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Aircraft Takeoff Characteristics

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16. Abstract

The document investigates three essential characteristics of takeoff; rotation point, liftoff point, and takeoff angle. In this memorandum distributions of the data are provided and analyzed. Trends in the data can be used to find the ideal location for wake vortex measuring equipment.

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1.0 Background

After the introduction of the B-747 in 1969, the separation standards for landing aircraft included a wake vortex component behind Heavies (gross certificated takeoff weight in excess of 300,000 pounds) added to the existing 3-nautical-mile radar separation. The wake vortex separations were determined based on flight tests (Ref. 1). In 1976, the standards were increased to the current 3-4-5-6 nautical miles separations based on the category (Heavy, Large, Small) of the leading and following aircraft. For departures, the time between the start of successive takeoff rolls changed from a uniform 1 minute to 1 or 2 minutes depending on the aircraft category; a 3-minute role was introduced later for intersection takeoffs.

In 1971 (Ref. 2), an extensive set of tests was begun at airports to study wake vortex behavior near the ground for landing aircraft. All landing aircraft pass through essentially the same airspace for the last 2 miles before touchdown, so it was apparent where vortex tracking apparatus needed to be placed.

In 1974 it was decided that takeoff wake vortices should be studied too. However, it was not obvious where to place vortex tracking equipment as takeoff profiles could vary significantly between aircraft types. For a specific aircraft, the takeoff profile can vary based on takeoff weight, flap setting, headwind, air density, and ambient temperature.

A contract was negotiated with the Applications Research Corporation (ARC) of Southampton, PA, to collect data on normal departures. One of the current authors (J.H.) served as the Contracting Officer's Technical Representative on the ARC effort. A detailed data report (Ref. 3) was prepared. The results therein were used to select the vortex tracking equipment locations for tests at Chicago's O'Hare International Airport (Ref. 4).

The intent of this Project Memorandum is to summarize the ARC data report methodology and results so that the information is more readily available. The ARC results are supplemented with takeoff characteristics as measured during the Chicago O'Hare tests. It is expected that the results herein will be useful as current efforts to address procedures for increased airport throughput are examined.

2.0 Data Collection

The ARC data collection was performed in two phases at Philadelphia International Airport. The first phase started at the beginning of August 1974 and stopped at the end of October 1974, while the second phase ran from the beginning of March 1975 to the middle of July 1975. During this combined period of about six and a half months, a total of 7000 takeoffs were observed.

For the analysis the following data was included: aircraft type, gross aircraft weight at takeoff, aircraft takeoff flap position, roll time, rotation point in feet from the runway threshold, and height above the ground at points after rotation. While much of the data was obtained from photographs, the gross weight and flap settings of the aircraft were forwarded by the airlines. To collect the photographic data, the camera needed to have a good view of the runway's center. The rooftop of a building in Tinicum, PA, afforded this view. After receiving permission from the Scott Paper Company, a camera was set up on the rooftop of the company's building. On this rooftop, the camera was 3050 feet away from runway 27L and 9R, the runway chosen for the testing. At this position, the wide-angle camera provided a camera view of 5625 feet of the 10500-foot long runway. (See Figure 1) Two roof markers were used, one on each side of the field of view, to align the camera each day. This process ensured that the same stretch of runway was observed each day.

In the early stages of the data collection process, one picture was taken at aircraft roll, one at aircraft rotation, and three while the plane was in the air. To improve the accuracy of the data, the number of pictures taken in the air was increased from three to six. (See Figure 2.1) In the camera's field of view a piece of plywood was placed that was approximately two feet by four feet with accommodations for the date (day, month), sample number, aircraft type, and a clock. This data board can be seen in the foreground of all the photographs. (See Figure 2.2) A radio receiver was used to get the wind update from the control tower prior to takeoff.

Scaling of the field of view was necessary to correct for distortion due to lens aberration. This procedure was done by photographing measured distances on the runway. A vehicle was driven across the field of view and filmed at evenly spaced distances. These distances were verified by making three runs in each direction on the runway.

3.0 Data Reduction

Reduction of the data (the film sequences, field observations, and air carriers' information) was completed through the use of four forms labeled A, B, C, and D. (See Ref. 3 for copies of the forms) Figure 3 displays the general flow of the data from the field to the final outputs.

Form A, the PhotoLog Sheet, is the master sheet for all of the collected data. It combines the information on forms B, C, and D. Form A is also the template for all of the computer punch cards. The information on Form A includes date, sample number, wind direction and magnitude (knots), air temperature (° F), runway in use (27L/9R), aircraft roll time, airline and flight number, aircraft type, aircraft gross weight (pounds), flap setting (°), the time between successive photos (seconds), and the x (distance along the runway) and y (distance above the runway) coordinates of the aircraft's trajectory while in the field of view of the photograph.

Form B was the Field Data Log Sheet. The observer completed as much of Form B as possible while photographing takeoff sequences. At the end of each week, the recorded takeoffs were listed on Form C and sent to the appropriate airline for completion. With the information received from the airlines, one could complete Form A.

Form D, the Projector Log Sheet, consists of two parts. These two parts were used in the calculations for recording all x and y measurements taken from the projected slides of the takeoffs. The data produced from this sheet was later transferred to Form A.

4.0 Data Analysis

Data was gathered at PHL for 9 aircraft types: (1) Douglas DC-10, (2) Lockheed L-1011, (3) Boeing B-707, (4) Douglas DC-8, (5) Boeing B-727, (6) Boeing B-737, (7) Douglas DC-9, (8) British Aircraft Corporation BAC-111, and (9) Business Jets.

The photographs were analyzed to find values for:

1. Rotation Point
2. Liftoff Point
3. Takeoff Angle

The Rotation Point is the position on the runway where the nosewheel of the plane lifts off the ground. The Liftoff Point is the position on the runway where the main wheels of the aircraft leave the ground and the plane becomes airborne. The Takeoff Angle is the acute angle between the aircraft's trajectory and the ground.

The distribution of these values for each aircraft type can be viewed graphically in subsequent sections. Along with the graphs, the mean, mode, and standard deviation of the data are presented.

There are three parameters that determine the characteristics of a plane's takeoff. These three conditions are flap setting, wind speed, and temperature. Ideally, these parameters would be uniform throughout the observations for a given aircraft. The variance of these parameters can skew the otherwise normal distribution of the data. Although variation does occur in these parameters, there is a consistency that exists, giving validity to the results. The consistency of these parameters can be seen in Table 4-1.

The flap settings were broken down into 5° intervals from 0° to 30°. Most of the aircraft types had over 90 % of the planes using flap settings within one 5° interval. The only model which did not appear to show this same consistency was the B-707. With the B-707, 54 % were in the 16°-20° interval and 46 % were in the 11°-15° interval. In this case, it is most likely that the B-707 fell victim to the choice of the flap setting intervals. Even though the aircraft may only be using 15° and 16° flap settings, the intervals make it look like the flap settings are not very consistent for the B-707.

The wind speed was divided into intervals of 10 knots. The intervals were: less than –10 knots, –9 to 0 knots, 1 to 10 knots, 11 to 20 knots, and more than 20 knots.

Negative wind speeds constitute a tailwind. To compute the headwind for runway 9R, one multiplies the reported velocity by the sine of the direction from which the wind was blowing. Conversely, for runway 27L, one multiplies the reported velocity by the cosine of the direction from which the wind was blowing. For all of the aircraft types roughly 70 percent of the takeoffs occurred in a headwind of 1 to 10 knots. The second most common wind at takeoff time was a weak tailwind ranging from 0 to -9 knots.

The temperature at takeoff was separated into two domains. Takeoffs were classified as "low" temperature takeoffs when the temperature was below 75° F and "high" temperature takeoffs when the temperature was at or above 75° F. The aircraft types experienced mostly low temperatures at takeoff; over 70 % of the takeoffs occurred at temperatures below 75° F.

The histograms in Sections 4.1, 4.2, and 4.3 illustrate the distribution of takeoffs for Takeoff Angle, Rotation Point Distance, and Liftoff Point Distance for each aircraft type. The aircraft types include with their classification in parentheses;

1. DC-10 (Heavy)
2. L-1011 (Heavy)
3. B-707 (Large)
4. DC-8 (Large)
5. B-727 (Large)
6. B-737 (Large)
7. DC-9 (Large)
8. BAC-111 (Large)
9. Business Jets (Small)

4.1 Rotation Points

As described earlier, the Rotation Point is the position along the runway where the nosewheel lifts off the ground. The average distance and the standard deviation of the data can be seen below for each type of aircraft.

	Heavy	Large	Small
Rotation Point (feet)	4200 ± 310	3800 ± 200	3400 ± 310

Table 4-2. Average Rotation Point Distance from Runway Threshold

4.2 Liftoff Points

The Liftoff Point is the position along the runway where the main wheels leave the ground and the aircraft becomes airborne. The average distance and the standard deviation of the data can be seen below for each type of aircraft.

	Heavy	Large	Small
Liftoff Point (feet)	5100 ± 380	4600 ± 320	3700 ± 260

Table 4-3. Average Liftoff Point Distance from Runway Threshold

4.3 Takeoff Angles

The Takeoff Angle is the acute angle between aircraft's trajectory and the ground. The average angle and the standard deviation of the data for each type of aircraft can be seen below.

	Heavy	Large	Small
Takeoff Angle (°)	3.9 ± 2.0	3.4 ± 1.1	3.9 ± 1.2

Table 4-4. Average Takeoff Angle

4.4 Aircraft Heights

Aircraft heights were measured at three distances from the runway threshold; 5900 feet, 6900 feet, and 8600 feet. The aircraft were split into two groups, the Heavy aircraft and the Non-Heavy aircraft. The Heavy aircraft included the DC-10 and the L-1011. The B-707, DC-8, B-727, B-737, DC-9, BAC-111, and Business Jets made up the Non-Heavy group. While these measurements were taken at Philadelphia International Airport, a similar study was also performed at Chicago O'Hare International Airport a few years later in 1980. In this section, we present the average heights and graphical illustrations of the results from each site.

Anemometer Line	Heavies in Chicago	Heavies in Philadelphia	Non-Heavies in Chicago	Non-Heavies in Philadelphia
1 (5900 feet)	77 feet	57 feet	73 feet	83 feet
2 (6900 feet)	183 feet	112 feet	175 feet	145 feet
3 (8600 feet)	337 feet	215 feet	299 feet	249 feet

Table 4-5. Average Aircraft Heights at Three Lines

4.5 Summary

In Table 4-6 and at the top of each graph the means, standard deviations, and modes of the rotation points, liftoff points, and takeoff angles are presented. In producing the final analysis, the outliers were omitted from the data. Most of the omissions occurred in the takeoff angle data, with only the business jet data for rotation point distance and liftoff point distance being altered. The omission of the outliers brought about a significant enough change in the average values and standard deviations that their removal was necessary.

5.0 Conclusions

6.0 References