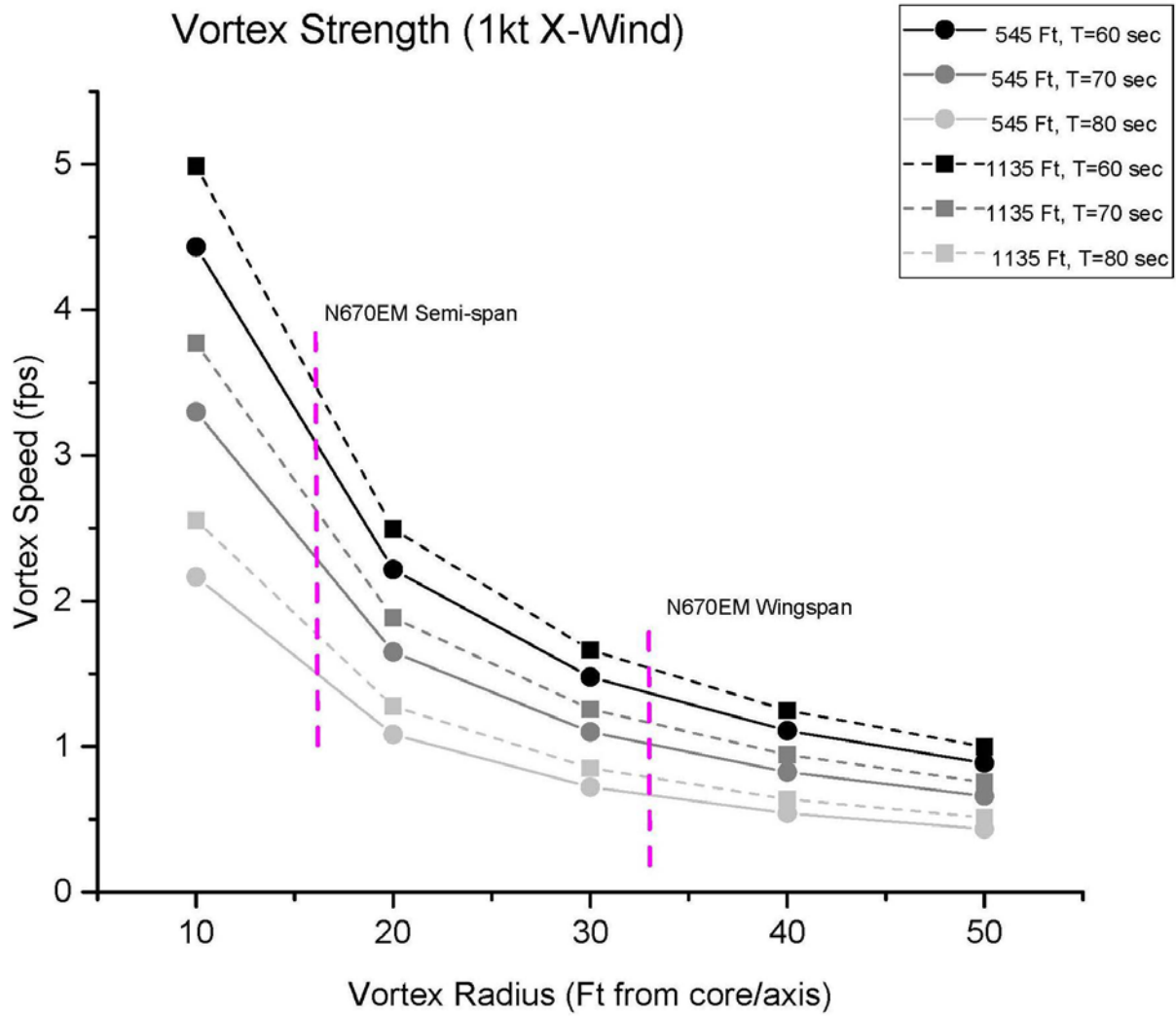
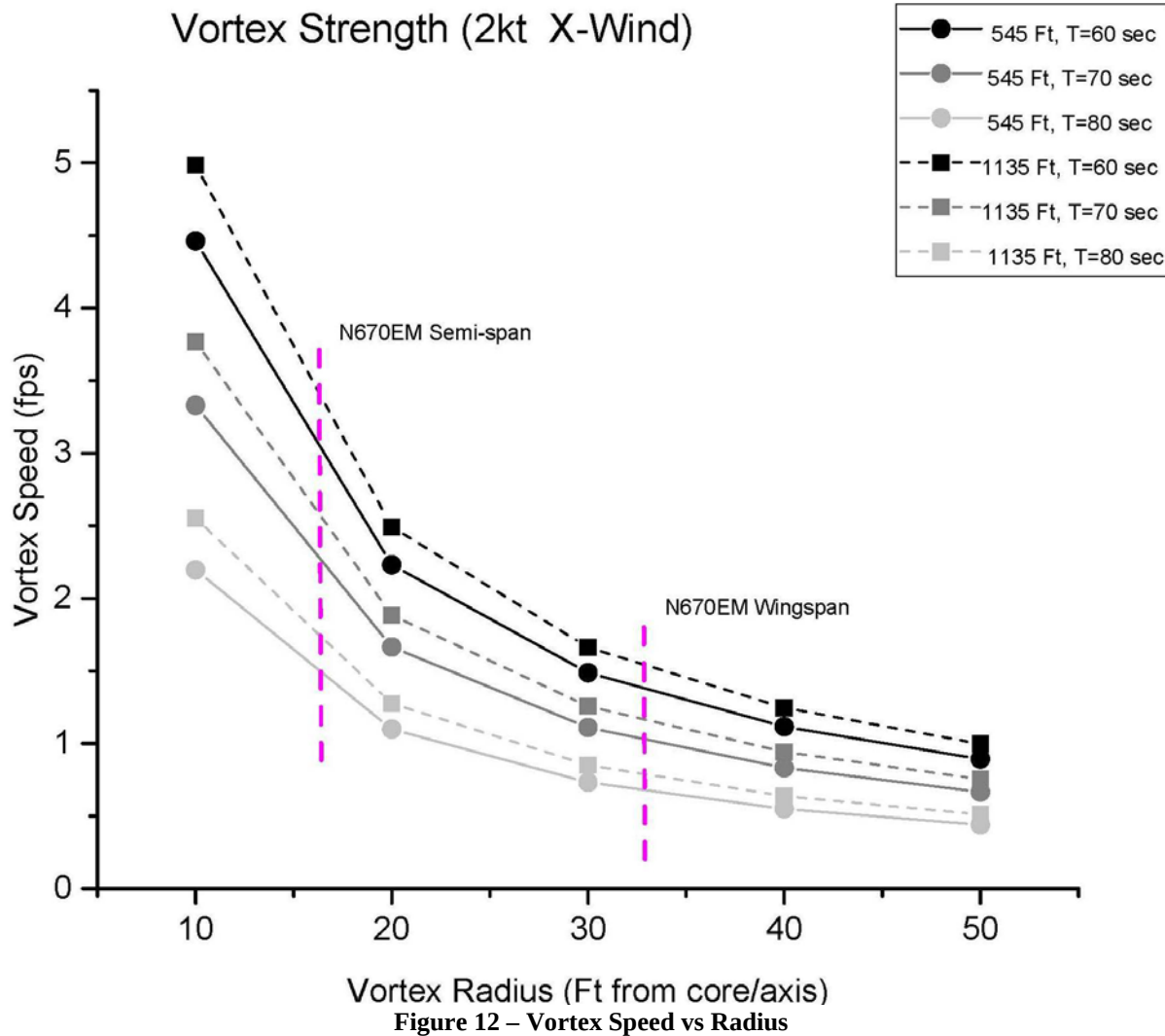


Figure 11 – Vortex Speed vs Radius



3.2 Vortex Rolling Moment Estimates

The rolling moment produced by a vortex on an aircraft arises from the differential angles of attack and sideslip distributed over the aircraft's aerodynamic surfaces as a result of the local velocities induced by the vortex. The strength of these local velocities depends on the circulation of the vortex, and the distance from the vortex core. The results presented in the previous subsection indicate that the circulation of the vortices from the DHC-6 at the time of the roll upset on N670EM could range from 137 ft²/s to 313 ft²/s.

This section presents an estimate of the potential total (integrated) rolling moment coefficients that could be exerted on N670EM by vortices within this range of circulation strengths.

Following the method described in the CEN13TA113 Study, the vortex-induced total rolling moment coefficient is computed by calculating the differential increments in lift at every point along the wingspan resulting from the local velocities induced by the vortex, and then integrating the product of these lift increments with their moment arms to obtain the total rolling moment. The differential lift increments are computed by calculating the local increment in angle of attack resulting from the induced velocities, and scaling the resulting change in local lift coefficient for the effects of an elliptical lift distribution. Input parameters (and their units and values) for each time point of interest include

- Circulation strength ('Gamma', ft²/sec) [see array below]
- N670EM Speed (kts) = [50]
- N670EM Wingspan (ft) = [32.8]
- N670EM 3D Lift Curve Slope (1/radian) = [4.694]

As noted above, the 545' and 1,135' vortices bracketed the N670 EM trajectory, and the most likely time window was determined to be between 60 and 80 seconds after the DHC-6 crossed the fence. Because the calculation program was only set up to calculate vortex rolling moments for a single time point, a total of 6 runs (2 vortex locations (545' and 1,135') at 3 times (60, 70, & 80 seconds)) had to be conducted. Because the wind effects on vortex strength were negligible, only the 0 wind case was used for strength calculations.

Gamma Input Array (0 wind case)

TIME (sec from DHC-6 fence crossing)	545' Vortex Gamma	1,135' Vortex Gamma
60	280	313
70	209	237
80	137	160

The program that was used to calculate the integrated vortex rolling moment coefficient provided output as a function of the vortex core location along N670EM's wingspan. There were a total of nine spanwise core locations; one coincident with the wing centerline, and four each relative to the left and right wings. The spanwise locations were equally spaced. Program output span stations were presented in units of semispan (span/2). Therefore the wing centerline would be 0, halfway out one wing would be 0.5, and the wingtip would be 1. A value of '2' denotes that the core location is one semispan outboard of the wingtip. Sign convention is right wing positive. Rolling moment coefficient sign convention is positive for RWD.

4.0 N670EM Roll Capability

4.1 Control Deflections

Because there was no aerodynamic coefficient data available for N670EM, the rolling moment capability had to be estimated. The rolling moment capability can be approximated by the

product of the lateral offset of the carriage CG from the wing centerline, and (multiplied by) the weight of the carriage. The lateral offset is the input translation of the control bar provided by the pilot. According to a representative of the N670EM manufacturer, "a 1 ft control deflection in roll would generally be the maximum. Normal deflection required to control [the aircraft] in moderate turbulence would be around 6 inches."

4.2 Carriage Weight

The following weights were obtained from the manufacturer's and accident site documentation:

N670EM Empty Weight (EW) = 500 lbs

N670EM Wing = 110 lbs

Pilot + Accsys = 140 lbs

Fuel = 60 lbs

Gross weight (GW) = EW + payload = 500 + 140 + 60 = 700 lbs

Carriage weight = GW – wing weight = 700 – 110 = 590 lbs

4.3 N670EM Rolling Moment Coefficients

The rolling moment was calculated for three carriage lateral offset cases (0.5, 1.0 , and 1.5 ft). Because the control bar was located at the approximate height of the carriage CG, control bar lateral displacement values were used directly to calculate the rolling moments; the calculated rolling moment is the product of the carriage weight times the control bar lateral displacement.

Rolling moment coefficients were calculated using the following equation

$C_R = \text{Rolling Moment} / (qSb)$ where:

C_R = Rolling moment coefficient

q = dynamic pressure = 8.46 lbs/ft² (50 kts, sea level, 66 degs F)

S = wing area = 145.7 ft²

b = wing span = 32.8 ft

Control Bar Deflection (ft)	Rolling Moment (ft-lbs)	Rolling Moment Coefficient
0.5	295	0.007
1.0	590	0.015
1.5	885	0.022

5.0 Vortex Strength & N670EM Roll Capability

Computations that yielded both vortex strength and N670EM rolling moments in coefficient form enabled direct comparison of the two datasets, which in turn enabled an assessment of the effect of the vortex on N670EM, and the ability of N670EM to counter that effect. Ideally, vortex-induced rolling moment values less than N670EM rolling moment capability could be successfully countered by N670EM. However, this comparison method does not account for pilot reactions, either in terms of time delays (startle & response times) or magnitude sufficiency, both of which can adversely affect the potential for a successful recovery. In turn, those reactions can be affected by the pilot's previous experience, and her perceptions of the situation with regard to causes, potential corrective actions, and the risks associated with each.

As discussed above, the induced rolling moment coefficients were calculated for 6 cases and 9 spanwise locations across the wing. Plotting these values and superimposing the N670EM rolling moment capability coefficient values on those plots revealed that there were multiple vortex core locations where the induced rolling moments could exceed the N670EM countering capability provided by normal or even extreme control inputs.

As discussed previously, due to the observed roll direction of N670EM, the vortex study and vortex strength calculations were based on the vortex shed from the left wing of the DHC-6, and therefore the directionality of the results in this study are specific to the left wing vortex only. For an airplane in symmetric flight, the left- and right-wing vortices would be of equal strength, but opposite in rotational direction.

Figure 13 depicts the residual vortex strength values (as rolling moment coefficients) for the two (545' & 1,135') vortices for three ages (60, 70, & 80 sec) plotted as a function of semispan. The horizontal dashed lines depict the N670EM roll authority (again as roll moment coefficients) for three control bar lateral deflections (0.5, 1.0, & 1.5 ft). The data indicates that for vortex core locations inboard of the quarter-span points of the left and right wings, the RWD vortex-induced rolling moment is significant, and generally exceeds N670EM roll authority.

As seen in Figure 14, vortex core encounter locations towards (and also beyond) the wingtips also resulted in significant rolling moments, although in the direction opposite (LWD) to inboard encounters. Again the data indicates that the residual vortex strength can exceed the N670EM roll authority.

Figure 15 represents the composited version of Figures 13 and 14. These results indicate the possibility that, with the only difference being the crosswind direction, N670EM could have encountered the vortex from the right wing of the DHC-6, and that such an encounter also could have resulted in induced rolling moments that exceeded N670EM roll capability. Thus, the results revealed that, contrary to the initial presumption that the N670EM right roll was due to an encounter with the left wing vortex of the DHC-6, an N670EM encounter, at certain spanwise locations, with the DHC-6 right wing vortex would also result in a potential loss of control in a RWD direction.

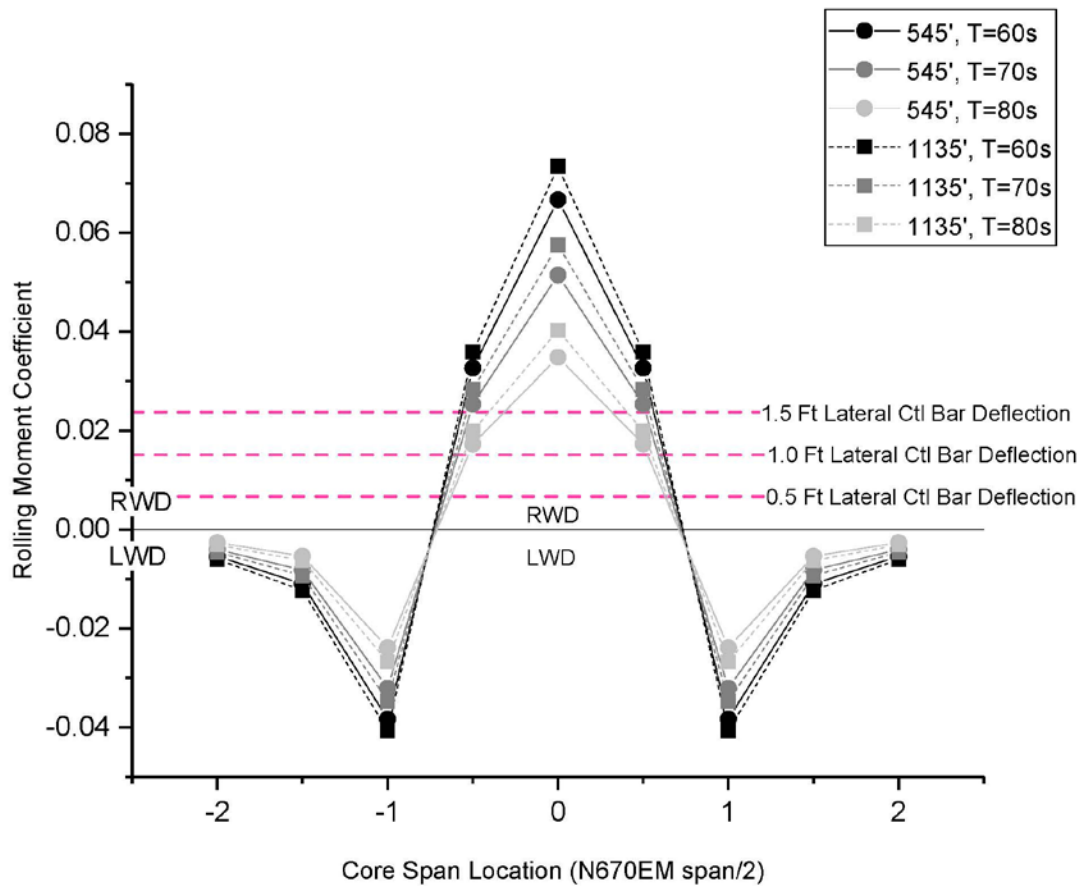


Figure 13 – Left Vortex (RWD) and N670EM Roll Authority

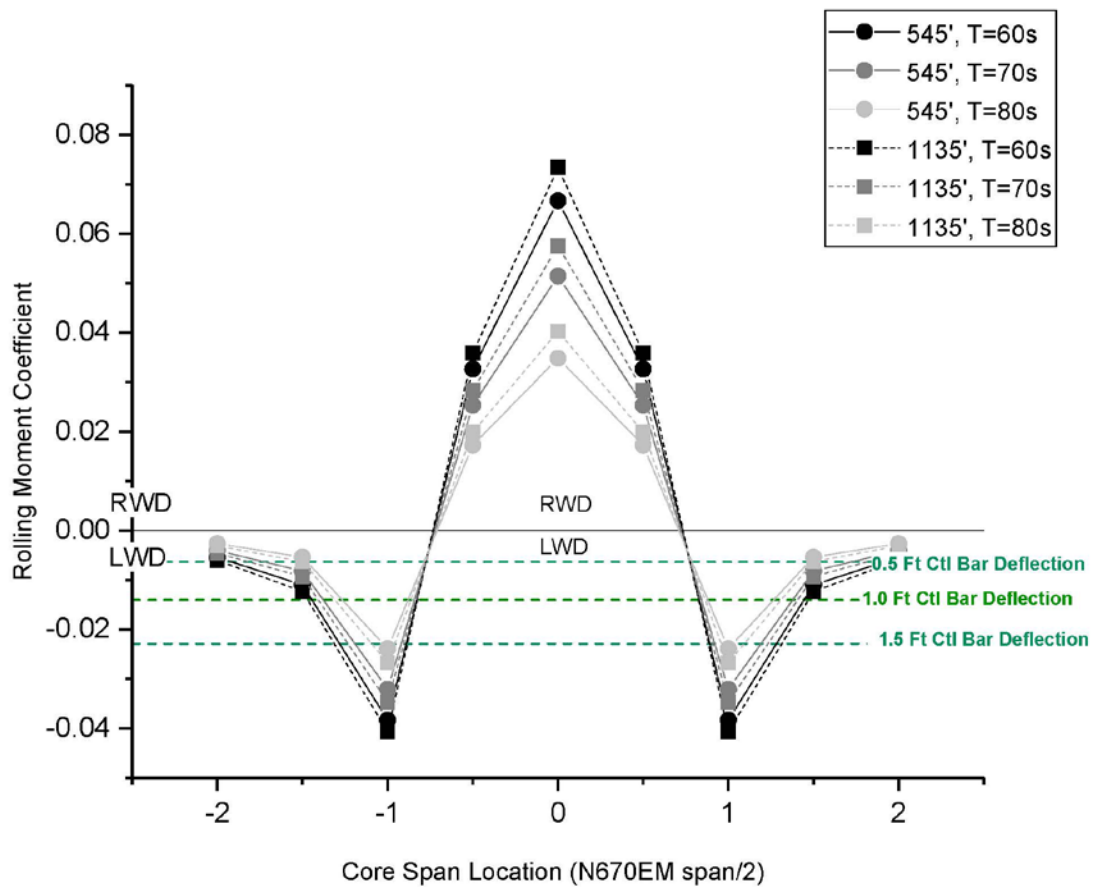


Figure 14 - Left Vortex (LWD) and N670EM Roll Authority

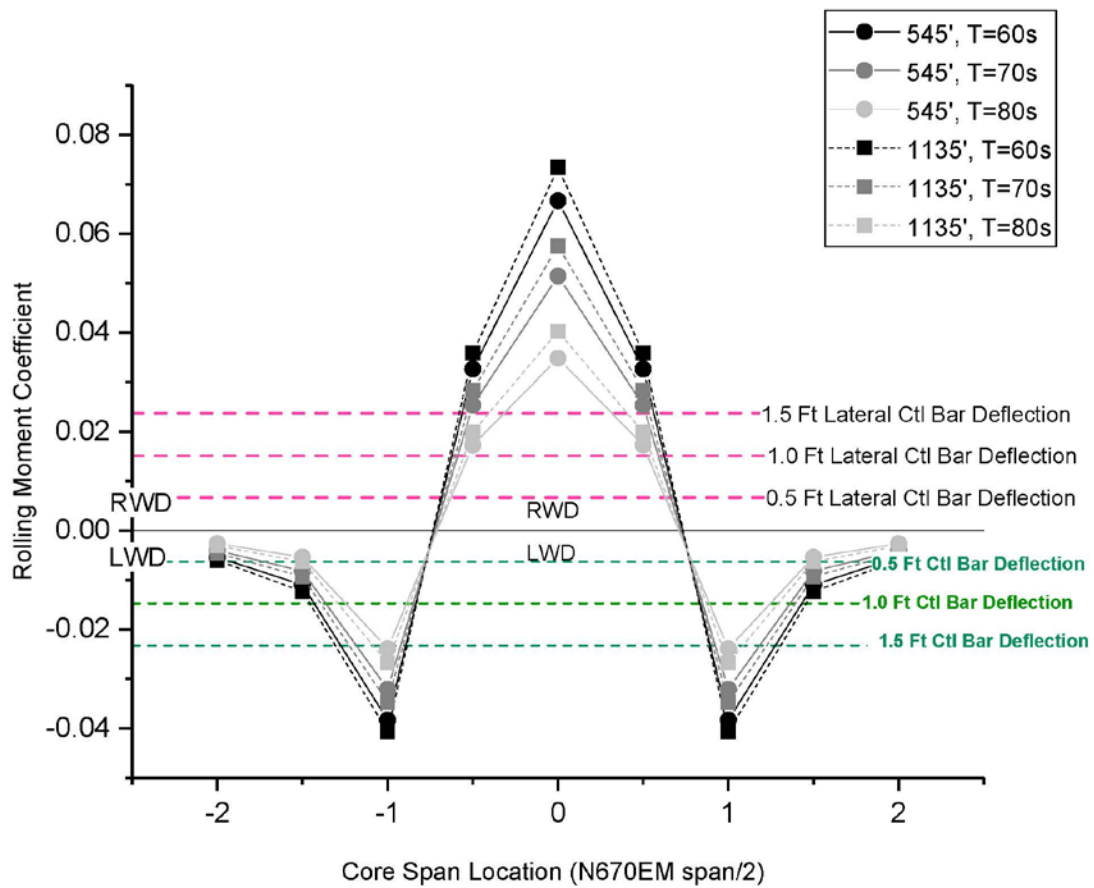


Figure 15 - Left Vortex (RWD & LWD) and N670EM Roll Authority

Appendix 1 – Program Inputs and Assumptions

DHC-6-300 N94AR (Operator-provided values unless noted)

Wingspan: 65'

Weight: 10,500 lbs

Flaps: 20°

Glide Path: 3.5° (4 box VASI)

TCH: 26'

TD Point: 1,100' beyond 25 Thold (displaced 463')

Appch Speed: 75k V ref, 65 TD (127 & 110 fps)

Assumptions

Airport 'reset' to 0 msl; thus msl = agl

A/C crosses rwy end at 55' at 75 kts, then alters approach path to TD at TD point at 65 kts

CAS =TAS

Constant deceleration from rwy end to TD

Straight flight paths (both segments)

Segment A = 300' msl/agl to 55'

Segment B from 55' msl to 8' msl

Pilot Eye Height= VASI GP= Wing Height

Wing height at TD = 8'

DHC-6 Trajectory Data

SGMNT	Time (sec)	V (fps)	Ground Distance (horiz Ft from origin)	Alt (ft MSL/AGL)
A	29	127	329	75
A	30	127	203	68
A	31	127	76	60
A	32	127	-51	52
B	33	126	-177	48
B	34	124	-301	44
B	35	123	-424	41
B	36	122	-546	37
B	37	121	-666	34
B	38	119	-786	30
B	39	118	-903	26
B	40	117	-1020	23
B	41	115	-1135	19
B	42	114	-1249	16
B	43	113	-1362	13
B	44	112	-1474	9
C	45	111	-1585	8
C	46	111	-1696	8

Calculated Results

GP intercepts Rwy: 425' beyond threshold:

GP crosses 25 paved end at 54.3' (round to 55')

Appendix 1 – Program Inputs and Assumptions

Trike Airborne XT-912 N670EM (POH or Mfg values, MTOW unless noted)

Zero Fuel EW: 500 lbs

SST Wing Weight: 110 lbs

Estimated Accident Flight Weight: $500 + 140$ (pilot & accessories) $+60$ (fuel) = 700 lbs

Wing Area: 145.7 sqft

Wing Span: 32.8 ft

T/O speed: Best Climb 49 KIAS = ~ 47 KCAS (79 fps)

T/O speed: Owner 55 KIAS = ~ 53 KCAS (89 fps)

Climb angle: Best climb 17.8% (825 fpm)

T/O Dist: 810 ft (to 50')

Assumptions

Constant accel during T/O ground run to 50 kts

Constant 50 kts in climb

Straight flight path

5 sec to take position on rwy & begin T/O roll

Calculated Results

Climb flight path angle (MTOW): 10 degrees

Ground Roll (MTOW): 527'

Ground Run Time = 13.2 sec

Air Run Time = 3 sec

TT from T/O clearance to LOC = $5 + 13.2 + 3 = 21$ sec

TRIKE	DIST	ALT
Start of 670EM	-30	2
T/O Roll		
Liftoff	-557	2
50 ft agl	-840	50

Appendix 1 – Program Inputs and Assumptions

TRIKE TIMELINE wrt DHC-6 Truncated Time history				
	OEM DIST	OEM ALT	DHC TIME	
DHC crosses Fence	-30	2	0	
DHC ~50' Alt	-30	2	~6 to 7	
DHC TD	-30	2	13	
OEM Clrd for T/O	-30	2	53	
Start of 670EM T/O Roll	-30	2	58	
670EM Liftoff	-557	2	~71	
670EM 50 ft agl/Event	-840	50	~74	

Meteorological Data

1853 UTC METAR (ax 1901)

KHHR 211853Z VRB03KT 10SM SCT024 18/11 A3015

Wake Program Inputs

Wind Speed: 0, 1, 2 & 4 kts

Wind Dir: Directly from south/pilots left (perp to rwy) since A/C rolled right

Altimeter setting 30.15

Temp: 19 C (66 F) = Std +7 F

DP: 11 C (52 F)

Elevation: 65' ➔ presume/force to SL/0

HHR Rwy 25

Hdg: 253M 267T

Elev: 61' msl

T/hold: 463' displaced

Slope: 0.1%

Appendix 1 – Program Inputs and Assumptions

VASI: 3.5°

Adjustments/assumptions

Rwy alignment 270 degs true

Rwy slope = 0

N670EM Lift Curve Slope

Actual SST wing lift curve slope not available, therefore must be derived as follows.

'Classic' lift curve slope equation: $a = a_0 / (1 + a_0 / (\pi * AR * e))$, where:

a = 3D lift curve slope, 1/radians

a_0 = 2D lift curve slope = $2 * \pi$

AR = aspect ratio of wing = $(\text{wing span})^2 / (\text{wing area})$

e = Oswald's efficiency factor ~ 0.8

Values from Airborne (mfg)

Wing Span = 32.8 ft

Wing Area = 145.7 sqft

Calculating:

$$AR = (32.8)^2 / 145.7 = 7.384$$

$$a = (2 * \pi) / (1 + (2 * \pi / (\pi * 7.384 * 0.8)))$$

$$a = 4.694$$