ICAS Paper No. 70-53

A COMMENTARY ON DESCENT CAPABILITY, LANDING PERFORANCE, AND LANDING IMPACT CRITERIA FOR V/STOL AIRCRAFT

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The Seventh Congress of the International Council of the Aeronautical Sciences

CONSIGLIO NAZIONALE DELLE RICERCHE, ROMA, ITALY / SEPTEMBER 14-18, 1970

Price: 400 Lire

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Abstract

There is continued pressure upon the designer to improve aerodynamic performance in the approach by reducing landing approach speeds and increasing rates of descent. At times, performance objectives are set which fail to consider the tradeoff aspects of high vertical impact velocities with their resultant weight penalties. In this paper the interplay between descent capability, landing performance and structural criteria is examined, with particular regard to STOL landings. An expression of the relationship between mean impact sink rate and design sink rate for the landing gear is presented which made use of statistical data from a wide variety of conventional aircraft. The point is made that the high order of direct lift control inherent in STOL airplanes should produce smaller differences between mean and design sink rates than those exhibited historically by such conventional aircraft, and an alternative method of deriving this relationship is discussed.

Introduction

The need for interurban short haul transportation systems between city pairs has resulted in numerous studies of the relative merits of air transportation versus high speed railway and highway systems. In air transportation systems the demand exists to provide new aircraft which have cruise speeds in the order of 300 to 500 knots, yet can operate safely and effectively from much shorter runways than are used for conventional aircraft. Most sources indicate that the certified field length should be less than 2500 feet. A companion requirement exists for steep climb and descent gradients to provide suitable obstacle clearance in confined areas. Glide slope angles of 15° are frequently indicated as a desirable objective for the landing approach with 6° being expressed as a minimum.

A variety of V/STOL aircraft have been created, generally in experimental form, which can equal or better those objectives. The general means for securing such performances is a combination of decreased landing approach speed and increased rate of descent. To establish a perspective on glide slope and rate-of-descent accomplishments in such aircraft, Figure 1 has been prepared. This figure summarizes information contained in a series of reports published by the National Aeronautics and Space Administration and the Federal Aeronautics Administration.

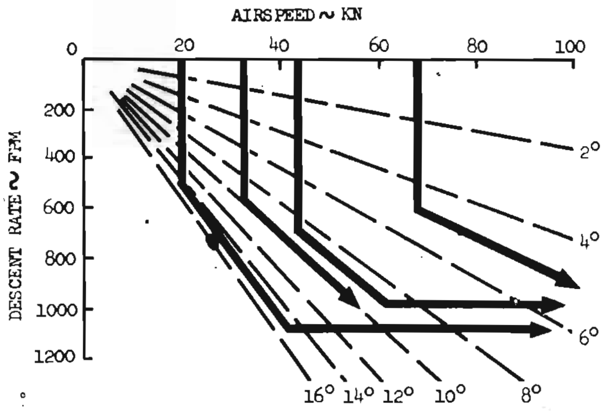


FIGURE 1 DESCENT CAPABILITY

Each line on this figure represents the minimum airspeed-maximum glide slope limits for a particular aircraft based upon pilot evaluation of handling qualities during approach and landing. The flight evaluations occured prior to 1963 since most of the reports were published in 1963. In general, it can be seen that the attainment of a 15° glide slope can only be realized by high rates of descent or conversely, by very low forward speeds.

In reviewing the wealth of published reports on V/STOL aircraft a pattern is apparent: One report will deal with the aerodynamic aspects of the landing problem, another with the structural aspects. None treat the subject as a combined problem. It is the purpose of this paper to discuss these two basic subjects as a single problem in order to highlight the need for combining them in future studies of STOL operational requirements and preliminary designs.

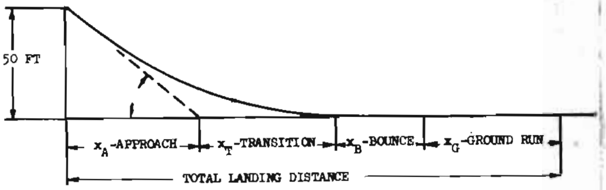
The most complete treatment of V/STOL landing impact criteria is a 1968 study sponsored by the Air Force Flight Dynamics Laboratory. Review of the pertinent portion of this study will be accomplished later in this paper.

Because the rate of descent and forward speed selected for a given design essentially set the landing impact initial conditions, the performance aspect of the landing problem will be discussed first.

Landing Performance Criteria

In this review, the parameters which dictate the trajectory of the aircraft from the time the vehicle is 50 feet off the ground until it is halted on the ground will be examined. Variations in these parameters will be made to determine the relative effects of each. The range of each parameter investigated is sufficiently large to encompass the most extreme values anticipated. This review will be limited to the specific effects of the various parameters. No attempt has been made to specify how the variations in these parameters can be achieved for a specific design concept.

In general, the landing problem can be evaluated in terms of four identifiable parts. These parts, shown pictorially below, consist of the approach, the transition, the bounce, and the ground run.



The Approach

The approach distance (x_A) can be defined in terms of the approach angle (γ) and the height of the obstacle which must be cleared. For this study the commonly specified 50 foot high obstacle will be used. This relationship is shown in the following equation:

$$x_A = \frac{50}{\tan \gamma}$$

Since the approach angle is a function of forward velocity (v_x) and the rate of descent (v_v), the approach distance (x_A) can be further defined as

$$x_A = \frac{50 v_x}{v_v}$$

Solution of this equation is presented in conventional format by Figure 2 for the speed range from 0 to 80 knots and at descent rates of 300, 600, 900, and 1200 feet per minute.

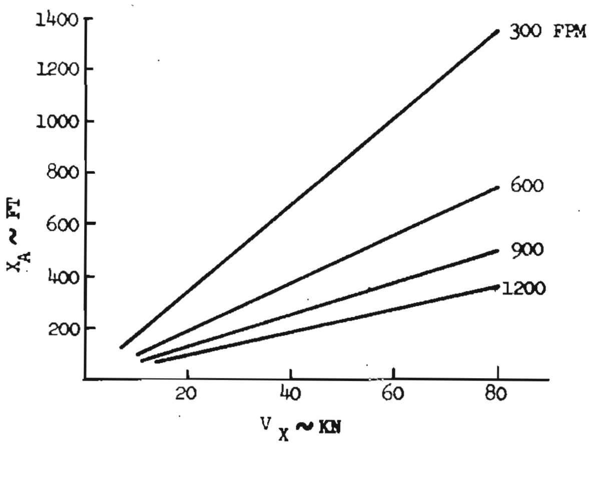


FIGURE 2 APPROACH DISTANCE

This form of presentation does not provide the means for readily visualizing the interaction between these parameters. Accordingly, the same data have been replotted in the form of a parametric carpet, Figure 3.

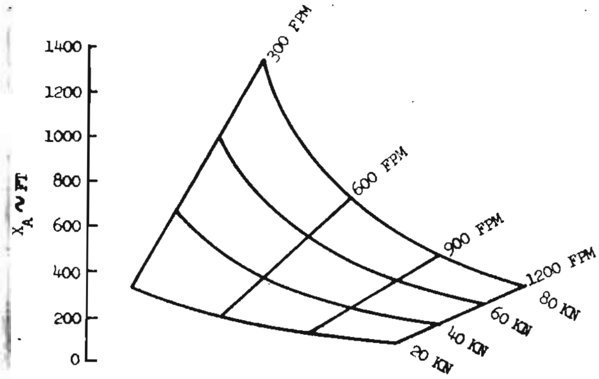


FIGURE 3 APPROACH DISTANCE

Now it can be seen that increasing the rate of descent beyond 600 fpm has negligible benefit at the low speed of 20 knots and only moderate benefit at the high speed of 80 knots. In essence, the payoff comes in reducing approach speeds rather than striving for very high rates of descent.

Reduction in approach speed also has a powerful effect upon shortening the ground run, as we shall see later.

The Transition

The transition distance is based upon the commonly used assumption that the aircraft follows a circular-arc path as it approaches the ground. This assumption results in an impact velocity of zero feet per second for all landings. The landing trajectory for aircraft which utilize the conventional flare maneuver during transition closely approximates the circular-arc. For the purpose of examining the case wherein the STOL airplane applies power to partially arrest the rate of descent, proportional reduction in transition distance has been used. It is believed that this assumption provides a reasonable approximation so that values of transition distance can be calculated for the purpose of establishing the relative effects of partial transition on the total landing distance.

Assuming a circular-arc trajectory, the full transition distance can be defined in terms of the approach speed (v), the approach angle (γ), and the normal acceleration (n_z) experienced throughout the maneuver. This relationship can be written as follows:

$$x_T = \frac{v^2 \tan \frac{\gamma}{2}}{\Delta n_z \cdot g}$$

where g = gravitational constant, and

$$v = \sqrt{v_x^2 + v_z^2}$$

A typical carpet plot, for the case where n_z is 0.2, is shown in Figure 4.

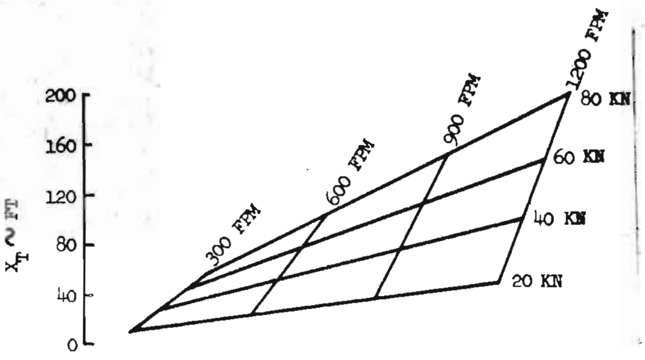


FIGURE 4 TRANSITION DISTANCE

Here it is apparent that increasing the rate of descent has a strong detrimental effect upon total landing distance, especially at the higher approach speeds.

The Bounce

Practically speaking, some time delay between ground impact and the application of brakes and/or reverse thrust needs to be introduced, allowing for pilot reaction and the time delay inherent in mechanical systems.

The distance consumed by this allowance is simply the forward velocity at impact multiplied by the chosen time delay:

$$x_B = (V_x) \text{ (time delay)}$$

Even though this is a simple arithmetic relationship, the carpet plot format, Figure 5, better illustrates the interplay.

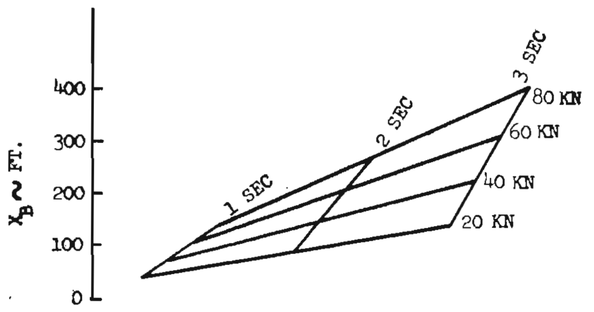


FIGURE 5 BOUNCE DISTANCE

As would be expected, an increase of one second in bounce time allowance has little effect upon total landing distance at 20 knots, but becomes quite significant at 80 knots.

The Ground Run

The ground run distance is a function of the forward velocity at touch-down (v_x) and the deceleration rate ($\dot{v}_v$) during the rollout.

This can be expressed as follows:

$$x_G = \frac{V_x^2}{2 \dot{v}_v}$$

The solution to this equation, for $\dot{v}_v$ values of 0.3, 0.5 and 0.8g is shown in Figure 6. The 0.3 value is a reasonable one for good brakes on dry concrete or macadam. The 0.5 and 0.8 levels are representative of values attainable with reverse thrust.

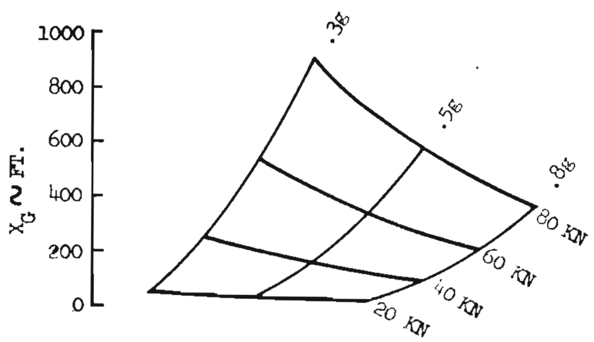


FIGURE 6 GROUND DISTANCE

From this figure it is apparent that while inclusion of reverse thrust offers little improvement in total landing performance at low speeds, it becomes very powerful at the higher speeds. The value of reverse thrust is further increased when wet runway or off-runway operations are considered.

Total Landing Distance

In the previous discussion each part of the landing maneuver was considered separately. Variations in parameters were made to show the effects of the entire range of possible values of each on the approach, transition, bounce, and ground run distances. The significant factor in determining whether or not an aircraft can operate from an area of limited size, however, is the total landing distance. Consequently, all parts of the landing maneuver must be examined in combination with a view towards establishing the relative effects of the various parameters which dictate the total distance.

Figure 7 shows total landing distance wherein a full transition is employed, one second bounce time is allowed, and 0.3g ground deceleration is assumed:

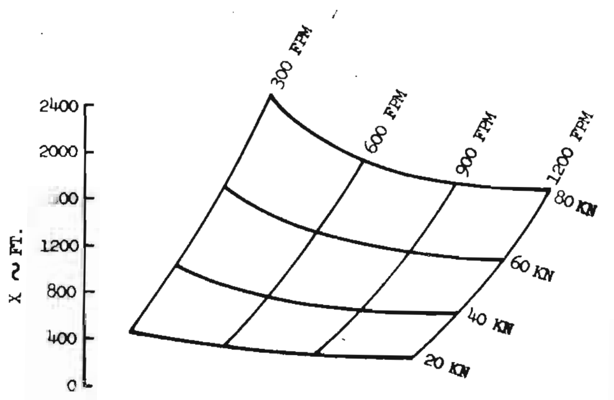


FIGURE 7 TOTAL LANDING DISTANCE

This figure is repeated below in dotted lines with the addition of a second carpet plot which shows the same conditions except that the transition has been eliminated:

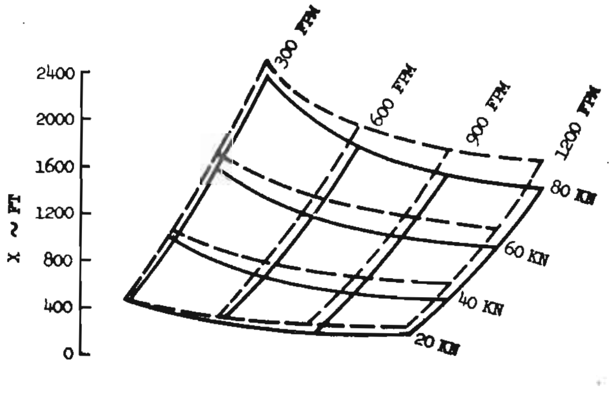


FIGURE 7A TOTAL LANDING DISTANCE

Now the effect of transition upon total landing distance can be seen and can be further evaluated in terms of either descent rates and/or airspeeds. Elimination of transition has negligible effect upon total distance at moderate sink rate but does become significant at the higher rates. Therefore, if a high sink rate were chosen for a given airplane design study, elimination of transition to improve landing performance would have to be evaluated against the increase in vertical impact velocity, especially if the airplane were also intended to have a high approach speed.

Another viewpoint which can be derived here is that the transition has little significance if sink rates and approach speeds are moderate, therefore the transition could be retained to hold vertical impact velocities to a minimum.

Figure 8 also shows total landing distance wherein a half-transition is performed, but the one second bounce time and 0.3g deceleration have been retained:

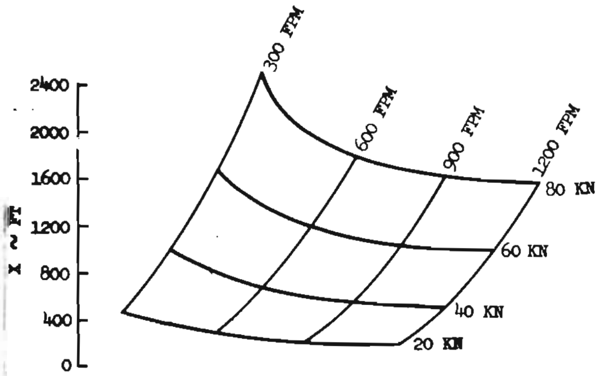


FIGURE 8 TOTAL LANDING DISTANCE

This figure is repeated below in dotted lines with the addition of a second carpet plot which shows the same conditions except that the ground deceleration has been increased from 0.3 to 0.8g. (The bounce time has been increased to two seconds also to provide more time for the development of reverse thrust.)

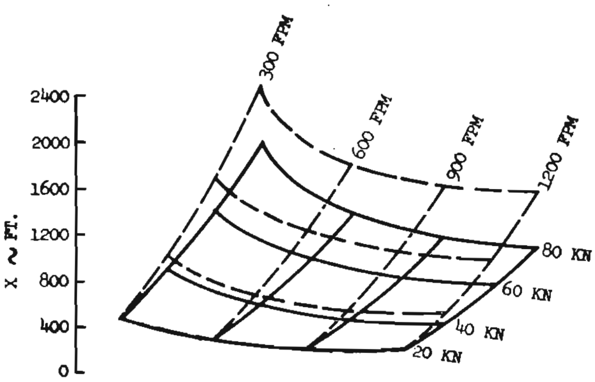


FIGURE 8A. TOTAL LANDING DISTANCE

Now the effect of a high level of reverse thrust can be seen. Reverse thrust has little effect at low speeds but becomes very significant at higher speeds. Also, at the higher speeds, it is evident that rate of descent can be reduced to a moderate degree without affecting total landing distance significantly.

Determination of STOL Design Sink Speed

The chosen landing performance criteria identify a nominal value of impact velocity. For landing gear design purposes this nominal value is considered to be the mean value which has a statistical probability of not being exceeded in 500 out of 1000 landings. Both higher and lower values exist in the remainder of the landings. Commonly, the higher value which will only occur in one out of 1000 landings, on a statistical probability basis, is used as the design sink speed for the landing gear. The problem, therefore, is to determine this value, using the mean sink speed as a basis.

Based on the previous discussion of landing performance, it is evident that STOL landings may be executed in a variety of ways. The maximum performance approach being one in which the glide path angle is maintained to ground impact. At the other end of the scale is the one generally employed by conventional aircraft where the sink rate is reduced, by some form of flaring, to essentially zero.

Since the glide-path-to-impact mode is the one which is most desirable from a performance standpoint, it is of primary interest. Such landings are analogous to carrier landings. Minimal-impact landings are analogous to conventional aircraft and helicopter landings. In view of the dearth of direct data obtained in the course of flight testing representative STOL airplane, recourse must be made to historical data on conventional airplanes and helicopters.

The carrier extreme impact velocity is based upon a specified mean value and the standard deviation. Collection of considerable data for many carrier based aircraft reveals that the distribution of landing impact velocity is approximately normal. Cognizance of this fact is reflected in the MIL-A-8866(ASG) Table IV distribution for carrier and FCLP landings. This distribution is related to the fact that the intent for each landing is to approach the deck at a specified approach angle which results in approximately the mean impact velocity. For STOL landings, where the intent likewise is to fly a predetermined approach angle, an appropriate normal distribution of impact velocities should result if the mean impact velocity is 8 to 12 feet/sec.

Data collected for the minimal type of landing where the mean sink speed is very low revealed that the distribution of impact velocities is considerably skewed away from the zero sinking speed. Thus, the distribution is not normal.

For STOL landings where the mean sinking speed could conceivably vary from the low conventional values to the higher values, the problem of relating mean impact velocity to the distribution shape needed to be resolved.

A unique solution to this question was included in an extensive 1968 study sponsored by the Air Force Flight Dynamics Laboratory. The following material, thru the presentation of Figure 13, summarizes that solution.

TABLE 1. NUMBER OF DEGREES OF FREEDOM FOR CHI-SQUARE DISTRIBUTION WHICH FIT SINK SPEED DISTRIBUTION FOR VARIOUS AIRCRAFT

DATA POINT NO.	AIRCRAFT	REF.	Z_p = .5 (FPS) SINK SPEED FOR P = .5	Z_p = .001 (FPS) SINK SPEED FOR P = .001	$Z_p = .001$ / $Z_p = .5$	NO. OF DEGREES OF FREEDOM FOR CHI-SQUARE DISTRIBUTION	DESCRIPTION OF LANDINGS
1	F-1	2	12.3	23.6	1.92	31	Carrier Qualification
2	F-1	2	12.1	21.9	1.81	45	Carrier Combat
3	A-1	2	9.8	19.7	2.01	31	Carrier Qualification
4	A-2, A-3, A-4	2	8.4	17.1	2.04	30	Carrier Combat
5	F-2	2	10.8	22.9	2.12	26	Carrier Qualification
6	F-2	2	10.2	21.9	2.15	26	Carrier Combat
7	C-1	2	3.2	8.5	2.66	15	Transport - Berlin Airlift

TABLE 1. NUMBER OF DEGREES OF FREEDOM FOR CHI-SQUARE DISTRIBUTION WHICH FIT SINK SPEED DISTRIBUTION FOR VARIOUS AIRCRAFT (Concluded)

DATA POINT NO.	AIRCRAFT	REF.	Z_p = .5 (FPS) SINK SPEED FOR P = .5	Z_p = .001 (FPS) SINK SPEED FOR P = .001	$\frac{Z_p = .001}{Z_p = .5}$	NO. OF DEGREES OF FREEDOM FOR CHI-SQUARE DISTRIBUTION	DESCRIPTION OF LANDINGS
8	H-1 H-2	2	1.6	6.1	3.81	7	Helicopter Autorotative
9	H-3	2	1.5	5.2	3.47	8	Helicopter - Carrier Power - On
10	Various Transports	11	1.3	4.3	3.31	9	478 Landing At Wash. Nat. Airport
	F-3	12	13.24	22.0	1.66	63	Carrier
12	F-4	12	13.58	22.8	1.68	61	Carrier
13	F-6	12	12.71	20.5	1.61	71	Carrier
14	A-5	12	13.56	22.5	1.66	63	Carrier
15	F-7	12	13.4	20.0	1.49	100	Carrier
16	A-6	12	12.76	20.7	1.62	70	Carrier
17	MIL-A-8866	18	2.6	9.1	3.50	8	Field

The chi-square distribution has the property of varying in shape from a skewed distribution to a nearly normal distribution as a function of "number of degrees of freedom." Since the chi-square distribution possesses the general shape characteristics of both the extremes of the landing impact velocity distributions for which data have been collected, (i. e., a skewed distribution for low mean values and a nearly normal distribution for high mean values) it can be shown that the chi-square distribution approximates both ends of the mean sink speed range. Thus, it can be assumed that the mid-range of mean impact velocities will also approximate the chi-square distribution.

To establish the relationship between the mean impact velocities and the shape of the sink speed distribution for many different types of aircraft and the chi-square distribution, the following procedure was followed. The ratio of the mean impact velocities which has a probability of .5 to the extreme impact velocity which has a probability of .001 was calculated for a particular collection of landing impact data. Then a probability table for the chi-square distribution was used to determine the "number of degrees of freedom" for which the same ratio exists. Thus, a relationship was established between the mean of a distribution and the "number of degrees of freedom." Table 1 presents this relationship for 17 different data samples which represent carrier, helicopter, and transport operations plus the current MIL-A-8866(ASG) field landing distribution. Then the mean sink speed was plotted against the number of degrees of freedom for the chi-square distribution in Figure 9.

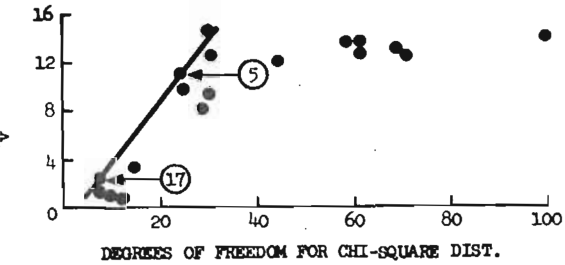


FIGURE 9 $\bar{V}_V$ vs DEGREES OF FREEDOM

This plot shows a cluster of points in the lower left hand corner where the mean sink speed and degrees of freedom are relatively small. These points represent helicopter and conventional transport operations. Also, the data for field landings of conventional aircraft specified in MIL-A-8866.17, was plotted to show its relative location to points representing actual test data. Another cluster of data points is seen where the mean is 8 to 14 feet/sec and the number of degrees of freedom is between 20 and 50. These points represent carrier experience for several types of aircraft, including propeller aircraft and first generation jet aircraft.

The points where the mean is between 12 and 14 feet/sec and the degrees of freedom are between 60 and 100 represent high performance jet aircraft, some of which are currently in service.

Since most STOL aircraft will be operated in the range of mean sink speed values less than 12 feet/sec, the points which are of most interest are those where the degrees of freedom are less than 30. The pattern of the two groups of points which have less than 30 degrees of freedom clearly show that as the mean sink speed increase, the degrees of freedom also increase. If it is assumed that the relationship between mean sink speed and degrees of freedom varies linearly between these two basic groupings, then a means would be available for determining the extreme impact velocity and the sink speed distribution by knowing only the mean sink speed as determined by the landing performance requirements. Since there is some scatter in these two basic groupings of points the question arises how they should be connected. In the absence of extensive data to verify the assumed relationship between the mean sink speed and the number of degrees of freedom, the extreme points of each pattern will be connected which lead to the most conservative (i. e., highest) extreme values. Hence, points 5 and 17 are connected to establish the relationship between mean sink speed and degrees of freedom.

To show the degree to which the chi-square distribution fits existing data a comparison of the chi-square and data point 5 and 17 probability curves is shown in Figure 10.

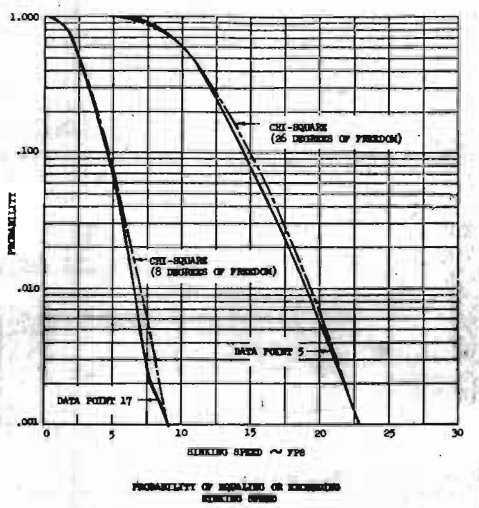


FIGURE 10 A COMPARISON OF CHI-SQUARE AND DATA POINT 5 AND 17 PROBABILITY CURVES

To show a typical variation in distributions and probabilities which would result from using the proposed relationship between mean sink speed and degrees of freedom for the chi-square distribution, Figures 11 and 12 have been prepared. Figure 12 shows that for mean impact velocity values of 3, 6, 9, and 12 feet/sec the extreme values at P = .001 are 9.5, 15.4, 20.3, and 24.5 feet/sec, respectively.

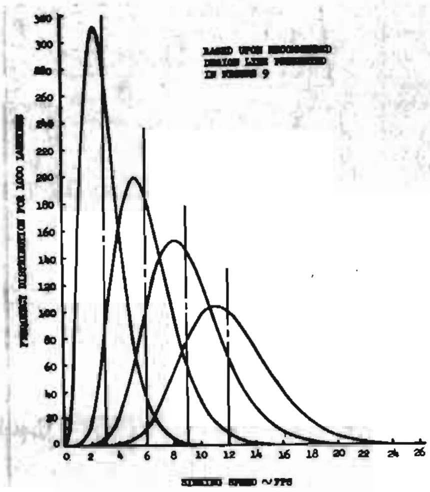


FIGURE 11 CHI-SQUARE FREQUENCY DISTRIBUTION FOR MEAN SINK SPEEDS OF 3, 6, 9, AND 12 FT/SEC

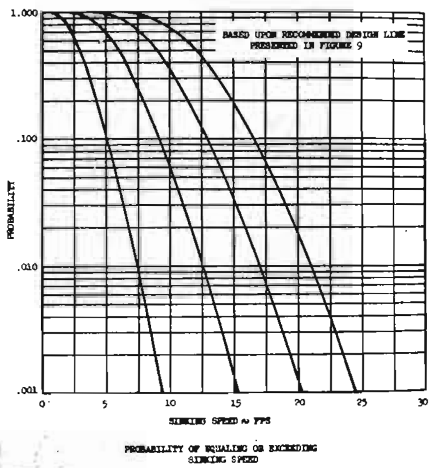


FIGURE 12 CHI-SQUARE PROBABILITY CURVES FOR MEAN SINK SPEEDS OF 3, 6, 9, and 12 FPS

Figure 13 shows the proposed relationship between mean impact velocity values and extreme impact velocity values based upon the preceding analysis:

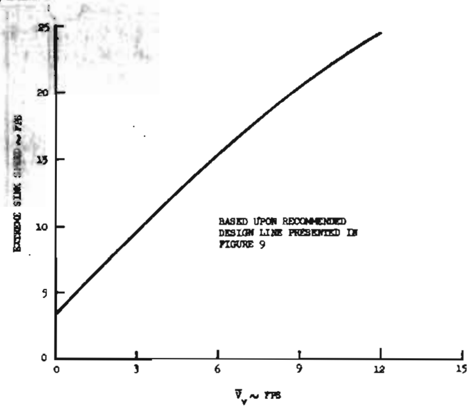


FIGURE 13 MEAN SINK SPEED VS EXTREME SINK SPEED

At this point we have a logical statistical derivation of the ratio between mean and design sink speeds which includes the effect of the actual value of the mean sink speed upon the distribution and upon the maximum value. This distribution would require, for example, a design value of 22 fps if the mean value were 10 fps. Before adopting Figure 13, however, let's review the basis upon which it was developed by referring to Figure 9, repeated herewith for convenience:

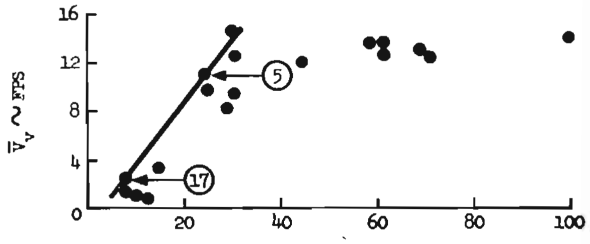


FIGURE 9 (REPEATED)

The line drawn on this figure was intentionally drawn to be conservative; i. e., encompass all the reference aircraft and the conditions under which they were flown. This approach ignores the question of the flying qualities of the individual aircraft and the question of whether or not the landings were made under the control of a mirror landing system or similar precision glide path control. The cluster of points below 20 degrees of freedom is not of interest in this critique. The points between 20 and 50 degrees of freedom represent carrier operations data obtained prior to 1952 in which the mirror landing system was not employed; also it is reasonable to assume that these aircraft had poorer flying qualities than later aircraft would possess. The grouping of points above 50 degrees of freedom for the chi-square distribution represent carrier operations as recent as 1962, and the mirror was believed to have been used in most cases. The significance here is that the higher degrees of freedom reduce the ratio between mean and design sink speeds.

In this critique we have progressed to the point of recognizing that use of a precision glide slope display by the pilot, mirror or otherwise, will reduce the sink speed ratio. It then follows that aircraft with some degree of direct or powered lift should exhibit lesser sink speed ratios, also.

Since we are beginning to think of the distribution of impact sink speeds as being the result of vertical perturbation about the flight path, the sample deviation of vertical speed will now be used as a frame of reference. Figure 14 relates this deviation to the mean sink speed.

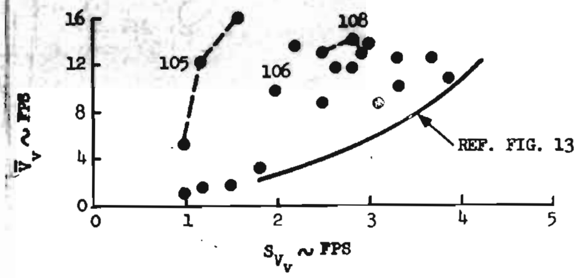


FIGURE 14 SAMPLE DEVIATION OF $\bar{V}_v$

On this figure some additional aircraft have been introduced. The grouping of points identified as 108 represents a jet carrier-based fighter in active duty with the Navy; landings were all mirror controlled. Point 106 is a variation of the same airplane which incorporated a direct lift control system which altered lift by using deflected flaps as a control surface. Speed variations were a problem in this airplane and undoubtedly degraded the pilot's ability to track the mirror. Nevertheless reduction in mean sink rate is evident as well as a tendency toward a smaller deviation. The three points numbered 105 represent another version of the point 108 airplane equipped with BLC. Marked reductions in vertical speed deviations are evident, regardless of mean sink speed. While this limited evidence is not conclusive due to small sample sizes, it does imply that standard deviations of less than 2 fps should be reasonable. Recognizing that normal distributions are characteristic of landings in the 8 to 12 fps range, multiplying the sample deviation by three will approximate the corresponding design sink speed. For example, a mean value of 10 fps would require 16 fps or less for design rather than 22 fps.

Development of Figure 14 generated the desire to find a means of directly calculating the standard deviation of vertical velocity for a proposed STOL airplane rather than depending upon historical data not necessarily representative of the handling qualities expected in the STOL design. Review of numerous documents brought to light an interesting equation published by the U. S. Navy Bureau of Aeronautics in 1959. While the original equation contained parameters peculiar to carrier operations, it was evident that it could be simplified for the problem at hand. In its simplified form, the equation will derive the standard deviation of vertical velocity based upon chosen values of glide slope tracking deviation and airspeed deviation at airplane touchdown.

At the time of its publication by the Navy in 1959, substantiation of its accuracy was provided by comparison of measured values to calculated for a number of Navy aircraft, using data available at that time. A 1962 Vought Aeronautics study of carrier landing design criteria, conducted under Navy sponsorship, included examination of the original Navy data and augmented it with additional comparisons. The summary table from the 1962 report is repeated herewith:

A/P Type	S_{V_v} FPS (Meas.)	σV_v FPS (Calc.)
Fighter	2.90	3.20
Fighter	3.06	3.26
Fighter	3.50	3.53
Fighter	2.62	2.87
Attack	2.95	3.12
Fighter	2.14	2.26
Attack	2.63	2.99
Fighter	2.85	3.08
Fighter	2.70	2.97
Fighter	2.52	2.77
Attack	2.45	2.42

Review of this table shows good agreement between measured and calculated deviations. The calculated values were obtained using the test sample values of carrier operations parameters: glide slope deviation, deck pitching angle deviation, engaging speed deviation, mean value of engaging speed, mean value of glide slope and mean value of deck pitching angle.

For the generalized STOL problem the deck pitching parameters become zero and the engaging speed is the same as horizontal velocity therefore the simplified equation is:

$$\sigma V_v = .0296\sqrt{(\bar{V}_x)^2 (\sigma\gamma)^2 + (\bar{\gamma})^2 (\sigma V_x)^2}$$

wherein the standard deviation of vertical velocity is expressed as a function of mean horizontal velocity in knots, glide slope deviation in degrees, mean glide slope in degrees, and horizontal velocity deviation in knots.

To illustrate the interplay of these parameters Figure 15 has been prepared in carpet format using as representative values a glide slope deviation or tracking error of 0.5 degrees and an airspeed deviation of 7% of the mean airspeed (the slight difference between horizontal velocity and airspeed in still air, due to glide slope angle, may be ignored.

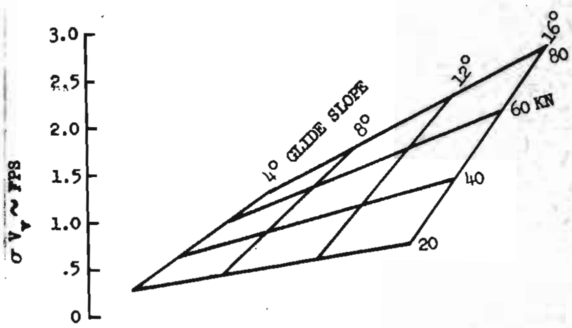


FIGURE 15 STANDARD DEVIATION OF $\bar{V}_v$

Space does not permit plotting of some of the representative airplanes from Figure 14 on this new plot for comparison, however if they were plotted the comparison would be:

	Sample Deviation (Fig. 14)	Standard Deviation (Fig. 15)
Point 105	.9 to 1.4	1.8 to 2.1
Point 106	2.0	1.6
Point 108	2.5 to 2.9	1.9 to 2.2

Several observations can be made. The point 105 airplane is probably performing with lesser tracking error and airspeed than assumed for the theoretical plot since its sample deviation is less than the calculated standard. The point 106 airplane probably had greater airspeed errors since its sample deviation is greater (larger airspeed perturbations were a problem in flight test). The point 108 airplane evidently had somewhat greater errors in tracking and/or airspeed. All of these observations should be tempered by the knowledge that the samples for each of these airplanes were small, whereas the statistical base for the equation was large.

The next step in developing this example is translation of the standard deviation relationships into design sink speeds. For simplicity, the case where the airplane follows the glide slope to ground impact was chosen. First the geometric relationship between mean sink speed and glide slope or airspeed was developed. Then the mean sink speeds were expanded to design sink speeds by adding 3 times the standard deviation values from Figure 15. The result is:

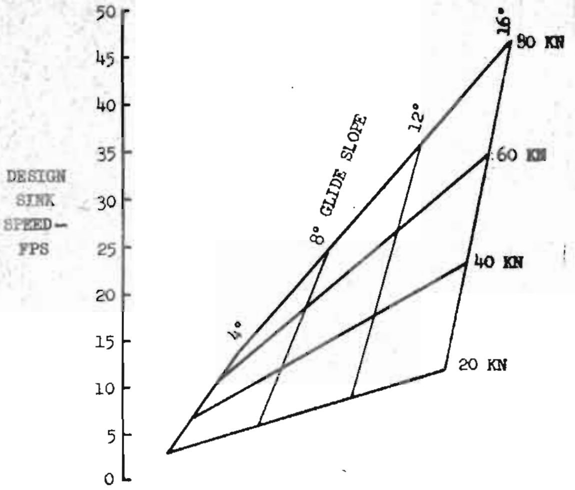


FIGURE 16 DESIGN SINK SPEED

Thus, this figure shows the design sink speed which results from any combination of glide slope and airspeed for the handling qualities criteria chosen for this example: glide slope deviation of 0.5 degrees and airspeed deviation of 7%.

The final step is relating this to the total landing distance when no transition is employed (i.e. Figure 7A). For visual simplicity the data is plotted in the more conventional rectangular coordinate format employed in Figure 1. In this form the result is:

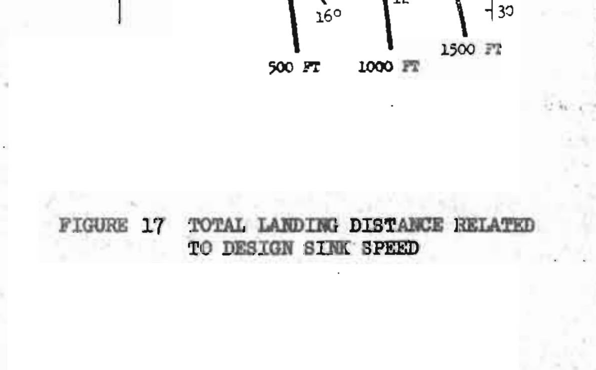


FIGURE 17 TOTAL LANDING DISTANCE RELATED TO DESIGN SINK SPEED

On this plot two vertical velocity scales are provided. The one on the left is the conventional performance rate of descent in feet per minute at any combination of airspeed and glide slope. At any chosen point, the corresponding design sink speed in feet per second can be read from the right hand scale. The criteria used for this example are:

- Total landing distance is that resulting from no transition, one second bounce time, and 0.3g ground deceleration.
- Glide slope tracking deviation is 0.5 degrees.
- Airspeed deviation is 7%.

Summary

Airspeed is the most powerful parameter in landing performance, regardless of descent rates. Therefore, reduction of total landing distance can be achieved most readily by reducing airspeed.

Rate of descent has little effect upon landing performance at very low airspeeds. However, it is effective and worthwhile in the 40 to 80 knot speed range up to values of 600 feet per minute. Greater rates of descent yield such small gains in landing performance that their use would seem to be justified only in cases where steep glide slopes for obstacle clearance had to be obtained in combination with relatively high airspeeds.

Glide slope has a progressively greater effect upon descent rates as the glide slope angle is increased. At the steeper angles, an incremental increase causes a large increase in rate of descent, but has little effect upon landing distance. The steeper glide slope angles also cause a rapid increase in the standard deviation of vertical impact velocity, resulting in large increases in design sink speed for the landing gear.

Transition, or the absence thereof, has little effect upon landing performance at the lesser rates of descent, regardless of airspeed. Elimination of transition does become effective when both airspeed and rate of descent are high.

Reverse thrust is effective at the higher approach airspeeds regardless of rate of descent.

Design sink speed criteria for STOL airplanes is virtually non-existent. It can be derived by statistical evaluation of the landing time histories of conventional aircraft or it can be derived by methods which recognize the superior handling qualities which the STOL airplane should have by virtue of its direct left control. The value of persuing further development of

the handling qualities approach can best be illustrated by a direct comparison of design sink speeds. In the following figure, the upper line is the summary curve from the statistical method (Figure 13). The lower line was derived from the handling qualities example which was summarized in Figure 16.

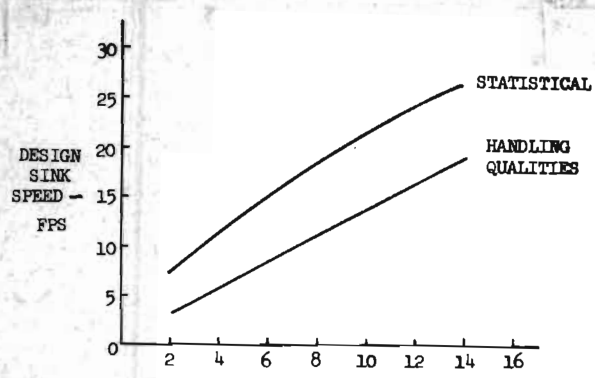


FIGURE 18 COMPARISON OF METHODS

Concluding Remarks

This commentary was prepared with several objectives in mind:

- To graphically illustrate the manner in which the various landing performance parameters interact with each other to affect total landing distance.
- To examine the nature of STOL landing impact criteria derived from statistical analysis of historical data obtained with conventional aircraft.
- To introduce the viewpoint that landing impact criteria for STOL airplanes should be developed by methods which recognize the effects of handling qualities upon landing impact conditions and to encourage development of methods for accomplishing this.