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RESEARCH MEMORANDUM

AN ANALYSIS OF AIRSPEEDS ATTAINED BY A DOUGLAS DC-4 AIRPLANE IN COMMERCIAL OPERATIONS DURING THE EARLY MONTHS OF 1947

By Roy Steiner

Langley Aeronautical Laboratory
Langley Air Force Base, Va.

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SUMMARY

Airspeed and altitude data for nonscheduled cargo operations obtained from a Douglas DC-4 airplane flying between Seattle, Washington and Alaska during February and March of 1947 have been analyzed to determine the probability of reaching or exceeding given values of airspeed and Mach number. The analysis indicated that, for data obtained during these flights, the total probability of exceeding a placard never-exceed speed of 266 miles per hour depends principally on the probability of exceeding this speed in descent. An extrapolation of the probability curve indicates that, on the average, this selected placard speed may be exceeded on the order of once in every 100 hours of descent or on the order of once in every 1000 hours of flight time.

INTRODUCTION

Concern has been expressed in the past about the possibility of inadvertently attaining excessive airspeeds and Mach numbers on large aerodynamically clean transport airplanes. Accordingly, data have been collected on one type of airplane and the results published in references 1 to 3, inclusive.

Subsequent to the publishing of the reference reports, time histories of airspeed and altitude have become available on a Douglas DC-4 airplane in commercial nonscheduled cargo operations on the Seattle-Anchorage-Fairbanks route. These data have been analyzed statistically to determine the probability of reaching or exceeding given values of airspeed and Mach number during different flight conditions.

APPARATUS AND TEST CONDITIONS

A cargo-type DC-4 airplane was used in the present investigation. The characteristics of the airplane as flown are:

Gross weight at take-off, pounds	73,000
Wing area, square feet	1,460
Wing loading at take-off, pounds per square foot	50
Span, feet	117.5
Mean aerodynamic chord, feet	13.6
Maximum indicated airspeed in level flight, miles per hour . . .	222.0
Placard never-exceed speed, miles per hour	266.0

The DC-4 airplane is placarded at 250 to 300 miles per hour for V_{ne} with the maximum permissible values within this range depending upon the weight conditions of the airplane at a given time. It might be noted that the placarded never-exceed speeds are, by CAA requirement, approximately 90 percent of those speeds to which the airplane is actually flight tested for certification. Since the probability of equaling or exceeding V_{ne} is taken, herein, as a measure of the possibility of an airplane to inadvertently attain excessive airspeeds, it is desirable to determine a more exact value for V_{ne}. Past experience with this type of analysis has indicated that the descent is the critical flight condition. A placard never-exceed speed of 266 miles per hour was obtained from the operations manual of the DC-4 airplane and is based on the approximate weight condition of the airplane at the time of landing. This value of airspeed should therefore be the approximate value of the placard never-exceed speed during the most critical conditions. The weight condition used was an airplane weight of 62,000 pounds which includes 4000 pounds of wing fuel weight. The maximum permissible speed in level flight would be 222 miles per hour under this weight condition.

The instruments installed in the airplane, which were used in the determination of airspeed and Mach number, were:

(1) NACA airspeed-altitude recorder

(2) NACA synchronous timer (1-min interval)

The pitot-static lines of the airspeed-altitude recorder were connected to the corresponding lines on the copilot's instrument panel and the film speed was adjusted to 1.3 inches per minute.

A total of 57.6 hours of records were available for analysis. The flights were nonscheduled cargo operations during February and March 1947 and were made both day and night at altitudes of 9,000 to 10,000 feet although flight was occasionally conducted at altitudes up to 14,000 feet to avoid icing. The route flown was Seattle—Anchorage—Fairbanks and return. (See fig. 1.)

The general information on the weather conditions supplied by an observer on the flights indicated that about 40 percent of the flight time was on instruments in stratus-type clouds. Icing conditions were frequently encountered, especially in the vicinity of fronts which extended across the route.

EVALUATION OF DATA AND RESULTS

For convenience in the statistical analysis, each flight was divided into three parts – climb, level flight, and descent. For each condition, the maximum airspeed and Mach number were determined during each 6 minutes of flight. All values of airspeed are the computed equivalent airspeed without a correction for installation error. The maximum Mach number in each interval was obtained by selecting, within each interval, airspeed-altitude combinations which would lead to the larger values of Mach number and then selecting the largest Mach number computed from these combinations. The frequency distributions of maximum airspeed and maximum Mach number for each of the three flight conditions are shown in tables I and II, respectively. The data for one descent were omitted since the observer's notes showed that the landing gear was down and flaps were used. These data would, therefore, belong to a different distribution than the data obtained when landing gear and flaps were not used.

Standard statistical methods were employed to fit Pearson type III probability curves (reference 4), on the assumption that they were a reasonable representation of the data, to each of the frequency distributions in tables I and II. Within appropriate limits, these probability curves, which are given in figures 2 and 3, give the probability that the airspeed or Mach number in any 6-minute interval of climb, level flight, or descent will attain or exceed a given value.

For ease in interpreting the results, probability curves have been referred to a time scale in the following manner. If P is the probability that a given value of airspeed or Mach number will be exceeded, on the average, once in a 6-minute interval, then that value will be exceeded, on the average, once in each $1/P$ interval, or once in each $1/10P$ hours of flight. Using this conversion factor, the average number of hours of flight to exceed given values of airspeed and Mach number have been determined and the results are shown in figures 4 and 5, respectively.

PRECISION

The major errors in the values of airspeed and Mach number may be attributed to the inaccuracy in reading the records, the installation error, and the instrument error. The values of airspeed used were the values of computed equivalent airspeed without a correction for the installation error and it is estimated that the combined errors in the values of airspeed and Mach number presented will not exceed ±2 percent.

Past experience with this type of data has, in general, indicated that extrapolated estimates of the frequency of exceeding given values can be considered reliable within a magnitude, that is, once in 10, 100, 1000, . . . hours, provided that the extrapolation is not excessive. In the case of the descent curve, the extrapolation of the curve over an airspeed range of 10 to 20 miles per hour and two cycles on the probability scale is not felt to be an excessive extrapolation. The value of the miles to exceed a never-exceed speed of 266 miles per hour is felt, therefore, to be reliable within the magnitude quoted. For the climb and level-flight data, the extrapolation required to reach a placard speed of 266 miles per hour is considerably greater, covering some 50-mile range of airspeed and 4 to 6 cycles on the probability scale. For these two flight conditions, the reliability of the estimated frequency of exceeding placard speed would of necessity be low.

DISCUSSION

An examination of figure 2 and past analyses (references 1 to 3) indicates that the descent condition is the only flight condition of concern in investigating the probability of airplanes reaching or exceeding the placard never-exceed speed. An extrapolation of the probability curve for the descent condition indicates that the probability of exceeding a selected never-exceed speed of 266 miles per hour in a 6-minute interval in descent is 1.8×10^{-3}. The transformed descent probability curve in figure 4 indicates that this is equivalent to stating that the never-exceed speed apparently will be exceeded once in 55 hours of descent. Since the descent time was approximately 7 percent of the total flight time an estimation of the total flight time to exceed a never-exceed speed of 266 miles per hour may be determined by dividing 55 hours by the percent of the time spent in descent. In this manner, the total flight time to exceed a never-exceed speed of 266 miles per hour is found to be some 860 hours, on the average, or of the order of 1000 hours.

As previously mentioned, the placard never-exceed speed of 266 miles per hour was selected from a permissible range of 250 and 300 miles per hour where the exact placard speed depends upon the weight condition at a given time. There remains the possibility, therefore, that the pilot may have been flying the airplane with a placard never-exceed speed greater than 266 miles per hour. It has been noted, through contacts with the airlines, that although the airplane may be flown with a variable speed when the appropriate weights and chart are used, the airlines have a tendency to placard the airplane at or near the lower airspeed. The flight observer noted, for the flights analyzed, that the V_L for the airplane was approximately 220 miles per hour. The corresponding placard never-exceed would be 266 miles per hour. It appears that although there is a possibility that the pilot regarded a higher airspeed as the placard speed, it is more likely that an airspeed of 266 miles per hour is more nearly the one used in these flights.

It may be noted in figure 2 that none of the experimental points on the descent curve actually exceeded the selected never-exceed speed. The question of the validity of extrapolation of the data to or beyond the never-exceed speed therefore naturally arises. Of course, a probability analysis such as has been made here provides a mathematical basis for such extrapolation, but the extrapolation will be valid only if the laws governing the data combine to follow the mathematical function throughout the range of extrapolation. In the present instance there may be some possibility that the laws governing the data will change beyond the present limits of the data because of the never-exceed speed placard, which warns the pilot to take appropriate action to avoid high speeds. However, it seems reasonable to suppose that speed increments above those values required for reasonable operation under ideal conditions are the result of inadvertencies or unusual operational demands. The existence of such inadvertencies under practical flying conditions removes complete control of the airspeed from the will of the pilot, and it follows, therefore, that the data for descent will follow a substantially continuous function even through the placard speed. It is reasonable, therefore, to accept at face value the extrapolated values of probability for descent through the placard speed to some unknown point beyond that speed. Accordingly, it is reasonable to say that the data show that, on the average, the placard speed may or will be reached or exceeded a given number of times, or that this speed may or will be reached or exceeded once in a given number of hours of flying.

A comparison of the results of the data contained herein and the results given in references 1 to 3 shows a similarity between the curves and the values of the probability or the flight hours to exceed a never-exceed speed. This comparison is made on the assumption that a placard never-exceed speed of 266 miles per hour for the DC-4 airplane is approximately the correct placard speed for the descent condition. Since the data in references 1 to 3 were obtained on Lockheed Constellation airplanes and these data on a Douglas DC-4 airplane, it appears that the speed tendencies are relatively independent of an airplane type and may be due to the high performance qualities of modern transport airplanes. The Constellation airplanes were flown on scheduled passenger flights while the DC-4 was flown on nonscheduled cargo flights. It might be expected that the nonscheduled cargo operations would be less conservative than the scheduled flights but this may be counterbalanced by the absence of the need for maintaining fixed schedules and restricted flight plans.

A value for the critical Mach number was not known. The curves pertaining to the Mach numbers are, therefore, given as general information.

CONCLUDING REMARKS

The analysis of airspeed and altitude data obtained at 9,000 to 10,000 feet altitude on a Douglas DC-4 airplane operated between Seattle, Washington and Alaska during February and March of 1947 has indicated that the probability of reaching or exceeding a never-exceed speed in descent is apparently the only condition of importance. An extrapolation of the probability curve indicates that a selected never-exceed speed of 266 miles per hour will probably be exceeded, on the average, once in the order of 100 hours of descent or once in the order of 1000 hours of total flying time. These results are similar in magnitude to the results obtained on a Lockheed Constellation airplane.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCES

1. Steiner, Roy, and Peiser, A. M.: An Analysis of Airspeeds and Mach Numbers Attained by Lockheed Constellation Airplanes in Trans-Atlantic Operation during the Spring of 1946. NACA MR L6G09a, 1946.

2. Steiner, Roy: An Analysis of Airspeeds and Mach Numbers Attained by Lockheed Constellation Airplanes in Transcontinental Operations during the Early Summer of 1946. NACA RM L7C06, 1947.

3. Steiner, Roy: Supplementary Data on Airspeeds and Mach Numbers Attained by Lockheed Constellation Airplanes in Transcontinental Operations. NACA RM L7F25, 1947.

4. Peiser, A. M., and Wilkerson, M.: A Method of Analysis of V-G Records from Transport Operations. NACA Rep. 807, 1945.

TABLE I

FREQUENCY DISTRIBUTIONS OF MAXIMUM AIRSPEEDS FOR VARIOUS FLIGHT CONDITIONS

Equivalent airspeed (mph)	Frequency		
	Climb	Level flight	Descent
150 - 155	1	2	
155 - 160	3	1	
160 - 165	8		
165 - 170	1	1	
170 - 175	1	2	1
175 - 180	4	12	1
180 - 185	1	22	
185 - 190	5	44	2
190 - 195	1	102	2
195 - 200	4	122	
200 - 205	1	83	5
205 - 210		73	4
210 - 215	1	31	5
215 - 220		9	3
220 - 225		5	3
225 - 230			1
230 - 235		2	5
235 - 240			1
240 - 245			1
245 - 250			
250 - 255			2
255 - 260			
Totals	31	511	36

TABLE II

FREQUENCY DISTRIBUTIONS OF MAXIMUM MACH NUMBERS FOR VARIOUS FLIGHT CONDITIONS

Mach number	Frequency		
	Climb	Level flight	Descent
0.20 - 0.21			
.21 - .22	1		
.22 - .23	4		
.23 - .24	5		
.24 - .25	4		
.25 - .26	3	2	1
.26 - .27			3
.27 - .28	2	3	1
.28 - .29	2	9	1
.29 - .30	3	17	3
.30 - .31	2	70	2
.31 - .32	2	113	4
.32 - .33	2	109	8
.33 - .34	1	107	5
.34 - .35		58	3
.35 - .36		14	3
.36 - .37		8	
.37 - .38		1	1
.38 - .39			1
.39 - .40			
.40 - .41			
Totals	31	511	36

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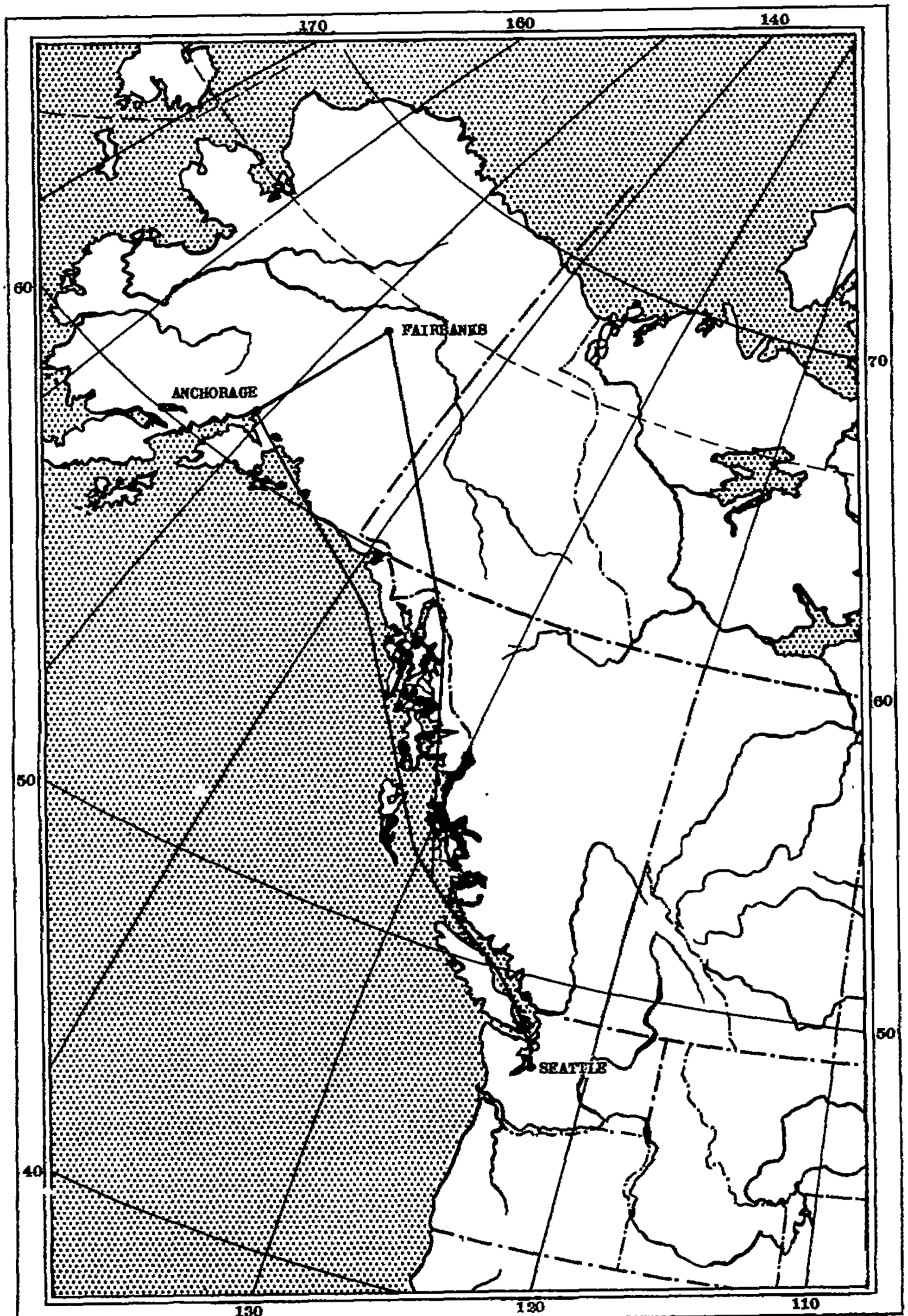

Figure 1.— Route of operations.

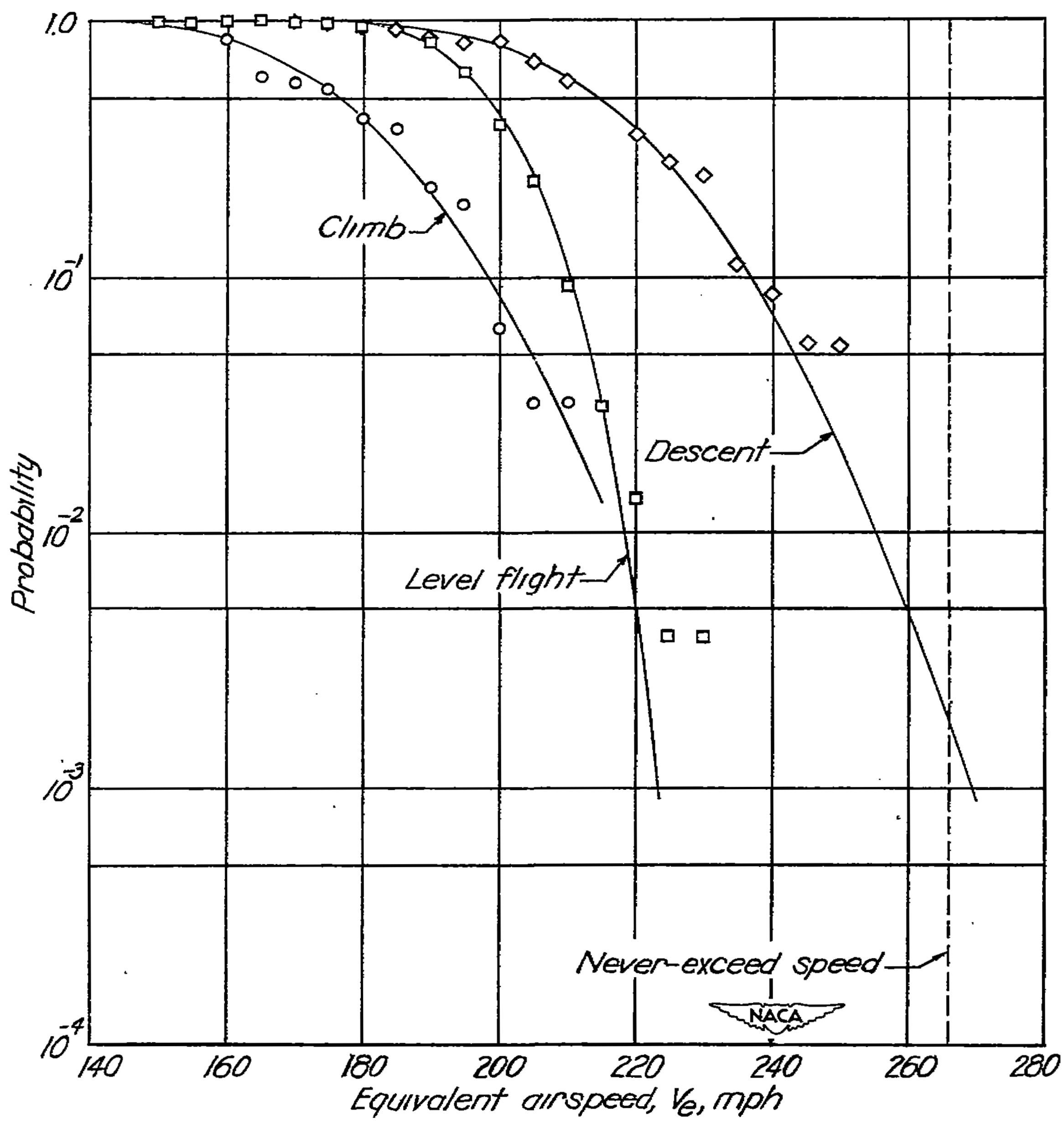

Figure 2.— Probability of exceeding a given value of airspeed.

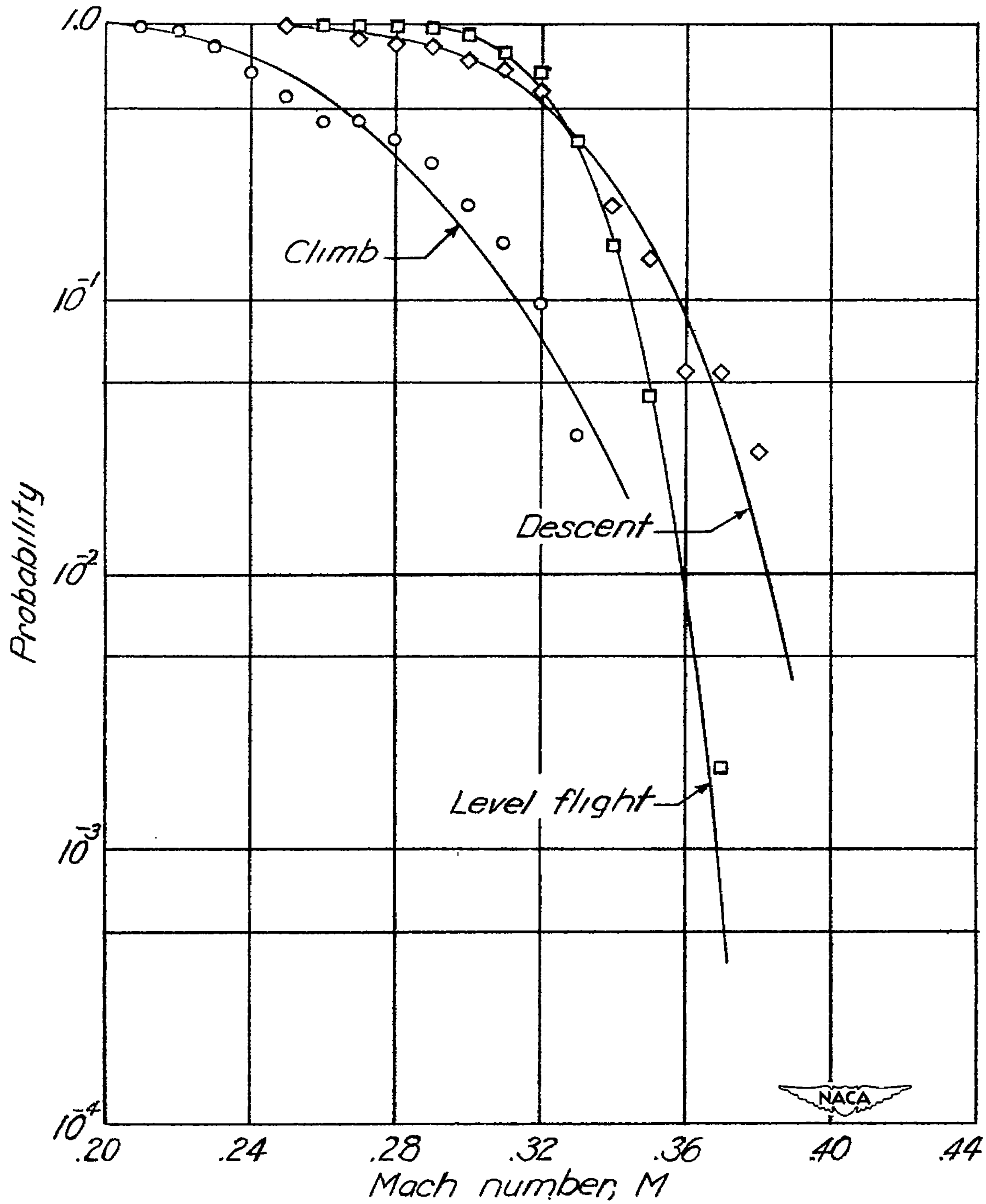

Figure 3.— Probability of exceeding a given value of Mach number.

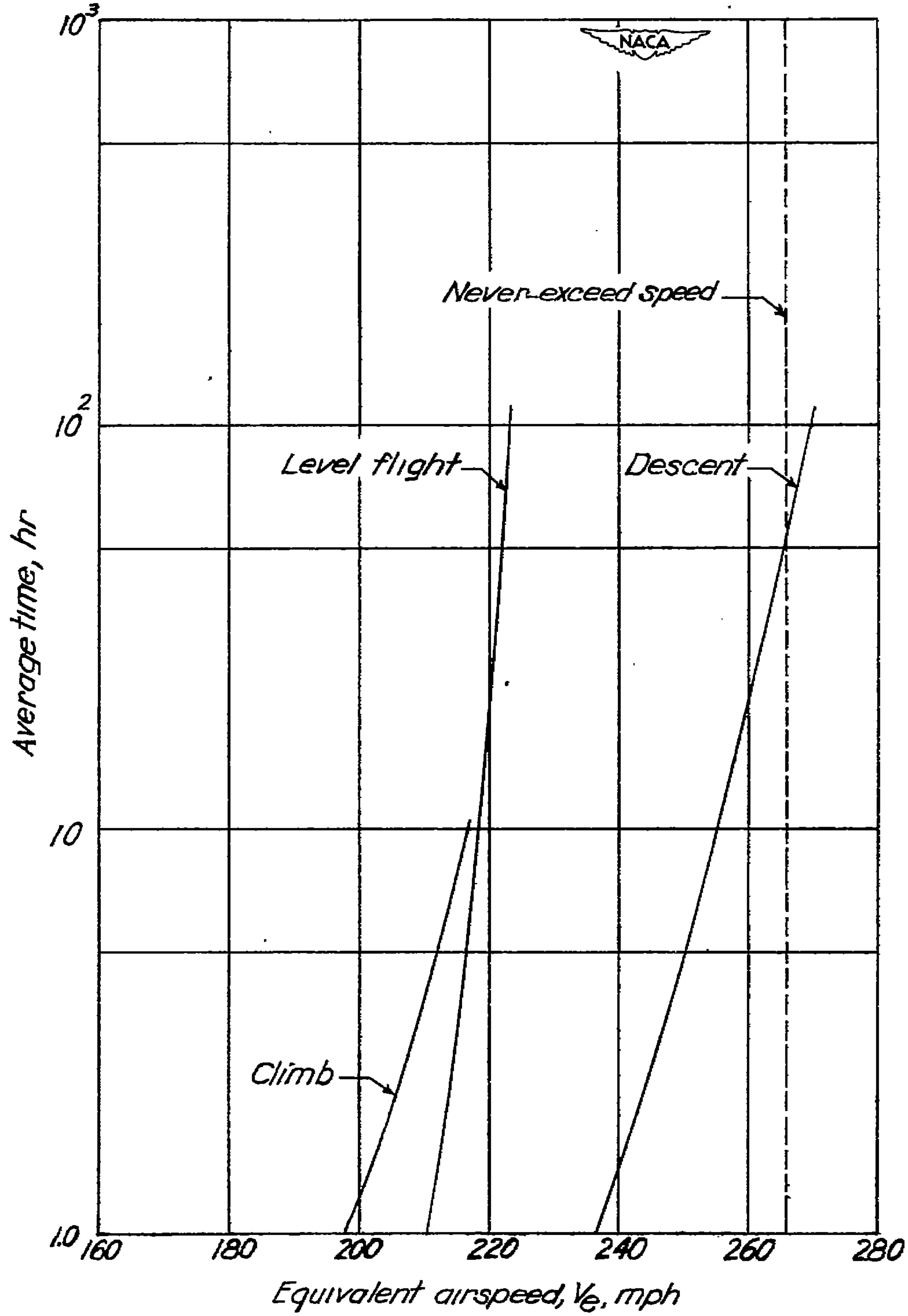

Figure 4.— Average time required to exceed a given value of airspeed.

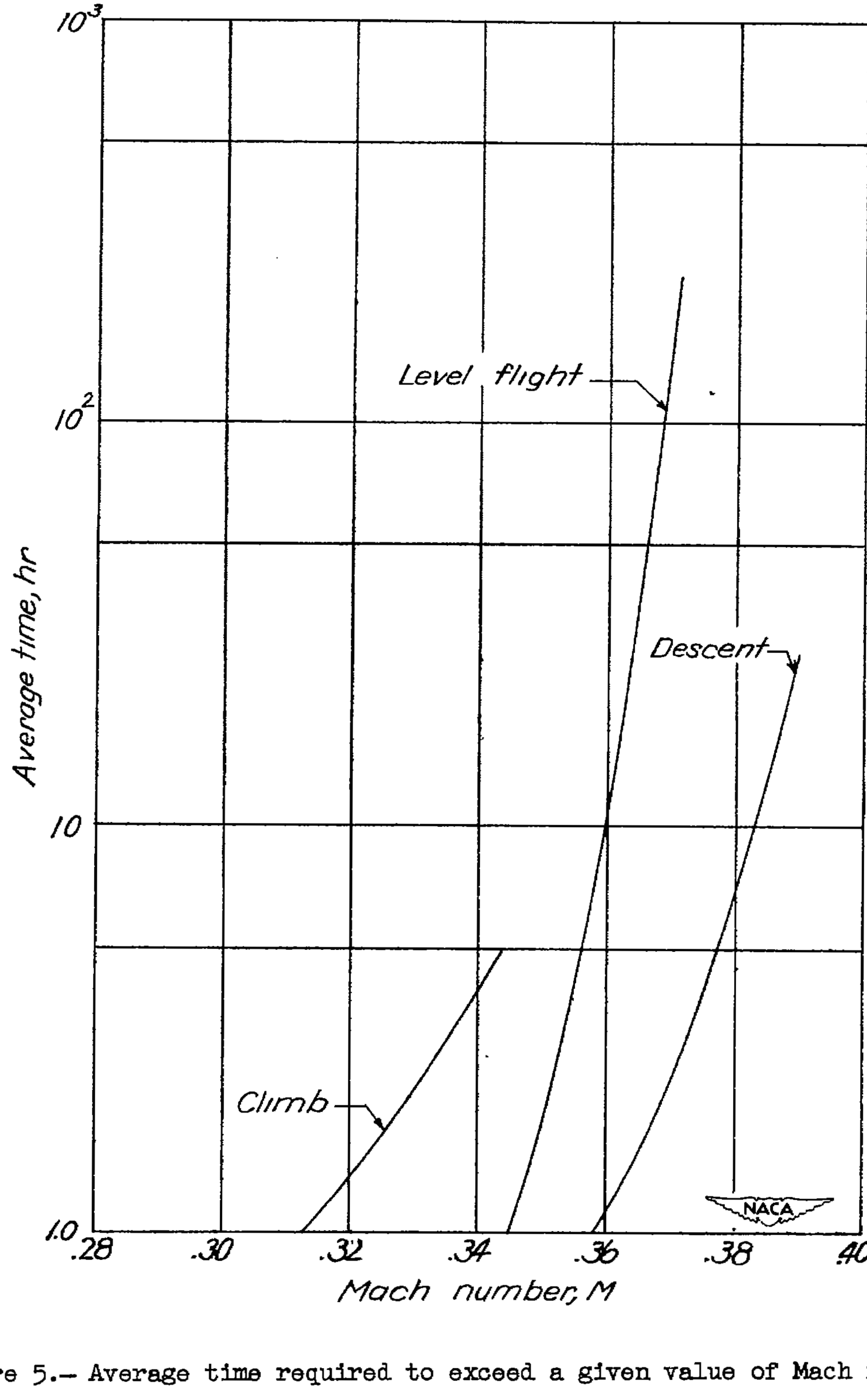

Figure 5.— Average time required to exceed a given value of Mach number.