18
Takeoff and Landing Theory and Methods

18.1 Introduction

Takeoff and landing distances are some of the most difficult and costly flight test data to obtain. They are difficult to obtain due to the large number of variables involved with some variables, such as pilot technique, being essentially uncontrollable. They are costly due to the size of the test team required, the amount of specialized test equipment required, and the amount of data reduction involved.

Also, takeoff and landing data may only be considered to be ballpark answers due to the large factor that pilot technique plays. This is especially true where less skilled pilots are involved and may be the reason why the FAA in CAR 3 and early FAR Part 23 did not have a regulatory requirement to collect takeoff and landing data for airplanes of less than 6000 lb gross weight.

For airplanes of more than 6000 lb gross weight, regulations do exist and are divided into those for light aircraft (aircraft of less than 12,500 lb gross weight) and transport aircraft (aircraft in excess of 12,500 lb gross weight). These categories are covered by FAR Part 23 for light aircraft and FAR Part 25 for transport aircraft. There are several differences between these regulations but the main difference is the obstacle height that must be cleared. For FAR Part 23 (light aircraft) it is 50 ft. For FAR Part 25 (transport aircraft) it is 35 ft for takeoff and 50 ft for landing. This seems to be reversed since the transport regulation is supposed to be a more difficult regulation with which to comply. However, if one considers the quality of airports from which these aircraft operate, one may begin to understand some of the reasoning behind it.

18.2 Federal Aviation Administration Regulations

18.2.1 Civil Aeronautics Regulation 3.84 Takeoff

For airplanes with a takeoff gross weight in excess of 6000 lb, the distance to takeoff and climb over a 50-ft obstacle shall be determined under the most unfavorable condition of weight and c.g. This is normally taken to be most forward c.g. at maximum TOGW. The engines must be operating within approved limitations and the cowl flaps should be set for the normal takeoff setting. Upon reaching the 50-ft obstacle, the airplane must have accelerated to an airspeed not less than $1.3V_{S1}$ unless a lower speed of V_X plus 5 can be shown to be safe under all conditions including turbulence and a complete engine failure. The takeoff distances along with configurations, speeds, and so forth, shall be included in the airplane flight manual.

The policy guidance of CAR 3.84 says that in addition to measuring the complete takeoff to 50 ft, a piece method may be used where the acceleration distance to an airspeed of $1.3V_{S1}$ is measured by camera and then a climb segment in the takeoff configuration at an airspeed of $1.3V_{S1}$ may be added to the ground distance segment.

18.2.2 CAR 3.84a Takeoff Requirements; Airplanes of 6000 lb or Less

This regulation covers airplanes of 6000 lb or less takeoff gross weight. The same wording applied to airplanes under 6000 lb TOGW in FAR Part 23 up until about the time of Amendment 34. For these airplanes there is no requirement to measure the takeoff distance, but these airplanes must demonstrate the ability to lift the nosewheel on the takeoff roll in the takeoff configuration (if nosewheel airplanes) at $0.85V_{S1}$. If they are tail wheel airplanes they must be able to lift the tailwheel at a speed of not more than $0.8V_{S1}$.

18.2.3 CAR 3.86 Landing

The landing distance to come to a complete stop from a point where the aircraft is at a height of 50 ft above the landing surface must be determined for airplanes over 6000 lb gross weight. Prior to reaching the 50-ft height, a steady gliding approach shall have been maintained at a calibrated airspeed of at least $1.3V_{S0}$. The landing shall be made in a manner that the vertical acceleration does not cause a bounce, nose over, ground loop, or porpoise, and it shall be made in such a manner that it does not require an exceptional degree of skill on the part of the pilot or exceptionally favorable conditions. The distance so obtained shall be entered in the airplane flight manual along with the airplane configuration in which they were obtained.

The policy guidance included with CAR 3.86 says that the FAA will not approve the use of reverse thrust for determining landing distances. It also says that the landing distance should be determined photographically.

18.2.4 CAR 3.87 Landing Requirements; Airplanes of 6000 lb or Less

For airplanes of 6000 lb or less it shall be demonstrated that the airplane can be safely landed and brought to a stop without requiring an exceptional degree of piloting skill, and without excessive vertical acceleration, tendency to bounce, nose over, ground loop, or porpoise.

18.2.5 FAR Part 23 Takeoff

Cover the takeoff in the modern regulation. FAR Parts 23.55, 23.57, 23.59, and 23.61 apply to commuter airliners and will not be discussed here. FAR Part 23.51 discusses the takeoff speeds for all categories of airplanes including commuter category airplanes. For normal, utility, and acrobatic categories a rotation speed, V_R, is defined as the speed at which the pilot makes a control input with the intention of lifting the airplane out of contact with the runway. For multiengine airplanes it must not be less than the greater of $1.05V_{MC}$ or $1.10V_{S1}$. For single engine airplanes it must not be less than V_{S1}.

The speed at 50 ft above the takeoff surface must be the higher of $1.10V_{MC}$ or $1.20V_{S1}$ for multiengine airplanes. For single-engine airplanes, the higher of a speed shown to be safe under all reasonably expected conditions including complete engine failure or $1.20V_{S1}$.

FAR 23.53 states that the takeoff distance must be determined using the speeds obtained under FAR 23.51 and the distance to takeoff and climb to 50 ft must be determined for each weight, altitude, and temperature within the operating limits established for takeoff with takeoff power on each engine, wing flaps in the takeoff position, and the landing gear extended.

18.2.6 FAR Part 23.73 Reference Landing Approach Speed

This regulation provides the criteria for determining the landing approach speed. For all airplanes except commuter category airplanes the landing approach speed, V_{REF}, shall not be less than the greater of V_{MC} or $1.3V_{S0}$.

18.2.7 FAR Part 23.75 Landing Distance

The landing distance to come to a complete stop must be determined from a point 50 ft above the landing surface. This must be accomplished using a steady approach speed not less than V_{REF} and an approach gradient that is not steeper than 5.2% (3 deg) down to the 50-ft point. The applicant may demonstrate that a gradient steeper than 5.2% is safe, but the demonstrated gradient must be established as an operating limitation and the pilot must have an instrument to display the gradient. A constant configuration must be maintained throughout the maneuver, and the landing must be made without excessive vertical acceleration or the tendency to bounce, nose over, ground loop, or porpoise. It must be possible to transition to a balked landing at the maximum landing weight or landing weight, altitude, and temperature as appropriate. The brakes must be used so as to not cause excessive wear on the brakes or the tires. Retardation devices, other than brakes, may be used if they are shown to provide consistent results and are safe and reliable. If a landing device depends upon the operation of an engine and the failure of that engine results in the increase of the landing distance, then the landing distance must be determined with that engine inoperative.

18.2.8 Advisory Circular 23-8A

This advisory circular discusses takeoff and landing in some detail and provides some clarification of the regulation. For instance, the term complete engine failure is taken to mean only one engine on a multiengine airplane. The circular also permits the use of the piece method for determining takeoff distances as did the CAR policy. It also clarifies the aircraft loading for the tests (forward c.g.) and cautions that the tire speed limits for Technical Standard Order tires should be observed for the high altitude, hot day cases. For landing the advisory circular clarifies the term steady gliding approach to mean an approach where power is used to control sink rate. The terms reliable and safe are discussed regarding landing as is the use of reverse thrust. Considerable detail is provided in the advisory circular and it should be consulted prior to conducting takeoff and landing tests.

18.2.9 Advisory Circular 23-15

Since it was the intent of the FAA, at industry insistence, to remove some of the more burdensome methods of AC 23-8A for small airplanes, this advisory circular allows the use of simple methods for measuring takeoff and landing distances such as the sighting bar method discussed later. If the project is a small airplane, AC 23-15 should be consulted prior to starting the test.

18.3 Theory

In considering either takeoffs or landings, it is customary to divide them into two segments: 1) ground distance segment; and 2) air distance segment.

18.3.1 Takeoff

First, let us consider the ground distance segment of the takeoff. The takeoff ground roll is affected by at least seven factors. They are:

1) wind
2) runway slope
3) aircraft weight
4) air density
5) air temperature
6) pilot technique
7) runway surface condition

Fig. 18.1 shows the forces acting on an aircraft during the takeoff roll. The equation for the aircraft acceleration during this roll may be stated as:

$$F - [D + \mu(W - L)] = \frac{W}{g}a \tag{18.1}$$

where

μ = the coefficient of friction for the tires on the runway

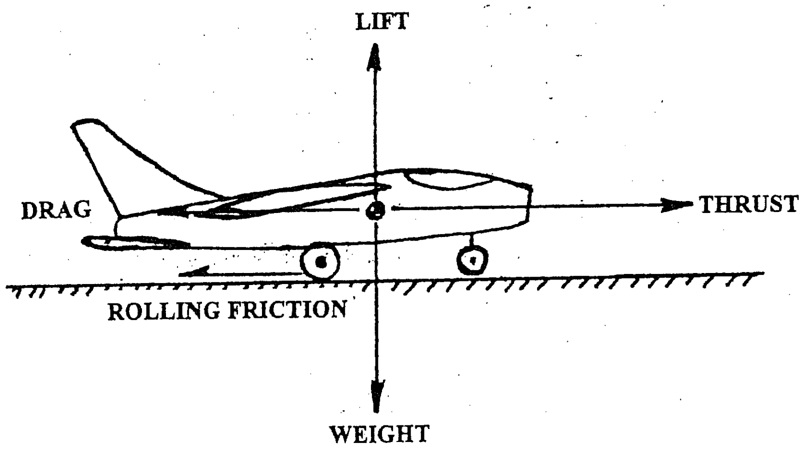


Fig. 18.1 Forces acting on the airplane during takeoff roll.

The term inside the brackets is the total resistance to the takeoff roll.

$$
\begin{aligned}
R &= D + \mu(W - L) \\
&= \left(C_{DP} + \frac{C_L^2}{\pi ARe}\right)qS + \mu(W - C_L qS)
\end{aligned}
\qquad (18.2)
$$

where
R = the total resistance during the takeoff roll

By differentiating Eq. (18.2) with respect to C_L or determining the change in resistance with change in C_L we have:

$$\frac{\mathrm{d}R}{\mathrm{d}C_L} = \frac{2C_L}{\pi ARe}qS - \mu qS \qquad (18.3)$$

If this change is zero we have the optimum C_L for achieving the minimum resistance R.

$$C_{Lopt} = \frac{\pi ARe\mu}{2} \qquad (18.4)$$

Determining C_{Lopt} may be somewhat difficult since values of Oswald's efficiency factor e may not be available for operation in ground effect. In addition, rotation to the angle of attack necessary for C_{Lopt} may not be possible due to control power limitations. If this problem does not exist the possibility of overrotation does. Since induced drag is a function of the square of the lift coefficient, overrotation could destroy any gains obtained by operating near C_{Lopt}. As a result, the procedure of rotating the aircraft to the angle of attack for C_{Lopt} during the takeoff roll is seldom used.

If we return again to Eq. (18.1) we can see that all of the variables are a function of aircraft velocity and are continuously changing during the takeoff roll. This would make an exact equation for the ground roll difficult to obtain. So, in order to simplify this somewhat, we take a mean value of the net thrust and resistance. The excess thrust can be expressed by the equation:

$$F_{xcess} = F_{net} - R \tag{18.5}$$

The work done during the takeoff roll is equal to the gain in kinetic energy. This can be expressed as:

$$(F_{net} - R)S_{gTO} = \left(\frac{W}{2g}\right)V_{TO}^2 \tag{18.6}$$

where
S_{gTO} = the takeoff ground roll distance
V_{TO} = the takeoff velocity

Solving for the ground roll we have:

$$S_{gTO} = \frac{W}{g(F_{net} - R_{mean})}\left(\frac{V_{TO}^2}{2}\right) \tag{18.7}$$

This equation shows that the ground roll distance is very dependent on the takeoff airspeed. Therefore, the use of flaps or high-lift devices is a very effective means of reducing the takeoff roll.

The shortest takeoff roll may not mean the shortest total distance over an obstacle since we also must consider the air distance. In examining this phase of the takeoff we should consider the following factors:

1) wind
2) wind shear
3) aircraft weight
4) air density
5) pilot technique
6) air temperature
7) ground effect

During the air distance phase of the takeoff, the aircraft both climbs and accelerates to the 50-ft obstacle. Again, it is much simpler if we take mean values for thrust and drag and examine the problem from the "work done" standpoint. In this case:

Work done = potential energy gain + kinetic energy gain or

$$(F_{net} - D)_{mean} S_{aTO} = 50W + \frac{W(V_{50}^2 - V_{TO}^2)}{2g} \tag{18.8}$$

where
S_{aTO} = the air distance for takeoff
V_{50} = the aircraft velocity at the 50-ft obstacle

If we solve Eq. (18.8) for the air distance we have:

$$S_{aTO} = \frac{W\left[50 + \left(\frac{V_{50}^2 - V_{TO}^2}{2g}\right)\right]}{(F_{net} - D)_{mean}} \tag{18.9}$$

By summing Eqs. (18.7) and (18.9) we arrive at the total distance over a 50-ft obstacle.

$$S_{total} = S_{gTO} + S_{aTO} \tag{18.10}$$

18.3.2 Landing

The landing problem is evaluated in a manner similar to the takeoff problem. It is based on the same equation and suffers from many of the same shortcomings in test methods.

The landing case is broken into two segments as was the takeoff case. Both segments of the landing are derived from Eq. (18.1).

In deriving the equations for the landing ground roll and landing air distance, we use the same methodology as was used for takeoff. We must, however, keep in mind that the landing is a reverse case to the takeoff.

Using this approach the landing ground roll can be stated as:

$$S_{gL} = -\left(\frac{W}{2g}\right)\frac{V_{TD}^2}{(F - R)_{mean}} \tag{18.11}$$

where
S_{gL} = the landing ground roll
V_{TD} = the touchdown speed

While the air distance is given by:

$$S_{aL} = -\frac{W}{(F - R)_{mean}}\left(\frac{V_{50}^2 - V_{TD}^2}{2g} + 50\right) \tag{18.12}$$

where
S_{aL} = the landing air distance
V_{50} = the aircraft speed at the 50-ft obstacle

18.4 Test Methods

There are a number of test methods used for takeoff and landing tests. These methods vary from relatively simple and inexpensive methods to very complex and expensive methods.

18.4.1 Sighting Bar Method

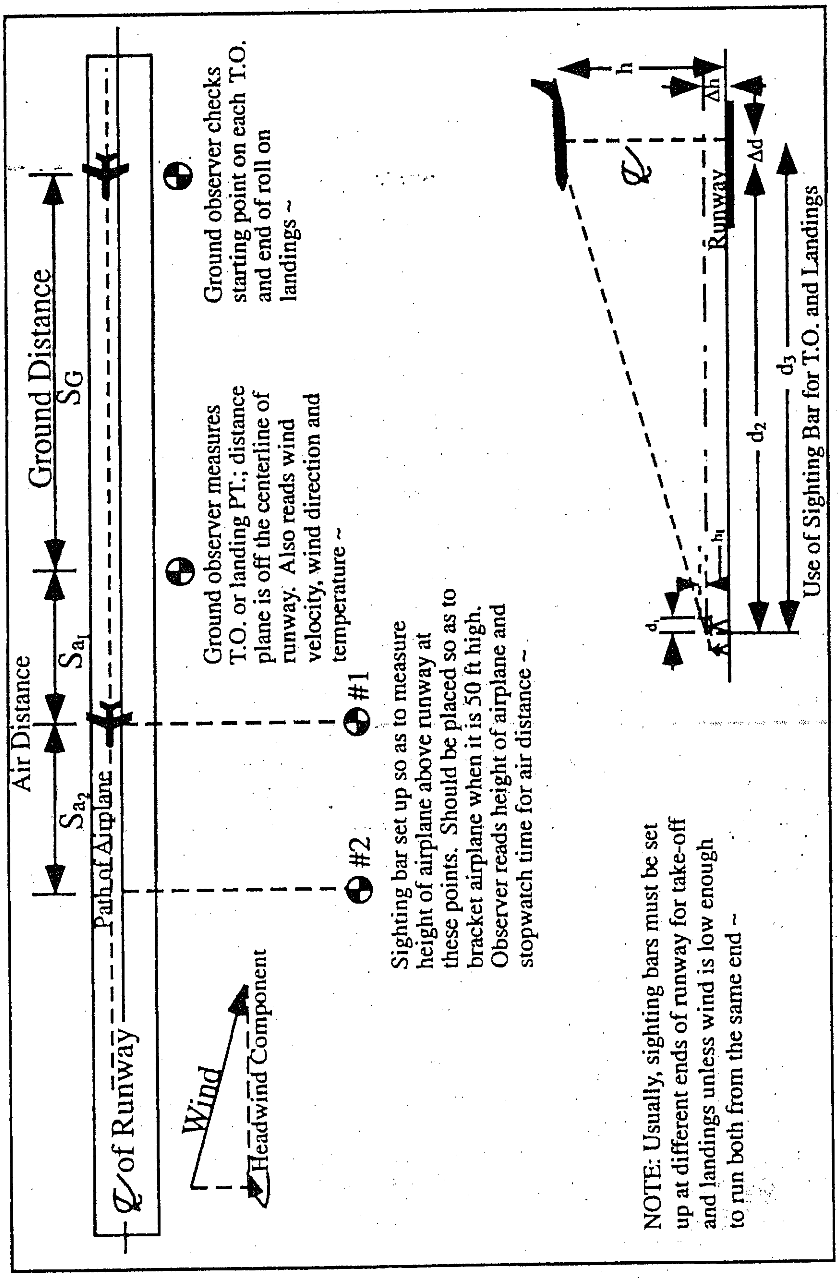
One of the simplest and least expensive methods is the sighting bar method. This method consists of one or two sighting bars located at a known distance from the runway. By the use of these devices, a stopwatch, runway observers, and hand-recorded flight data, takeoff or landing data may be obtained. A typical sighting bar takeoff and landing course is shown in Fig. 18.2. Variations of this basic method include a single sighting bar that obtains both horizontal and vertical distance information. The sighting bar method is very dependent upon the observer operating the sight bar and upon the runway observers. This dependence reduces the accuracy of the method. However, the loss in accuracy is compensated for by the simplicity of the method. Since the raw data is immediately available without film reading or other preliminary reduction, it is possible to conduct more data runs and obtain a larger statistical sample.

18.4.2 Strip Camera Method

The strip camera method uses a camera that takes a picture at fixed time intervals while tracking the test aircraft and records the strip picture on a photographic plate. In this manner, one takeoff or landing run is recorded on a single photographic plate as a series of strip pictures. By knowing the location of the camera site with respect to the runway, the takeoff distance and height information along with a time reference can be obtained from the photographic plate. This method is more expensive than the sighting bar method due to the cost of processing the film and obtaining the data from it. Runway observers are still required to help pin down the liftoff or touchdown point and collect wind and temperature information. This method does provide a permanent record of the takeoff or landing and is accurate.

18.4.3 Movie Theodolite

The movie theodolite method is similar to the strip camera method except that a movie camera is substituted for the strip camera. Fig. 18.3 shows a movie theodolite takeoff and landing course. As can be seen from this figure, the movie film can be used to record other data such as time and azimuth in addition to filming the airplane. This method offers accuracy equal to or slightly better than the strip camera method. Accuracy may also be improved if there is correlation between the movie theodolite and the data recording devices onboard the aircraft. This method is more sophisticated and costly than the previously discussed methods, and the data film is more difficult and time-consuming to analyze.



Take-Off and Landing Course (Sighting Bar)

Fig. 18.2 Sighting bar takeoff and landing course.[4]

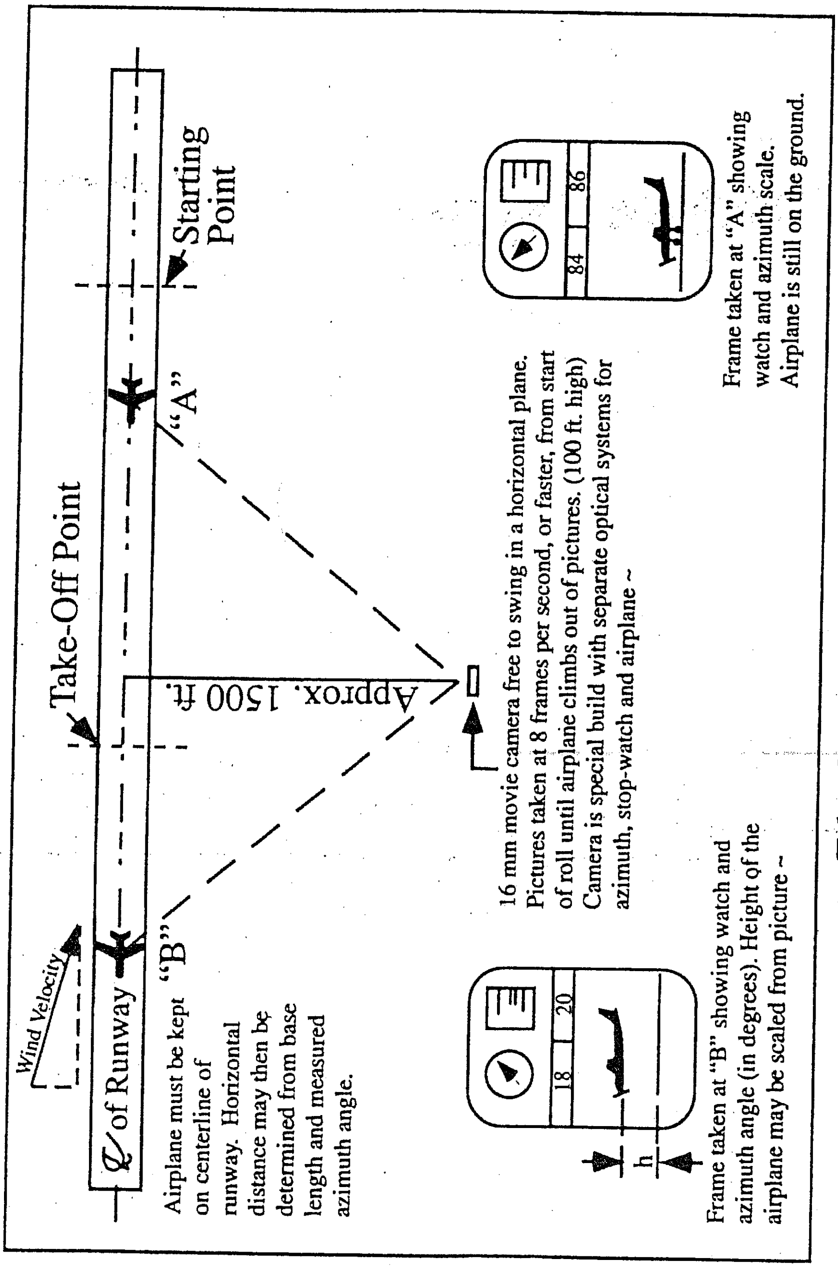


Fig. 18.3 Movie theodolite takeoff and landing course.[4]

18.4.4 *Onboard Theodolite*

A more recent method than those previously described is the on-board theodolite. In this method a camera is mounted on the airplane to obtain three-axis position information. Runway lights and other objects on or along the runway of known size are used with photogrammetric techniques and perspective geometry to obtain airplane position and altitude. A time readout is also displayed, usually on the edge of the film. This system also provides for easy coordination with other onboard data systems since they are all contained within the test airplane. An onboard system is expensive and requires special equipment for film analysis. It offers the advantage of not requiring a large test crew.

18.4.5 *Del Norte Trisponder*

A new system for determining takeoff and landing distances has recently been developed by Del Norte Technology, Inc., called the Trisponder 202. This unit measures horizontal distance and, when combined with a radio altimeter for height information, provides all the distance and height information necessary for determining takeoff and landing distances.

The Trisponder consists of a distance measuring unit (DMU), a master transponder, a remote transponder, and associated antennae, cables, and power sources. The master transponder and DMU can be located on the aircraft while the remote transponder is located on the ground or vice versa. If space and loading limitations allow, it is preferable to locate the DMU and master transponder onboard the aircraft since this will simplify the problem of time correlating the distance and height data.

The beauty of this system is that it does not require any surveyed test site. This allows the system to be loaded aboard the test aircraft and flown to another site should weather or traffic prevent conducting the test at the primary test site.

The drawback to the system is its initial cost and its electronic complexity.

18.5 Test Procedures

Since there are a large number of uncontrollable variables in takeoff and landing testing, every effort should be made to control those variables that can be controlled. First, let us look at items that apply for both takeoff and landing.

The atmospheric variables (wind, outside air temperature, and pressure altitude) should be recorded at the time of the test run for each run. The wind velocity and direction at both the 50-ft obstacle height and 6 ft above the runway should be recorded for each run. Tests should not be conducted if the wind velocity exceeds 10 kn, since wind corrections become unreliable above that wind speed.

18.5.1 *Takeoff*

Now let us turn our attention to the takeoff procedure. In order to reduce data scatter the aircraft should be stopped at the starting point, the power increased to takeoff power, allowed to stabilize, and then the brakes released. The pilot technique for ground roll, rotation, and climb should be, as nearly as possible, the same for each series of takeoffs. Experimentation to determine the optimum technique should be conducted prior to taking data and not during the actual tests.

Flight data should be collected during the entire takeoff and climb to the obstacle on a photo panel or other suitable recording device. A time reference and some method of correlating flight data with distance and height data such as event lights is also useful. If the events of brake release and liftoff are shown on both flight and height-distance data along with time, correlation between these two sets of data is greatly simplified and accuracy improved. If it is not possible to continuously collect flight data during the takeoff run then flight data should be recorded 1) just prior to brake release; 2) at liftoff; and 3) at the approximate 50-ft obstacle height.

18.5.2 Landing

The procedures for landing tests are somewhat like the takeoff only in a reverse direction. In the landing, test power information is not so important as in the takeoff; however, it should be monitored closely to insure that residual power does not remain after touchdown. Braking should be applied to the maximum without skidding the tires. The brakes should be given enough time to cool between runs so that they do not drag on the next takeoff or fade during the next landing. As in the takeoff, the piloting and braking technique should be as consistent as possible.

At the end of the landing run the airplane should be brought to a complete stop and held there several seconds so the end of the run may be easily identified on the film or other data trace. Event lights, or marks, are also handy in this identification.

18.6 Data Reduction

The final data plot for each takeoff or landing run from any of the test methods should look similar to those obtained from the Trisponder and shown in Figs. 18.4 and 18.5. Once we have this data and flight data we can start the data reduction to standard conditions.

18.6.1 Takeoff

The first step in reducing the takeoff data is to make the correction for wind. The wind correction must be made to both the observed ground distance S_{gO} and the observed air distance S_{aO} as shown in the following equations:

$$S_{gT} = S_{gO}\left(1 + \frac{V_W}{V_{TOw}}\right)^{1.85} \tag{18.13}$$

$$S_{aT} = S_{aO} + V_W t \tag{18.14}$$

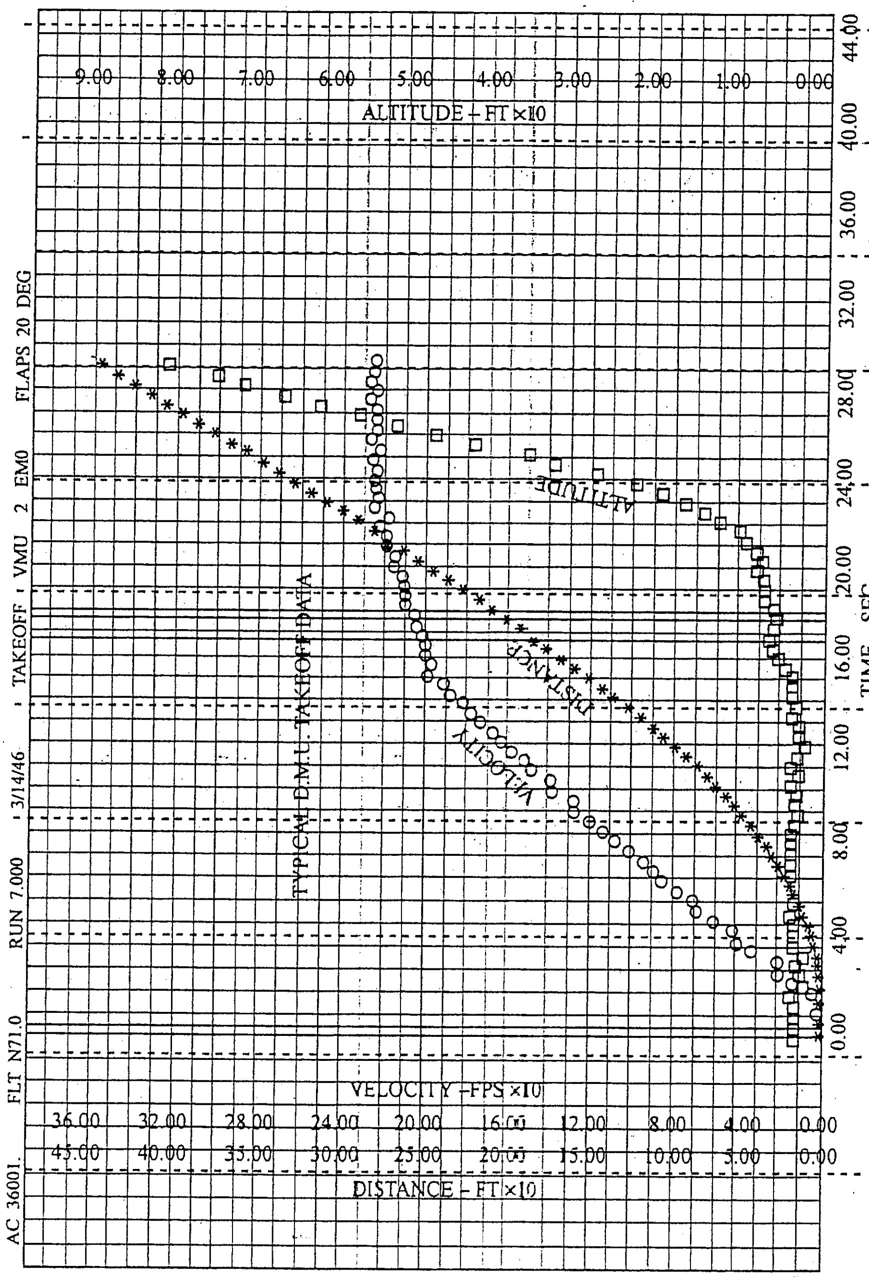


Fig. 18.4 Typical Trisponder takeoff data.[5] (Reprinted with permission from SAE 770477 ©1977 SAE International.)

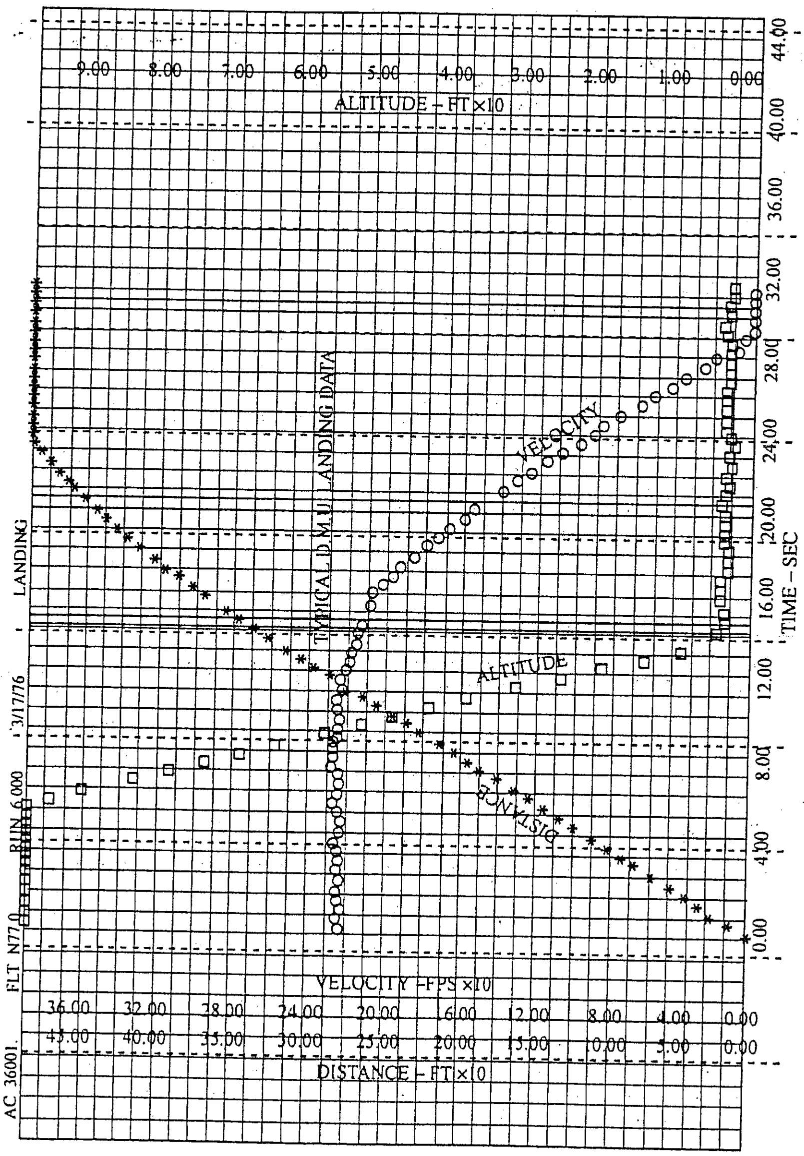


Fig. 18.5 Typical Trisponder landing data.[5] (Reprinted with permission from SAE 770477 ©1977 SAE International.)

where

S_{gT} = the test ground distance or wind corrected ground distance
S_{aT} = the test air distance or wind corrected air distance
V_W = the component of the wind velocity along the runway
V_{TOw} = the true ground speed at takeoff
t = the time from liftoff to the 50-ft obstacle

Once the wind corrected distances have been obtained it is necessary to correct the distances to sea level standard conditions. To do this by exact methods requires the knowledge of thrust, thrust minus resistance, and thrust minus drag. Since this information is not usually available for the takeoff configuration, empirical forms have been developed through experience that provide a reasonable correction. The empirical equations for correcting takeoff distances to standard conditions for jet and constant speed propeller-driven airplanes are given below. Empirical equations for other types of aircraft (fixed-pitch propeller and so on) are given in the "Flight Test Engineers Handbook."[3]

18.6.1.1 Jet aircraft.

$$S_{gS} = S_{gT}\left(\frac{W_S}{W_T}\right)^{2.3}\left(\frac{\sigma_T}{\sigma_S}\right)\left(\frac{F_T}{F_S}\right)^{1.3} \tag{18.15}$$

$$S_{aS} = S_{aT}\left(\frac{W_S}{W_T}\right)^{2.3}\left(\frac{\sigma_T}{\sigma_S}\right)^{0.7}\left(\frac{F_T}{F_S}\right)^{1.6} \tag{18.16}$$

where

S_{gS} = sea level standard ground distance
S_{aS} = sea level standard air distance
F_T = test thrust
F_S = standard thrust

18.6.1.2 Constant speed propeller-driven aircraft.

$$S_{gS} = S_{gT}\left(\frac{W_S}{W_T}\right)^{2.6}\left(\frac{\sigma_T}{\sigma_S}\right)^{1.9}\left(\frac{N_T}{N_S}\right)^{0.7}\left(\frac{BHP_T}{BHP_S}\right)^{0.5} \tag{18.17}$$

$$S_{aS} = S_{aT}\left(\frac{W_S}{W_T}\right)^{2.6}\left(\frac{\sigma_T}{\sigma_S}\right)^{1.9}\left(\frac{N_T}{N_S}\right)^{0.8}\left(\frac{BHP_T}{BHP_S}\right)^{0.6} \tag{18.18}$$

where

N_S = maximum takeoff rpm
N_T = actual rpm during the test run

Once the standard ground and air distances are obtained by one of the above methods, the standard distance over a 50-ft obstacle S_{50} is obtained by adding the air and ground distances together.

$$S_{50} = S_{gS} + S_{aS} \tag{18.19}$$

This process is done for each test run and an average taken of all the runs to determine the final distance.

After the average distances have been determined the data may be expanded to nonstandard conditions, such as those shown in Fig. 18.6, by reverse use of the above equations.

18.6.2 Landing

The correction of landing distances is much simpler than is the correction of takeoff distances. The reason for this is that the power is either at idle or held constant at some low value from the obstacle height to touchdown. This removes the power corrections from the empirical equations and greatly simplifies them.

The landing data, like the takeoff data, is first corrected for wind. The equations for wind correction of landing distances are quite similar to the takeoff wind corrections and are shown below.

$$S_{gT} = S_{gO}\left(\frac{V_{TD} + V_W}{V_{TD}}\right)^{1.85} \tag{18.20}$$

$$S_{aT} = S_{aO} + V_W t \tag{18.21}$$

where

V_{TD} = the touchdown airspeed

To correct these distances to standard conditions the following empirical equations may be used:

$$S_{gS} = S_{gT}\left(\frac{W_S}{W_T}\right)^2\left(\frac{\sigma_T}{\sigma_S}\right) \tag{18.22}$$

It has been found that the weight correction to the landing ground distance is not accurate and that weight does not affect landing ground distance in any predictable form. For this reason landing tests are usually conducted as close to maximum gross weight as possible and the weight correction of Eq. (18.22) ignored.

$$S_{gS} = S_{gT}\left(\frac{\sigma_T}{\sigma_S}\right) \tag{18.23}$$

$$S_{aS} = S_{aT} \tag{18.24}$$

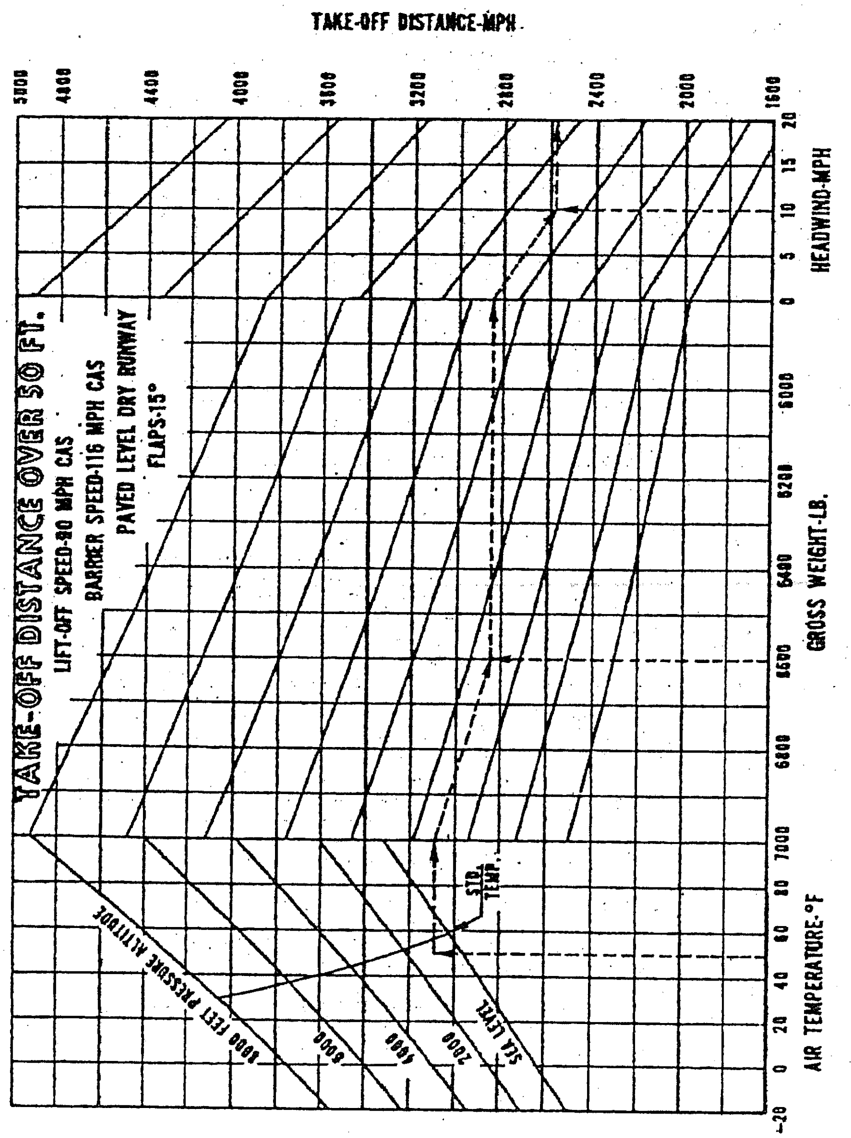


Fig. 18.6 Expanded handbook takeoff data.[6]

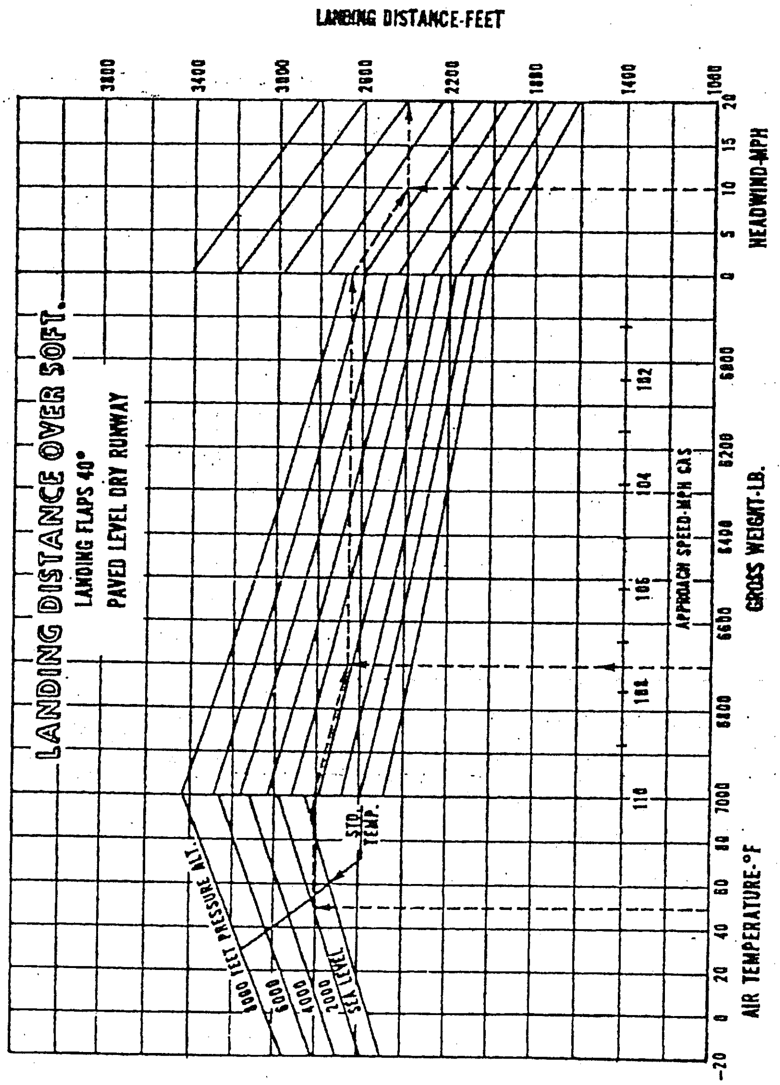


Fig. 18.7 Expanded handbook landing data.[6]

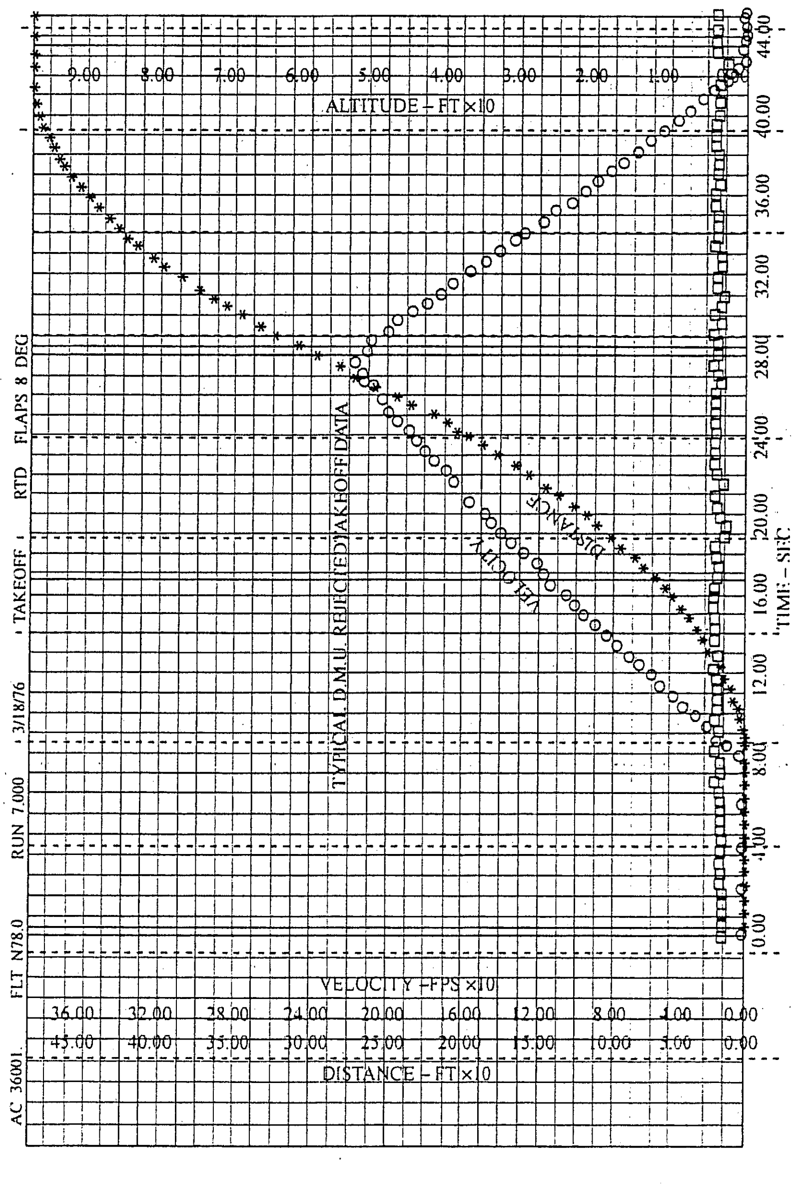


Fig. 18.8 Typical Trisponder rejected takeoff data.[5] (Reprinted with permission from SAE 770477 ©1977 SAE International.)

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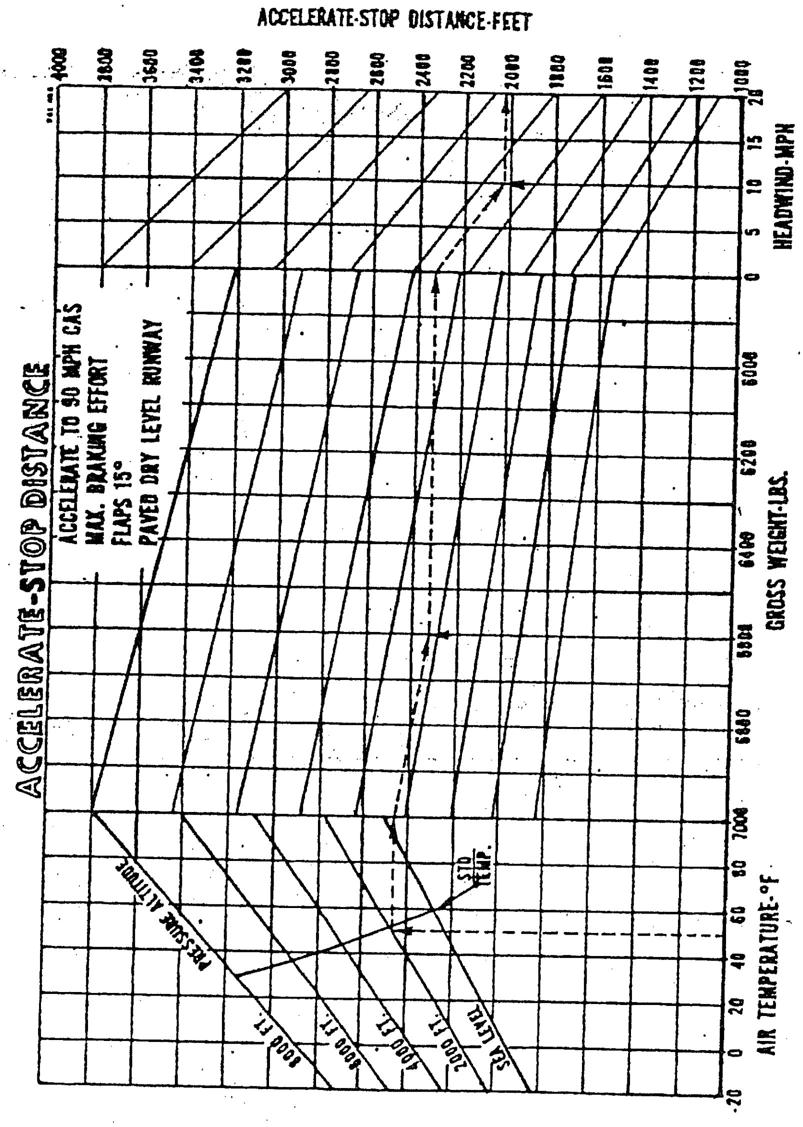

Fig. 18.9 Expanded handbook rejected takeoff data.[6]

The total standard landing distance can then be expressed as:

$$S_{50} = S_{gT}\left(\frac{\sigma_T}{\sigma_S}\right) + (S_{ao} + V_W t) \tag{18.25}$$

Expansion to nonstandard conditions, such as is shown in Fig. 18.7, may be accomplished by a reverse use of the correction equations.

18.7 Rejected Takeoff Distances

The distance required to accelerate to takeoff speed and then abort the takeoff and stop is called a rejected takeoff. It is also sometimes called balance field length. It applies primarily to multiengine airplanes where the takeoff is rejected because of an engine failure at takeoff speed.

The test is conducted by accelerating the aircraft to liftoff speed as in the takeoff test, failing an engine, waiting a specified number of seconds to simulate failure recognition time, then closing the throttle on the good engine and applying brakes as in the landing ground run. Data is recorded, and time, distance, and velocity plots similar to the one shown in Fig. 18.8 are generated. Since this procedure is essentially a takeoff ground run tied to a landing ground run with an intermediate segment in the middle, the data reduction to standard conditions can be accomplished by using the takeoff and landing ground distance reduction methods.

Data may be expanded to nonstandard conditions as shown in Fig. 18.9 by reverse use of these equations.

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