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TECHNICAL NOTE

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AN INVESTIGATION OF LANDING-CONTACT CONDITIONS FOR TWO LARGE TURBOJET TRANSPORTS AND A TURBOPROP TRANSPORT DURING ROUTINE DAYLIGHT OPERATIONS

By Joseph W. Stickle

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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SUMMARY

The National Aeronautics and Space Administration has recently completed a statistical investigation of landing-contact conditions for two large turbojet transports and a turboprop transport landing on a dry runway during routine daylight operations at the Los Angeles International Airport. Measurements were made to obtain vertical velocity, airspeed, rolling velocity, bank angle, and distance from the runway threshold, just prior to ground contact.

The vertical velocities at touchdown for one of the turbojet airplanes measured in this investigation were essentially the same as those measured on the same type of airplane during a similar investigation (see NASA Technical Note D-527) conducted approximately 8 months earlier. Thus, it appeared that 8 months of additional pilot experience has had no noticeable tendency toward lowering the vertical velocities of this transport. Distributions of vertical velocities for the turbojet transports covered in this investigation were similar and considerably higher than those for the turboprop transport. The data for the turboprop transport were in good agreement with the data for the piston-engine transports (see NACA Report 1214 and NASA Technical Note D-147) for all the measured parameters. For the turbojet transports, 1 landing in 100 would be expected to equal or exceed a vertical velocity of approximately 4.2 ft/sec; whereas, for the turboprop transport, 1 landing in 100 would be expected to equal or exceed 3.2 ft/sec. The mean airspeeds at touchdown for the three transports ranged from 22.5 percent to 26.6 percent above the stalling speed. Rolling velocities for the turbojet transports were considerably higher than those for the turboprop transport. Distributions of bank angles at contact for the three transports were similar. For each type of airplane, 1 landing in 100 would be expected to equal or exceed a bank angle at touchdown of approximately 3.0°. Distributions of touchdown distances for the three transports were also quite similar. Touchdown distances from the threshold for 1 landing in 100 ranged from 2,500 feet for the turboprop transport to 2,800 feet for one of the turbojet transports.

INTRODUCTION

For several years the NASA has conducted statistical studies of landing-contact conditions for various types of both military and commercial airplanes. These studies have proven useful primarily in assessing landing-loads requirements and in the design of new runways. In September 1959 an investigation was conducted on the landing-contact conditions of the first turbojet transport to be introduced into commercial service on U.S. routes (ref. 1). The results of that investigation showed that the vertical velocities at touchdown were significantly higher for the turbojet transport airplane than for piston-engine airplanes (refs. 2 and 3). The major factor contributing to these higher vertical velocities was assumed to be the design characteristics of the aircraft itself, although it was also thought that the lack of pilot experience in handling the new turbojet transport might also have been a substantial contributing factor.

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In order to determine the effect that pilot experience might have had on the vertical velocities, a second investigation was undertaken in the spring of 1960, approximately 8 months after the first investigation. In addition to measurements on the type of turbojet transport studied in the initial investigation, measurements of landing-contact conditions were made on another type of four-engine turbojet transport which had since entered into commercial service, and on a four-engine turboprop transport. This report presents the results of a total of 395 landings of these three types of airplanes. Landings were made on a dry runway during daylight operations at the Los Angeles International Airport between April 29 and May 19, 1960. Statistical data are presented on measurements of vertical velocity, airspeed, rolling velocity, bank angle, and distance from the runway threshold, just prior to touchdown.

APPARATUS AND METHOD

Landing contact data were obtained photographically by the method described in reference 4. The equipment was set up at the Los Angeles International Airport approximately 1,100 feet from runway 25R at a spot where a clear view could be obtained of the most probable area of runway contact for the transports. A diagram indicating the locations of the camera sites for both the present investigation and that of reference 1 is shown in figure 1. This runway extends 10,000 feet in an east-northeast, west-southwest direction, and all landings photographed were made during daylight hours in the westerly direction.

Photographs were obtained of 182 landings of the same type of turbojet transport reported in reference 1 (hereinafter referred to as turbojet A), 112 landings of the newer turbojet transport (turbojet B), and 101 landings of the turboprop transport. The general characteristics of these airplanes are listed in table I. The data were reduced according to methods described in references 2 and 4 to obtain values at touchdown of vertical velocity, airspeed, rolling velocity, bank angle, and distance from the runway threshold. (Location of the threshold is shown in fig. 1.) The airspeed values used in this investigation are true airspeeds as determined from the airplane ground speed and wind velocity. Wind velocities used in determining airspeeds, normally taken from hourly sequence reports at the airport weather bureau, were also measured prior to each landing with a wind measuring instrument located at the camera site to determine whether wind variations during the hour would affect the statistical results.

The gross weights for most of the landings were obtained through the cooperation of the various airlines operating the transports. The range of landing weights obtained for each type of airplane is presented with the general characteristics in table I. This weight information was used to obtain the stalling speeds from the operation manuals of the three types of airplanes for the purpose of determining the percentage by which the landing speed exceeded the stall speed at landing contact.

RESULTS AND DISCUSSION

Results from this investigation are presented in the form of distributions which indicate the probability of equaling or exceeding a given value of a measured parameter. In order to provide a systematic fairing of the data and to provide a mathematical basis for extrapolation, Pearson Type III curves (described in ref. 5) were fitted to the distributions. Values of the statistical parameters (mean, standard deviation, and coefficient of skewness) are given in table II. The maximum and minimum measured values for each contact condition are also listed.

All landings observed in this investigation were for the nongusty-wind condition. It was found in reference 2 that the gusty-wind condition had a substantial effect in increasing the magnitude of several of the landing-contact conditions. Therefore, whenever a comparison is made in which the results from reference 2 are utilized, data for the nongusty-wind condition are compared.

Vertical Velocity

Shown in figure 2 is a comparison of probability distributions of vertical velocities at touchdown for turbojet A as determined from the data obtained in this investigation (May 1960) and from the data obtained in September 1959 (ref. 1). The comparison indicates that no essential difference exists in distributions for the periods covered by the investigations. Thus it appears that the 8 months of additional pilot experience in the operation of turbojet A had no noticeable effect toward reducing the vertical velocities at touchdown. The probability distributions of vertical velocities for the three turbine-powered transports observed in this investigation and for a range of values representing piston-engine airplanes observed in the investigations of references 2 and 3 are presented in figure 3. The distributions for turbojets A and B are similar and indicate, for example, that 1 landing in 100 would be expected to equal or exceed a vertical velocity at touchdown of approximately 4.2 ft/sec. The vertical velocities for both turbojet transports are considerably higher than those for the turboprop transport for which the vertical velocities are in good agreement with those for the piston-engine transports. For the turboprop transport 1 landing in 100 would be expected to equal or exceed a vertical velocity at touchdown of approximately 3.2 ft/sec.

Airspeed

Two probability distributions of airspeeds at touchdown obtained for turbojet A are shown in figure 4. The upper curve obtained from reference 1 is approximately 5 knots higher than the curve obtained from this investigation. Although the reasons for the lower landing airspeeds encountered in this investigation are not known, possible influencing factors are as follows:

(a) Increased pilot experience

(b) Raising of the glide slope angle from 2.75° to 3.0° at the Los Angeles International Airport

(c) Possible lower landing gross weights at the time of this investigation

(d) The use of different runways, although adjacent and parallel, for the two investigations

For the three transports covered in this investigation, turbojet A has the highest probability of equaling or exceeding a given airspeed at touchdown with 1 landing in 100 being expected to exceed 146 knots. (See fig. 5.) The curve for turbojet B is approximately 10 knots lower than that for turbojet A with 1 landing in 100 expected to exceed 137 knots at touchdown. The turboprop transport has the lowest probability curve with 1 landing in 100 expected to equal or exceed 123 knots.

In order to present a better comparison of airspeeds at touchdown for the three transports, probability distributions of the percentages by which the landing airspeed exceeded the stalling airspeed were obtained based on landing weight and are presented in figure 6. In this comparison the three transports constitute a relatively narrow band of values throughout the probability spectrum. At probabilities of 1 landing in 100, the expected landing speeds range from 37 percent above the stalling speed for turbojet B to 42 percent for turbojet A. The mean values range from 22.5 percent above the stalling speed for turbojet B to 26.6 percent for turbojet A. This range of values is in good agreement with the mean value of approximately 25 percent above the stalling speed found in reference 2 for piston-engine airplanes.

When the airspeeds determined with the use of the wind velocities taken from sequence reports were compared with the recorded measurements at the ground camera site, no significant differences were found in the statistical results between the two methods.

Rolling Velocity

Probability distributions of rolling velocities are presented in figure 7 as either rolling toward or away from the first wheel to touch. For turbojet A (fig. 7(a)), the probability distributions indicate that approximately 60 percent of the landings were made rolling toward the first wheel to touch, and that 1 landing in 100 might be expected to equal or exceed a rolling velocity of 4.9 deg/sec rolling toward or 4.1 deg/sec rolling away from the first wheel to touch. The distributions for turbojet B (fig. 7(b)) show that the directions of roll were about evenly divided (52 percent toward and 48 percent away) and that 1 landing in 100 would be expected to equal or exceed a rolling velocity of 4.6 deg/sec rolling toward or 3.4 deg/sec rolling away from the first wheel to touch. Probability distributions of rolling velocities for the turboprop transport (fig. 7(c)) indicate that approximately twice as many landings (63 compared with 31) were made rolling toward than away from the first wheel to touch. One landing in 100 might be expected to equal or exceed a rolling velocity of 2.7 deg/sec rolling toward or 2.3 deg/sec rolling away from the first wheel to touch. Rolling velocities for the turboprop transport were in good agreement with those for piston-engine transports.

Bank Angle

The probability distributions of bank angles at contact (fig. 8) for all three transports were in agreement within a band of approximately $\pm 0.2^{\circ}$. The three transports would be expected to equal or exceed an angle of bank at touchdown of approximately 3.0° once in 100 landings. The range of values for piston-engine transports (refs. 2 and 3) at the same probability was from 2.7° to 3.8°.

Touchdown Distance

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A comparison of probability distributions of touchdown distances for turbojet A (fig. 9) between data obtained from reference 1 and data from this investigation shows an apparent reduction in the mean touchdown distance of approximately 300 feet (1,560 feet to 1,300 feet) during the time lapse between the two investigations. This small reduction may possibly be attributed to the fact that airplanes landing on runway 25R used in this investigation have the most probable turnoff point, approximately 1,100 feet nearer the threshold than those landing on runway 25L used in the previous investigation (ref. 1). Comparison in figure 10 of the distributions of touchdown distances for the three transports covered in this investigation shows that all three have approximately the same probability of equaling or exceeding a given touchdown distance from the runway threshold. Touchdown distances from the threshold for 1 landing in 100 range from 2,500 feet for the turboprop transport to 2,800 feet for turbojet A. The range of values for piston-engine airplanes at this same probability was from approximately 2,200 feet to 2,500 feet from the threshold.

CONCLUSIONS

Results of an investigation of landing-contact conditions for two large turbojet transports and one turboprop transport, landing on a dry runway during daylight operations at the Los Angeles International Airport, has led to the following conclusions:

1. The vertical velocities at touchdown for one of the turbojet transports measured in the present investigation were essentially the same as those measured on this same type of airplane during a similar investigation (see NASA Technical Note D-527) which had been carried out 8 months earlier. (These airplanes were designated turbojets A.) Thus, it appeared that 8 months of additional pilot experience has had no noticeable tendency toward lowering the vertical velocities for turbojets A.

2. The distributions of vertical velocities for turbojets A were similar to those obtained for another type of turbojet transport (designated turbojet B) and indicated that 1 landing in 100 would be expected to equal or exceed a vertical velocity at touchdown of approximately 4.2 ft/sec. The vertical velocities for the turboprop transport were considerably lower than those for the two turbojets and indicated that 1 landing in 100 would equal or exceed 3.2 ft/sec. The vertical velocities for the two turbojets were higher than those measured for piston-engine airplanes (see NACA Report 1214 and NASA Technical Note D-147), whereas vertical velocities for the turboprop were in good agreement with those for the piston-engine airplanes.

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3. The mean airspeeds at touchdown for the three transports ranged from 22.5 to 26.6 percent above the stalling speeds. These touchdown speeds were in good agreement with the mean value of approximately 25 percent above stalling speed for piston-engine transports.

4. Rolling velocities, both toward and away from the first wheel to touch, were considerably higher for the two turbojet transports than for the turboprop transport. Values for the turboprop transport were in good agreement with those for piston-engine transports.

5. The distributions of bank angles at contact for the three transports were similar and were in good agreement with results for piston-engine transports. For each airplane, 1 landing in 100 would be expected to equal or exceed a bank angle of approximately 3.0°.

6. Touchdown distances for 1 landing in 100 for the three transports ranged from 2,500 feet from the runway threshold for the turboprop transport to 2,800 feet for turbojet A. This range was in good agreement with that obtained for the piston-engine transports; that is, for the same probability, the touchdown distances ranged from 2,200 feet to 2,500 feet from the threshold.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., April 4, 1961.

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2. Silsby, Norman S.: Statistical Measurements of Contact Conditions of 478 Transport-Airplane Landings During Routine Daytime Operations. NACA Rep. 1214, 1955. (Supersedes NACA TN 3194.)

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4. Rind, Emanuel: A Photographic Method for Determining Vertical Velocities of Aircraft Immediately Prior to Landing. NACA TN 3050, 1954.

5. Peiser, A. M., and Wilkerson, M.: A Method of Analysis of V-G Records From Transport Operations. NACA Rep. 807, 1945. (Supersedes NACA ARR L5J04.)

TABLE I.- GENERAL CHARACTERISTICS FOR THE THREE TEST AIRPLANES

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Turbojet transport A:

Maximum gross take-off weight, lb	245,000
Maximum permissible landing weight, lb	175,000
Empty weight, lb	113,640
Wing area, sq ft	2,433
Wing span, ft	130.8
Stall speed (175,000 lb), knots	105.6
Mean landing weight at Los Angeles International Airport, lb	154,000
Sweepback (25-percent-chord line), deg	35
Range of landing weights, lb	137,000 to 175,000

Turbojet transport B:

Maximum gross take-off weight, lb	265,000
Maximum permissible landing weight, lb	190,500
Wing area, sq ft	2,770.6
Wing span, ft	142.4
Stall speed (200,000 lb), knots	105.0
Mean landing weight at Los Angeles International Airport, lb	170,257
Sweepback (25-percent-chord line), deg	30.0
Range of landing weights, lb	154,000 to 188,000

Turboprop transport:

Maximum gross take-off weight, lb	113,000
Maximum permissible landing weight, lb	95,650
Empty weight, lb	59,600
Wing area, sq ft	1,300
Wing span, ft	99
Stall speed (85,000 lb), knots	88
Mean landing weight at Los Angeles International Airport, lb	83,076
Range of landing weights, lb	70,289 to 93,974

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TABLE II.- VALUES OF STATISTICAL PARAMETERS

FOR LANDING-CONTACT CONDITIONS

Statistical parameter	Turbojet A	Turbojet B	Turboprop transport
Vertical velocity:			
Maximum vertical velocity, ft/sec	5.1	4.6	3.8
Minimum vertical velocity, ft/sec	≈0.0	≈0.0	≈0.0
Mean vertical velocity, ft/sec	1.46	1.45	1.06
Standard deviation, ft/sec	0.923	0.944	0.713
Coefficient of skewness	0.905	1.01	1.05
Airspeed:			
Maximum airspeed, knots	152.9	136.1	121.8
Minimum airspeed, knots	107.7	105.9	92.1
Mean airspeed, knots	126.9	118.5	108
Standard deviation, knots	8.604	7.48	6.605
Coefficient of skewness	0.455	0.471	0.091
Maximum airspeed, percent above stall	43.8	40.8	43.3
Minimum airspeed, percent above stall	13.6	10.5	6.0
Mean airspeed, percent above stall	26.6	22.5	22.6
Standard deviation, percent above stall	6.42	6.15	6.88
Coefficient of skewness	0.019	0.069	0.163
Rolling velocity toward first wheel to touch:			
Maximum rolling velocity, deg/sec	6.5	5.3	3.1
Minimum rolling velocity, deg/sec	≈0.0	≈0.0	≈0.0
Mean rolling velocity, deg/sec	1.76	1.29	1.102
Standard deviation, deg/sec	1.20	1.163	0.747
Coefficient of skewness	0.803	1.645	-0.277
Rolling velocity away from first wheel to touch:			
Maximum rolling velocity, deg/sec	4.9	3.6	2.2
Minimum rolling velocity, deg/sec	≈0.0	≈0.0	≈0.0
Mean rolling velocity, deg/sec	1.47	1.361	0.876
Standard deviation, deg/sec	1.09	0.822	0.683
Coefficient of skewness	0.791	0.73	0.586
Bank angle:			
Maximum bank angle, deg	3.5	3.6	3.6
Minimum bank angle, deg	≈0.0	≈0.0	≈0.0
Mean bank angle, deg	0.822	0.759	0.935
Standard deviation, deg	0.645	0.586	0.703
Coefficient of skewness	1.51	1.793	1.32
Touchdown distance from runway threshold:			
Maximum touchdown distance, ft	3,435	2,614	2,740
Minimum touchdown distance, ft	290.0	100.0	204.0
Mean touchdown distance, ft	1,300.8	1,187.5	1,203.5
Standard deviation, ft	538.8	553.2	523.6
Coefficient of skewness	0.576	0.433	0.286

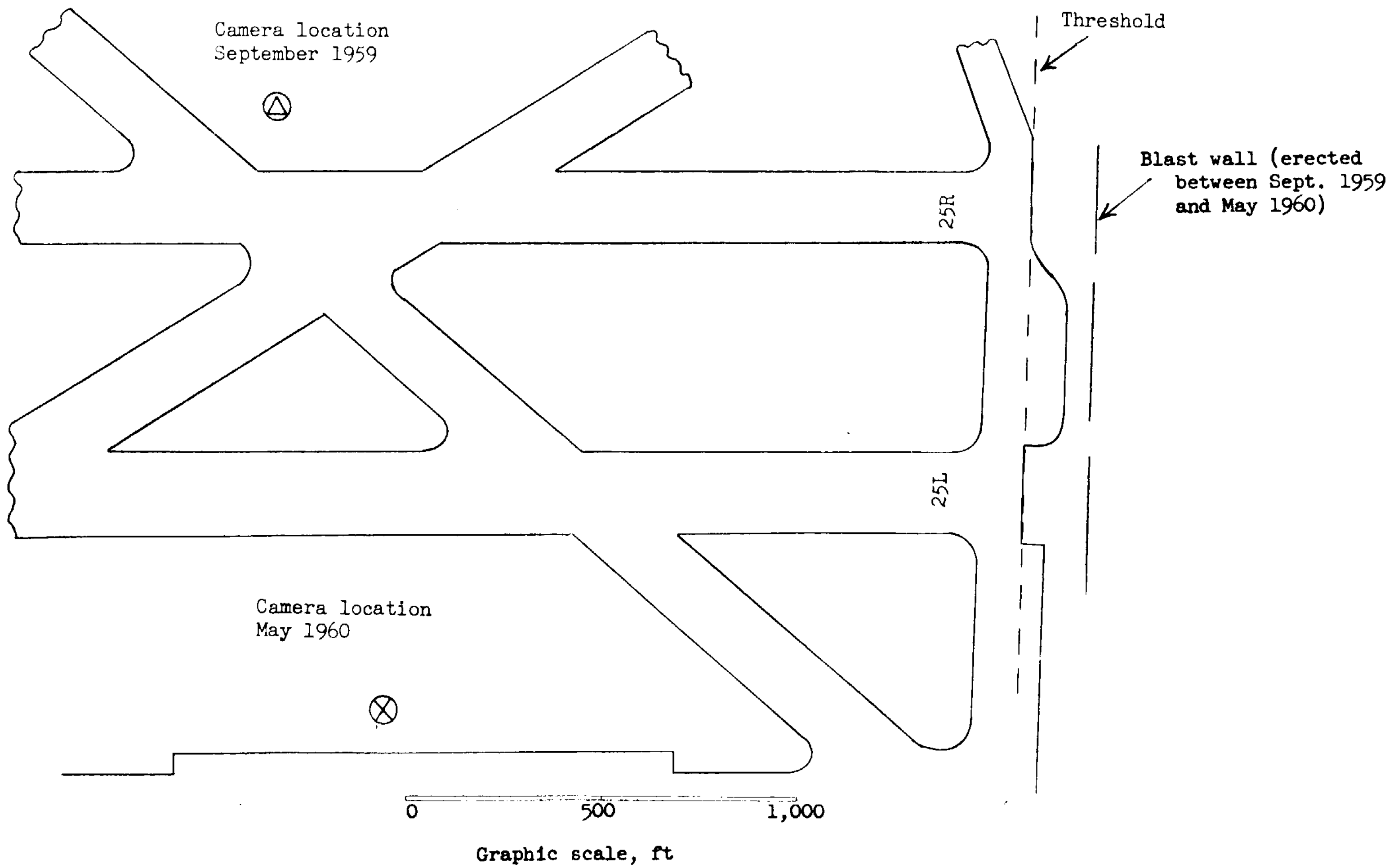

Figure 1.- Diagram showing camera location with respect to runways for present investigation and also that for the investigation of reference 1.

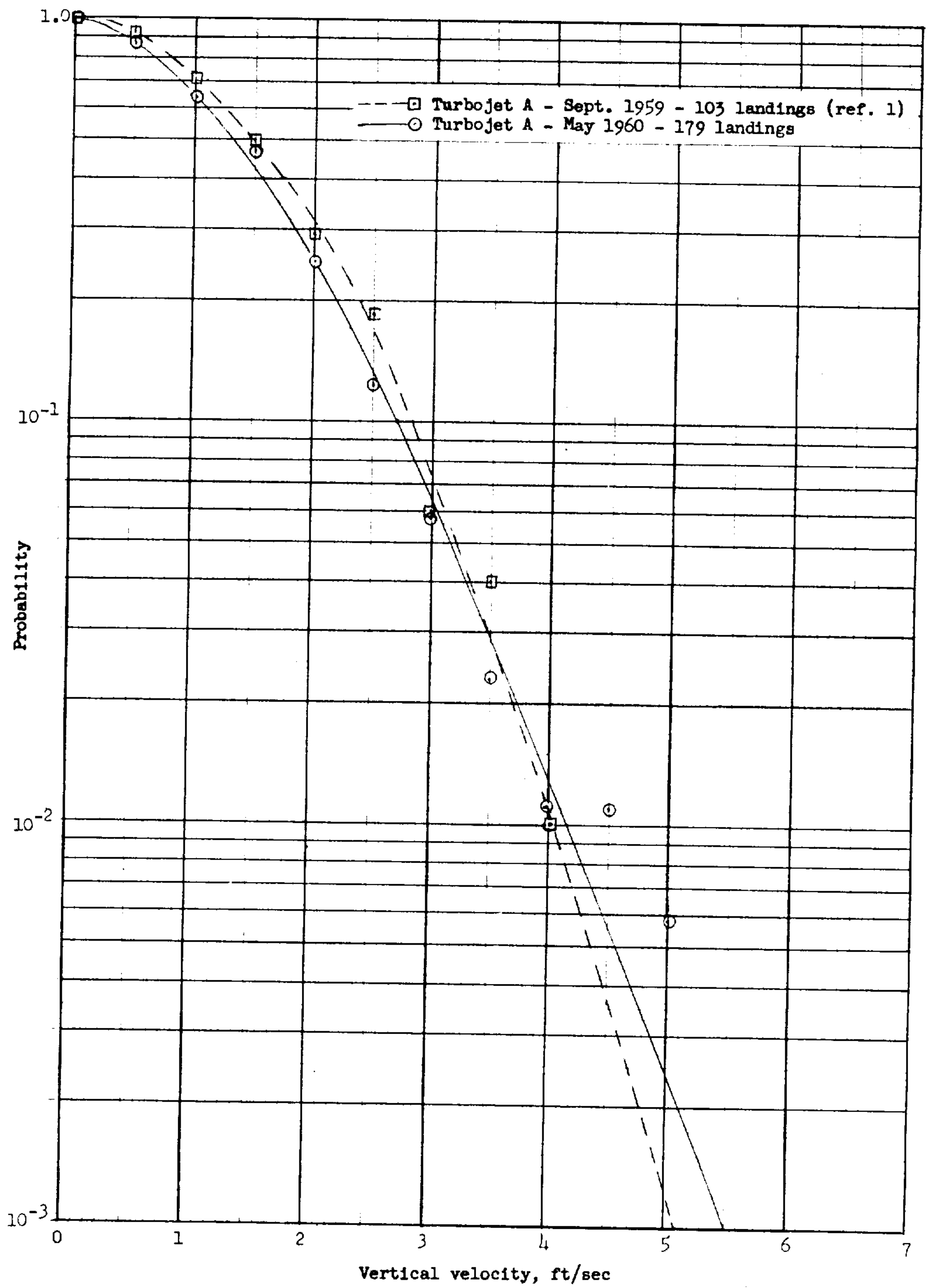

Figure 2.- Comparison of two probability distributions of vertical velocities at touchdown obtained for turbojet A.

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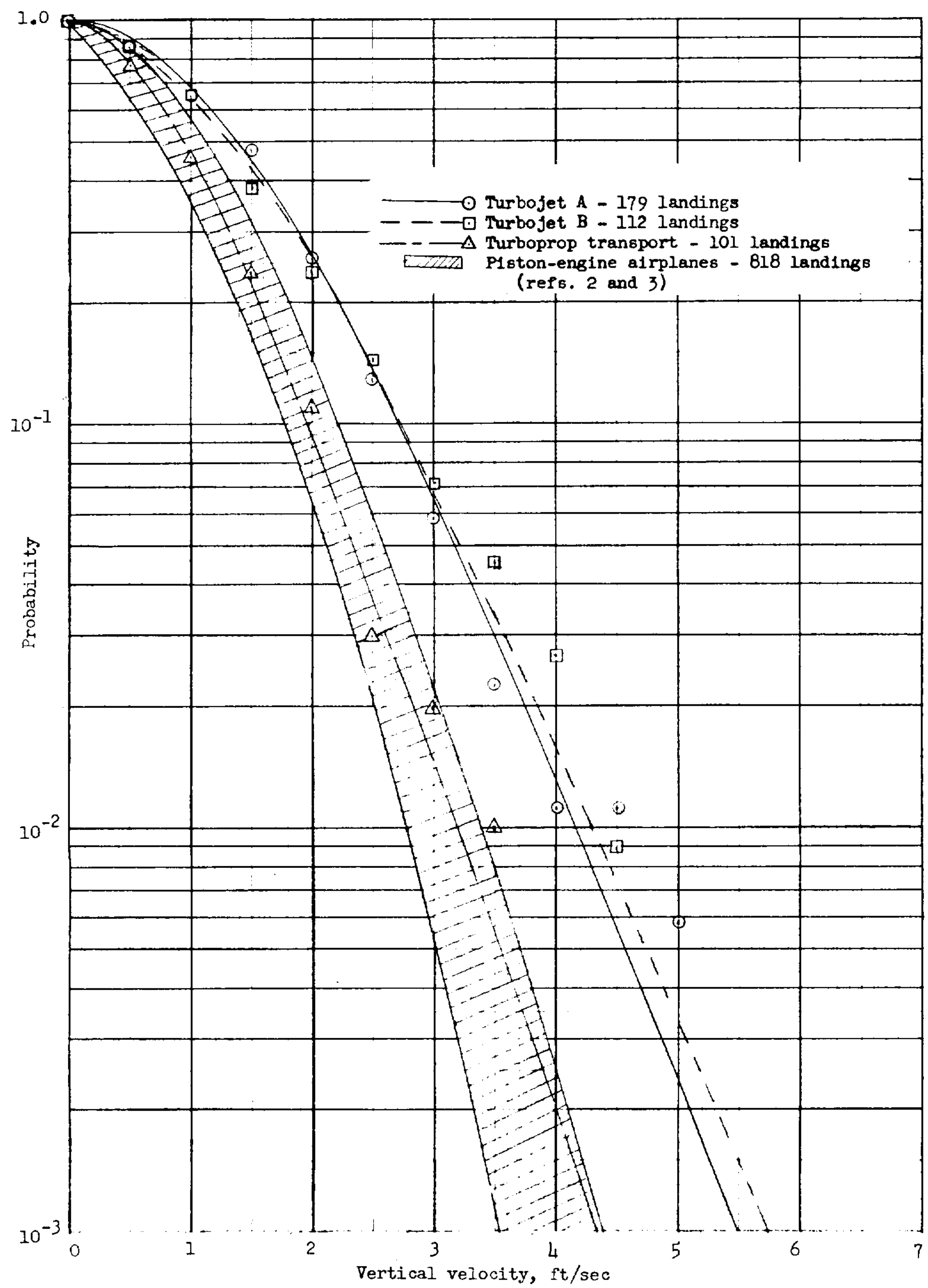

Figure 3.- Comparison of probability distributions of vertical velocities at touchdown for two turbojet transports, a turboprop transport, and a range of values for piston-engine transports.

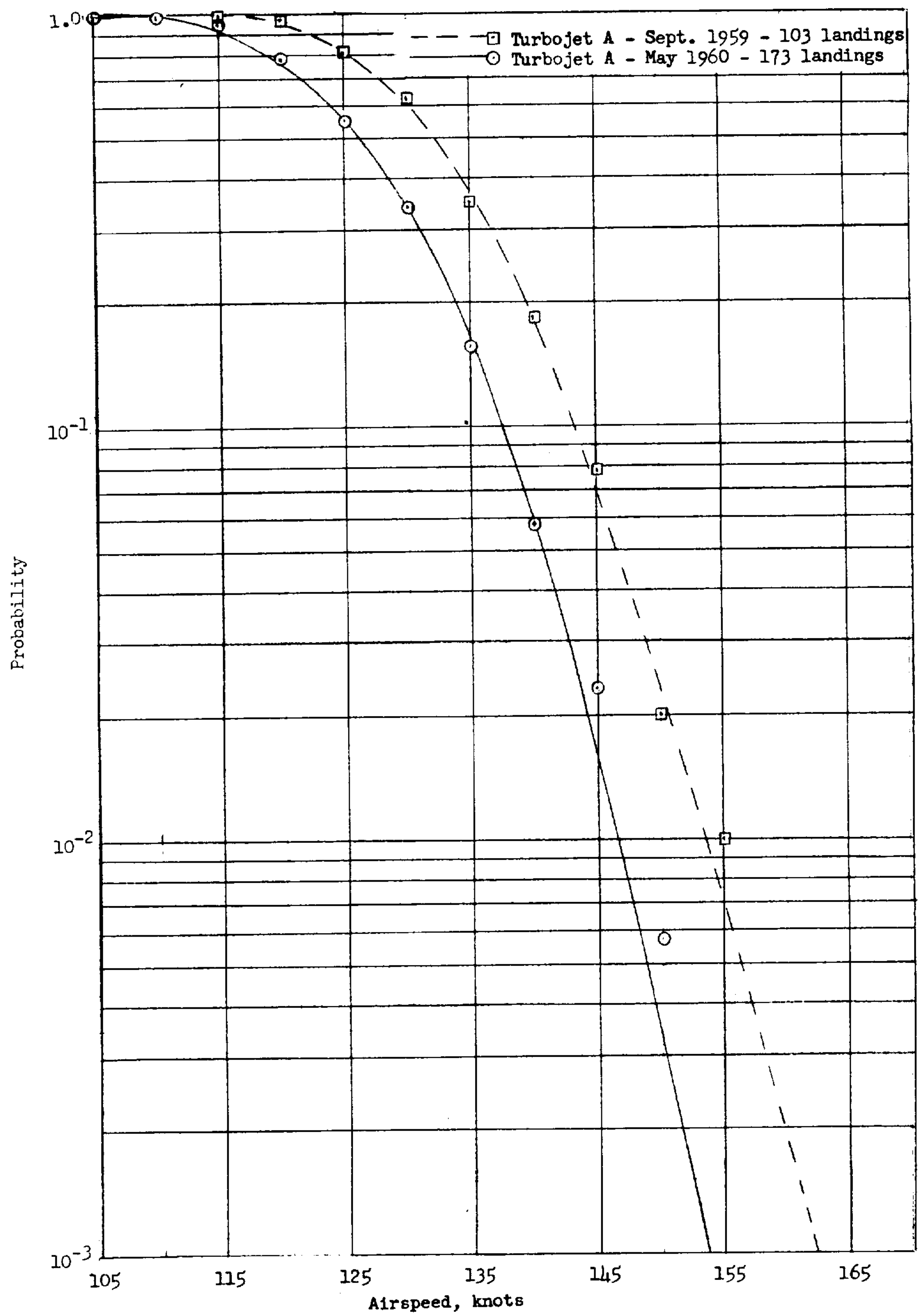

Figure 4.- Comparison of two probability distributions of airspeeds at touchdown obtained for turbojet A.

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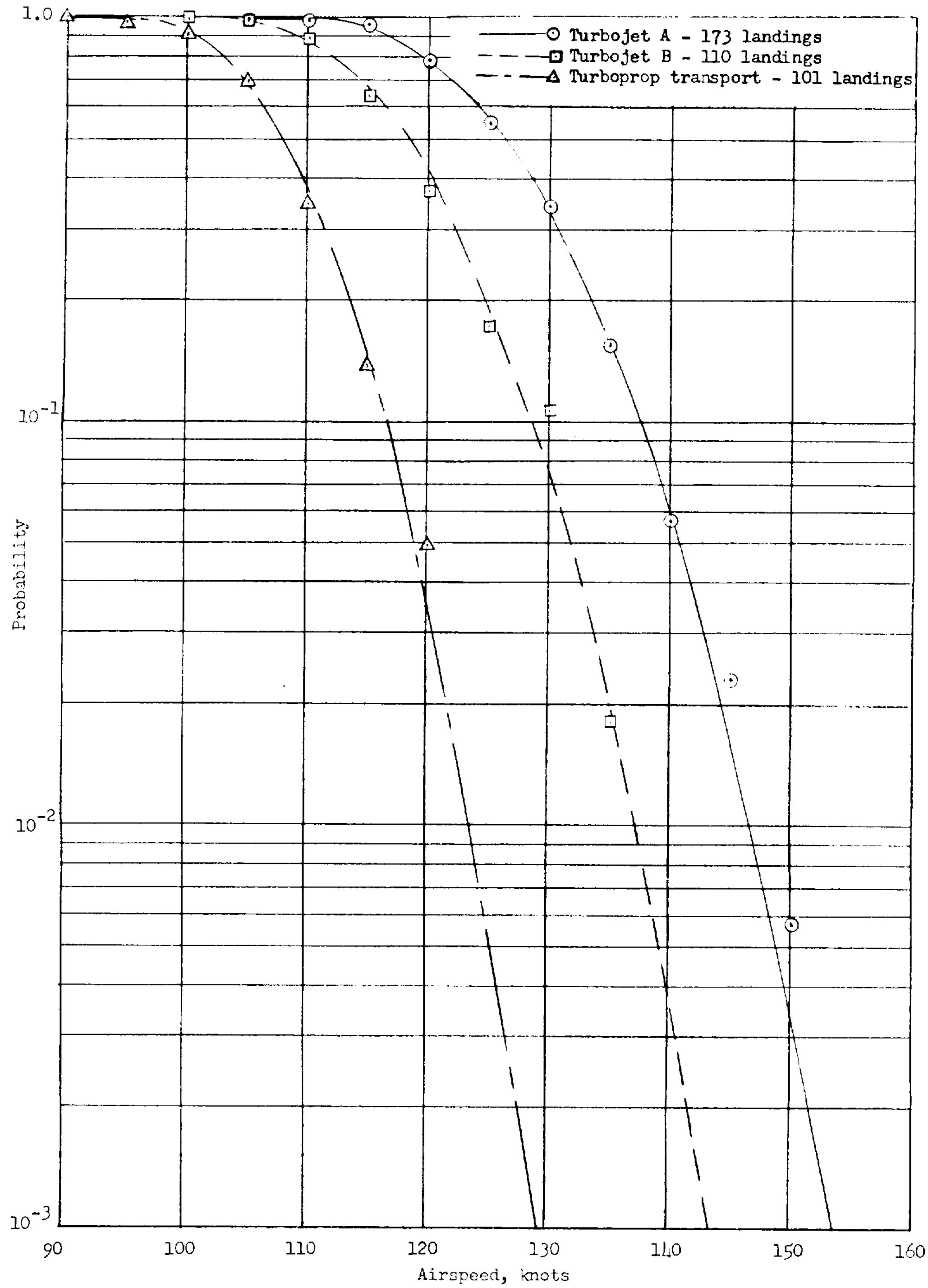

Figure 5.- Comparison of probability distributions of airspeeds at touchdown for two turbojet transports and a turboprop transport.

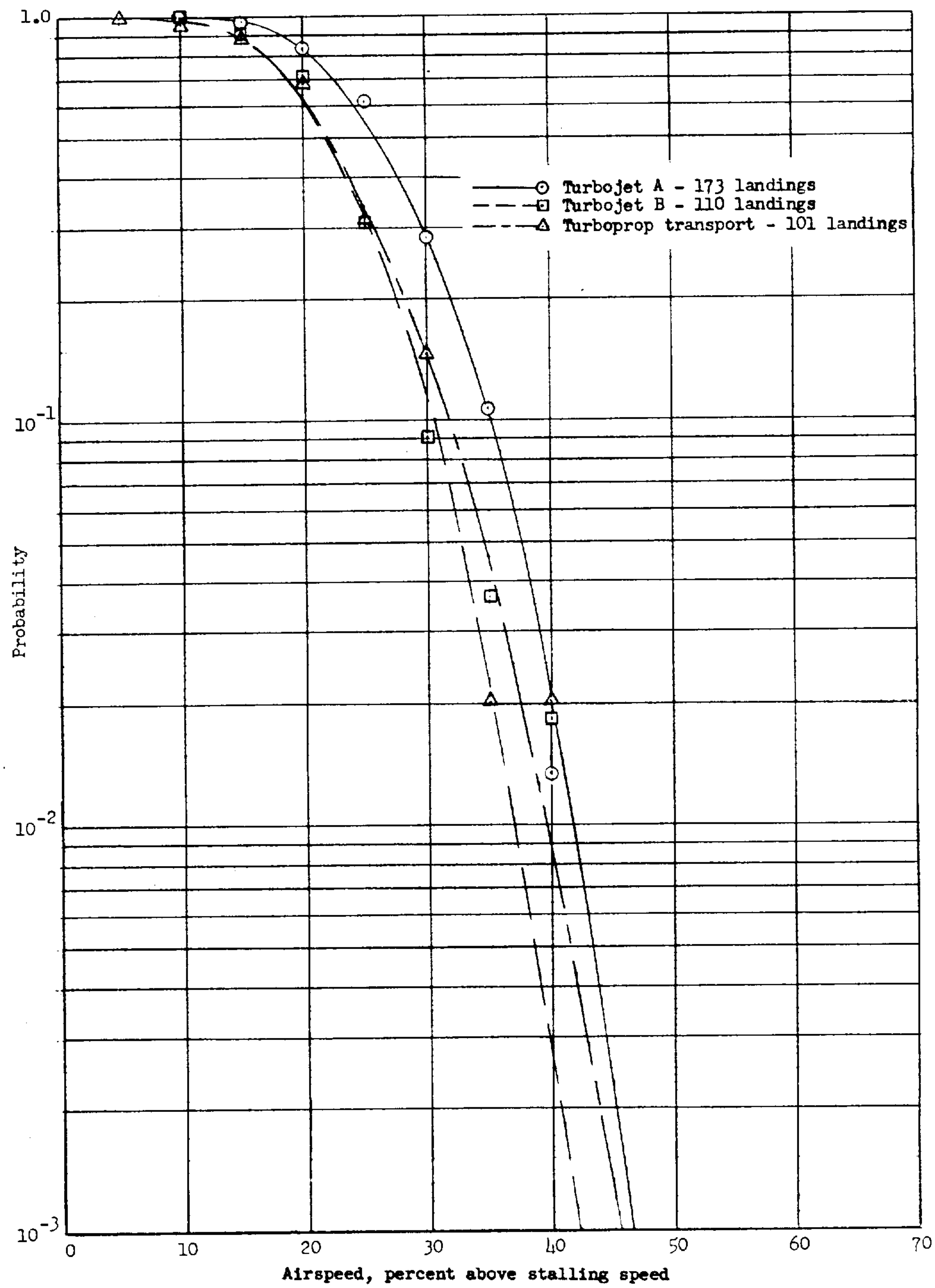

Figure 6.- Comparison of probability distributions of percentages by which the landing speeds exceeded the stalling speeds for two turbojets and a turboprop transport.

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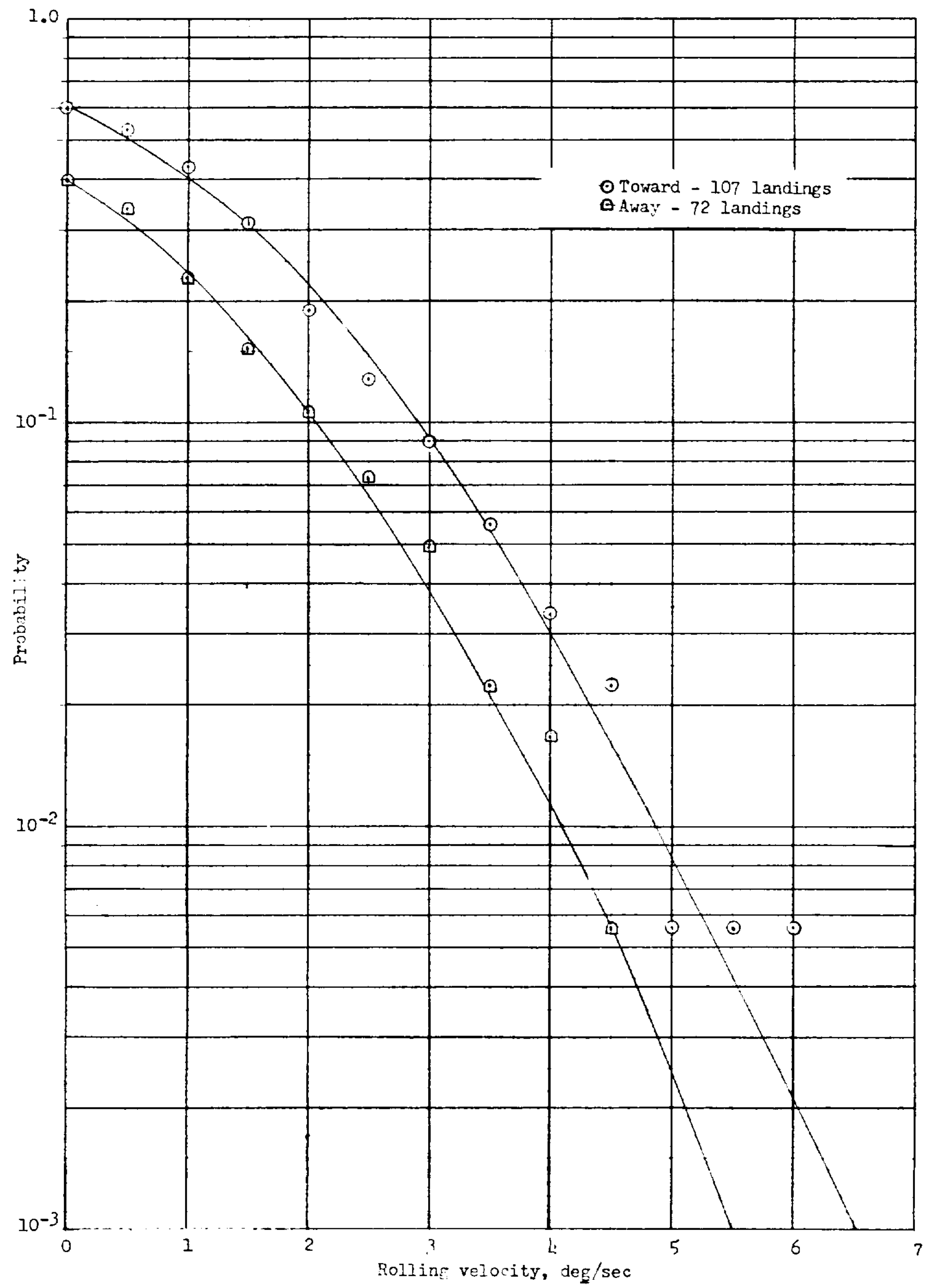
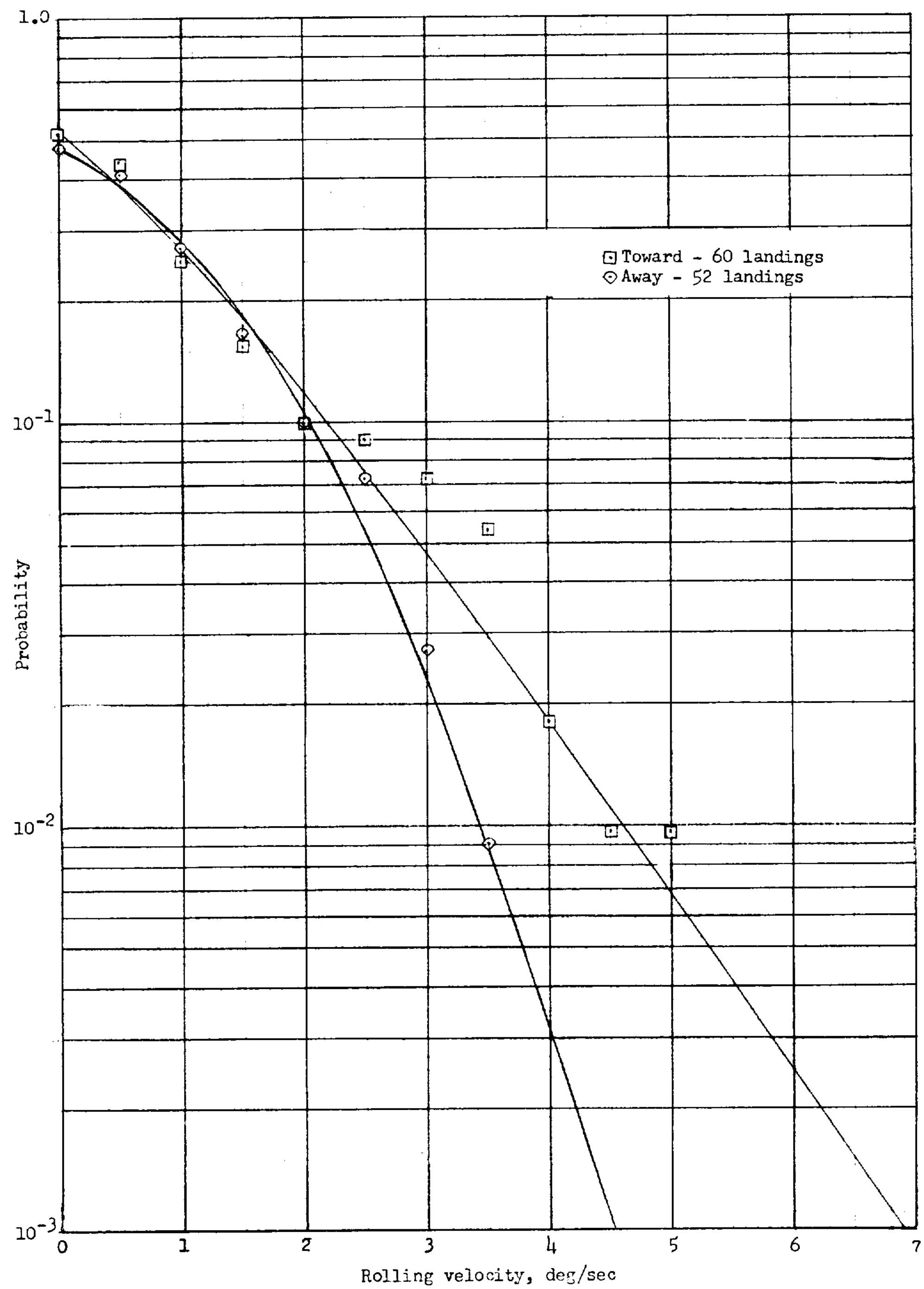


(a) Turbojet A.

Figure 7.- Probability distributions of rolling velocities for rolling both toward the first wheel to touch and away from the first wheel to touch.



(b) Turbojet B.

Figure 7.- Continued.

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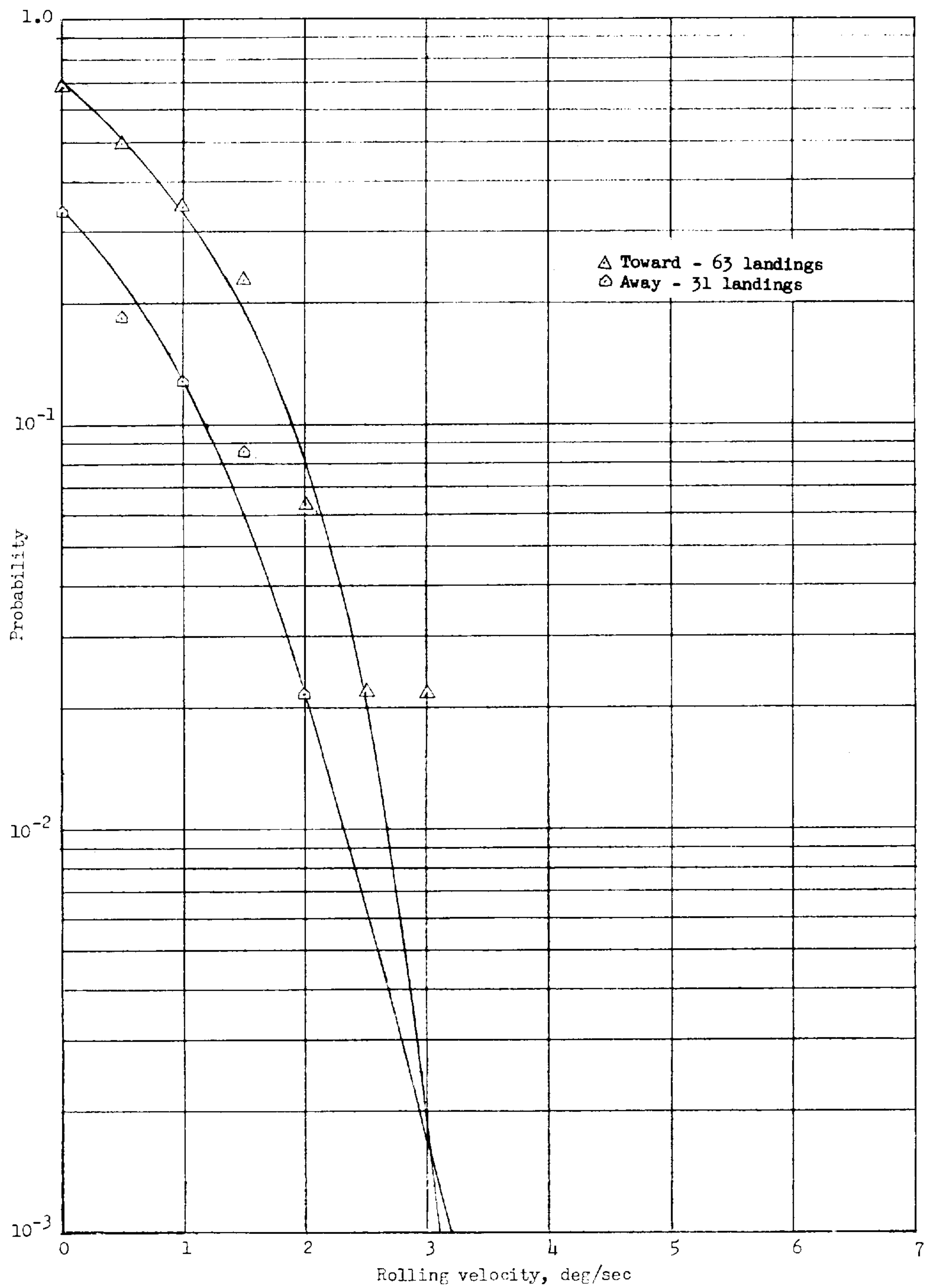

(c) Turboprop transport.

Figure 7.- Concluded.

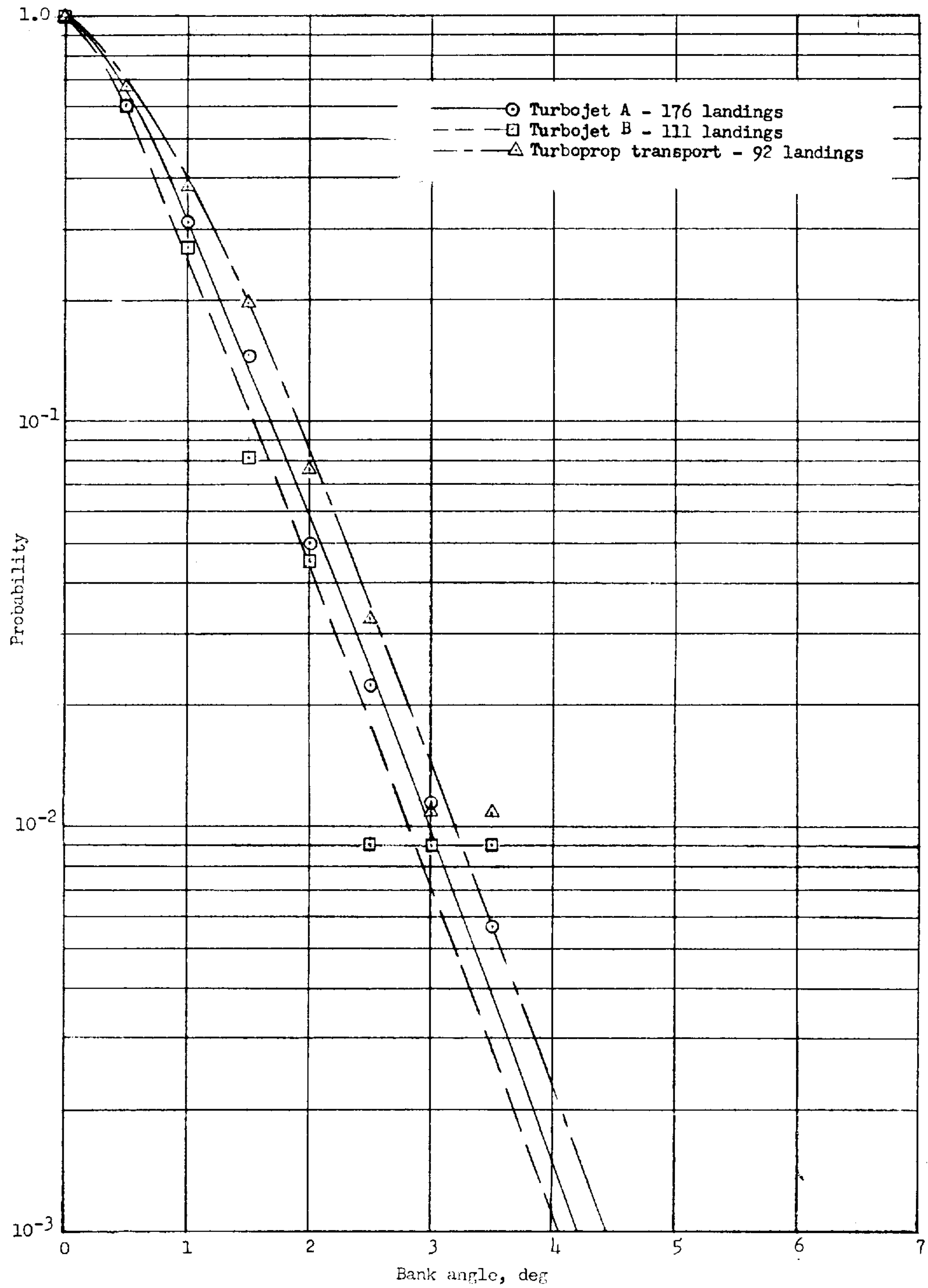

Figure 8.- Comparison of probability distributions of bank angles at touchdown for two turbojet transports and a turboprop transport.

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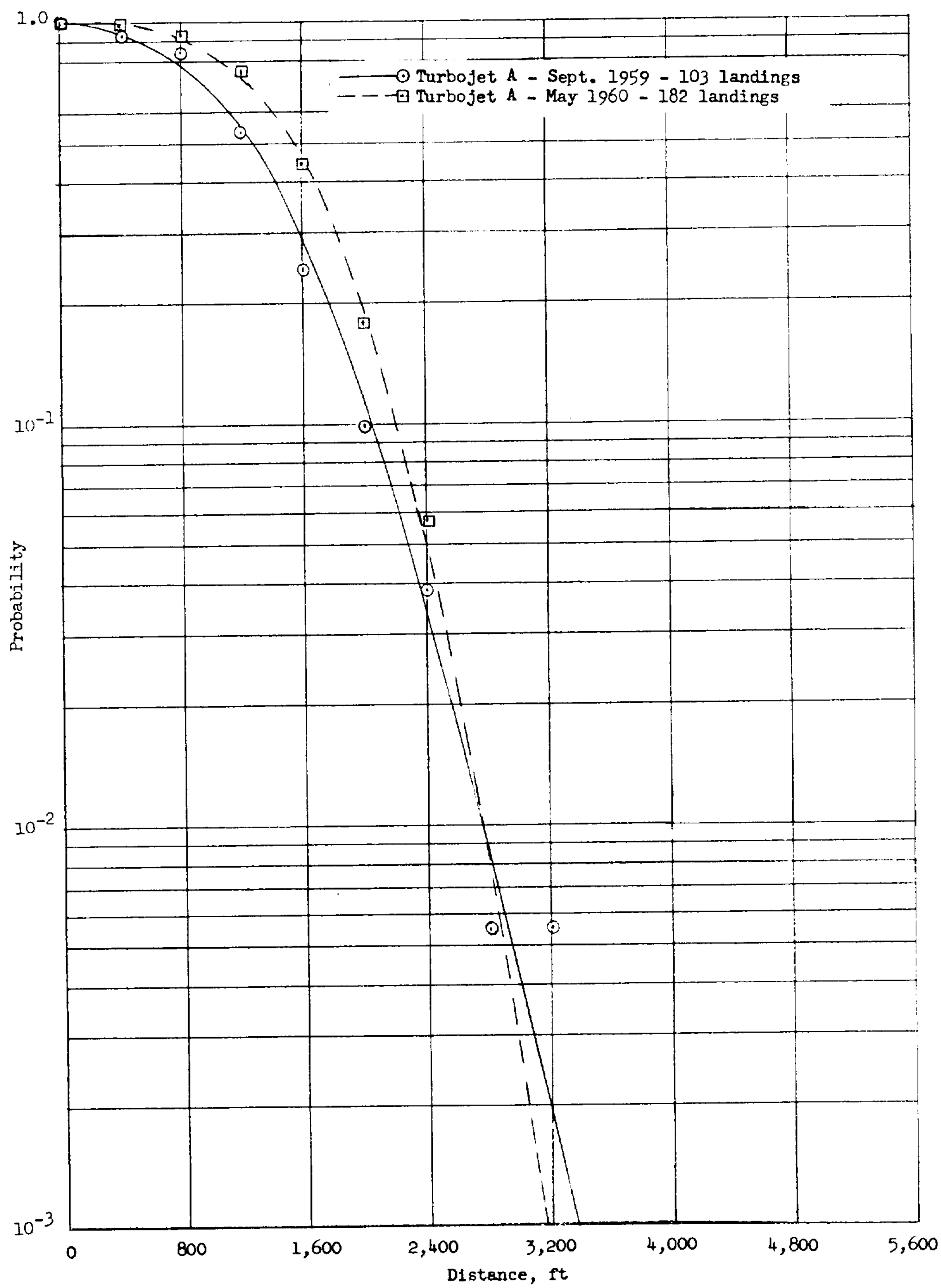

Figure 9.- Comparison of two probability distributions of touchdown distances from the runway threshold obtained for turbojet A.

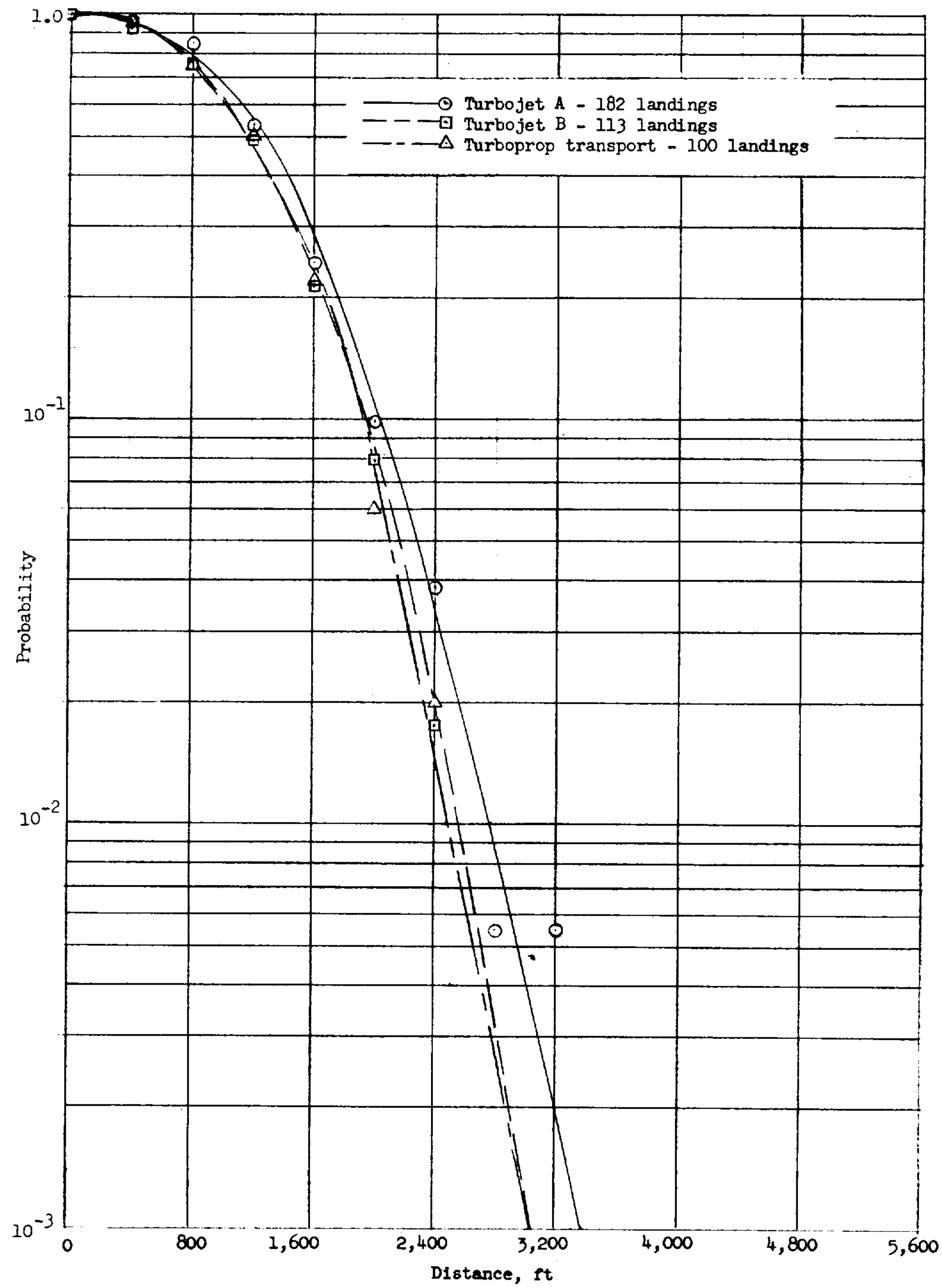

Figure 10.- Comparison of probability distributions of touchdown distances from the runway threshold for two turbojet transports and a turboprop transport.

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(NASA TECHNICAL NOTE D-899)

The report presents statistical results of an investigation to determine the vertical velocity, airspeed, rolling velocity, bank angle, and distance from the runway threshold, just prior to ground contact. A total of 395 landings of two turbojet transports and a turboprop transport were made on a dry runway at the Los Angeles International Airport.

Copies obtainable from NASA, Washington

I. Stickle, Joseph W.
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