Y3.N21/5:6/1477

GOVT. DOC.

NACA TN No. 1477

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1477

GENERALIZED PERFORMANCE COMPARISON OF LARGE CONVENTIONAL, TAIL-BOOM, AND TAILLESS AIRPLANES

By Herman O. Ankenbruck and Marion O. McKinney, Jr.

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington

October 1947

~~GOVT. STATE LIBRARY~~

BUSINESS, SCIENCE
& TECHNOLOGY DEP'T.

NOV 3 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 1477

GENERALIZED PERFORMANCE COMPARISON OF LARGE CONVENTIONAL, TAIL-BOOM, AND TAILLESS AIRPLANES

By Herman O. Ankenbruck and Marion O. McKinney, Jr.

SUMMARY

An analytical investigation has been made to determine the relative performance of large tailless and conventional airplanes. Inasmuch as there has been a great deal of interest in tail-boom-type airplanes having only a wing, booms, and tails, this type of airplane has also been included in the performance comparison.

In the analysis certain assumptions were made regarding weight, drag, and stability which have not been wholly confirmed. The findings must therefore be considered as tentative pending confirmation by additional research. The principal conclusion drawn from this analysis was that large all-wing tailless airplanes may have better performance characteristics than their equivalent conventional airplane or tail-boom airplanes for certain types of missions.

INTRODUCTION

In recent years much interest has been shown in all-wing tailless airplanes because it has been believed that this type might have considerably better performance than conventional airplanes having a normal fuselage and tails. Some research has been conducted on the problem of providing satisfactory stability and control for tailless airplanes. The results of this research as summarized in reference 1 have indicated that the flying qualities of tailless airplanes might be made satisfactory. Before continuing the studies of the flying qualities of tailless airplanes, however, it appeared to be desirable to determine whether this type of airplane offers any real advantage in performance over the conventional type. A generalized performance comparison of tailless and conventional airplanes has been made, therefore, in an effort to determine the relative performance of these two types of airplanes. This analysis considered only performance and did not include special considerations such as reduction of troubles due to compressibility at high speeds or facility of loading the airplanes.

It was realized that tailless airplanes could not be expected to show an appreciable advantage over the conventional-type airplane unless the tailless airplane was large enough to carry all its load within the wing and thus eliminate the whole fuselage. A direct comparison of the all-wing tailless-type airplane with the conventional-type airplane, however, is generally difficult because in order for the tailless airplane to have the same landing speed as that of a conventional airplane a lower wing loading is required. This difference in wing loading of the two types, caused by the absence of the tail as an efficient means of trimming the airplane at high lift coefficients, immediately suggested the tail-boom type of airplane. This type might have the same wing loading as the conventional airplane, tail booms that are smaller and lighter than a fuselage, and slightly smaller tail surfaces than the conventional airplane. The tail-boom airplane, like the tailless airplane, however, should be large enough to carry all its load within the wing if any performance gain is to be expected.

The results of an analysis, which was made to establish a generalized comparison between conventional, tail-boom, and tailless airplanes and would aid in determining the desirability of further research on the tail-boom and tailless types, are presented herein. The results show the performance possibilities of the three types and supply information that will aid a designer in selecting the configurations that will give the optimum performance characteristics.

In the present investigation, calculations were made for the three types of airplanes (conventional, tail boom, and tailless), illustrative sketches of which are shown as figure 1. These sketches do not necessarily show the airplanes for which the calculations were made but merely illustrate the general characteristics of the three types of airplanes as they might be designed according to the assumptions made in the present paper. The performance characteristics considered were top speed, range, rate of climb, take-off distance, and service ceiling. An analysis was also made of the space available for passengers, cargo, and bombs.

The results of the calculations are presented as plots of the performance characteristics on identical coordinates of power loading and wing loading; thus, the optimum performance to meet a given set of requirements is very simple to choose.

Performance comparisons of the three types of airplanes were made on several bases - equal power loading and wing loading, equal landing speed, equal take-off distance, and a requirement specifying number of passengers, range, and landing speed.

SYMBOLS

A	aspect ratio (b^2/S)
b	wing span, feet
η	total propulsive efficiency
P	brake horsepower
c	minimum specific fuel consumption
C_L	lift coefficient $\left(\frac{\text{Lift}}{\frac{\rho}{2}S(1.467V)^2}\right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{\frac{\rho}{2}S(1.467V)^2}\right)$
C_{D_o}	airplane profile-drag coefficient
$C_{D_{flaps}}$	drag coefficient due to flap deflection
C_{D_T}	total effective drag coefficient for take-off run
C_{D_i}	induced-drag coefficient
C_{D_μ}	drag coefficient due to ground friction.
$C_{D_{gear}}$	drag coefficient due to landing gear
C_{L_T}	lift coefficient at instant of take-off
D	drag, pounds
V	airspeed, miles per hour except where otherwise indicated
V_L	landing speed, miles per hour
V_{max}	top speed, miles per hour

V_T	take-off speed, miles per hour except where otherwise indicated
S	wing area, square feet
c_w	wing chord, feet
W	airplane gross weight, pounds
W/S	wing loading, pounds per square foot
W/P	power loading, pounds per brake horsepower
F	maximum frontal area of fuselage, tail boom, and nacelle, square feet
f	design load factor
W_f	fuel weight, pounds
μ	ground-friction coefficient
T	thrust, pounds
e	span efficiency factor, taken as 0.80 in this analysis
$(L/D)_{max}$	maximum lift-drag ratio
ρ	mass density of air, slugs per cubic foot
S_t	total tail area, square feet
R	range, miles
s	take-off distance, feet
v_c	rate of climb, feet per minute
H_s	service ceiling, feet
V_i	indicated airspeed, miles per hour
N	number of passengers
W_b	bomb load, pounds

METHODS

Description of the Airplanes

In order to realize the maximum performance possibilities of the tail-boom or tailless airplanes, all the load should be carried within the wing. The design of one all-wing airplane indicated that an airplane of about 10,000 brake horsepower was large enough to be an all-wing tailless bomber and carry all its load within the wing. Previous calculations, the results of which are presented in figure 2, were analyzed to determine approximately how large a tail-boom or tailless airplane should be in order to carry passengers within its wing. In analyzing this chart it was realized that, at a given wing loading, lower power loading indicates better performance; thus, if the power loading required for a tail-boom or tailless airplane to carry the same number of passengers at about the same wing loading as a conventional airplane were much greater than the power loading of the conventional airplane, the conventional type could be expected to have the best performance. The analysis of figure 2 indicated that calculations of relative performance were warranted for airplanes with 21,000 and 42,000 brake horsepower, but that airplanes with 10,500 brake horsepower were too small to be all-wing passenger or low-density cargo transports. The performance calculations for these larger airplanes were considered to be indicative of the relative performance of bombers down to 10,000 brake horsepower; therefore, no performance calculations were made for the airplanes with 10,500 brake horsepower.

The same total power was assumed for each of the three types of airplanes. The 21,000-horsepower airplanes were assumed to be powered by six 3500 brake-horsepower engines, and the 42,000-horsepower airplanes were assumed to be powered by twelve 3500 brake-horsepower engines. The range of power loading covered in the present investigation was from 4 to 28 pounds per brake horsepower and the range of wing loading covered was from 20 to 100 pounds per square foot.

An aspect ratio of 10 was assumed for each of the three types of airplanes. The other wing plan-form parameters were not established except that the tailless airplanes incorporated some sweep so that the deflection of the high-lift flap need cause no change in trim. Reasonable variation of the wing plan form would not be expected to affect the performance appreciably.

The tailless airplane would probably be unable to obtain as high a value of maximum lift coefficient as the conventional and tail-boom types. The assumed values of maximum lift coefficient

were 2.4 for the conventional and tail-boom airplanes and 2.0 for the tailless airplane. These values were considered to be about the maximum practical values. The flaps were assumed to be of the balanced-split-flap type which, when deflected to small angles for take-off, produce comparatively low drag.

It was assumed that each of the three types of airplanes should have the same directional stability; the sizes of the vertical tails were computed accordingly. The areas of the vertical tails of the conventional airplanes, the tail-boom airplanes, and the tailless airplane were 12, 9, and 15 percent of the wing areas, respectively. The areas of the horizontal tails of the conventional and tail-boom airplanes were assumed to be 18 and 15 percent of the wing areas, respectively.

Appendix A and references 2 and 3 present additional details regarding the assumptions concerned with the design of the airplanes.

Calculations

The first step toward making generalized performance calculations for a series of airplanes, such as was required in the present investigation, was to make certain general assumptions regarding factors affecting the power, drag, weight, and cargo space. These assumptions, which are discussed in detail in appendix A, actually constitute a further and more detailed description of the airplane than was given in the preceding section of the text. The justification for the formulation of these general assumptions is fully discussed in reference 2. After these basic assumptions were established, the performance calculations were made in a conventional manner for a systematic series of airplanes of various sizes. A detailed description of the methods employed is given in appendix B. The performance characteristics of the various types of airplanes were then plotted as functions of power loading and wing loading. This system of presentation of the data and the use of the charts are discussed in appendix C.

Previous investigations for conventional airplanes, including comparisons of calculated performance characteristics with those measured in flight, have indicated that all the calculated characteristics, except range, are probably accurate within 2 or 3 percent. Because of the great effect of structural weight on range, small errors in estimating the structural weight may cause appreciable error in the range computation. For instance, a 5-percent change in structural weight may alter the computed range by 10 percent.

Experience has shown that the structural weights for conventional airplanes can be estimated with a fair degree of accuracy. The assumed relative structural weights of the three types of airplanes are believed to be quite logical, and the results of the range calculations are believed to be qualitatively correct in all cases. Nevertheless, the range calculations for the tail-boom and tailless airplanes were repeated for airplanes having 90 and 110 percent of the estimated structural weight in order that the effects of such variations in structural weight might be interpreted.

It should be pointed out that the calculated performance characteristics of these airplanes may not be directly comparable to those of some present-day airplanes. This fact is true partly because the drag and particularly the weight estimates used in the present calculations are fairly conservative and partly because of differences in design load factor.

RESULTS AND DISCUSSION

General Performance Comparison

The results of the performance calculations are presented in figures 3 to 6 as generalized performance selection charts which give the performance characteristics of each of the three types of airplanes at each combination of power loading and wing loading. The charts are plotted on identical coordinates of power loading and wing loading and may be superimposed to get a general comparison of the three types of airplanes over a large range of power loading and wing loading. Figures 4 and 6 are composite selection charts presenting a direct comparison of the top speed, range, and take-off distance for the conventional, tail-boom, and tailless airplanes. These figures were evolved from the data from figures 3 and 5 in order to facilitate the selection of the proper power loading and wing loading to give the optimum performance.

The selection charts (figs. 3 to 6) show that, at the same values of power loading and wing loading, the performance of the tailless airplanes will be definitely superior to either of the other two types and that the tail-boom airplanes will have slightly better performance than conventional airplanes. The difference in top speed and range among the three types of airplanes is appreciable. The top speeds of the tail-boom airplanes were of the order of 5 miles per hour faster than those of the conventional airplanes; whereas the top speeds of the tailless airplanes varied from about 25 to 40 miles per hour faster than the speeds for the conventional

airplanes. The ranges of the tail-boom and tailless airplanes were 150 to 800 miles and 900 to 2000 miles greater, respectively, than the range of the conventional airplanes. Little or no difference, however, existed among the service ceiling, take-off distance, and rate of climb of the three types of airplanes. The service ceiling and take-off distance are primarily functions of power loading and wing loading, and the rate of climb at low altitudes and at the speed corresponding to the maximum lift-drag ratio is almost entirely a function of power loading.

It appears that the tail-boom airplanes will have a small margin of performance over the conventional airplanes and that the tailless airplanes will be definitely superior to each of the other types. A direct comparison of the selection charts, however, neglects several features which are very important in a comparison of the three types of airplanes. For instance, such a comparison does not show the relative performance if certain landing-speed requirements are met, nor does the comparison indicate whether the airplanes will have sufficient space to carry their pay load in the form of passengers or low-density cargo. A comparison of the airplanes is therefore made based on consideration of several parameters which are of concern to the airplane designer or operator.

Performance Variations with Structural Weight, Landing Speed, and Take-Off Distance

The structural weight of the airplanes does not affect any of the performance characteristics except the range. The variation of range with structural weight for the tail-boom and tailless airplanes is shown in figure 7 as range selection charts calculated for the airplanes at 90 and 110 percent of the estimated structural weight. The results shown in figure 7 are presented more simply in figure 8. The range varies inversely with structural weight and, for small changes in structural weight, the variation is almost rectilinear. The range data may therefore be extrapolated to cover airplanes having structural weights slightly greater or less than those used in these calculations. In order to determine exactly the effect of variations of structural weight, cross plots of the data from the range selection charts may be made similar to those of figure 8. Figure 8 shows that a 1-percent reduction in structural weight may increase the range of these airplanes from 50 to 100 miles.

A comparison of the performance characteristics of conventional, tail-boom, and tailless airplanes having the same landing speed is not readily apparent from examination of the selection charts

because of the lower maximum lift coefficient which the tailless airplane may be expected to obtain. Figure 9 was therefore prepared to illustrate the relative performance of the three types over a range of landing speed. The data presented in figure 9 are quantitatively correct only for a power loading of 14, but the comparison of the three types of airplanes is qualitatively correct at any power loading. The performance margin of the tail-boom airplanes over the conventional airplanes is the same as that obtained by a comparison on a basis of equal power loading and wing loading, because the maximum lift coefficient of the two types is equal. The tailless airplanes, again, are superior to either of the other two airplane types, but the margin of superiority is somewhat less than that obtained when the comparison was based on equal power loading and wing loading for each of the three airplane types. Although this comparison does not show the top speed of the tailless airplanes to be so much greater than the conventional airplane as a brief examination of the selection charts might indicate, some improvement in the performance is gained by a shorter take-off run.

In order to illustrate the comparison of the other performance characteristics of the airplanes for equal take-off distance, figure 10 was prepared so that a performance comparison could be made for a range of take-off distances. Figure 10 was constructed by cross-plotting the data from the selection charts for a power loading of 14 and is directly applicable only for this power loading. Similar charts, however, could be prepared for comparison on any basis. The data presented in figure 10 indicate that the tail-boom airplane has a small advantage in performance over the conventional airplane when their take-off distances are the same. Similarly, the tailless airplane is shown to be definitely superior to either of the other airplane types except that the landing speed, as indicated by the wing loading, would be higher.

Performance Comparison Based on an Arbitrary Design Specification

The most logical comparison of the performance of conventional, tail-boom, and tailless airplanes should be based on a design specification similar to that which confronts an airplane designer when he commences the design of the new airplane. A design specification was set up which gave the number of passengers or weight of bombs to be carried for a given range by an airplane having a given landing speed. A comparison was made of the conventional, tail-boom, and tailless airplanes, consistent with the specifications and having the highest possible performance (top speed, take-off distance, rate of climb, and service ceiling).

Before the proposed comparison could be made, it was necessary to prepare an additional selection chart to determine the load-carrying capacity of the various airplanes. These charts considered both the space available for the pay load and weight of the pay load for a given range. Such charts are presented in figure 11 and show the number of passengers or amount of bomb load that can be carried for a given range. The charts are made up by using the space charts of figure 2 and an interpretation of the range charts where the disposable load not required to obtain the given range is assigned as pay load. The curved (left) part of the lines of constant load represents the region in which the pay load of the airplane is limited by its weight-carrying capacity, and the straight (right) part of the lines represents the region in which the pay load of the airplane is limited by the space available for that load.

The selection charts of figures 3, 5, and 11 were used to determine the performance characteristics of the best possible airplane designed to meet the following specifications for both the 42,000- and 21,000-horsepower airplanes:

Landing speed (mph)	Range (miles)	Load
70	3000; 5000	Passengers
100	3000; 5000	Passengers
100	5000	Bombs

The performance characteristics of the airplanes selected as having the best performance consistent with a specified landing speed and range are presented in figure 12 as functions of the load-carrying capacity (passengers or bombs).

Examination of figure 12 shows that the tailless airplanes had the best performance of the three airplanes types for all the conditions investigated except for the examples involving passenger transports having 100-mile-per-hour landing speed and 3000-mile range. For this case the conventional airplanes were found to have the best performance.

The three types of airplanes were also compared on the basis of the same arbitrary design specification but with assumed values of maximum lift coefficient of 2.0 for the conventional and tail-boom

airplanes and 1.4 for the tailless airplanes. The results of this comparison are not presented but they were similar to the results shown in figure 12 except that the margin of superiority of the tailless airplanes in most cases was diminished.

The reason the tailless airplane has the best performance for some tasks whereas the conventional airplane has the best performance for others may be ascertained from figure 11 if it is recognized that (1) at a given wing loading, lower power loading means better performance and (2) the difference in wing loading of the airplanes required to give the same landing speed is relatively small. At low landing speeds (that is, low wing loading) the power loading required to have an airplane large enough to carry a given number of passengers is limited by the weight-carrying capacity of the airplane; whereas at high landing speeds (that is, high wing loading) the power loading required is limited by the space available for pay load. Because of the lower structural weight, the tailless airplanes may have lower power loadings and carry the same weight and hence have the best performance when weight-carrying capacity is the limiting factor as it is at low wing loadings. Similarly, because of the greater cargo space available, the conventional airplanes have the lower power loadings and better performance when cargo space is the limiting factor as it is at high wing loadings. At moderate wing loadings, of course, either type of airplane might have the better performance depending upon the design range.

It is interesting to note that the tail-boom airplanes have the limitations which caused the conventional or tailless airplanes each to be the poorer in a given region. That is, the structural weight of the tail-boom airplane is very nearly the same as that of the conventional airplane; therefore, in the low wing-loading range where the weight-carrying capacity is the determining factor, the performance of the tail-boom airplane is not nearly so good as that of the tailless airplane. The cargo space of the tail-boom airplane is the same as that of the tailless airplane; therefore, in the high-wing-loading range where cargo space is the limiting factor, the performance of the tail-boom airplane, again, is not so good as that of the tailless airplane.

None of the bombers considered in the present comparison were small enough to be limited by the space available, therefore, the tailless airplanes were always shown to have much better performance than either the tail-boom or the conventional airplanes.

On the basis of the design specification previously discussed, a general conclusion may be made regarding the relative performance of the three types. For airplanes having 21,000 or more brake

horsepower, the all-wing tailless airplane will have the best performance for carrying low-density cargo in airplanes having low wing loadings. At high wing loadings and for low-density cargo, the tailless design will still be the best for long-range airplanes but the conventional design will be the best for short-range airplanes. The tail-boom-type airplane may never be expected to have the best performance of the three types.

CONCLUSIONS

A comparison of the calculated performance characteristics of conventional, tail-boom, and all-wing tailless airplanes having 21,000 and 42,000 horsepower indicated the following conclusions:

1. Large all-wing tailless airplanes may have better performance characteristics than their equivalent conventional or tail-boom airplanes, when designed as bombers or long-range transports.

2. Conventional airplanes may have the best performance of the three types of airplanes when designed as short-range transports with high wing loadings.

3. Tail-boom airplanes having only a wing, booms, and tails do not appear to have as good performance as either of the other two types for any type of mission considered.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., March 3, 1947

APPENDIX A

ASSUMPTIONS USED IN CALCULATIONS

The basic assumptions regarding power, drag, weights, and passenger or cargo space of the three types of airplanes (conventional, tail boom, and tailless) are discussed in the following paragraphs.

Power

The 21,000-horsepower airplanes were assumed to be powered by six 3500-horsepower engines driving six pairs of 15-foot diameter, four-blade, counterrotating propellers; the 42,000-horsepower airplanes were assumed to be powered by twelve 3500-horsepower engines driving six pairs of 15-foot diameter, eight-blade, counterrotating propellers. These engines were equipped with two-stage turbosuperchargers and had a critical altitude of 50,000 feet. The power loadings given in this paper are based on 21,000 and 42,000 horsepower per airplane. The assumed minimum specific fuel consumption of these engines at various powers are given in figure 13.

The propulsive efficiency at sea level was assumed to vary with velocity as shown in figure 14. Cooling power was assumed to be proportional to brake horsepower and was expressed as a reduction in propeller efficiency. The variation of cooling power (reduction of propeller efficiency) with altitude is shown in figure 15.

Drag

The parasite-drag coefficient based on the effective frontal area of the fuselage, tail booms, and nacelles is assumed to be 0.10. This value represents the drag of carefully designed airplanes (in the case of bombers, all turrets retracted). Wings on these airplanes have a profile-drag coefficient of about 0.0090. The drag coefficient of the thin-airfoil tail surfaces was assumed to be 0.0085. The total profile-drag coefficient of the airplane is then:

$$C_{D_o} = 0.0090 + 0.0085\frac{S_t}{S} + 0.10\frac{F}{S}$$

where the total tail area and the fuselage, tail-boom, and nacelle frontal area were assumed to be as follows:

Brake horsepower	Type of airplane	$\frac{S_t}{S}$	F (sq ft)
21,000	Conventional	0.30	170
21,000	Tail boom	.24	116
21,000	Tailless	.15	66
42,000	Conventional	.30	184
42,000	Tail boom	.24	130
42,000	Tailless	.15	80

The small changes in frontal area with power caused so little difference in the profile-drag coefficients that the curves of relative drag coefficients of the three types of airplanes (fig. 16) show the same profile-drag coefficients for the 21,000-horsepower and 42,000-horsepower airplanes.

It was assumed that the airplanes were so designed that their critical speed was not exceeded in level flight.

The induced-drag coefficient was calculated from the conventional expression

$$C_{D_i} = \frac{C_L{}^2}{e\pi A}$$

where the aspect ratio A was 10 and the span efficiency factor e was assumed to be 0.80.

The drag coefficient during the take-off was determined from the expression

$$C_{D_T} = C_{D_o} + C_{D_i} + C_{D_\mu} + C_{D_{flaps}} + C_{D_{gear}}$$

in which the effect of ground proximity on the lift and the drag of the airplane was not included. The minimum drag coefficient during the take-off run was assumed to be attained at a lift coefficient of 0.28. The ground-friction coefficient μ was assumed to be 0.020, which is the value generally used in connection with concrete runways.

The drag coefficient of the flaps $C_{D_{flaps}}$ was assumed to be 0.0051 for half-span, balanced split flaps having a chord of $0.20c_w$ at 20° deflection. The landing-gear drag coefficient $C_{D_{gear}}$ was assumed to be equal to the profile drag of the clean airplane.

Weight

From studies of airplane weights the following weights were selected for use in the present investigation:

(1) The landing gear is 7 percent of the gross weight.

(2) Weights of the hydraulic system, surface controls, cabin furnishings, electrical equipment, and cabin supercharging equipment are shown in figure 17.

(3) A crew of 10 members was assumed for all airplanes. A weight of 215 pounds was allowed for each crew member. This weight includes oxygen equipment and other personal items.

(4) The instruments and autopilot weighed 650 pounds.

(5) The weight of the communication system is assumed to be equal to 0.003W.

(6) Wing weight is determined by considerations of strength. An expression equating the internal resisting moment to the external bending moment at the center section gives the following relationship:

$$K = \frac{W - (C_1W_2 + W_1)}{W_1} \frac{fA^{3/2}\ S^{1/2}}{t}$$

where

W airplane gross weight

W_1 wing weight

W_2 distributed load on wing

C_1 distributed-load effectiveness (for a perfectly distributed load, $C_1 = 1.0$)

f design load factor (assumed to be 4 in the present investigation)

A wing aspect ratio

S wing area

t wing thickness (assumed to be 20 percent)

and K is a coefficient dependent on the distribution of lift along the span, the strength-weight ratio of the material used in the construction of the wing, and the perfection of the design as an efficient weight-to-strength beam. The higher the value of K, the more efficient is the beam as a weight-carrying structure. For the purpose of this analysis a value of $K = 100,000$ was used. For the 42,000-horsepower airplanes, C_1 was assumed to be 0.90 and W_2 to be 0.50W. For the 21,000-horsepower airplanes, C_1 was assumed to be 0.85 and W_2 to be 0.30W.

Although the tail-boom and the tailless airplanes would probably have slightly lower wing weights because of a better load distribution, the weights calculated for the conventional airplanes were used for all three types because of the uncertainty of the design and the possibility of other factors such as the influence of flutter and torsional bending on the wing weight. It was also assumed that the small amount of sweepback required by the tailless airplanes would not appreciably affect the wing weight.

(7) The fuselage weight of large conventional airplanes was assumed to vary as the 1/3 power of the gross weight. (See fig. 18.) The weights of the flooring, fittings, bomb-bay doors, and other structures usually in the fuselage, but necessarily in the wings of the tail-boom and tailless airplanes, were arbitrarily chosen as 1/3 the fuselage weight of the conventional airplane.

(8) The weights of the tail booms on the tail-boom airplane were computed from considerations of strength. These values were approximately 0.02W.

(9) The weights of the tail surfaces were assumed proportional to the wing weight, or equal to $0.43W_1\frac{S_t}{S}$.

(10) The weights in pounds of each power plant unit and accessories are:

Engine	6750
Intercooler	800
Supercharger installation	1750
Controls and starting	200
Oil coolers	600
Water injector	600
Ducting	400
Shafting	400

(11) The weights of the nacelle groups are assumed to be 6000 pounds and 12,000 pounds for the 21,000-horsepower and 42,000-horsepower airplanes, respectively.

(12) The total propeller weights for six counterrotating propellers were determined from figure 19 to be 4200 and 8400 pounds, respectively, for the 21,000-horsepower and 42,000-horsepower airplanes.

(13) The weight of the fuel or the oil is 6.0 pounds per gallon. The weight of the fuel system is 0.55 pound per gallon and the weight of the oil system is 1.25 pounds per gallon. The tanks are assumed to be carried in the wings. Sufficient tankage weight is included to obtain maximum range with no pay load. It was assumed that 1 gallon of oil is required for every 16 gallons of fuel.

(14) All other weights not specified, such as armor, armament, cargo, bombs, and passengers, were assumed to be part of the pay load. This load may be carried in any form or combination desired.

Space

The space available for the accommodation of passengers or cargo was computed for each of the three types of airplanes (conventional, tail boom, and tailless) by determining the floor area over which a ceiling height of 6 feet could be obtained. Passenger accommodations within the wing never included more than one deck although the accommodations in the fuselage might be provided in multiple decks. All the pay load in the tailless and tail-boom airplanes was assumed to be within the wing inasmuch as the tailless airplanes had no fuselage or "pod" and storage in the booms of a tail-boom airplane would probably cause the center of gravity to be too far rearward. The pay load was assumed to be carried in both the wings and fuselage of the conventional airplanes. The fuselage size was assumed to be 100 square feet of frontal area, exclusive of that submerged in the wing, and the usable length was assumed to be 1/2 the wing span. The space available for pay load was then converted into passenger capacity by assuming that 12 square feet of floor space would be required for each passenger. This amount of floor space per passenger was determined by an analysis of present-day transport airplanes. Sufficient space was always available for carrying the full disposable load in fuel without using space which was of suitable size for passengers or cargo.

General computations of the space available for the bomb load were not made, but investigations at several extreme sizes indicated that the airplanes represented on the charts in the present paper could carry their full pay load in bombs.

APPENDIX B

METHODS OF COMPUTATIONS

All the performance characteristics were computed in a conventional manner, using constants and variables based on the assumptions given in appendix A.

Maximum Speed

The maximum speed was computed from the basic relations:

$$P = \frac{DV}{\eta}$$

$$C_L = \frac{W}{\frac{\rho}{2}SV^2}$$

$$D = \left(C_{D_o} + \frac{C_L^2}{e\pi A}\right)\frac{\rho}{2}SV^2$$

These expressions can be combined to give:

$$W = \sqrt{\frac{e\pi A}{2}\rho SV\left(550P\eta - C_{D_o}\frac{\rho}{2}SV^3\right)}$$

where V is in feet per second. Substituting the appropriate constants and values of the variables V and S in the foregoing equation can give curves of constant velocity as in figures 3(a) and 5(a).

Take-Off Distance

The take-off distance (ground run) on a level field with no wind was computed.

If it is assumed that the take-off distance is proportional to the excess thrust at 0.71 times the take-off speed, the following relations are obtained:

$$s = \frac{V_T^2 W}{64 T_{ex}}$$

where V_T is the take-off speed in feet per second and T_{ex}, the excess thrust at $0.71V_T$, equals $T - D$ where

$$T = \frac{550P\eta}{0.71V_T}$$

$$D = C_{D_T} \frac{\rho}{2} S(0.71V_T)^2$$

and

$$V_T = \sqrt{\frac{W/S}{\frac{\rho}{2} C_{L_T}}}$$

with C_{L_T} taken as 1.3. These formulas combine to give

$$s = \frac{0.71V_T^3 W}{64 \left\{550P\eta - \left[C_{D_T} \frac{\rho}{2} S(0.71V_T)^3\right]\right\}}$$

where η is determined from figure 14 at $0.71V_T$. By solving this formula for minimum take-off distance over a range of weight and wing area and by plotting curves of constant wing area, cross plots of constant take-off distance may be made as in figures 3(b) and 5(b).

Rate of Climb at Maximum L/D

It is assumed that maximum rate of climb occurs very near the speed for the maximum value of the ratio of lift to drag. The formula used is:

$$v_c = \frac{33000P\eta}{W} - \frac{189\rho V^3}{W/S} C_{D_o}$$

where V is the airspeed in miles per hour at maximum L/D and is equal to

$$V = \frac{\sqrt{\dfrac{W}{\frac{\rho_o}{2} S C_L \frac{\rho}{\rho_o}}}}{1.467}$$

where

$$C_L = \sqrt{\pi e A C_{D_o}}$$

The rate of climb will be obtained at constant indicated airspeed. Therefore, a correction for the acceleration must be introduced by multiplying the computed rate of climb by the appropriate values taken from figure 20.

Service Ceiling

Service ceiling is computed as the altitude at which the maximum rate of climb equals 100 feet per minute if the supercharged engine is assumed to deliver full power up to 50,000 feet. Service ceilings above 50,000 feet were not considered in the present investigation.

Rearranging the rate-of-climb formula gives

$$\rho = \frac{28800 C_{D_o}{}^2 W^3}{(33000 P\eta - 100W)^2 S C_L{}^3}$$

This formula is solved and the results are plotted in the same manner as take-off distance.

Range

The range was computed by use of Breguet's formula:

$$R = 375 \frac{\eta}{c} \left(\frac{L}{D}\right)_{max} \log_e \left(\frac{W}{W - W_f}\right)$$

Specific fuel consumption is assumed to be proportional to the brake horsepower required to fly at maximum lift-drag ratio when rate of climb equals zero. Propeller efficiency and cooling power are taken from figures 14 and 15. The fuel weight is found by adding all the weights in the airplane except the weight of the fuel, fuel system, oil, and oil system. The fuel weight is then a constant percentage of the sum of the weights of fuel, fuel system, oil, and oil system.

APPENDIX C

GENERALIZED SELECTION CHARTS

Methods have been developed by the NACA (references 2 and 3) for presenting performance calculations by plotting the performance characteristics on identical coordinates of wing loading and power loading, thus making it possible to choose the optimum performance characteristics to meet a given set of requirements.

Figures 4 and 6 show selection charts made by superimposing curves from figures 3 and 5. Each point on every chart represents a consistent group of airplane characteristics. Performance charts, such as figures 4 and 6, give a picture of the relation between speed, range, climb, take-off distance, and service ceiling and relate these characteristics to the principal airplane parameters of wing loading and power loading. These charts facilitate the selection of the parameters which give a certain type of performance. The charts may also be used, as in the present paper, to make generalized comparisons over a large range of weight, power, and wing area.

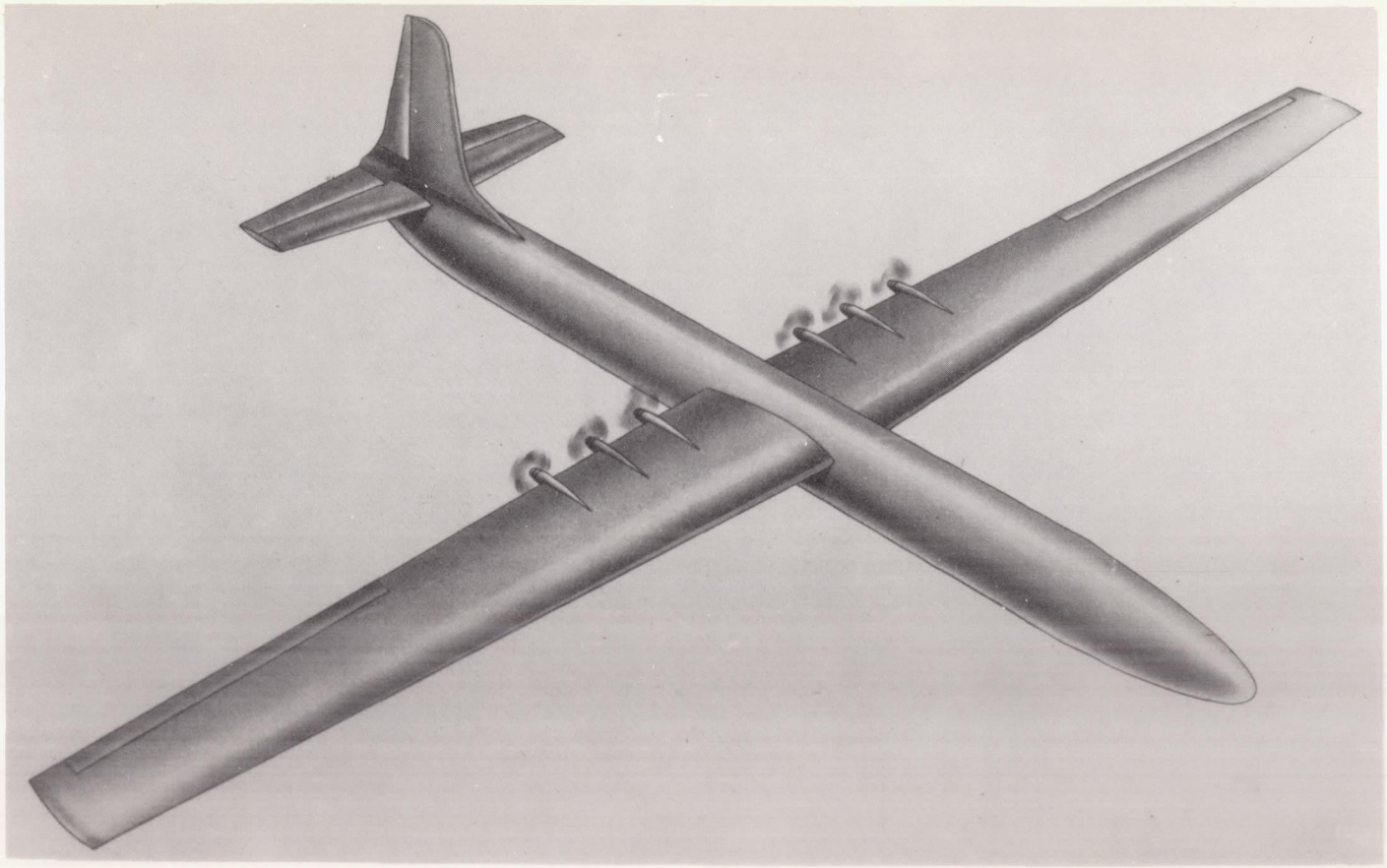
This system should not be interpreted as a new method of performance calculation to supersede accepted methods, but rather as an adaptation of accepted methods to making generalized calculations for many airplanes.

REFERENCES

1. Stability Research Division: An Interim Report on the Stability and Control of Tailless Airplanes. NACA Rep. No. 796, 1944.

2. Brevoort, Maurice J., Stickle, George W., and Hill, Paul R.: Generalized Selection Charts for Bombers with Four 2000-Horsepower Engines. NACA MR, May 11, 1942.

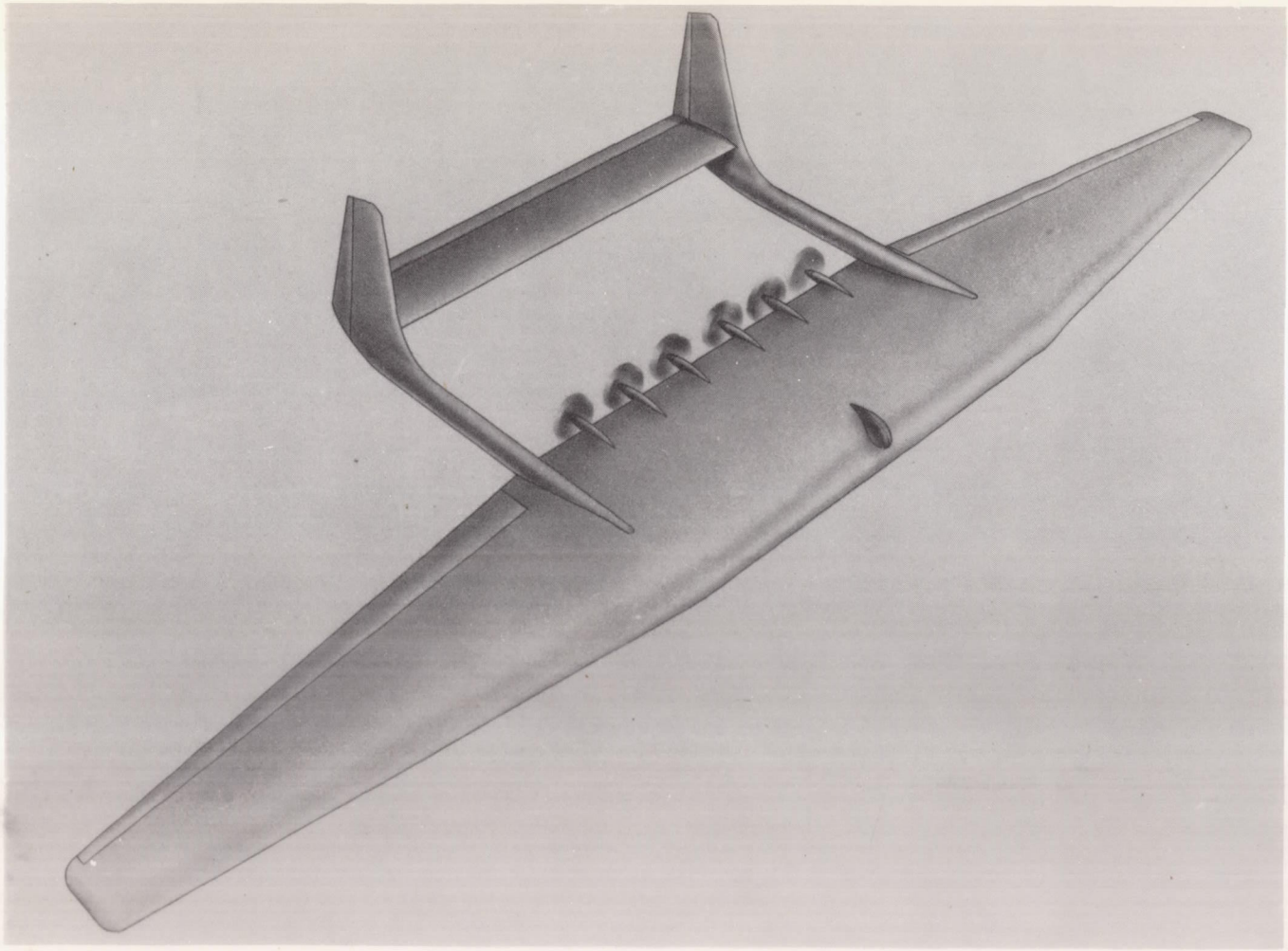
3. Brevoort, M. J., Stickle, G. W., and Hill, Paul R.: Generalized Selection Charts for Bombers Powered by One, Two, Four, and Six 2000-Horsepower Engines. NACA MR, July 6, 1942.



(a) Conventional airplane.

Figure 1.- Sketches of possible airplane designs.

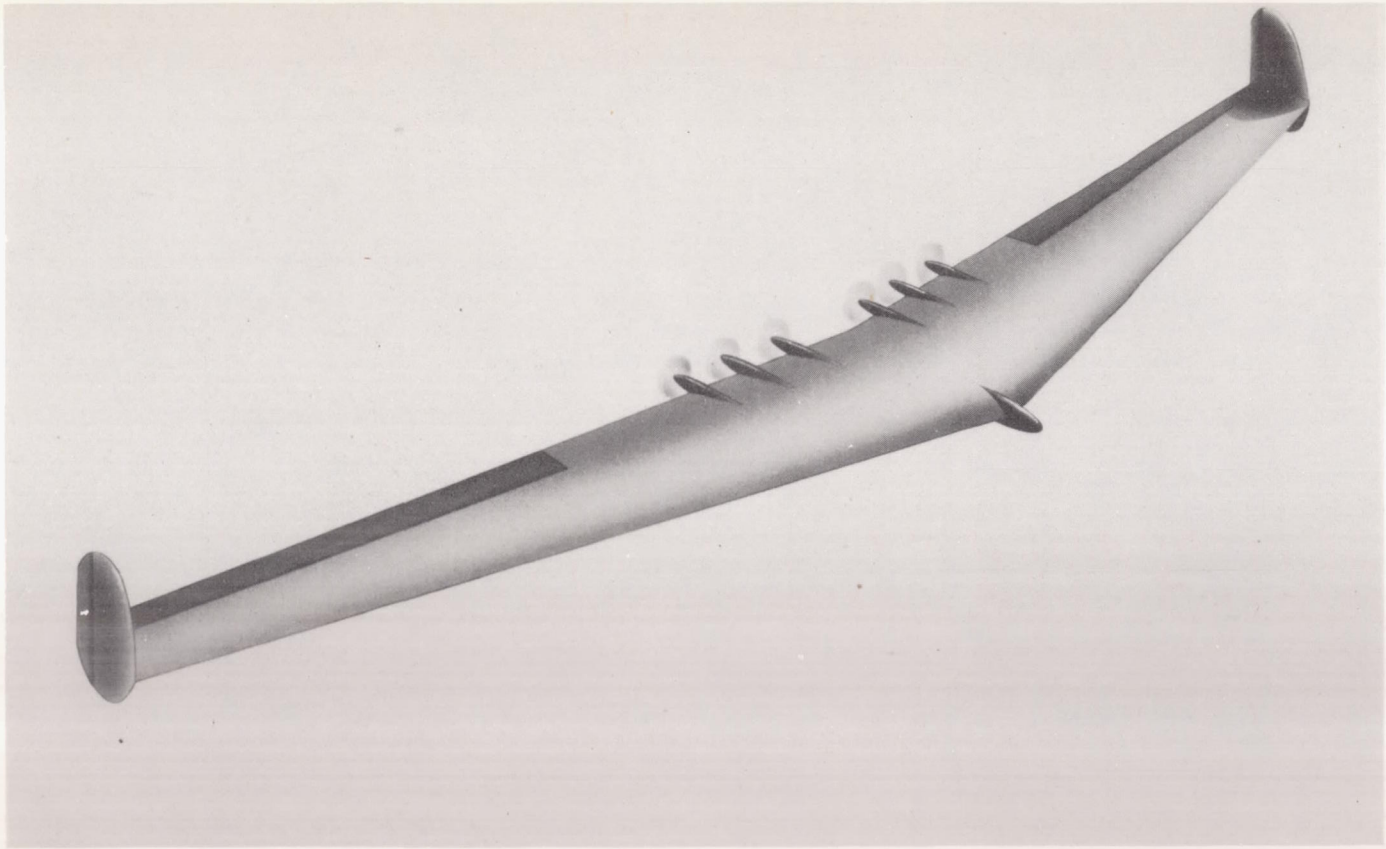
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LANGLEY MEMORIAL AERONAUTICAL LABORATORY - LANGLEY FIELD, VA.



(b) Tail-boom airplane.

Figure 1.- Continued.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LANGLEY MEMORIAL AERONAUTICAL LABORATORY - LANGLEY FIELD, VA.



(c) Tailless airplane.

Figure 1.- Concluded.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LANGLEY MEMORIAL AERONAUTICAL LABORATORY - LANGLEY FIELD, VA.

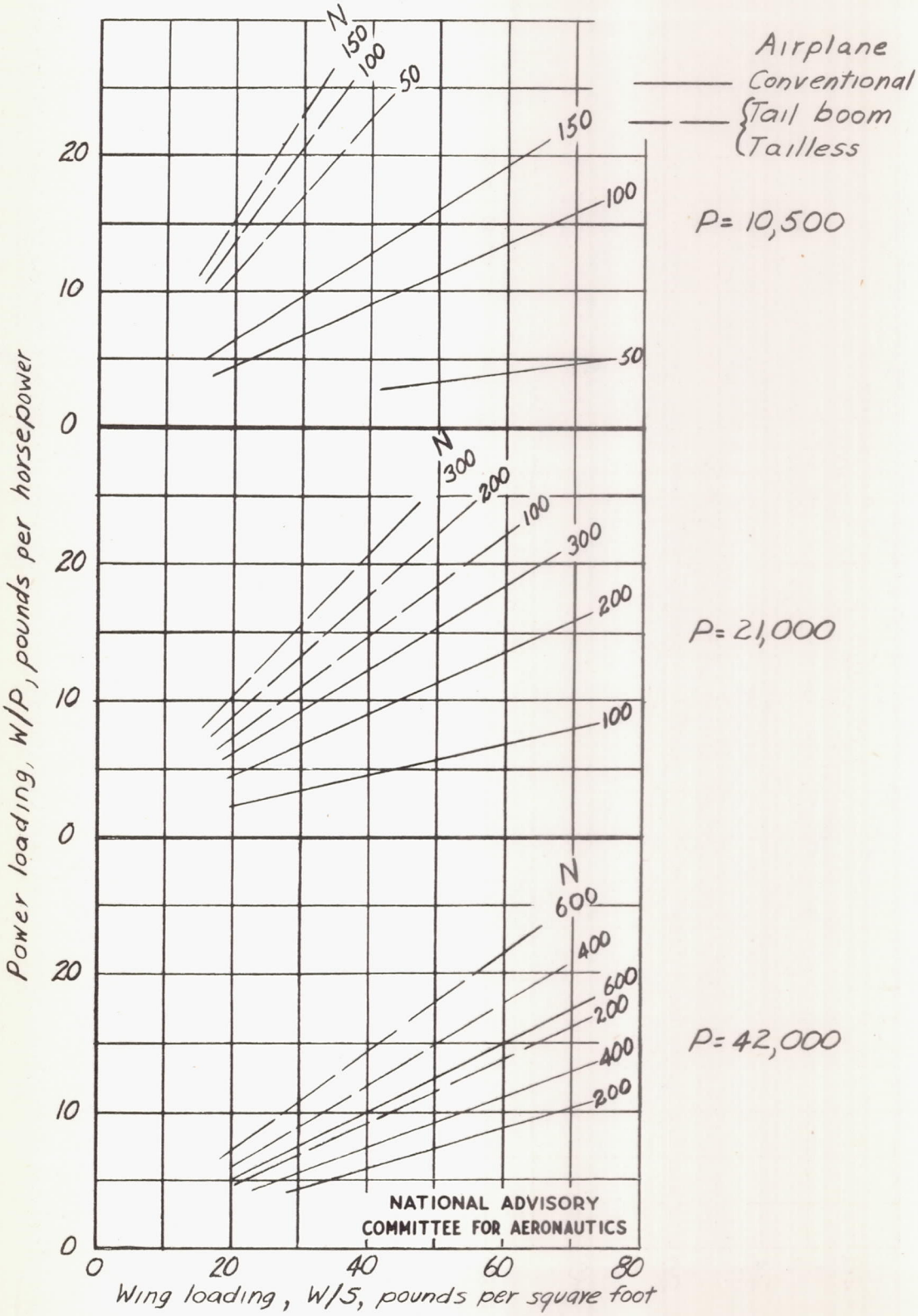
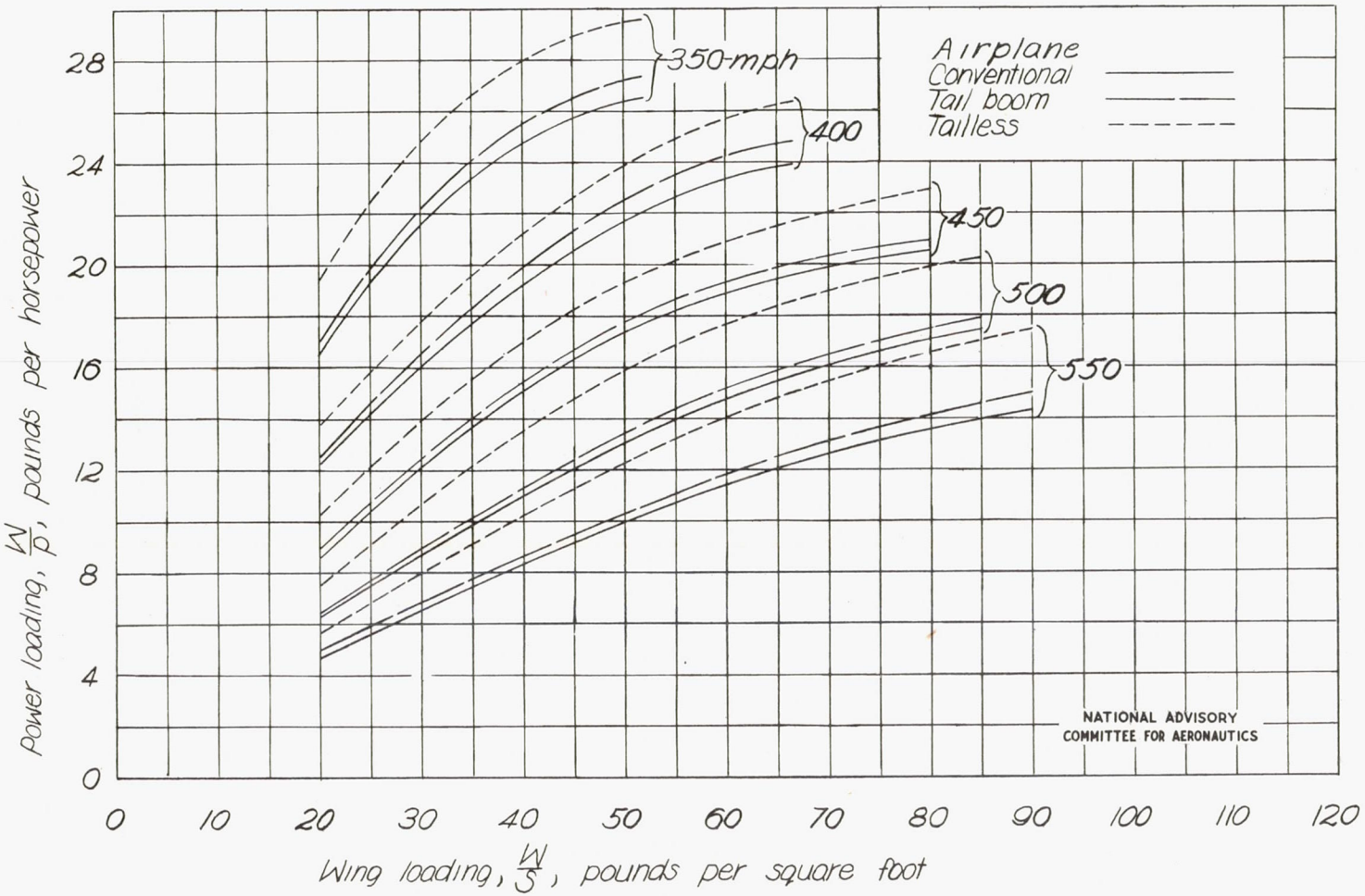
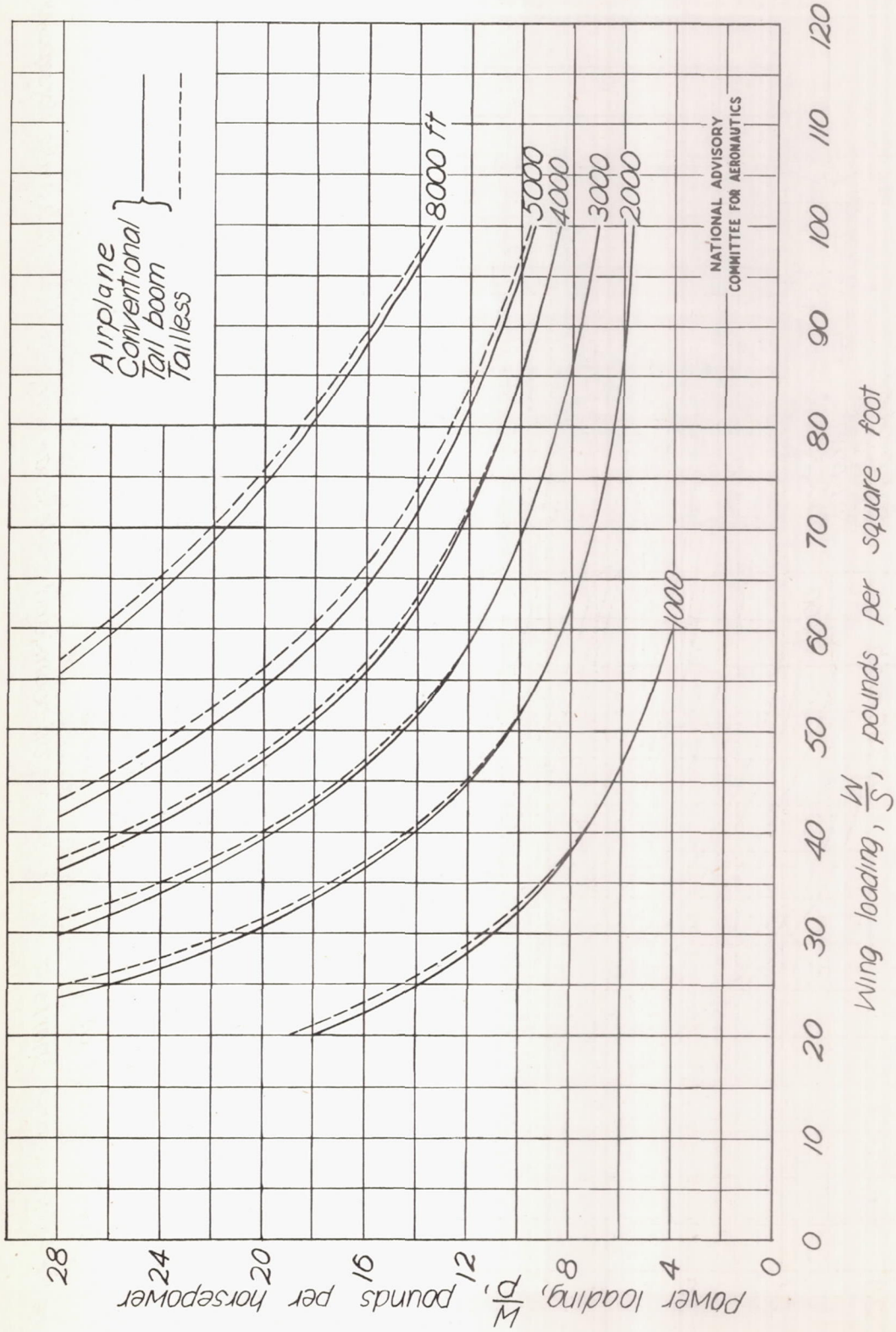


Figure 2.— Space limitation on passenger capacity.



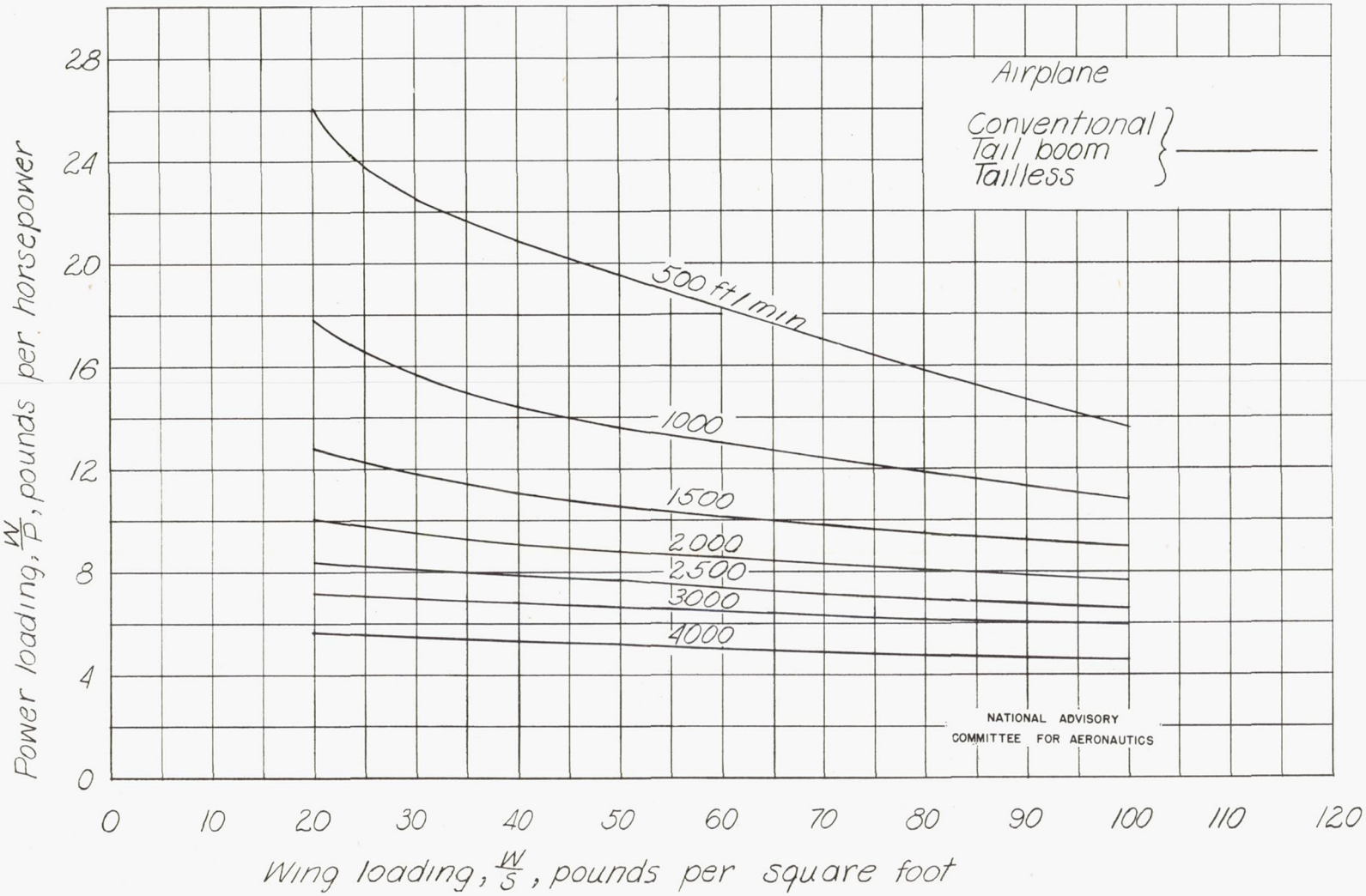
(a) Top speed at 10,000-foot altitude.

Figure 3.- Performance charts for conventional, tail-boom, and tailless airplanes with 42,000 brake horsepower.



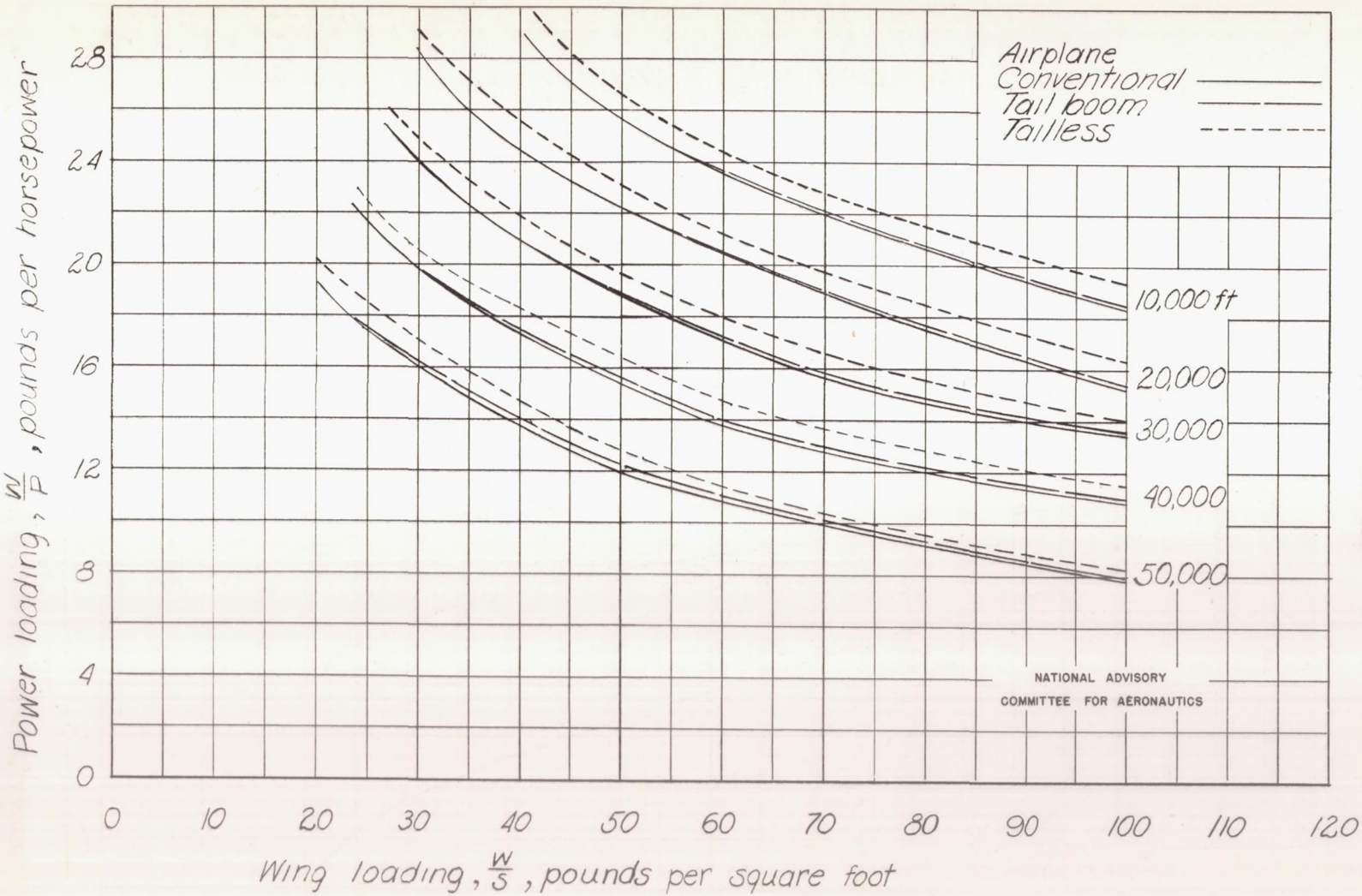
(b) Take-off distance.

Figure 3.-Continued.



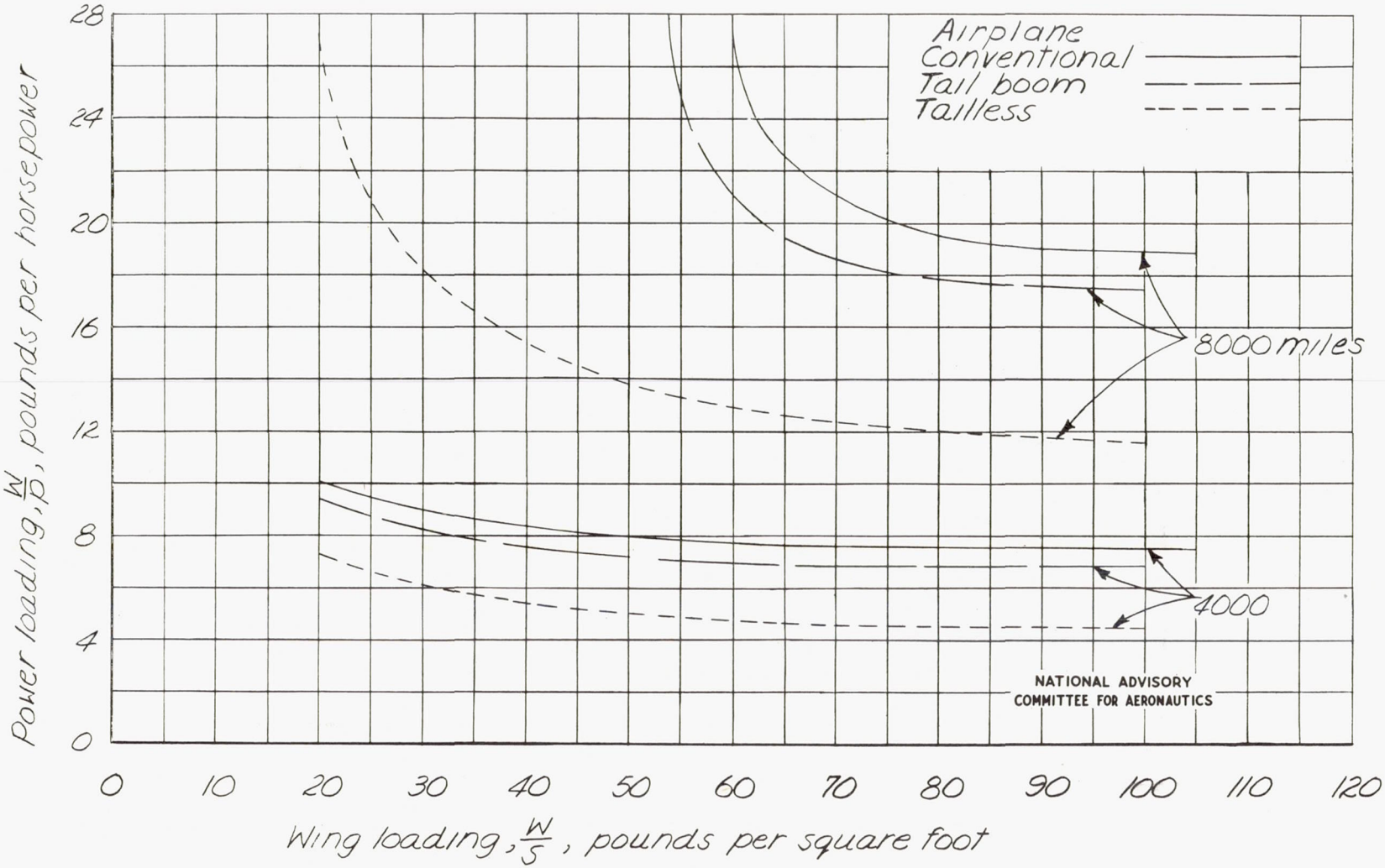
(c) Rate of climb at maximum L/D at 10,000-foot altitude.

Figure 3.-Continued.



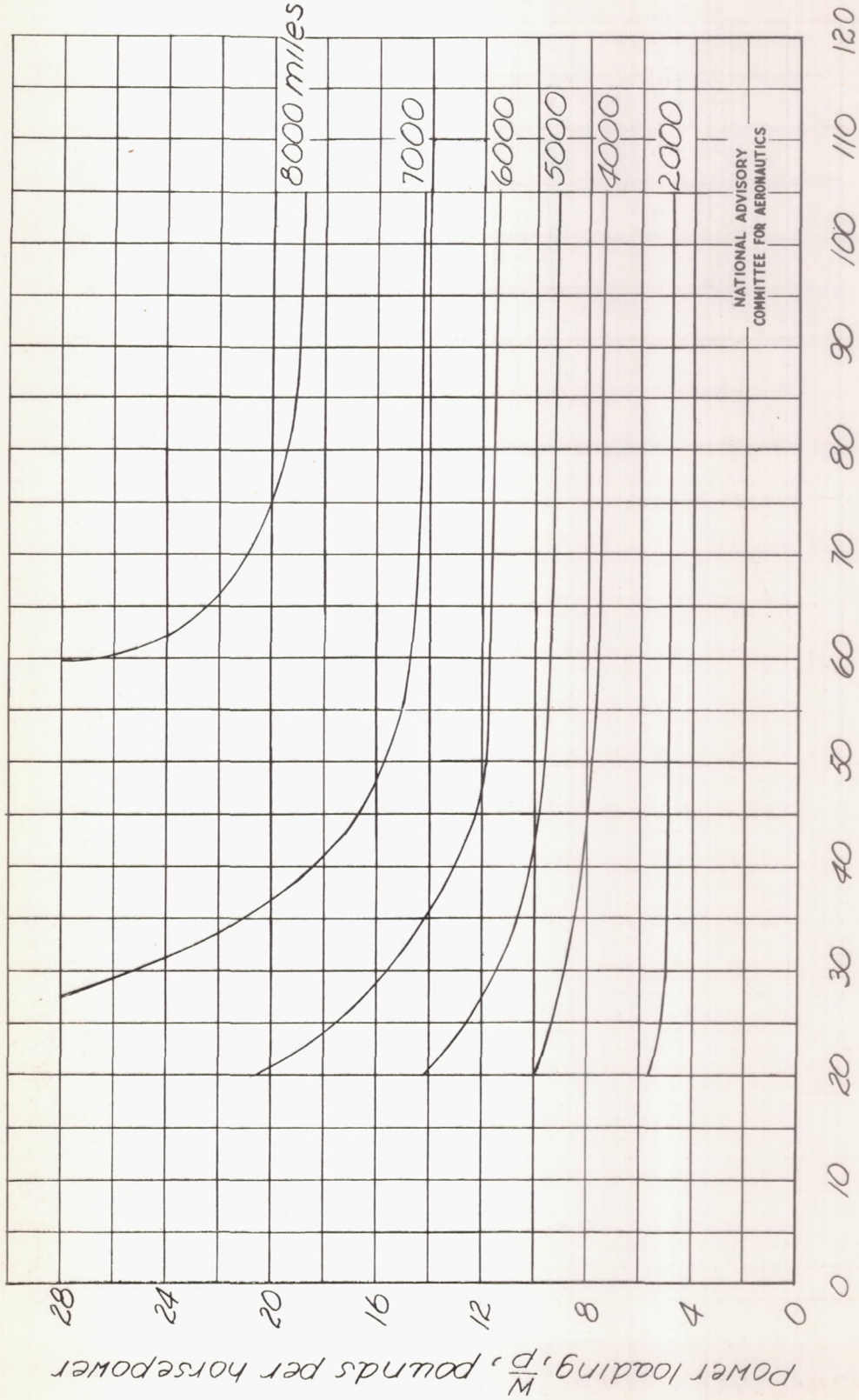
(d) Service ceiling.

Figure 3.- Continued.



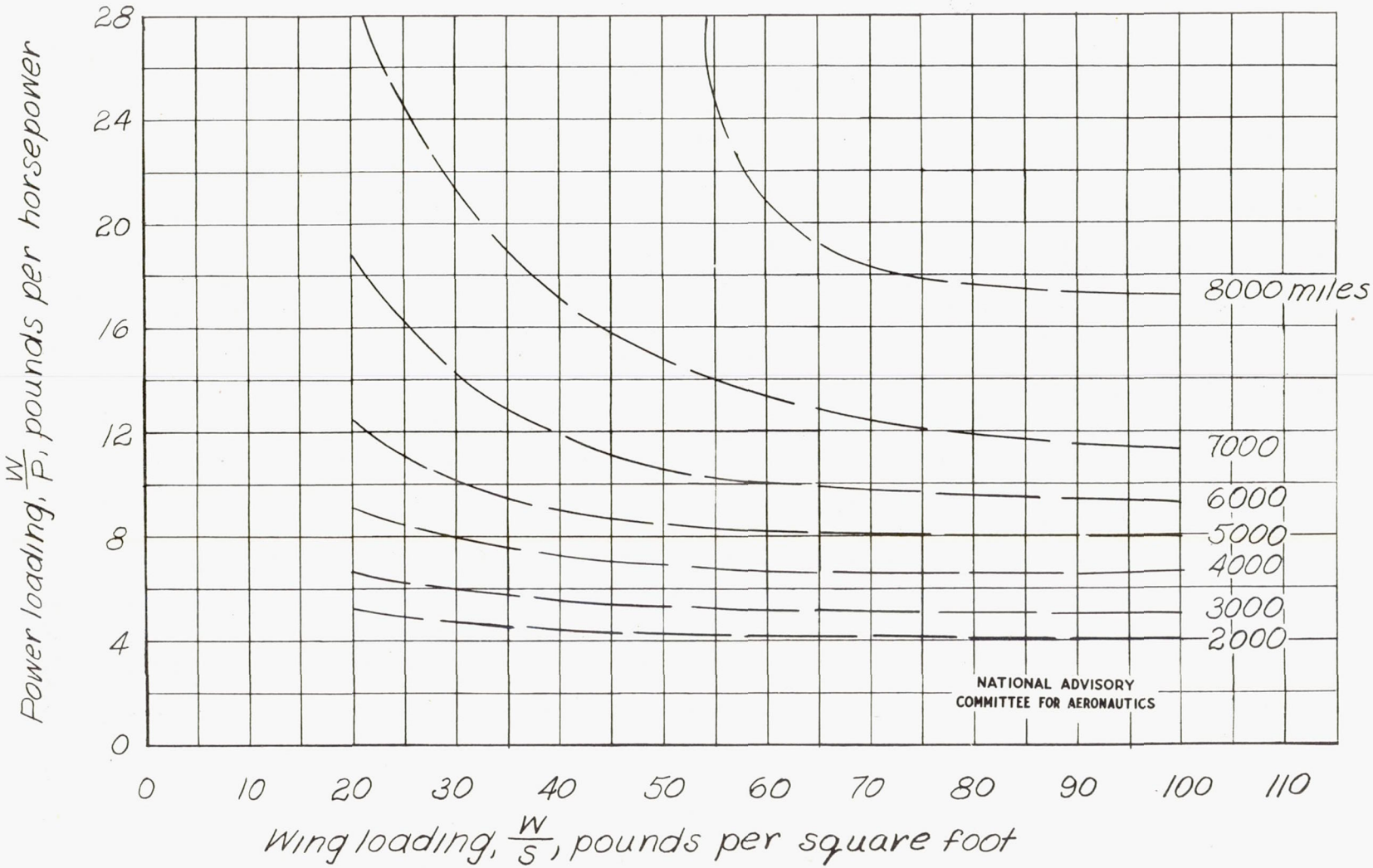
(e) Range at 10,000-foot altitude.

Figure 3.-Continued.



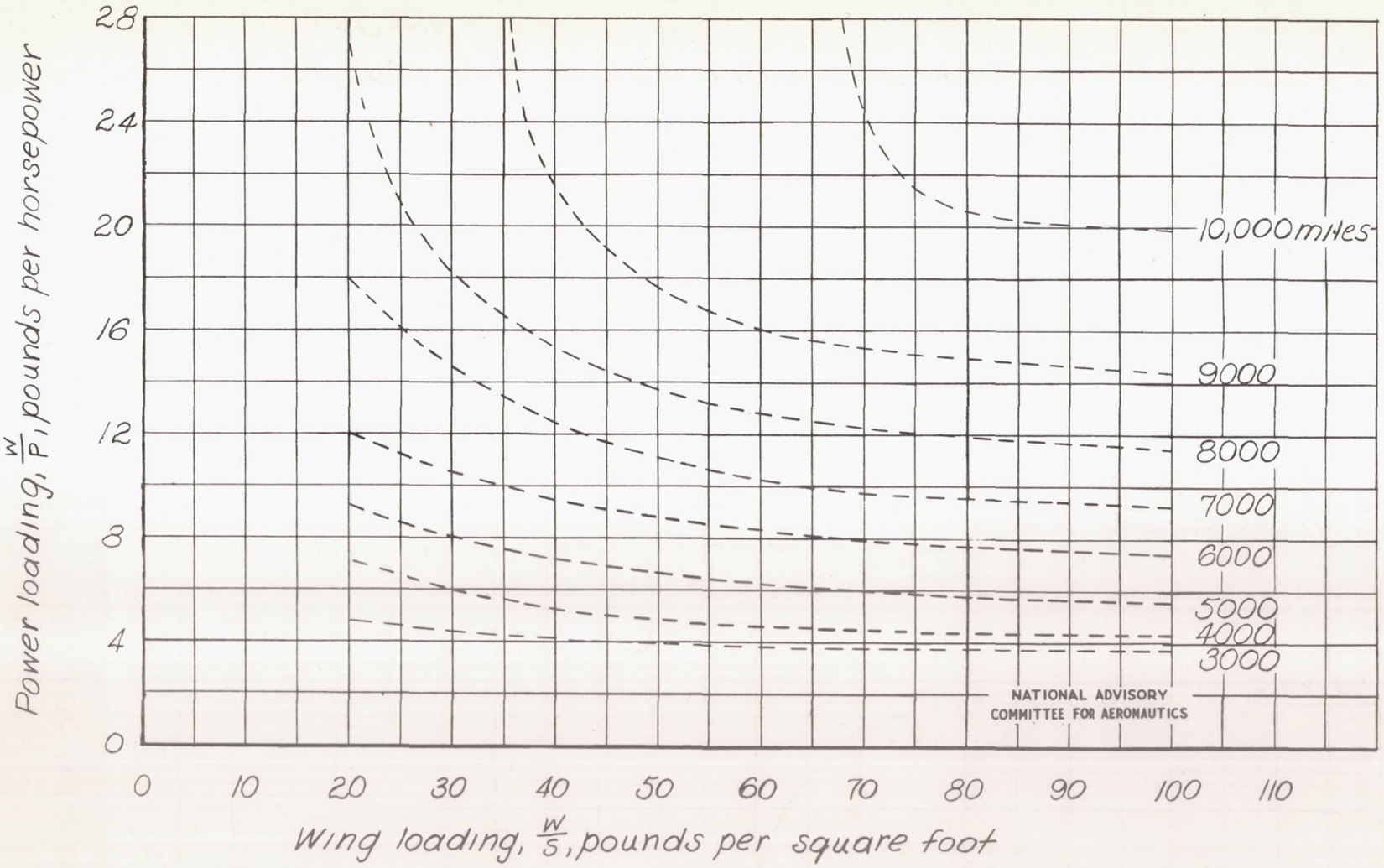
(f) Range for conventional airplane at 10,000-foot altitude.

Figure 3.-Continued.



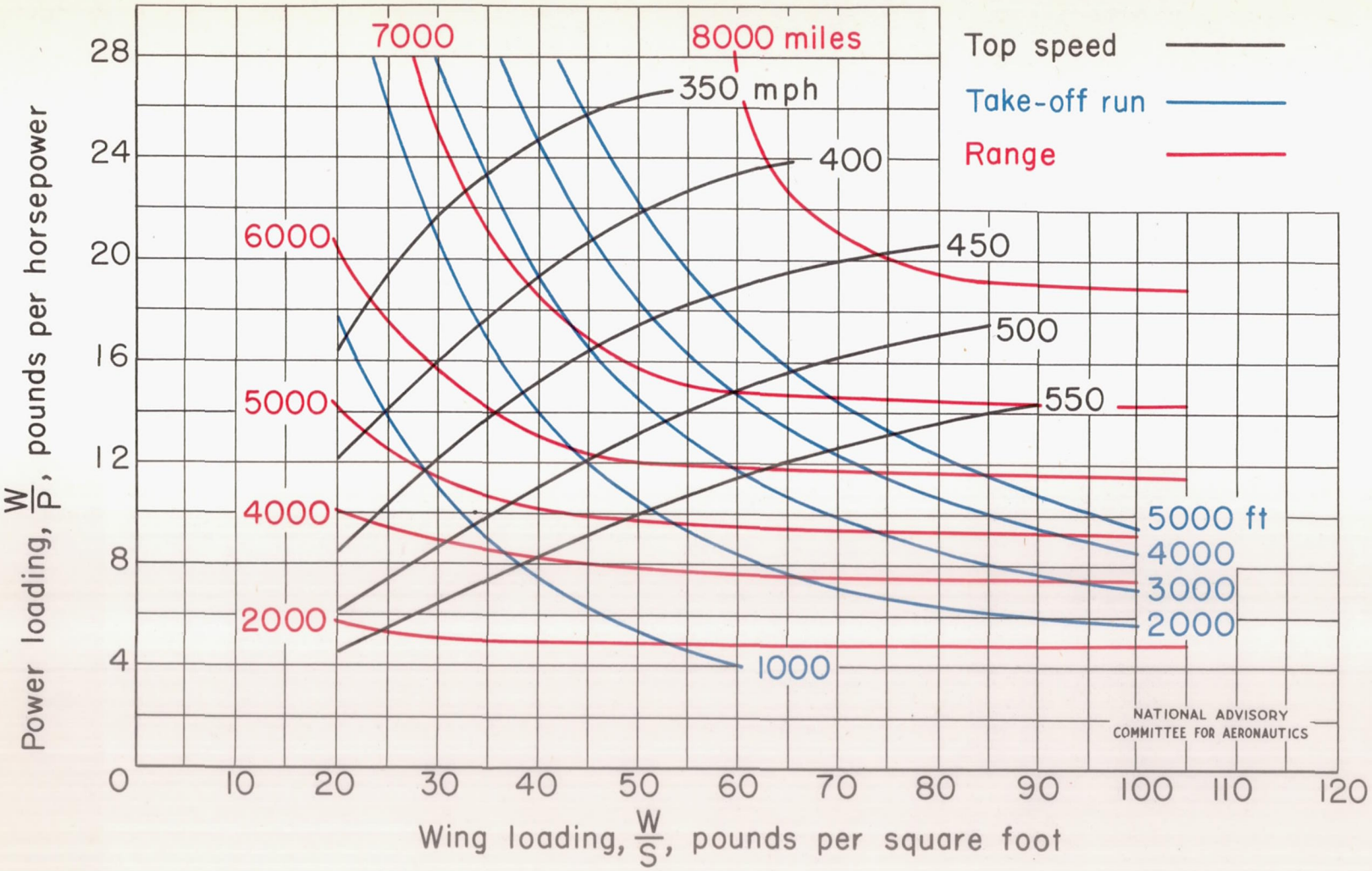
(g) Range for tail-boom airplane at 10,000-foot altitude.

Figure 3.- Continued.



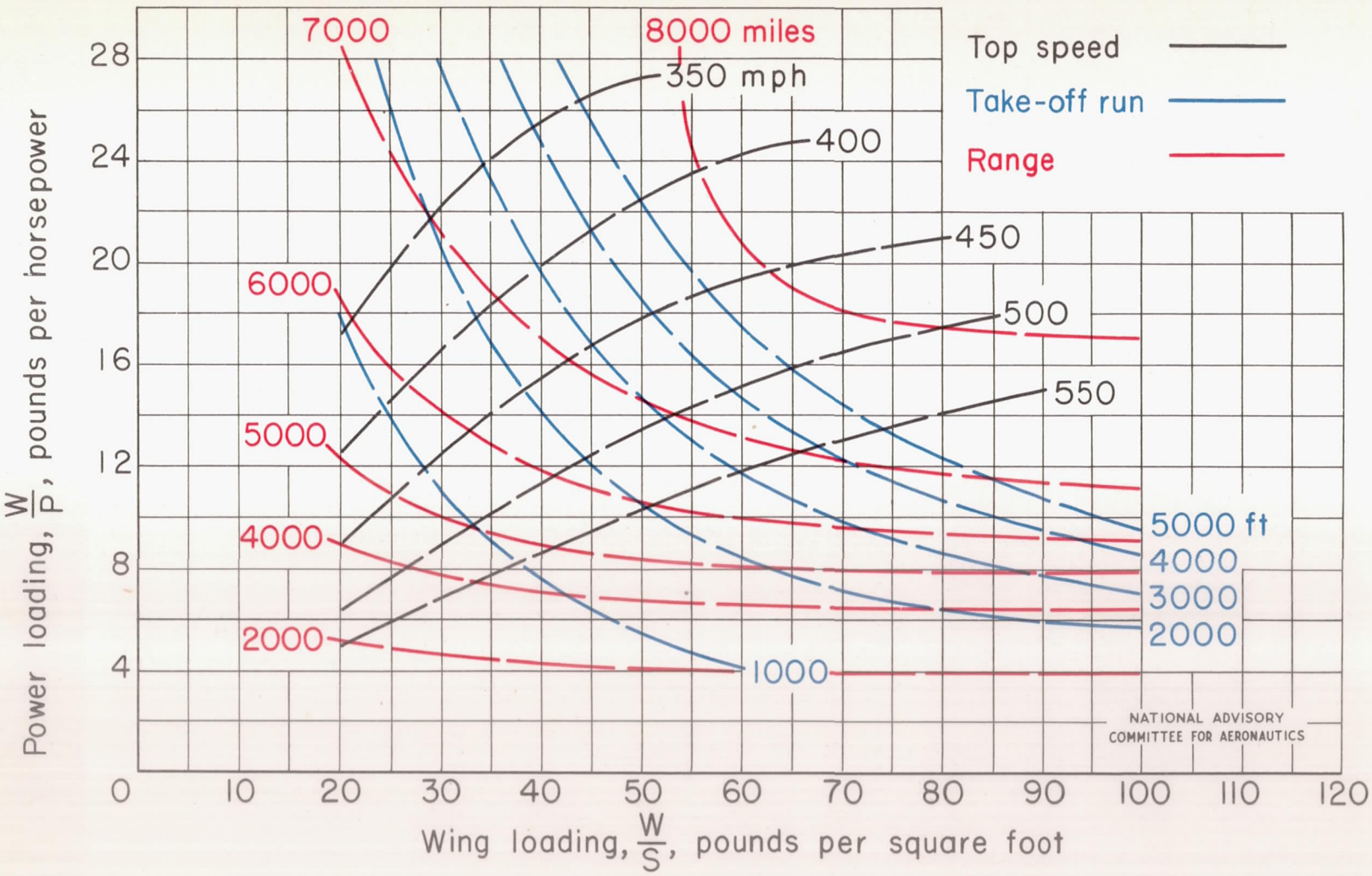
(h) Range for tailless airplanes at 10,000-foot altitude.

Figure 3.- Concluded.



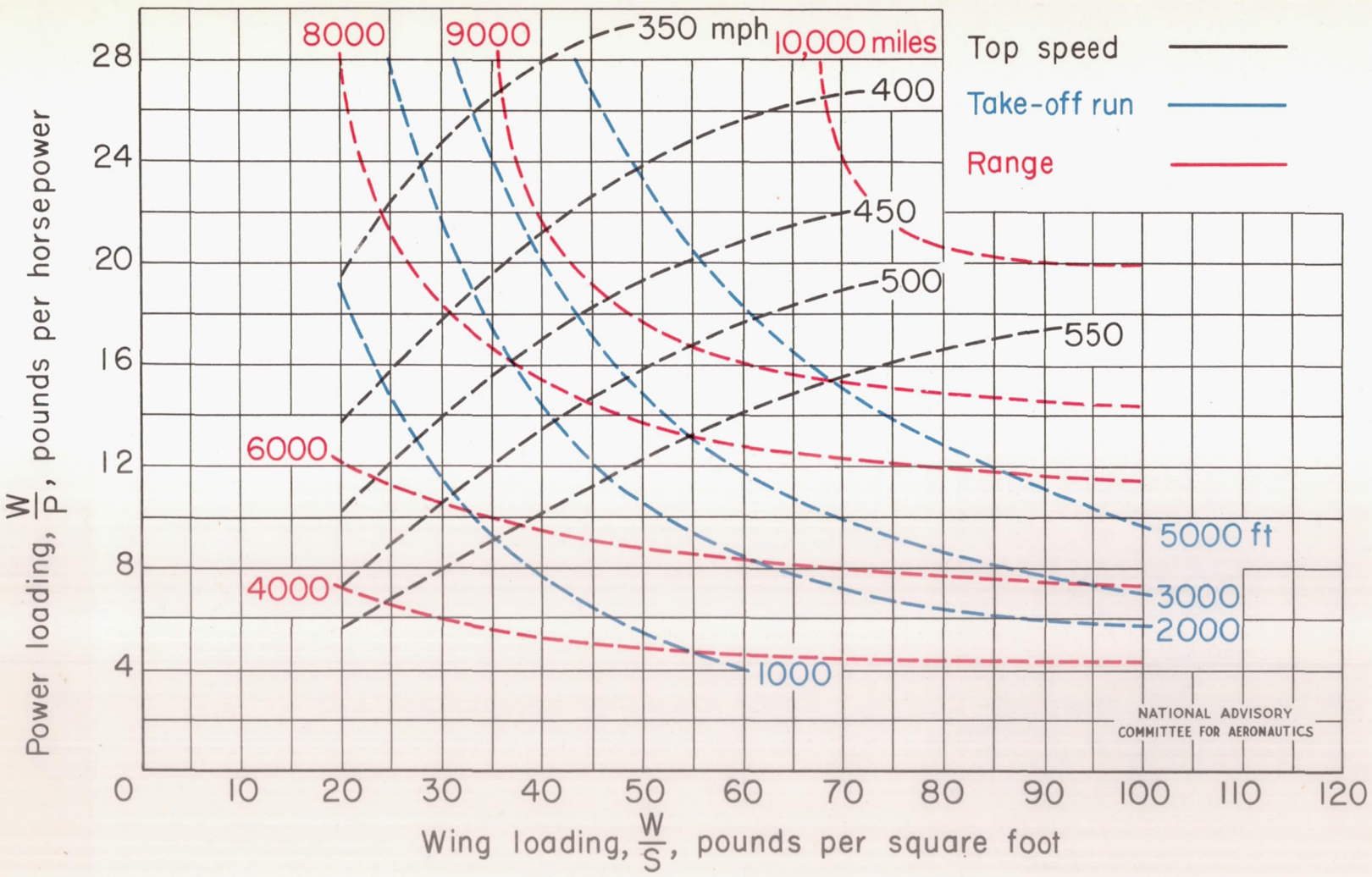
(a) Conventional airplanes.

Figure 4.- Composite performance charts for airplanes with 42,000 brake horsepower.



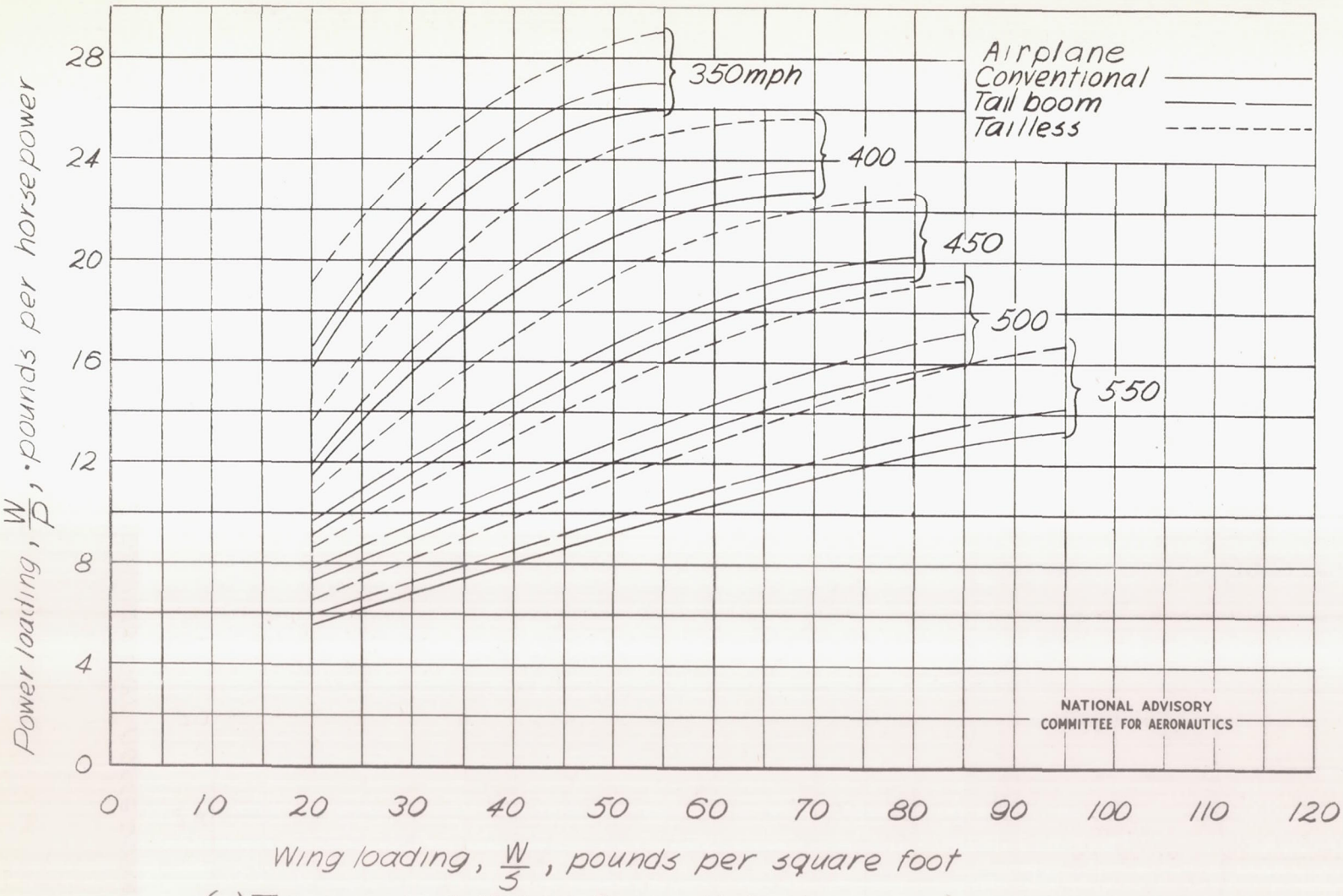
(b) Tail-boom airplanes.

Figure 4.- Continued.



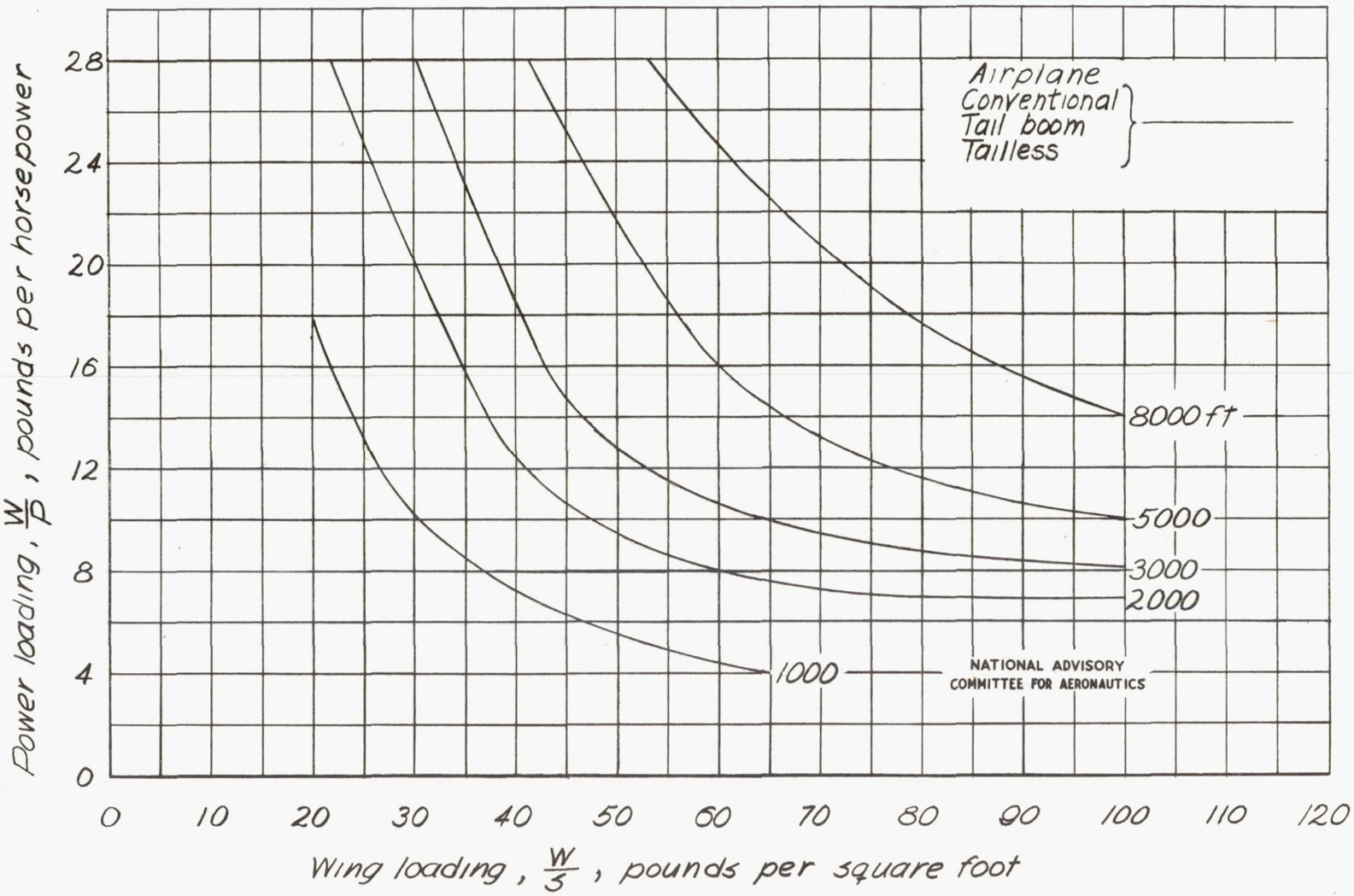
(c) Tailless airplanes.

Figure 4.- Concluded.



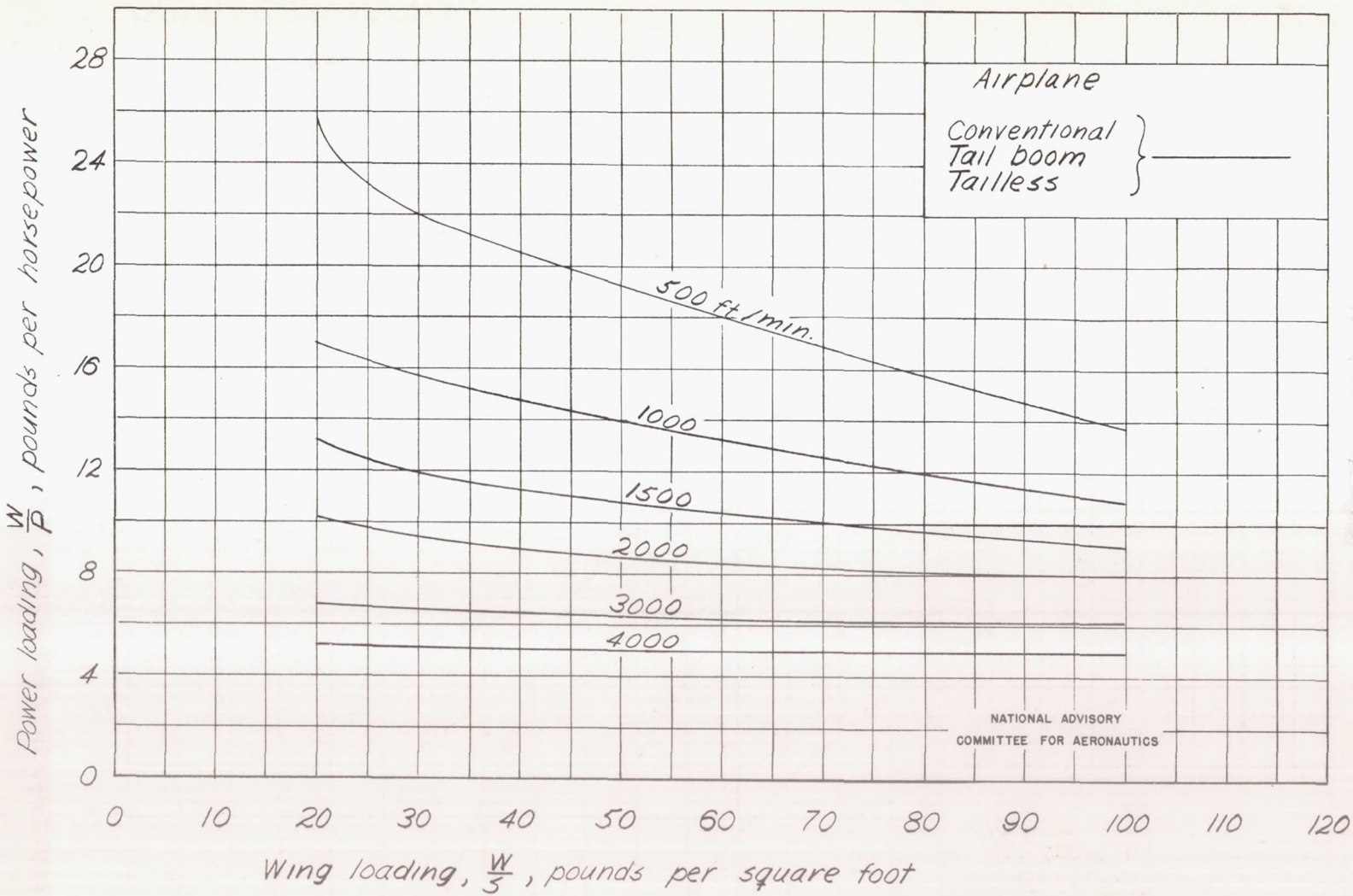
(a) Top speed at 10,000-foot altitude.

Figure 5.- Performance charts for conventional, tail-boom, and tailless airplanes with 21,000 brake horsepower.



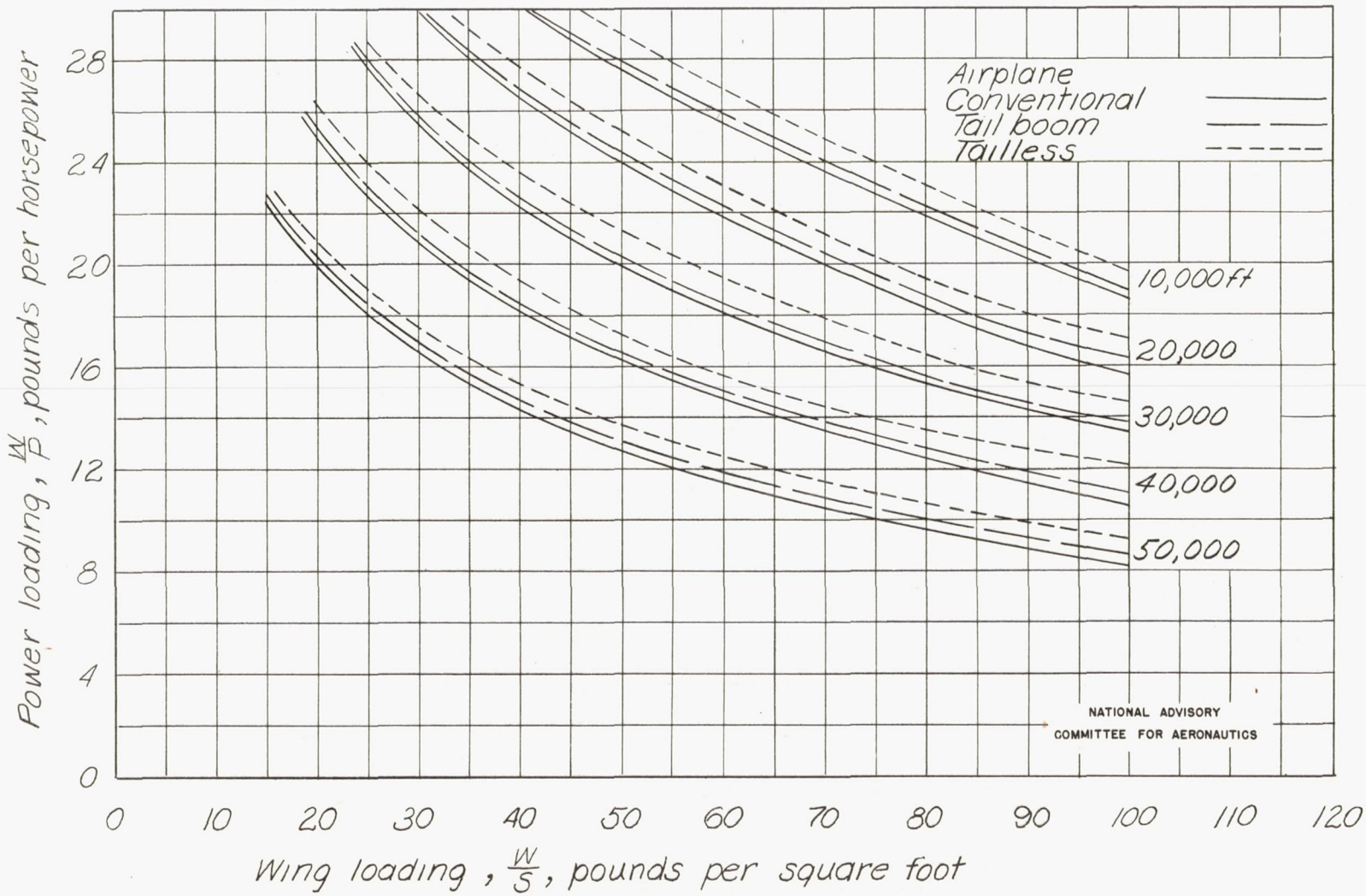
(b) Take-off distance.

Figure 5.-Continued.



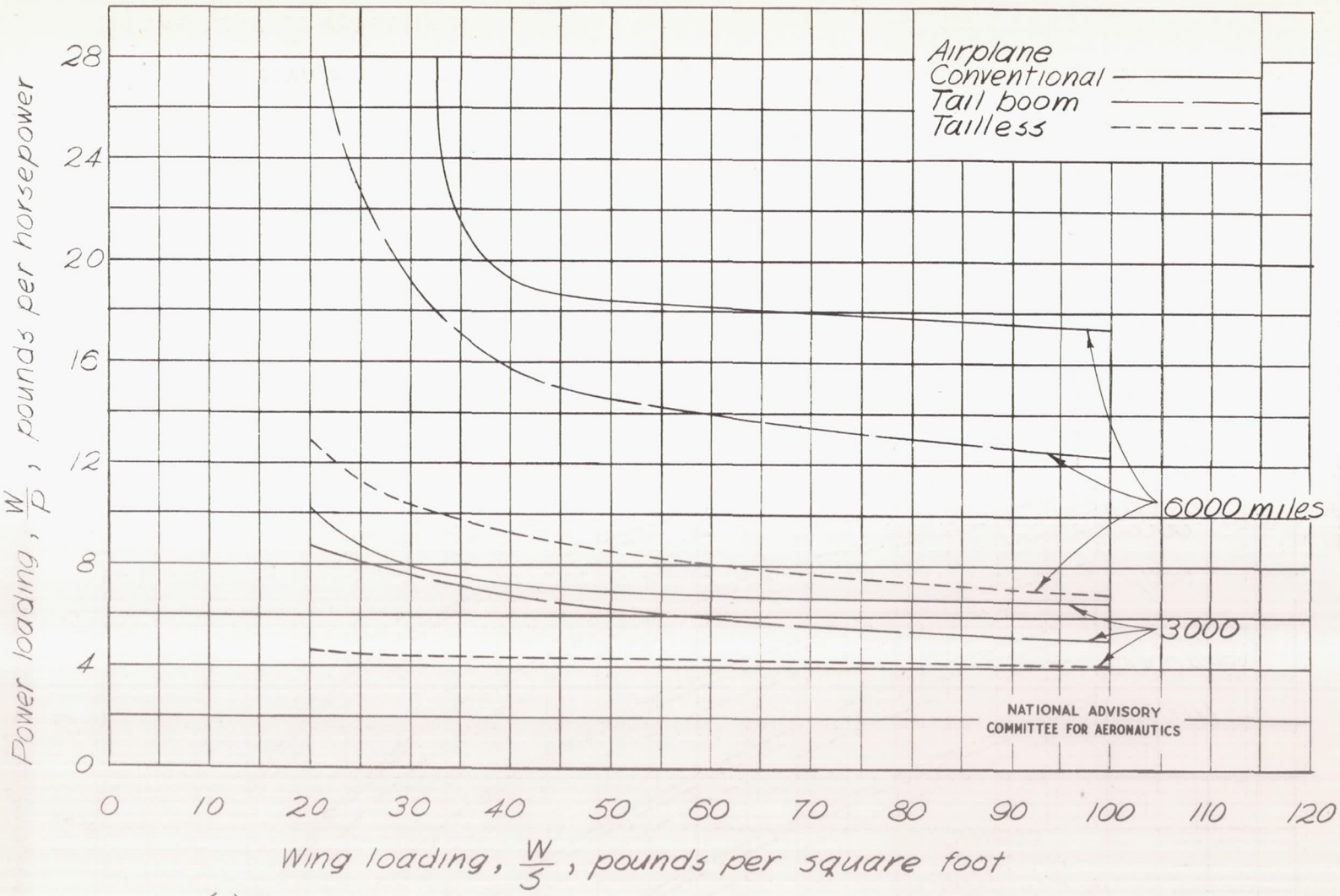
(c) Rate of climb at maximum L/D at 10,000-foot altitude.

Figure 5.- Continued.



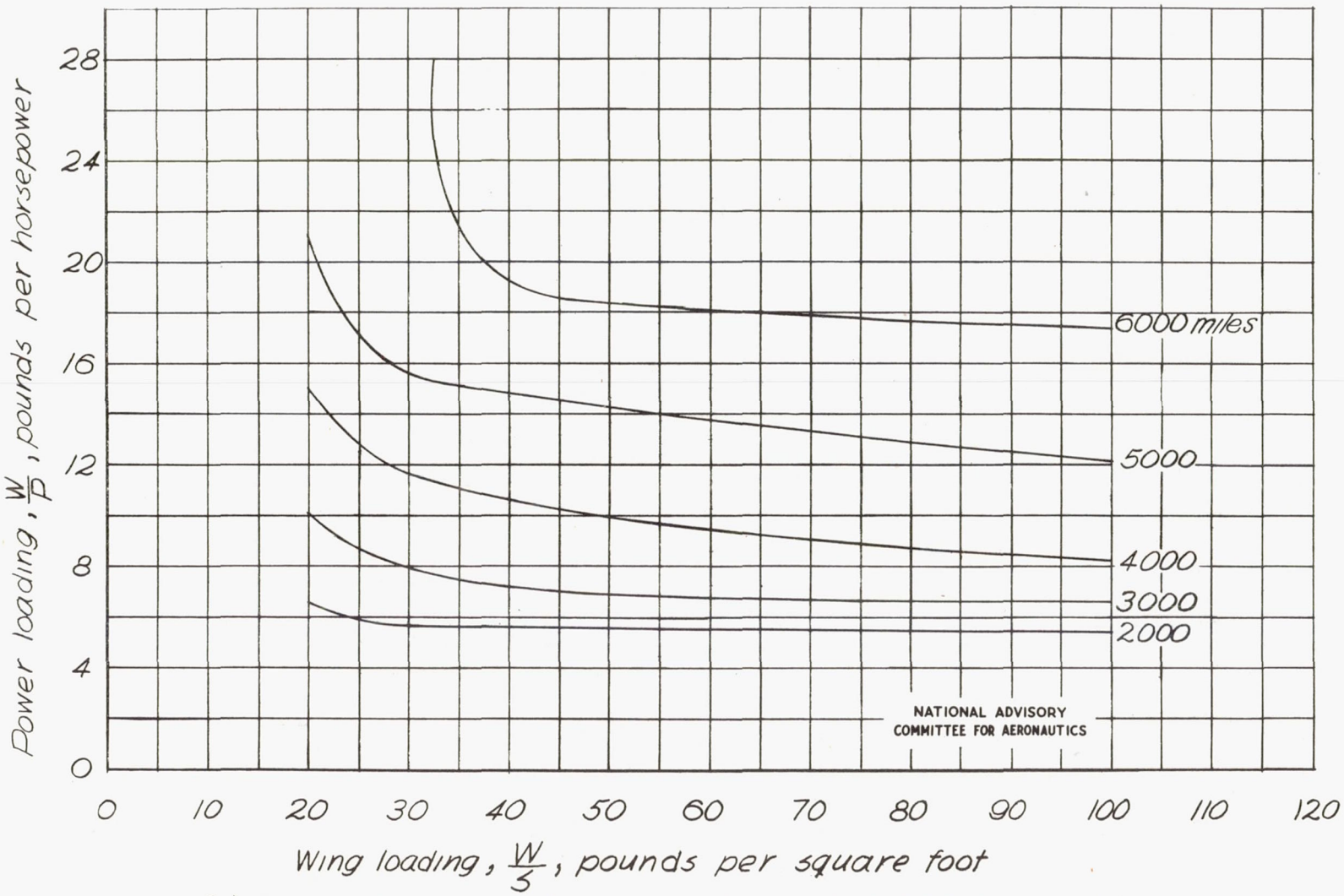
(d) Service ceiling.

Figure 5.-Continued.



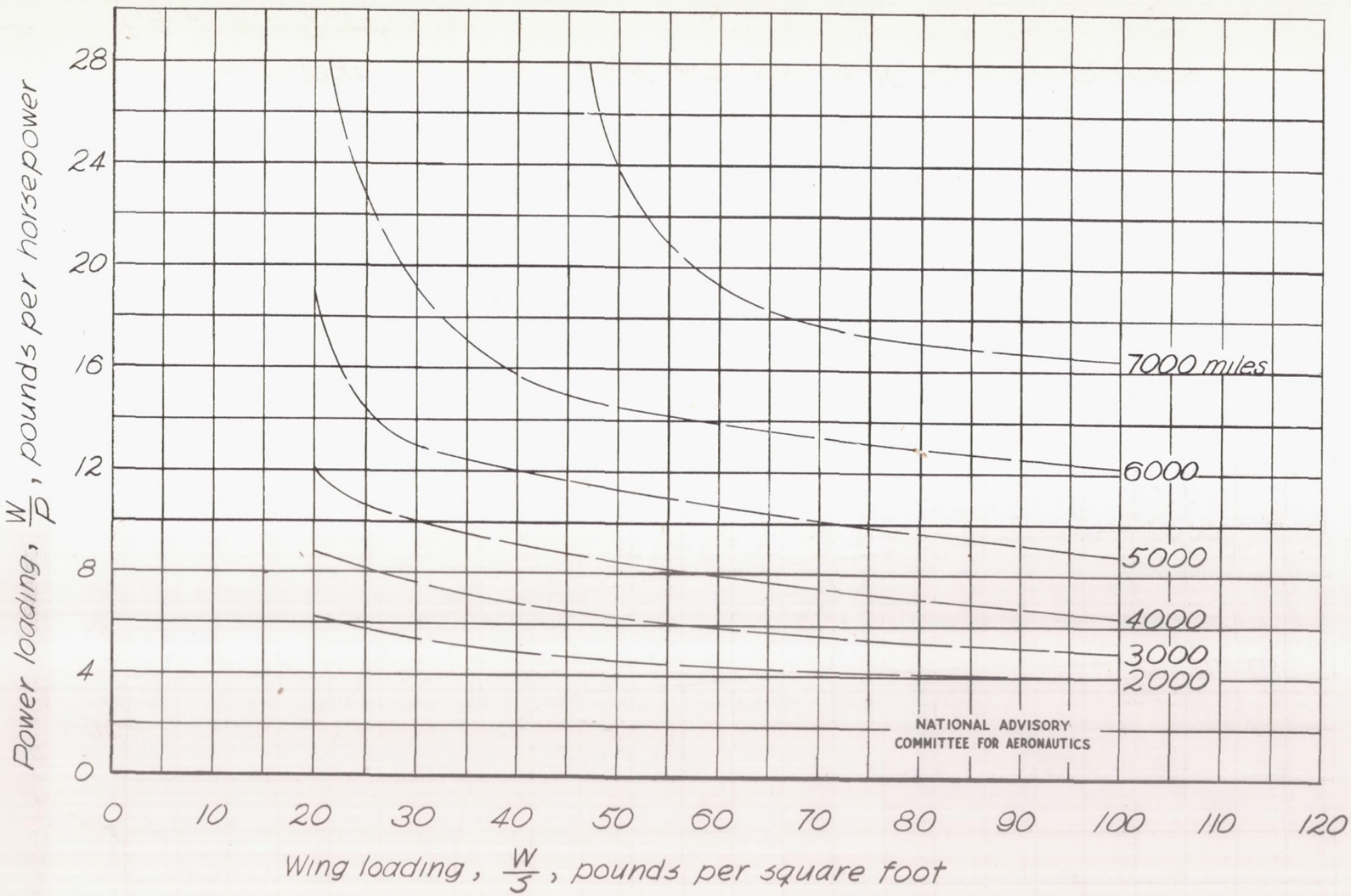
(e) Range at 10,000-foot altitude.

Figure 5.- Continued.



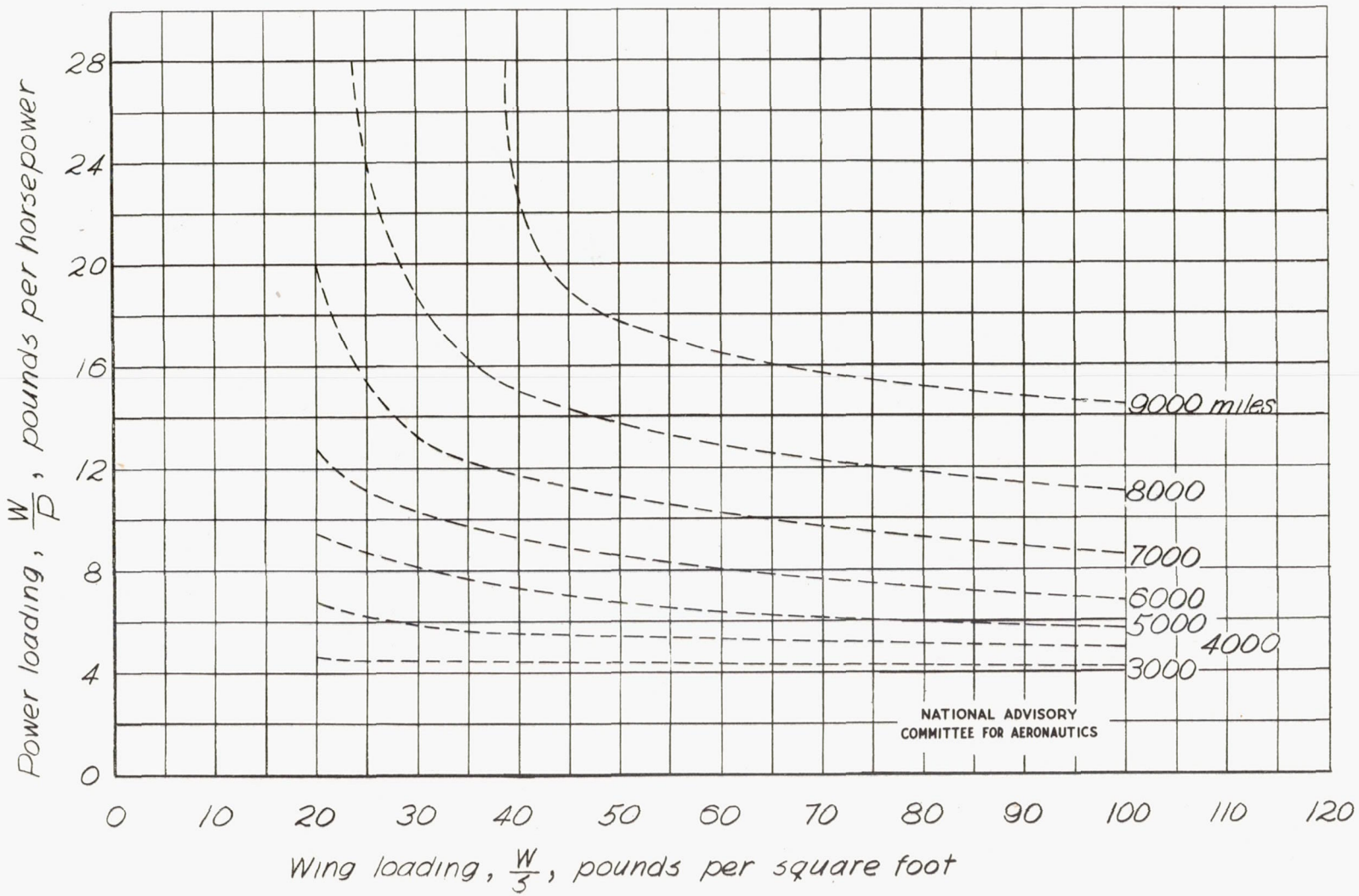
(f) Range for conventional airplane at 10,000-foot altitude.

Figure 5.-Continued.



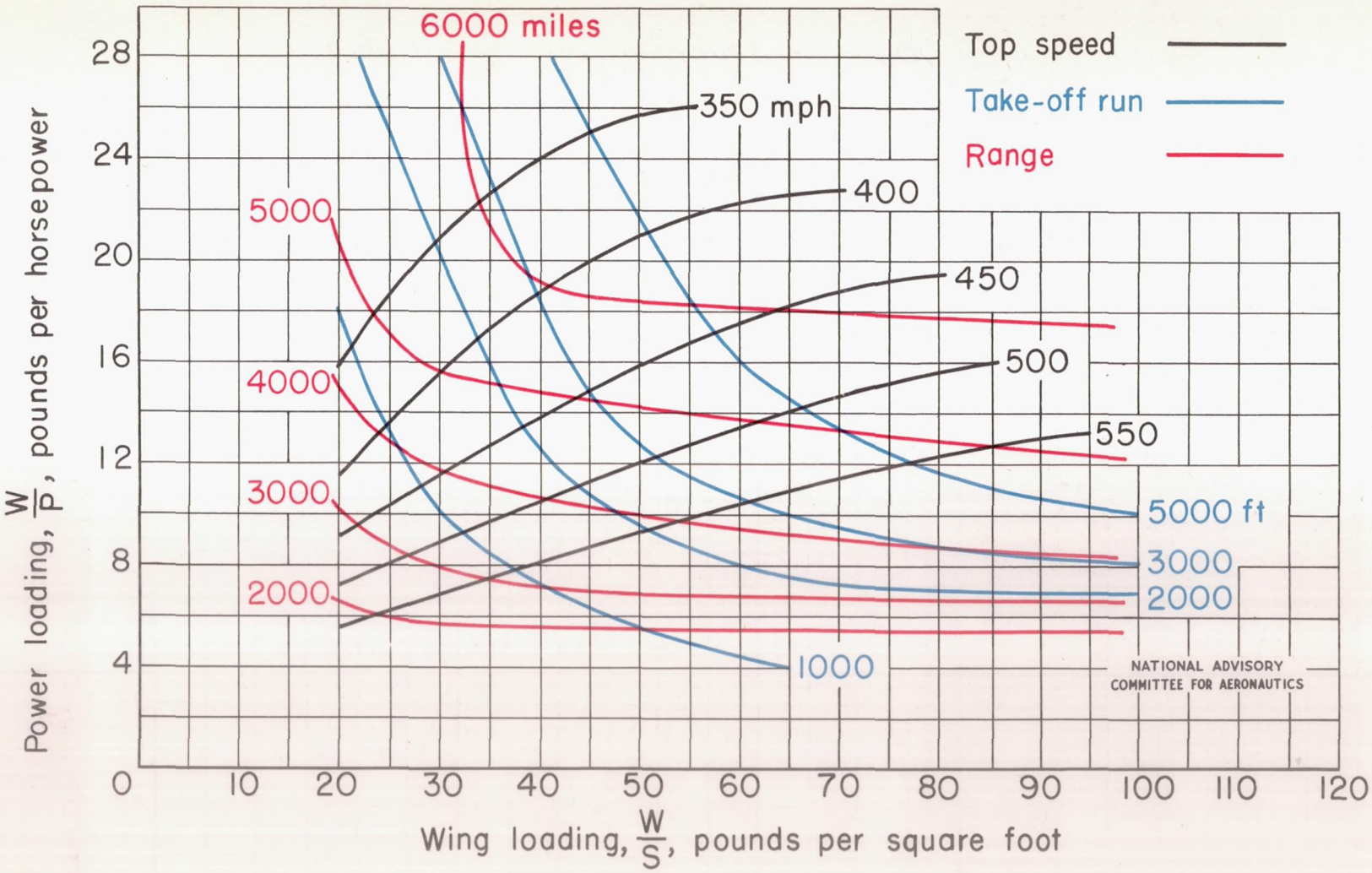
(g) Range for tail-boom airplane at 10,000-foot altitude.

Figure 5.- Continued.



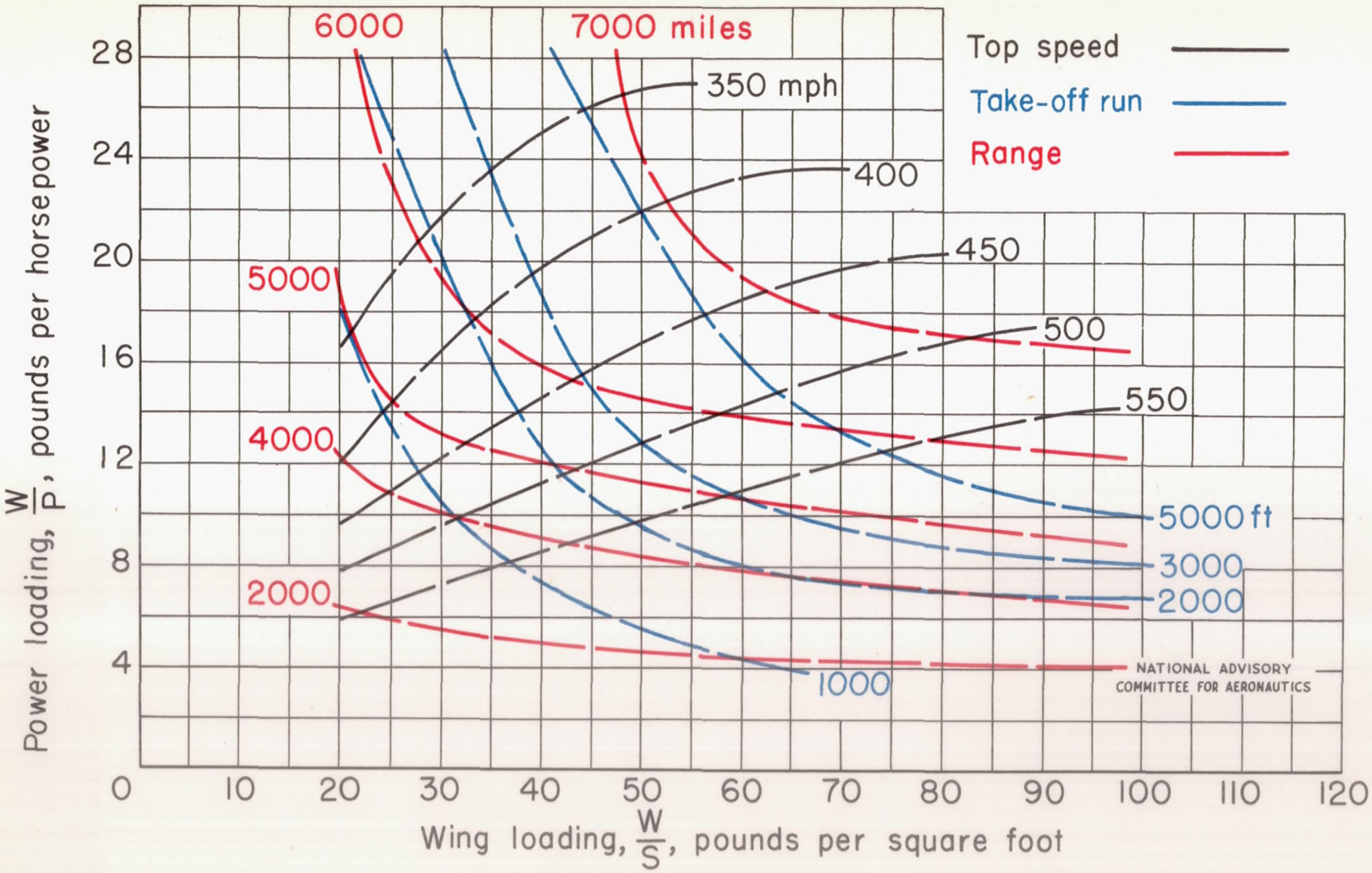
(h) Range for tailless airplanes at 10,000-foot altitude.

Figure 5.-Concluded.



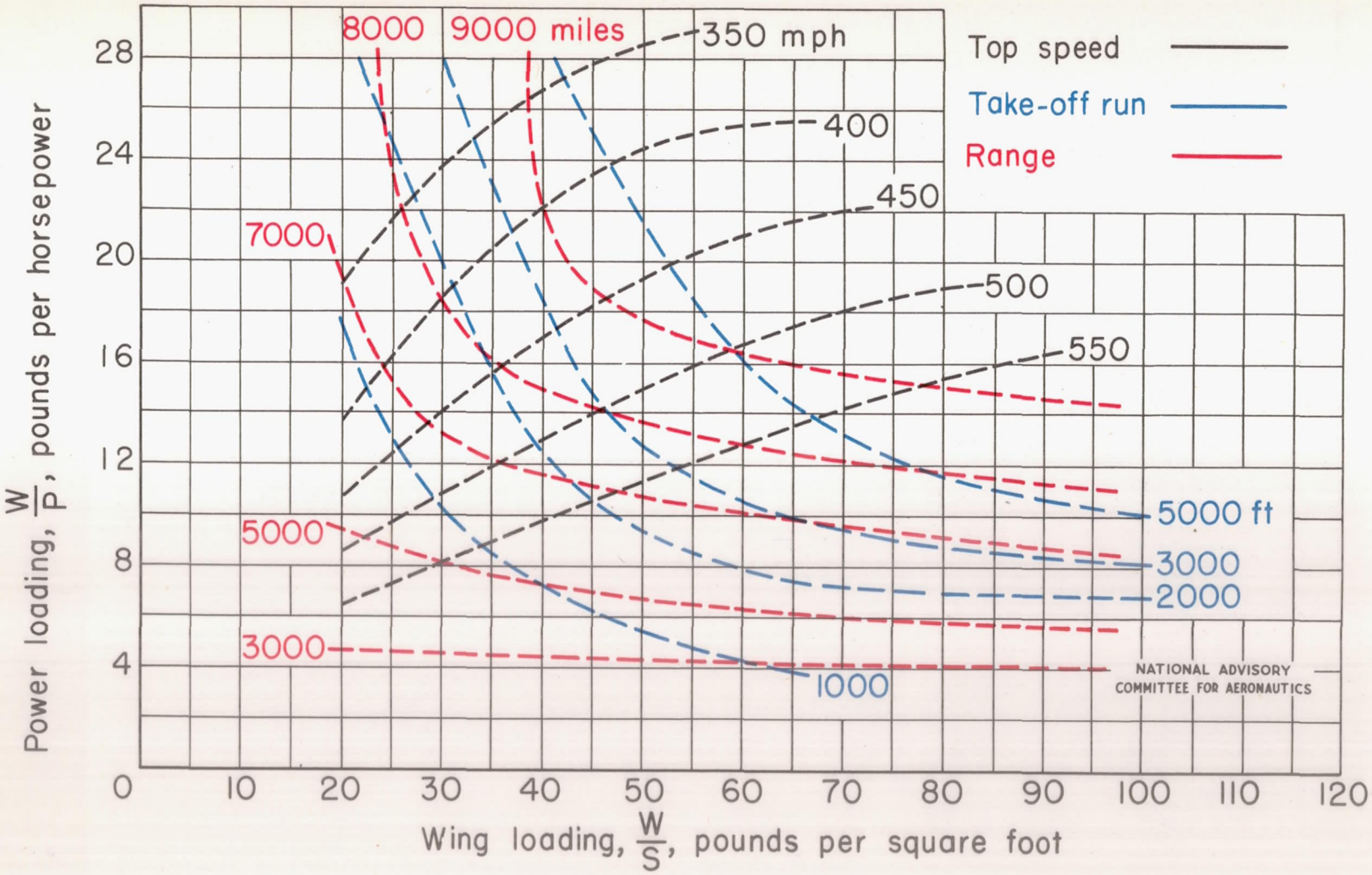
(a) Conventional airplanes.

Figure 6.- Composite performance charts for airplanes with 21,000 brake horsepower.



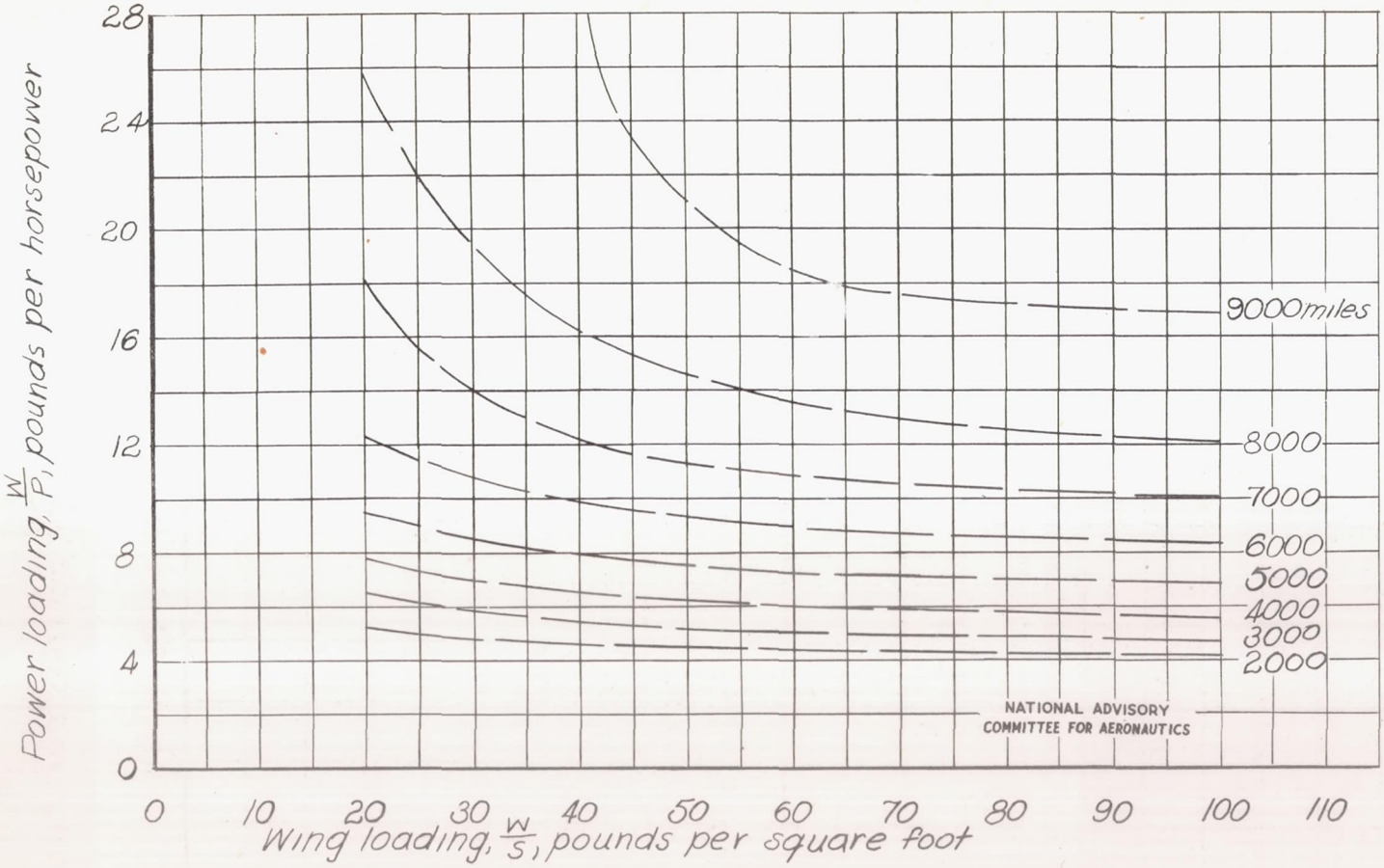
(b) Tail-boom airplanes.

Figure 6.- Continued.



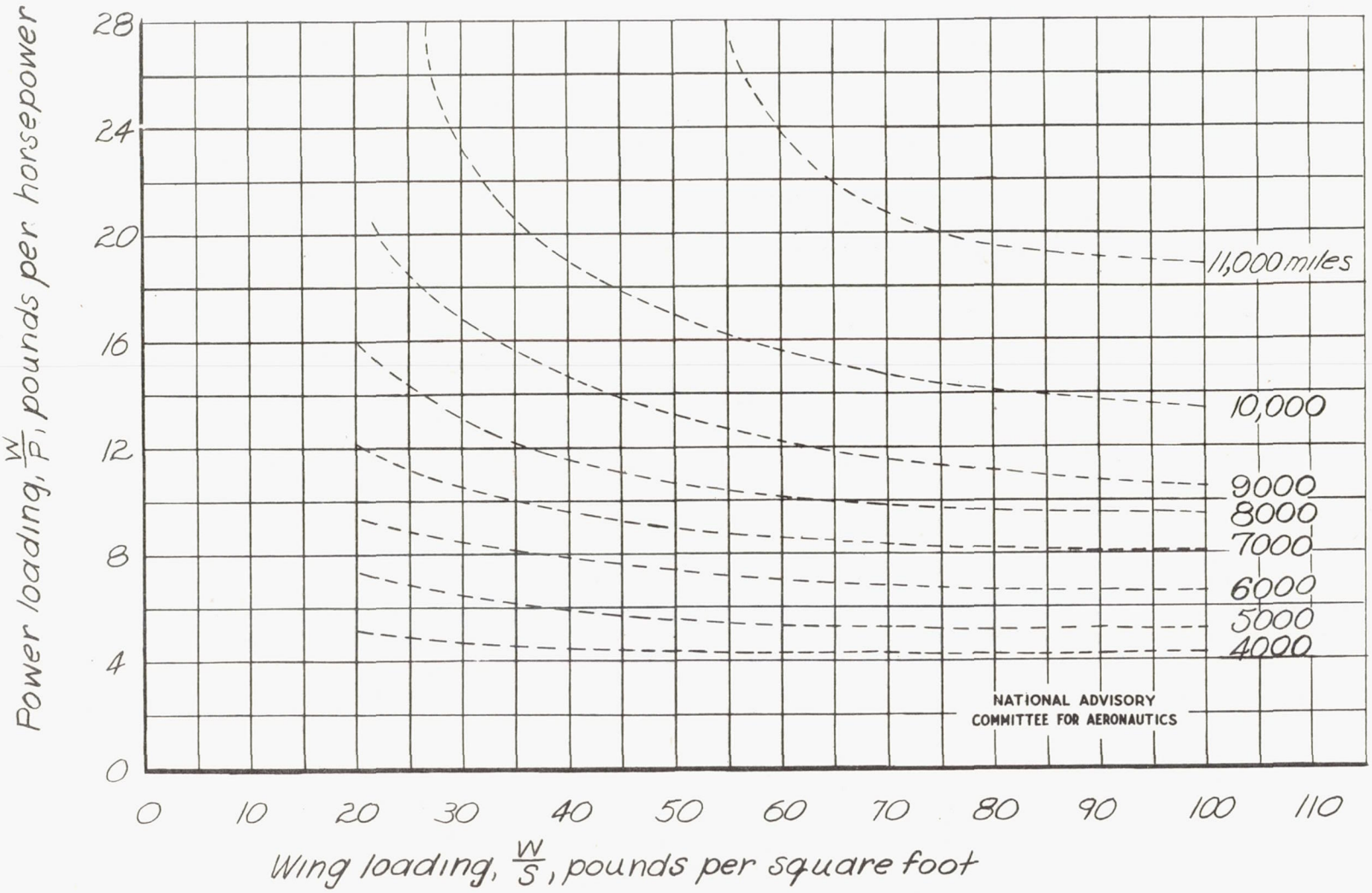
(c) Tailless airplanes.

Figure 6.- Concluded.



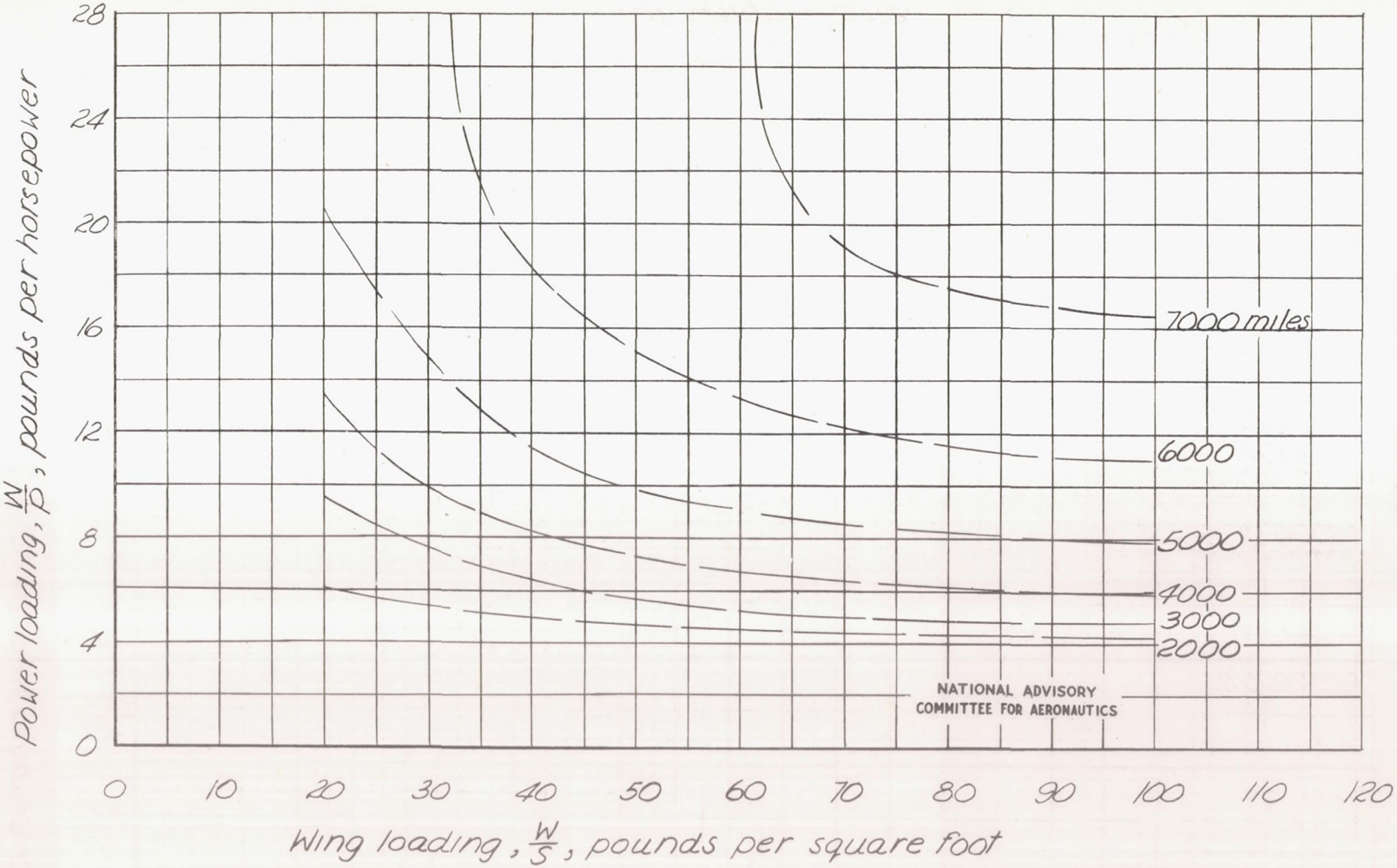
(a) 90 percent structural weight, tail-boom airplane.

Figure 7.- Range for tail-boom and tailless airplane for various percentages of computed structural weight; 42,000 brake horsepower.



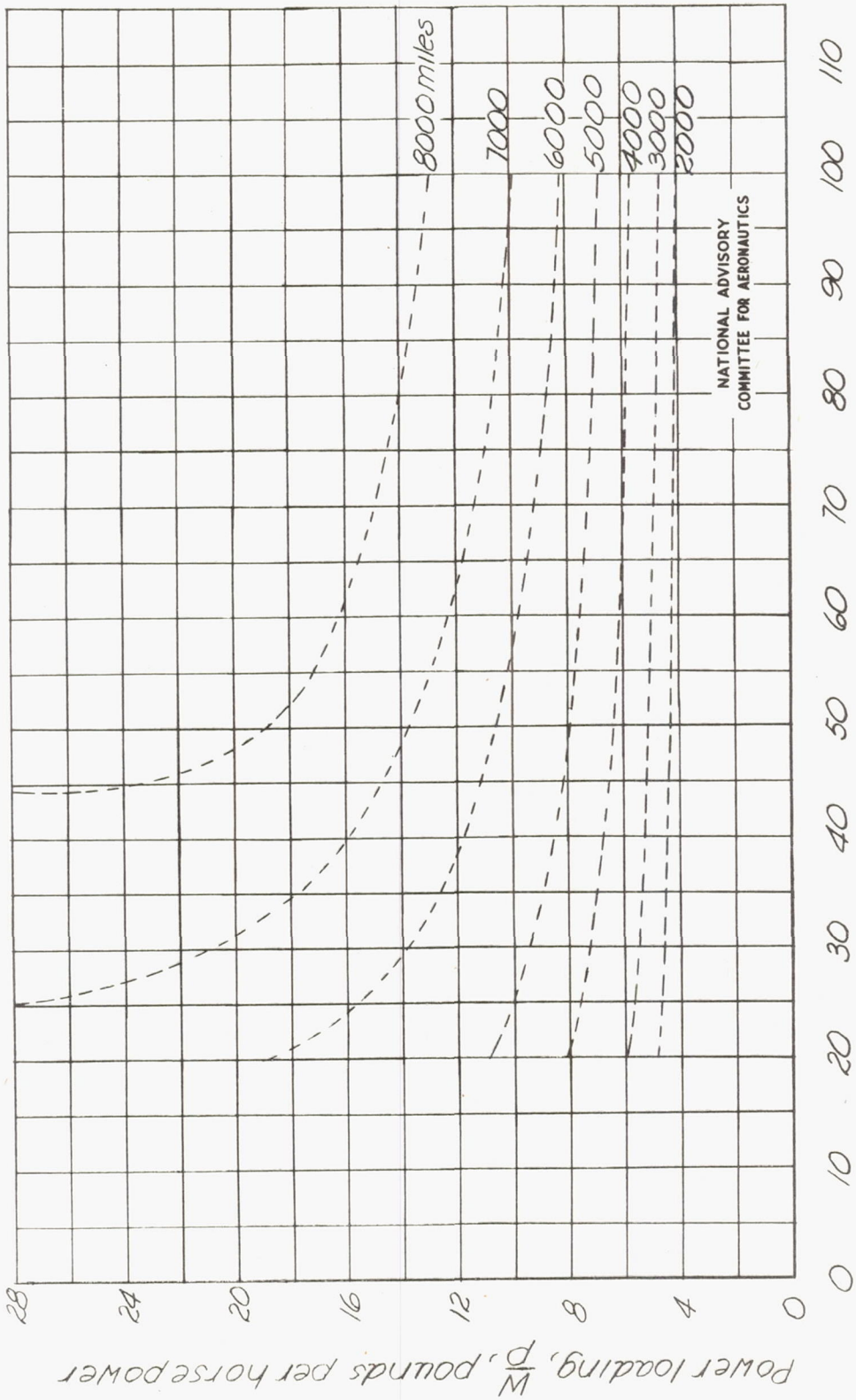
(b) 90 percent structural weight, tailless airplane.

Figure 7.- Continued.



(c) 110 percent structural weight, tail-boom airplane.

Figure 7.- Continued.



(d) 110 percent structural weight, tailless airplane.

Figure 7.-Concluded.

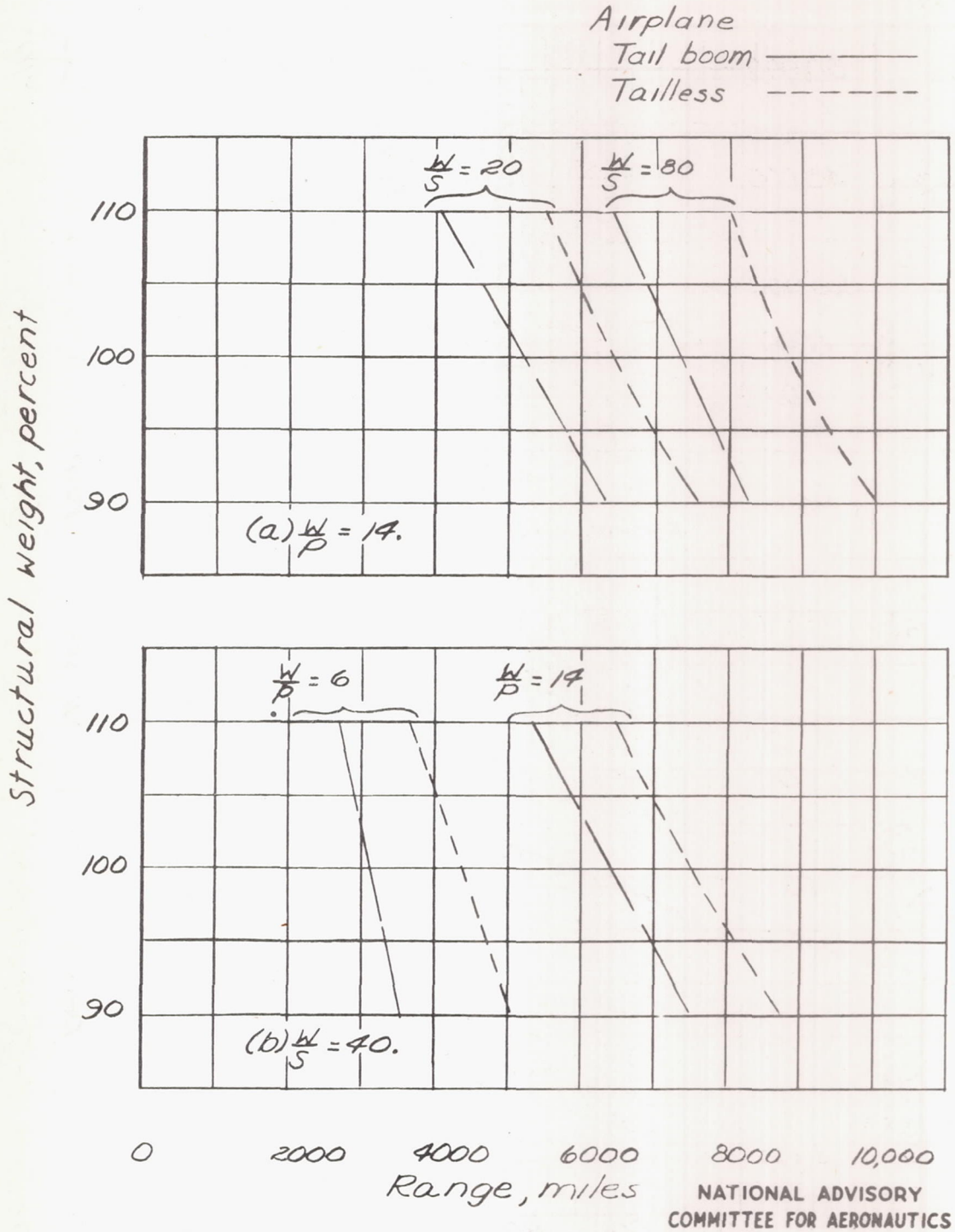
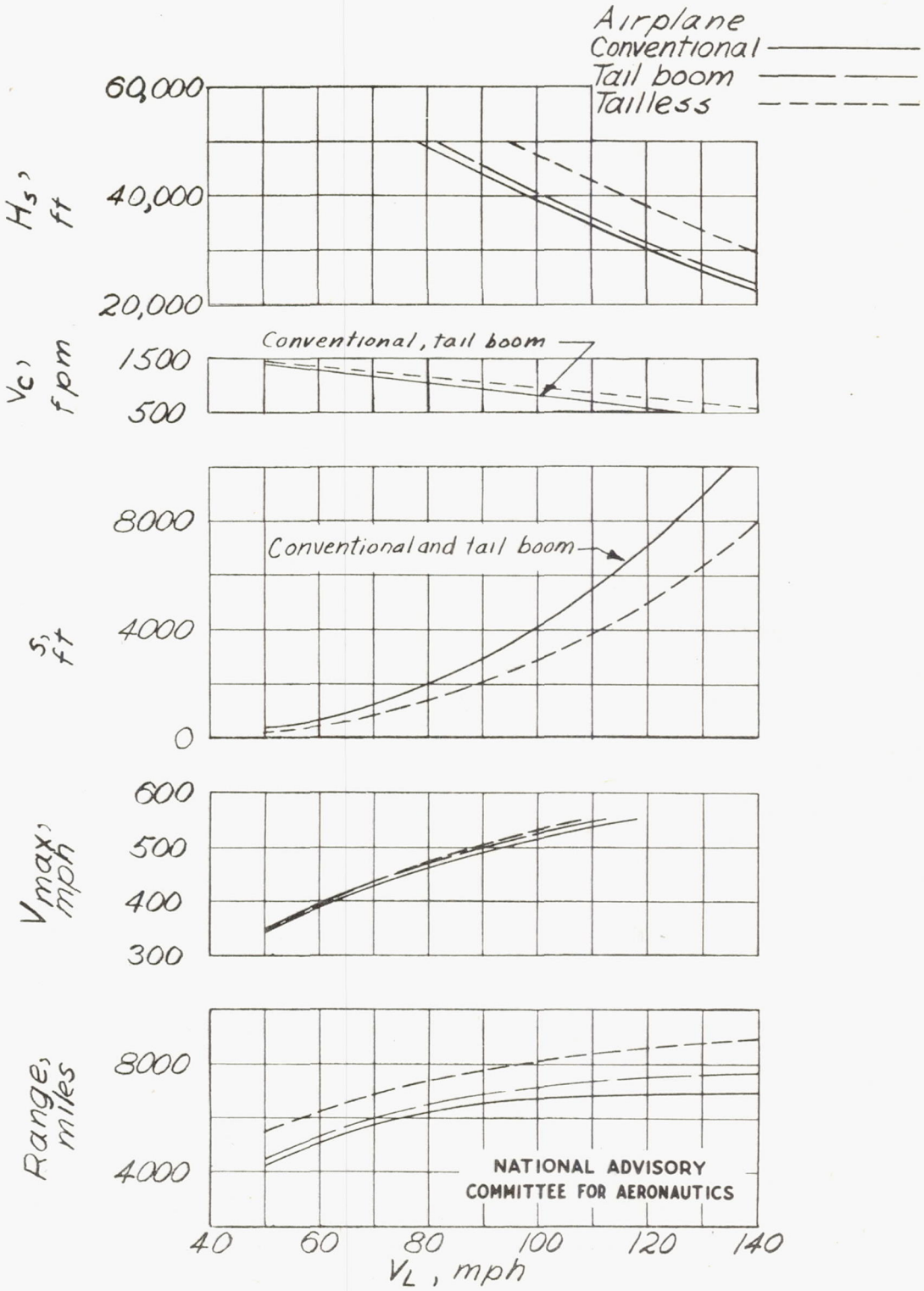
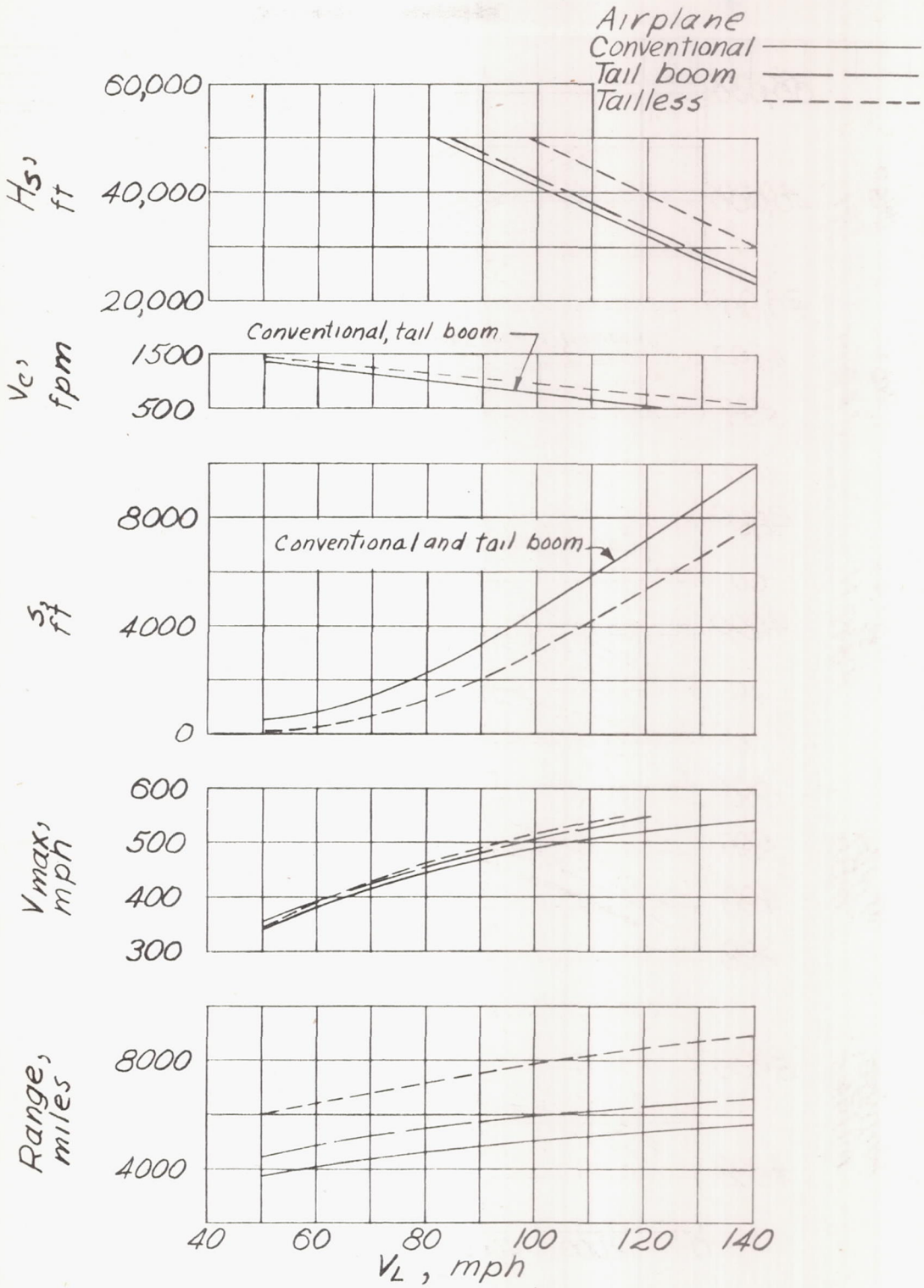


Figure 8.- Variation of range with structural weight for tail-boom and tailless airplanes with 42,000 brake horsepower.



(a) $P = 42{,}000$; $\frac{W}{P} = 14$.

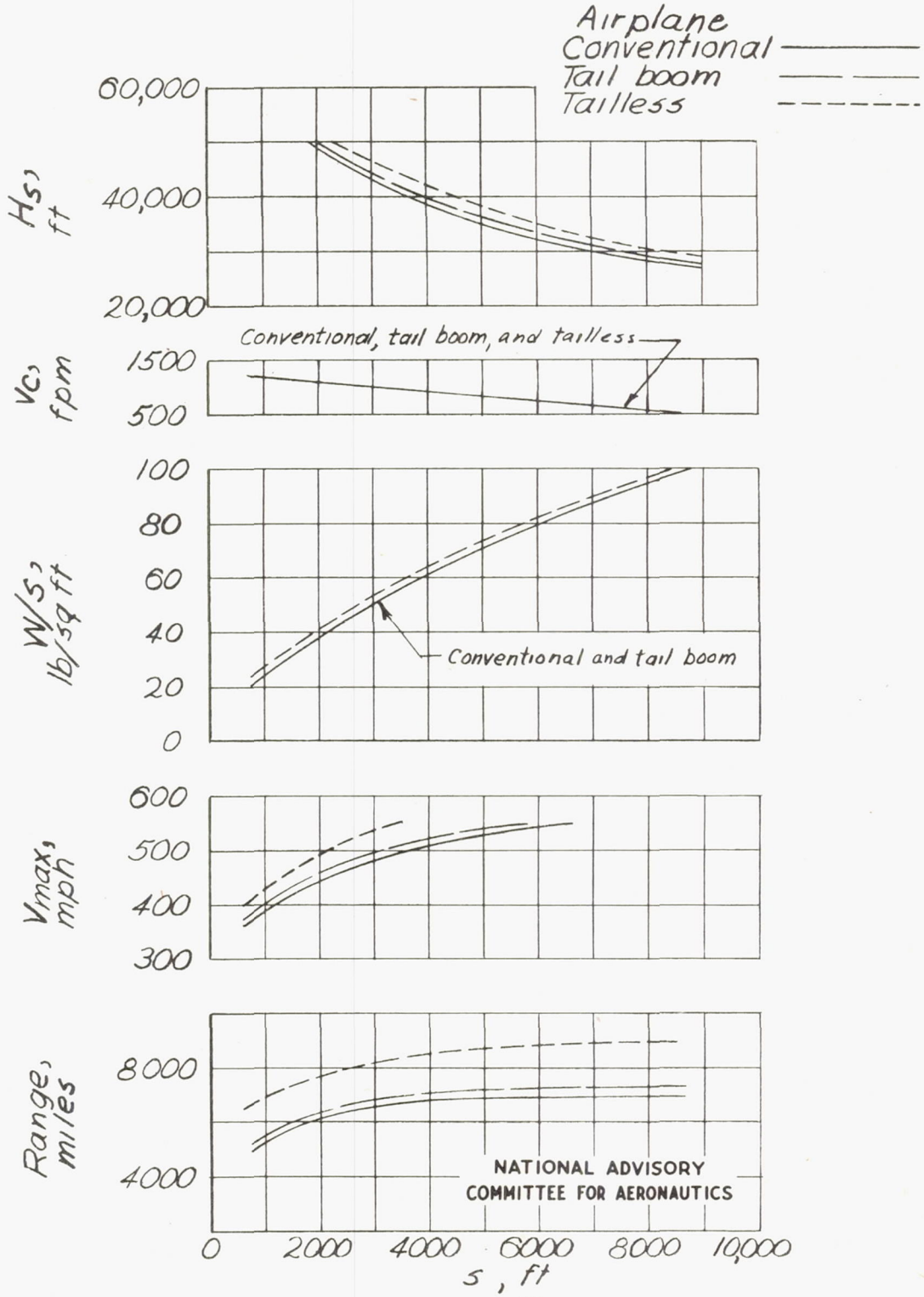
Figure 9.- Variation of performance with landing speed.



(b) $P = 21{,}000$; $\frac{W}{P} = 14$.

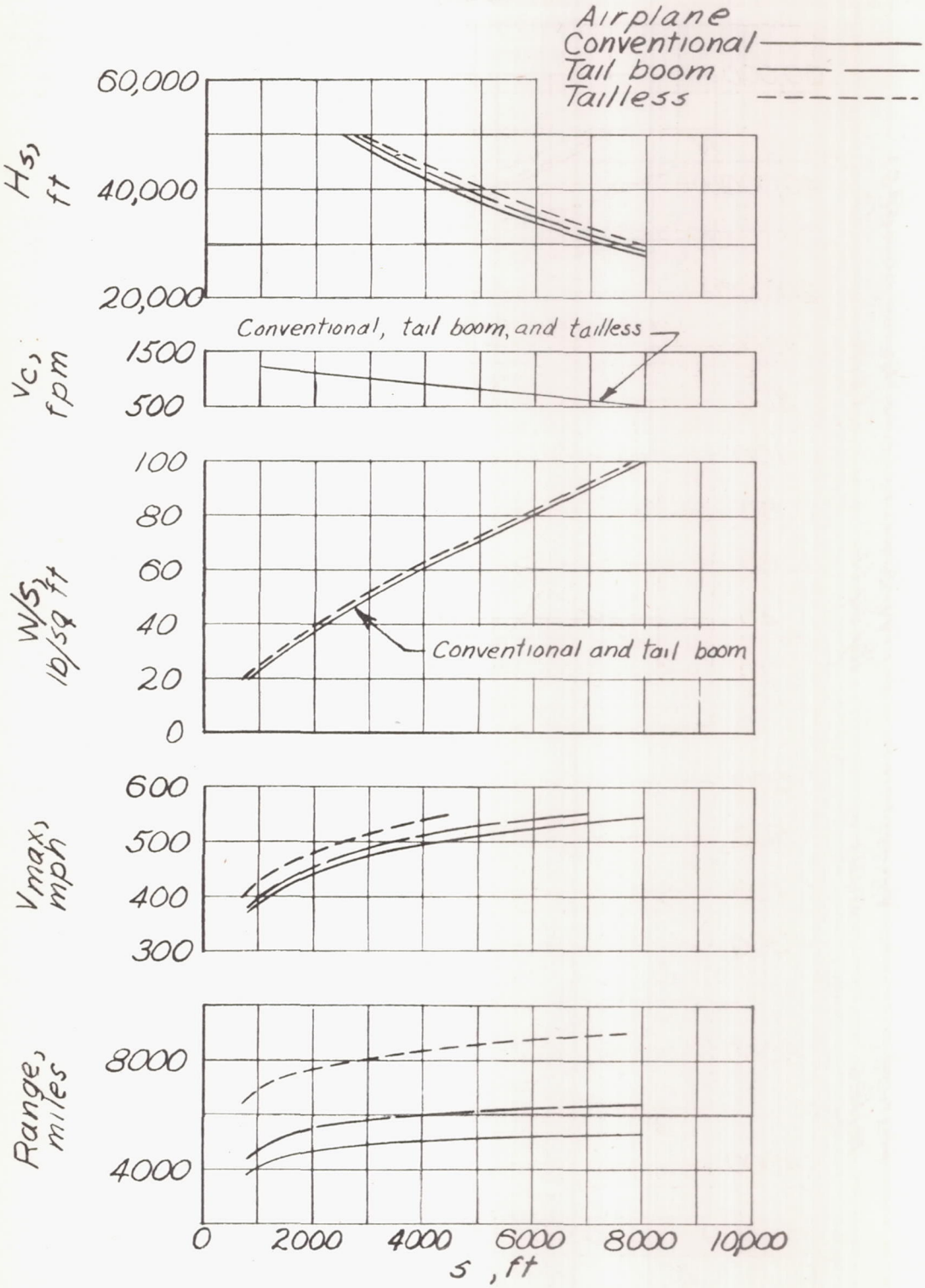
Figure 9.- Concluded.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(a) $P = 42,000$; $\frac{W}{P} = 14$.

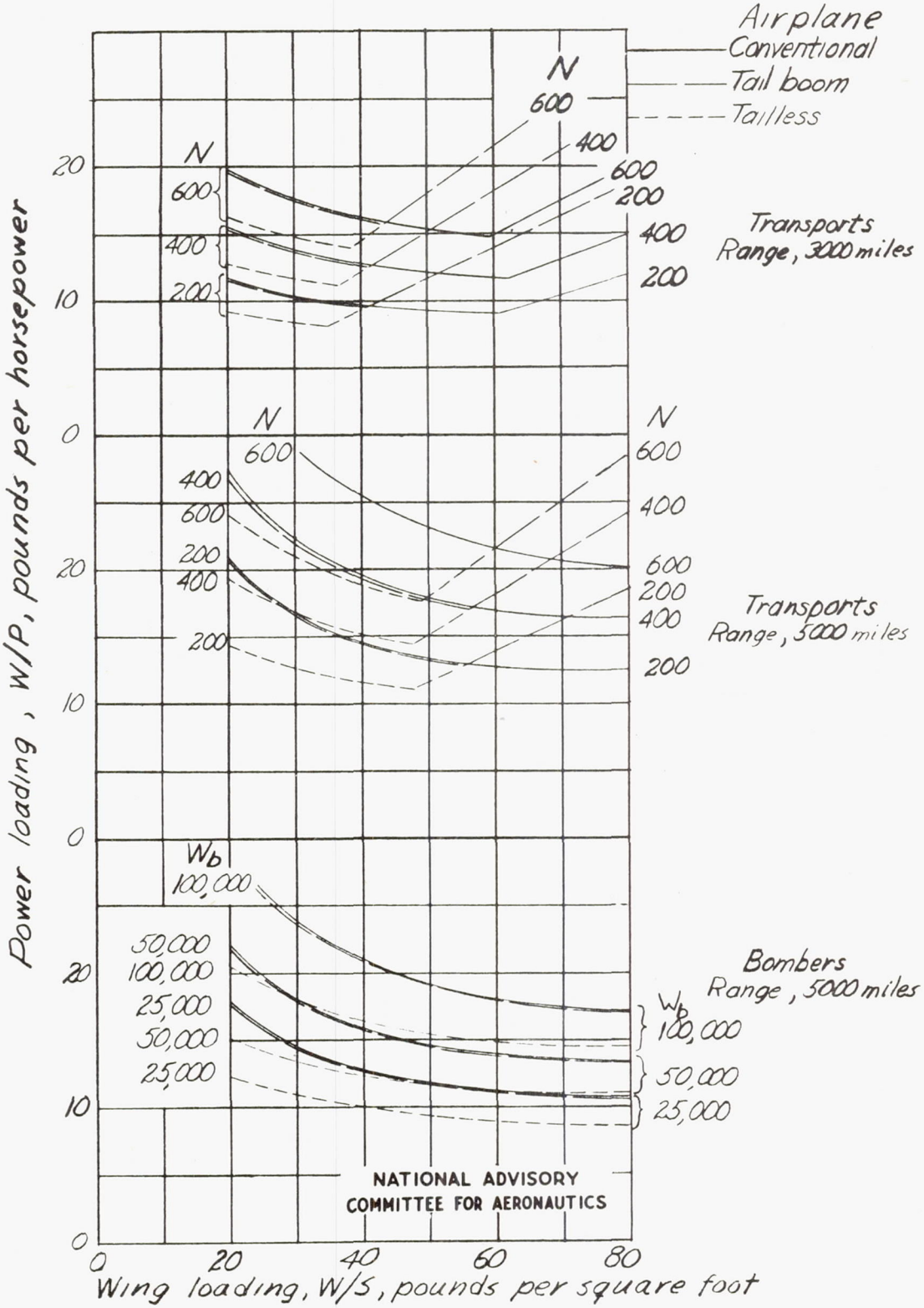
Figure 10.- Variation of performance factors with take-off distance.



(b) $P = 21{,}000$; $\frac{W}{P} = 14$.

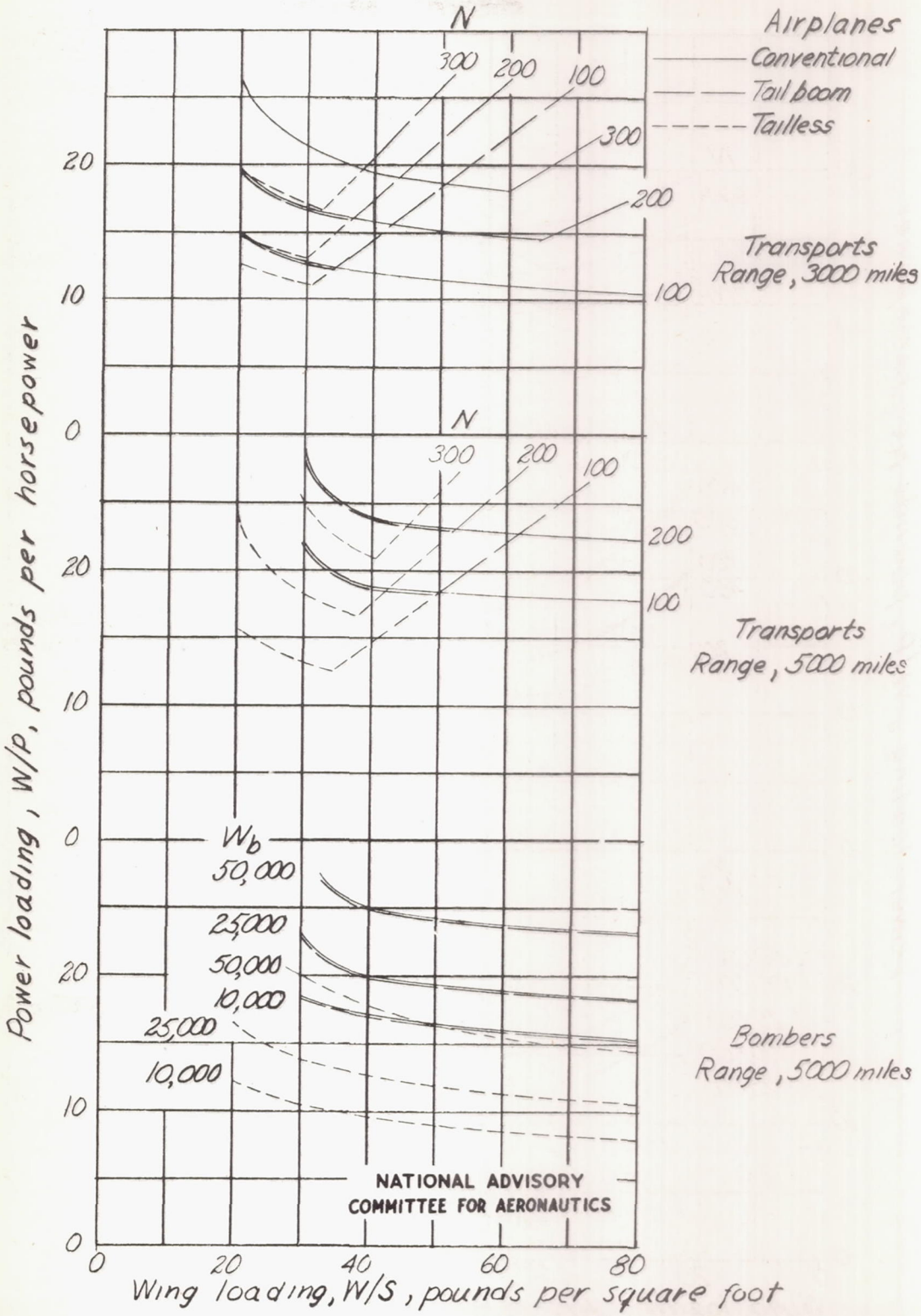
Figure 10.- Concluded.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

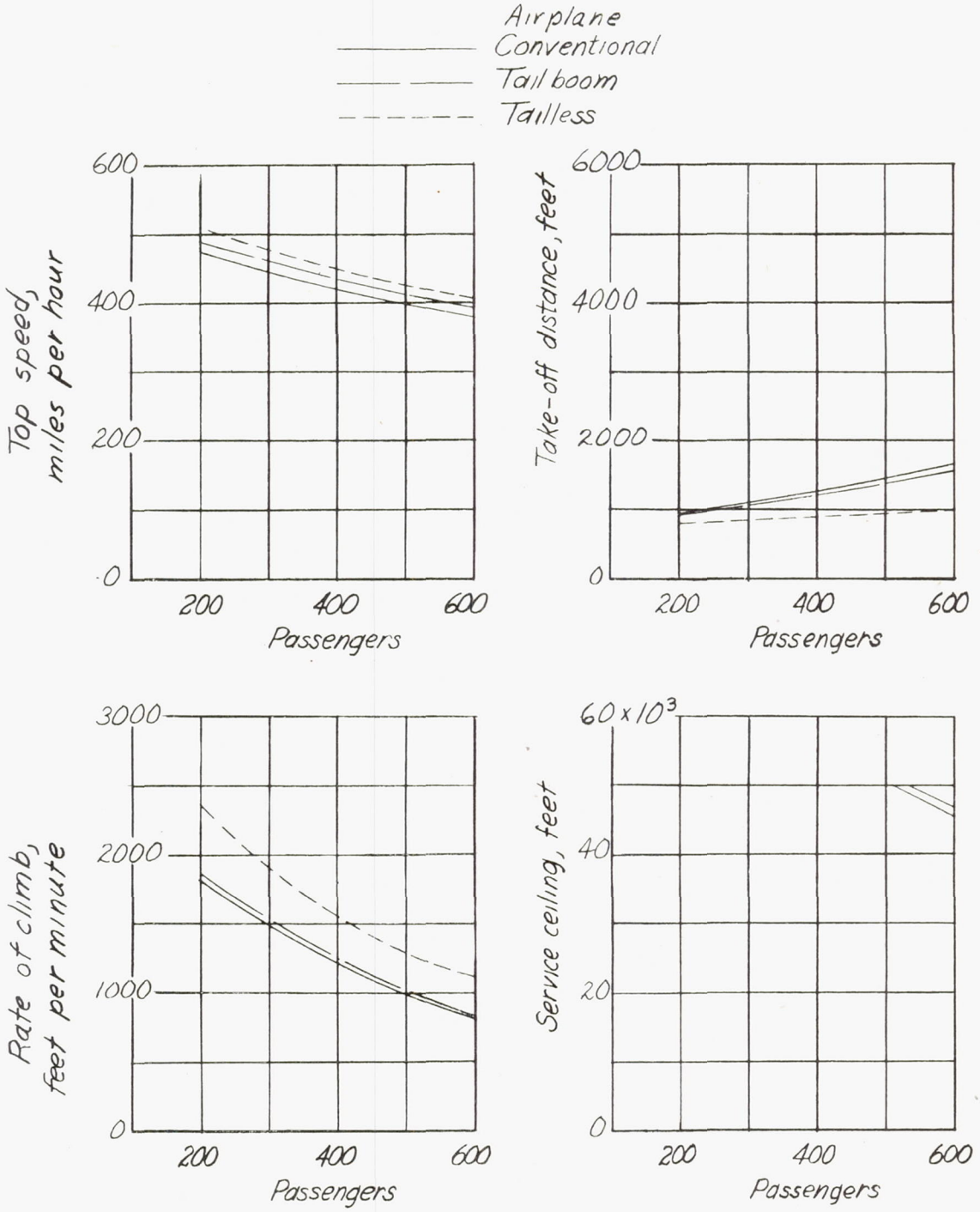


(a) P = 42,000

Figure 11.- Passenger capacity and bomb load.



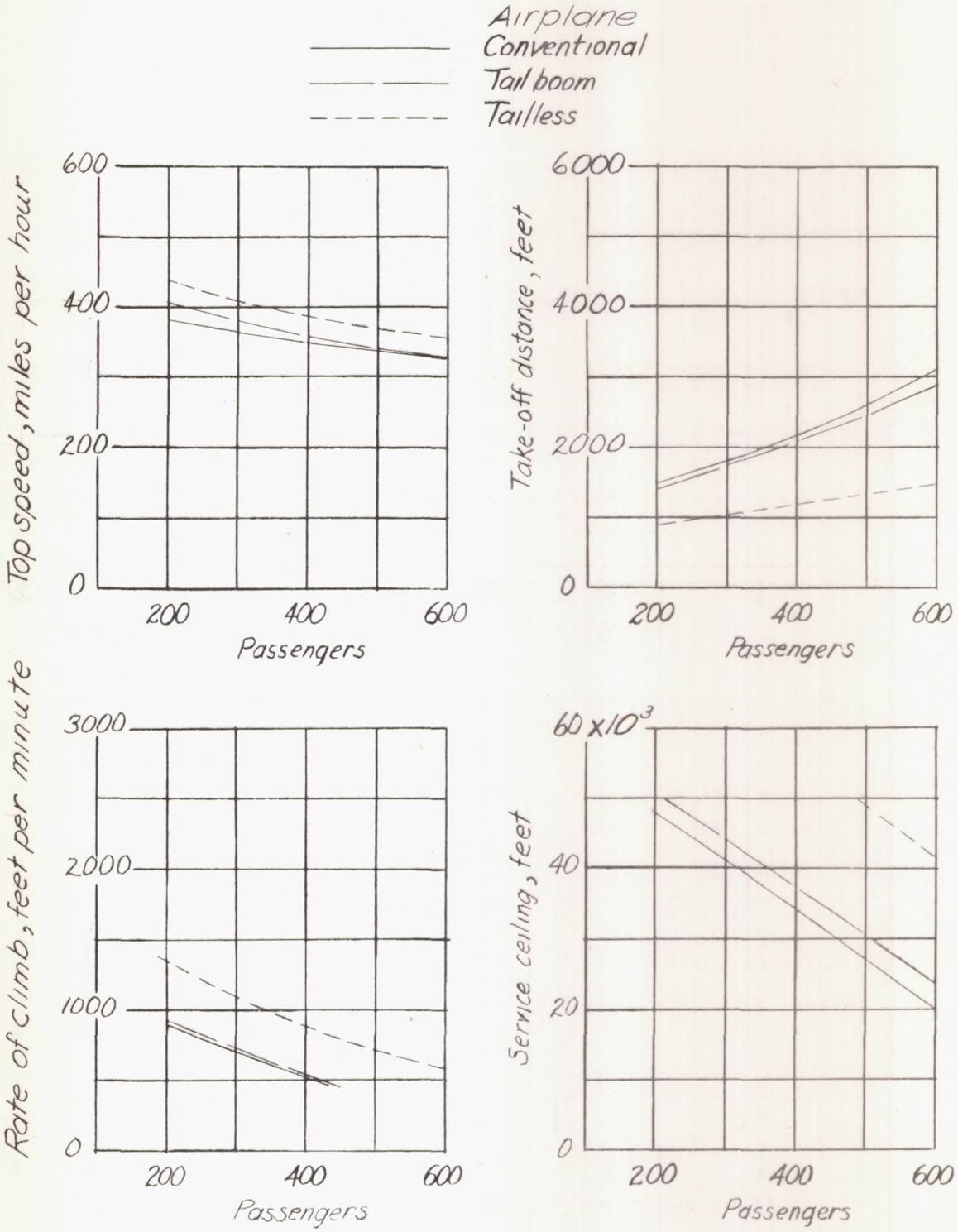
(b) P = 21,000.
Figure 11.- Concluded.



(a) $P = 42{,}000$; $V_L = 70$ miles per hour ; $R = 3000$ miles.

Figure 12.— Performance comparison of conventional, tail boom, and tailless airplanes designed for various missions.

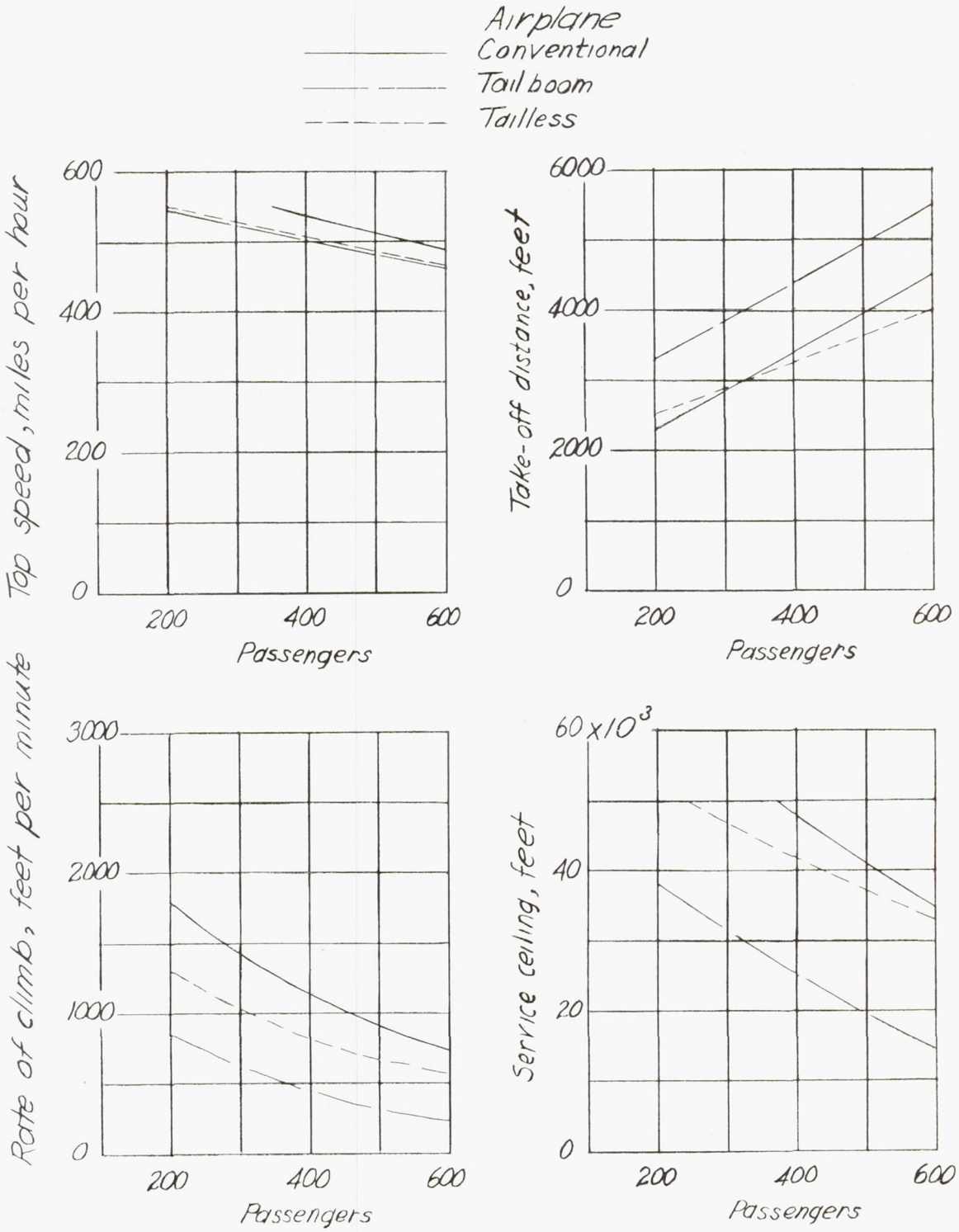
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(b) P=42,000; V_L=70 miles per hour; R=5000 miles.

Figure 12.— Continued.

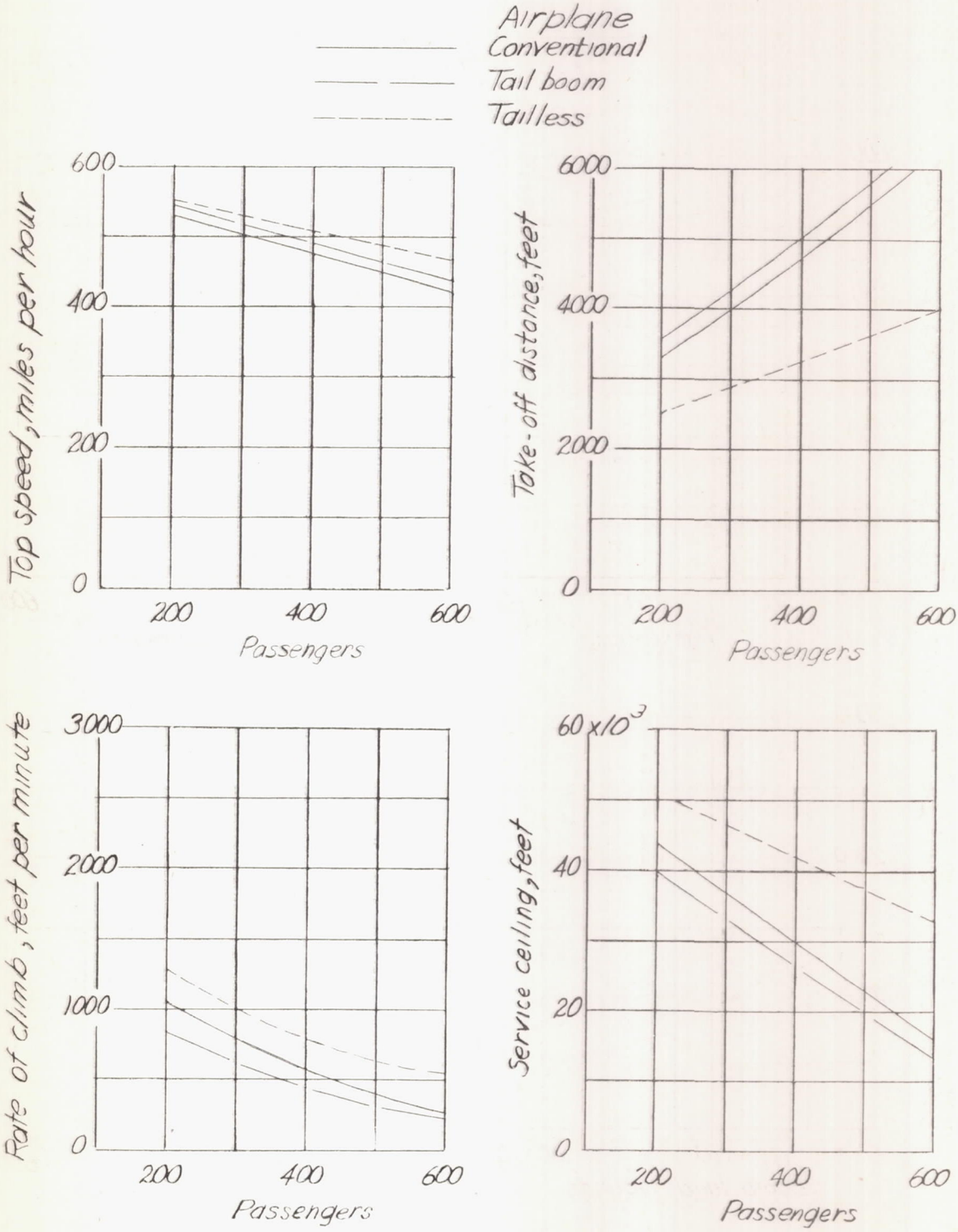
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(c) $P = 42{,}000$; $V_L = 100$ miles per hour; $R = 3000$ miles.

Figure 12.— Continued.

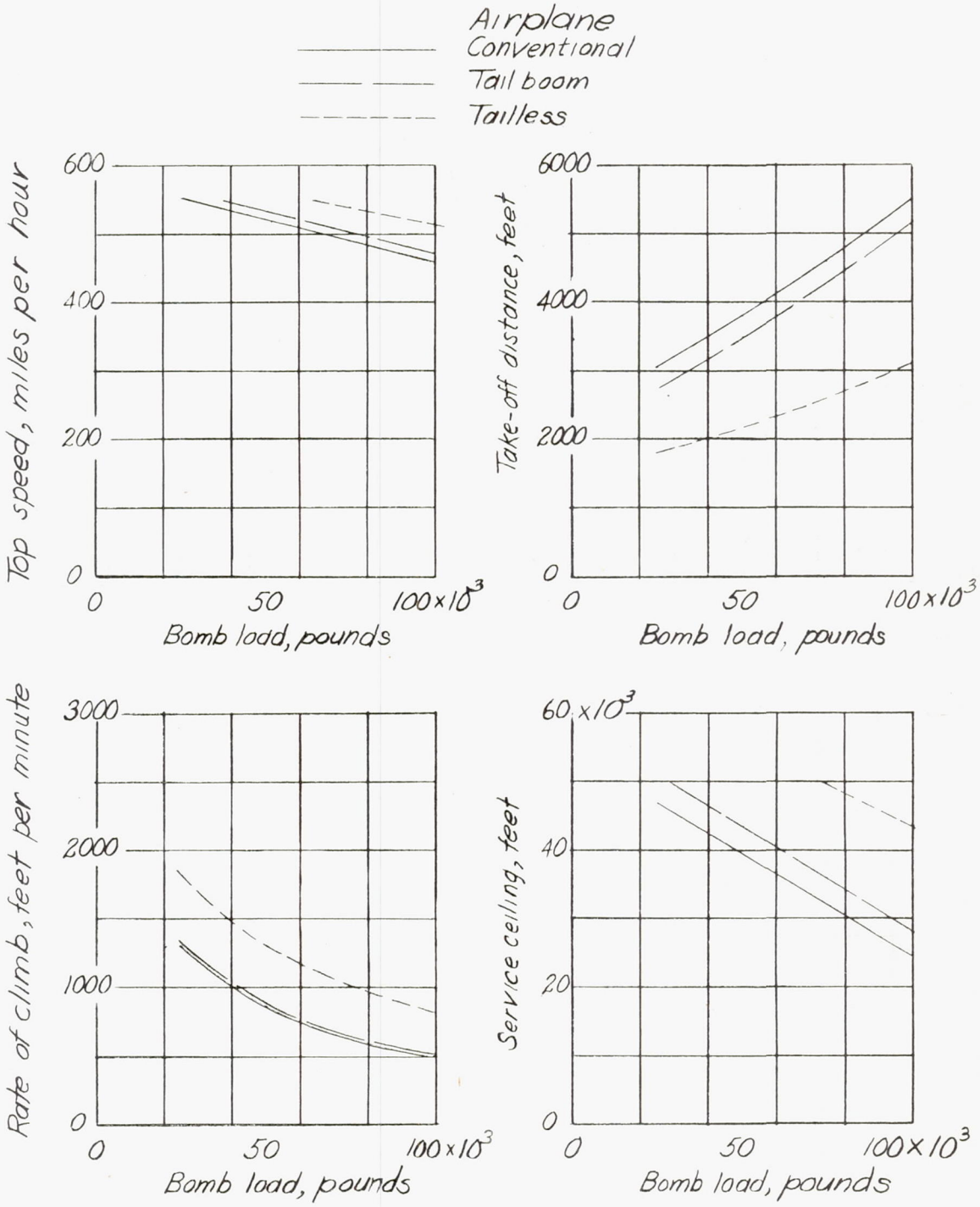
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(d) P=42,000 ; V_L=100 miles per hour ; R=5000 miles.

Figure 12.— Continued

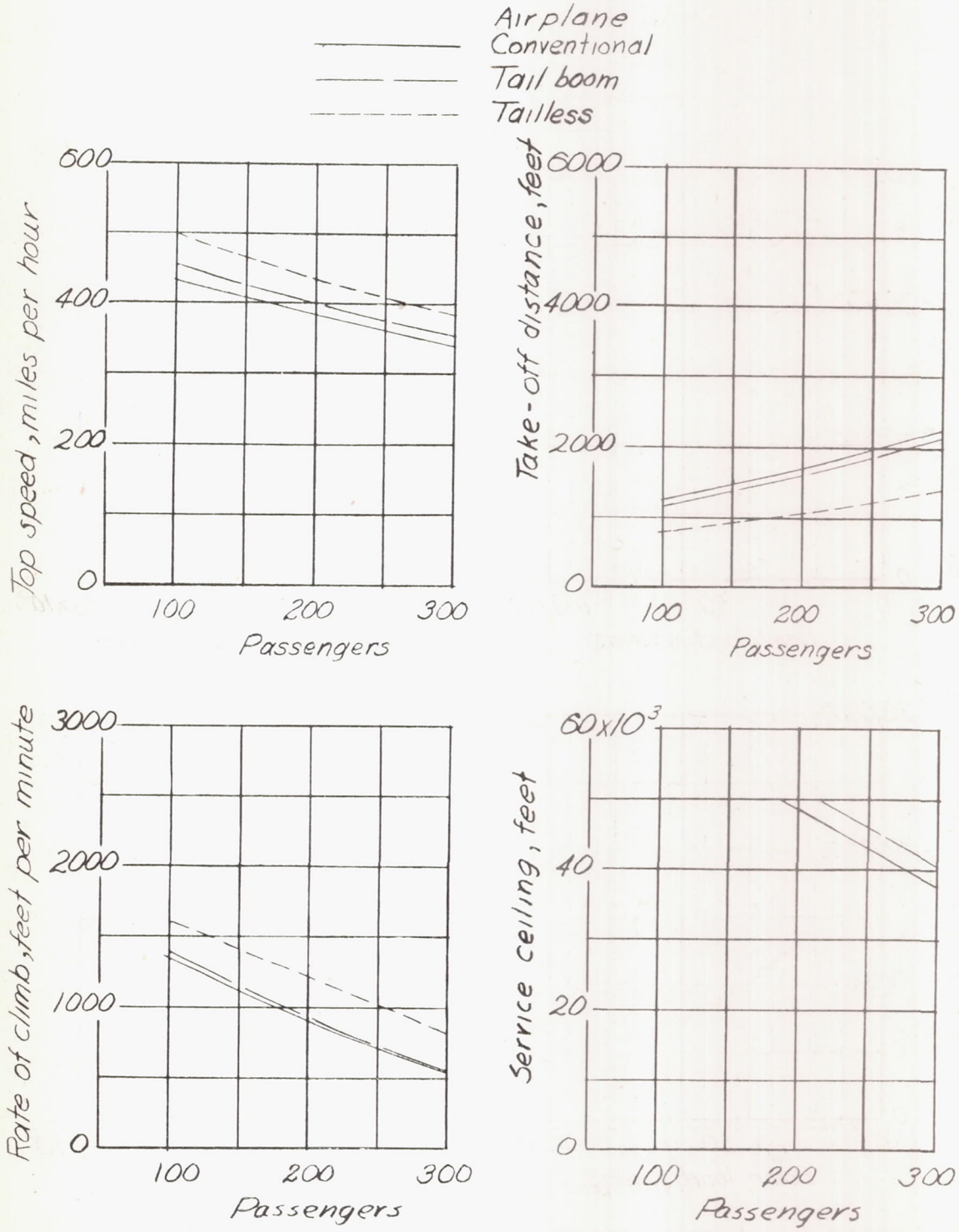
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(e) $P = 42{,}000$; $V_L = 100$ miles per hour ; $R = 5000$ miles.

Figure 12.— Continued.

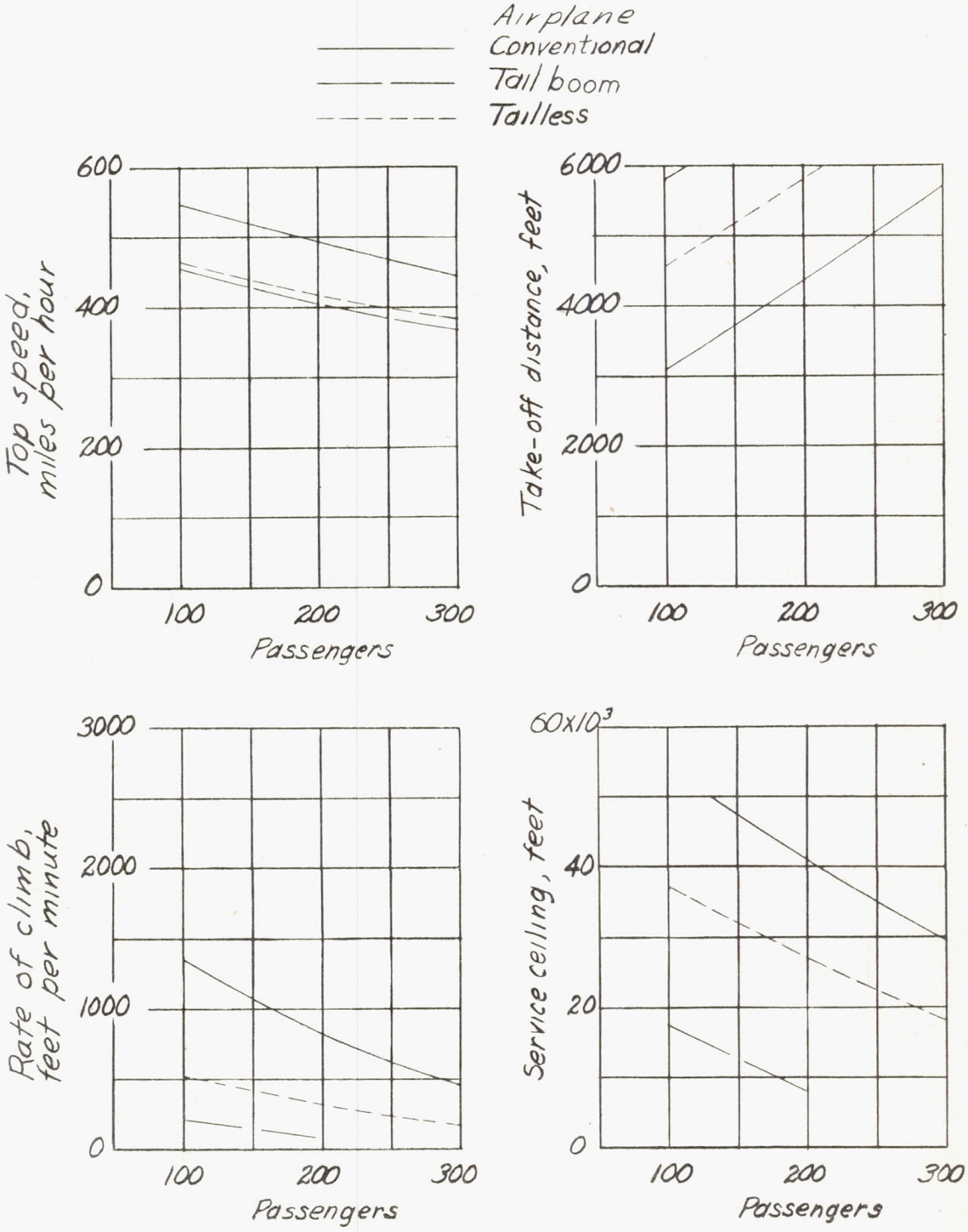
NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(f) $P = 21{,}000$; $V_L = 70$ miles per hour; $R = 3000$ miles.

Figure 12.— Continued.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(g) $P = 21{,}000$; $V_L = 100$ miles per hour; $R = 3000$ miles.

Figure 12.— Concluded.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

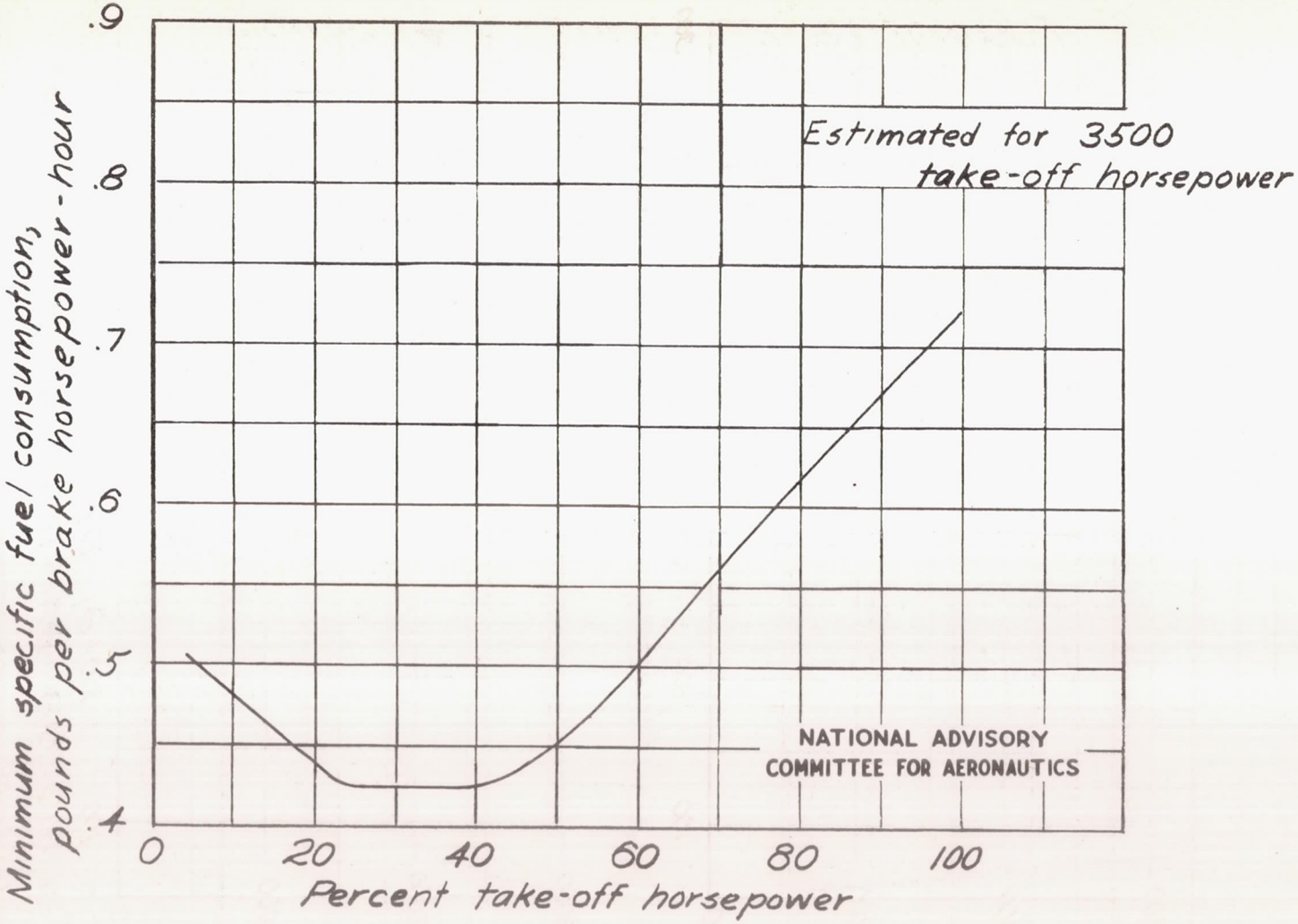


Figure 13.- Assumed minimum specific fuel consumption.

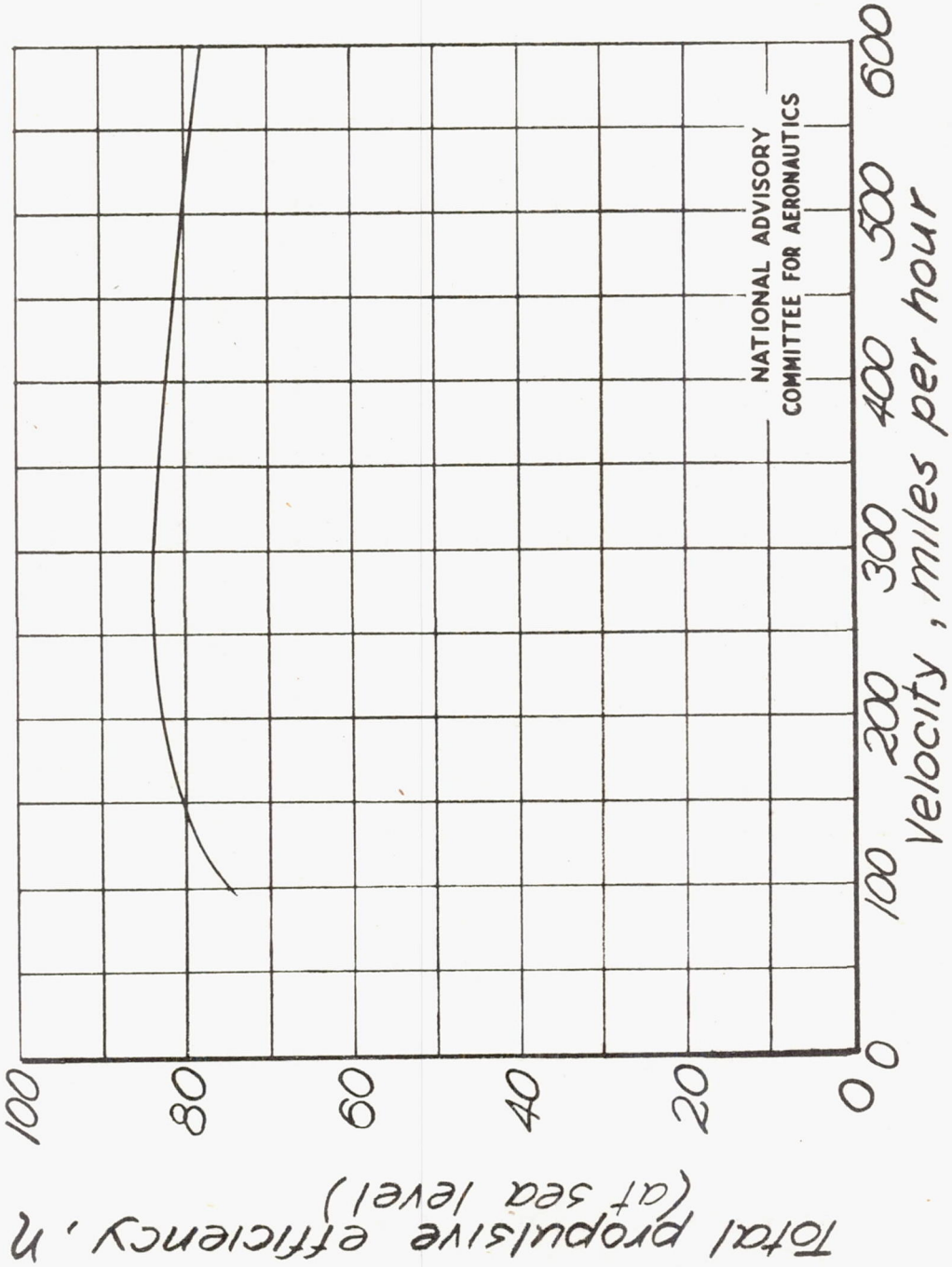


Figure 14. - Propulsive efficiency.

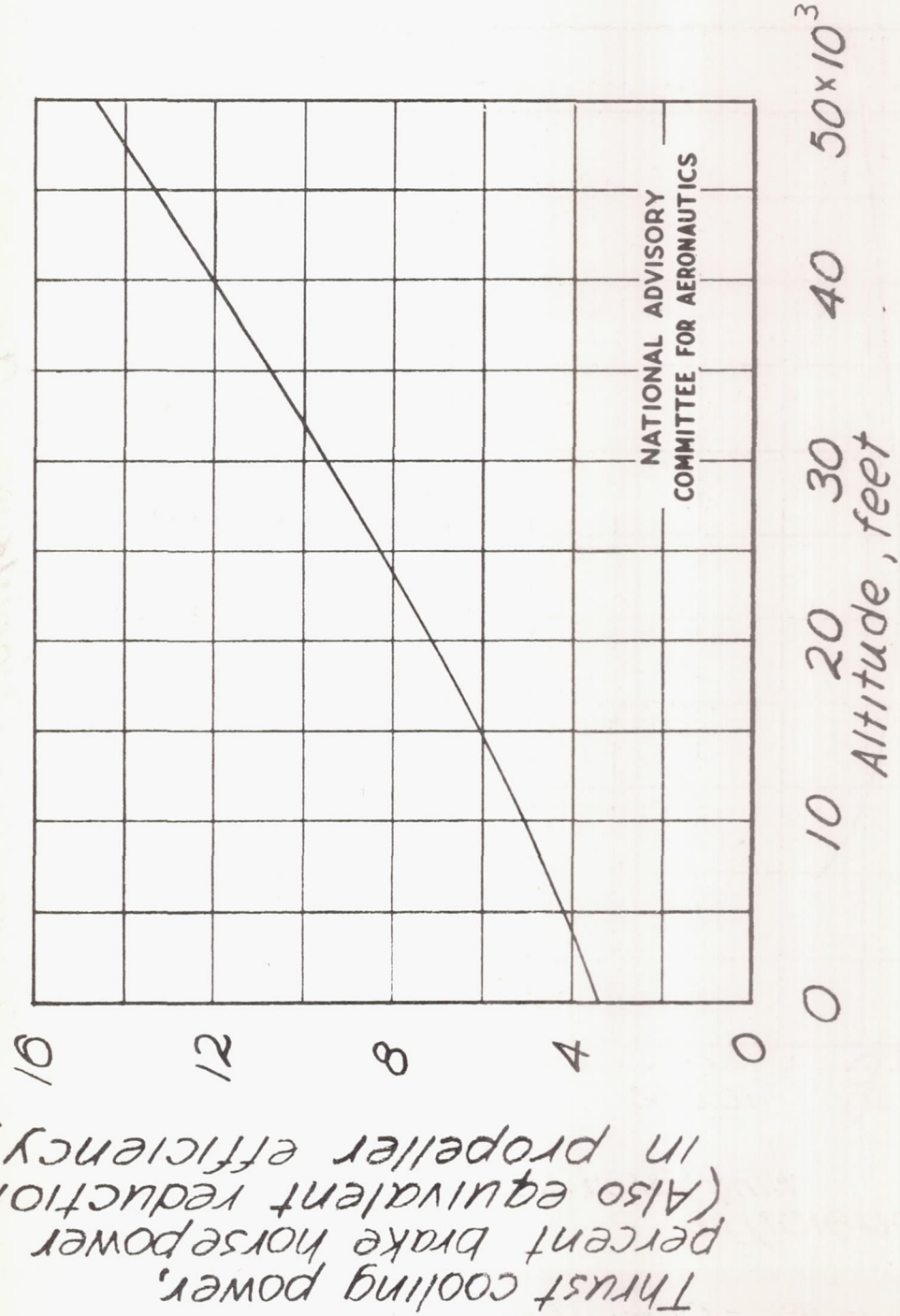


Figure 15.- Cooling power.

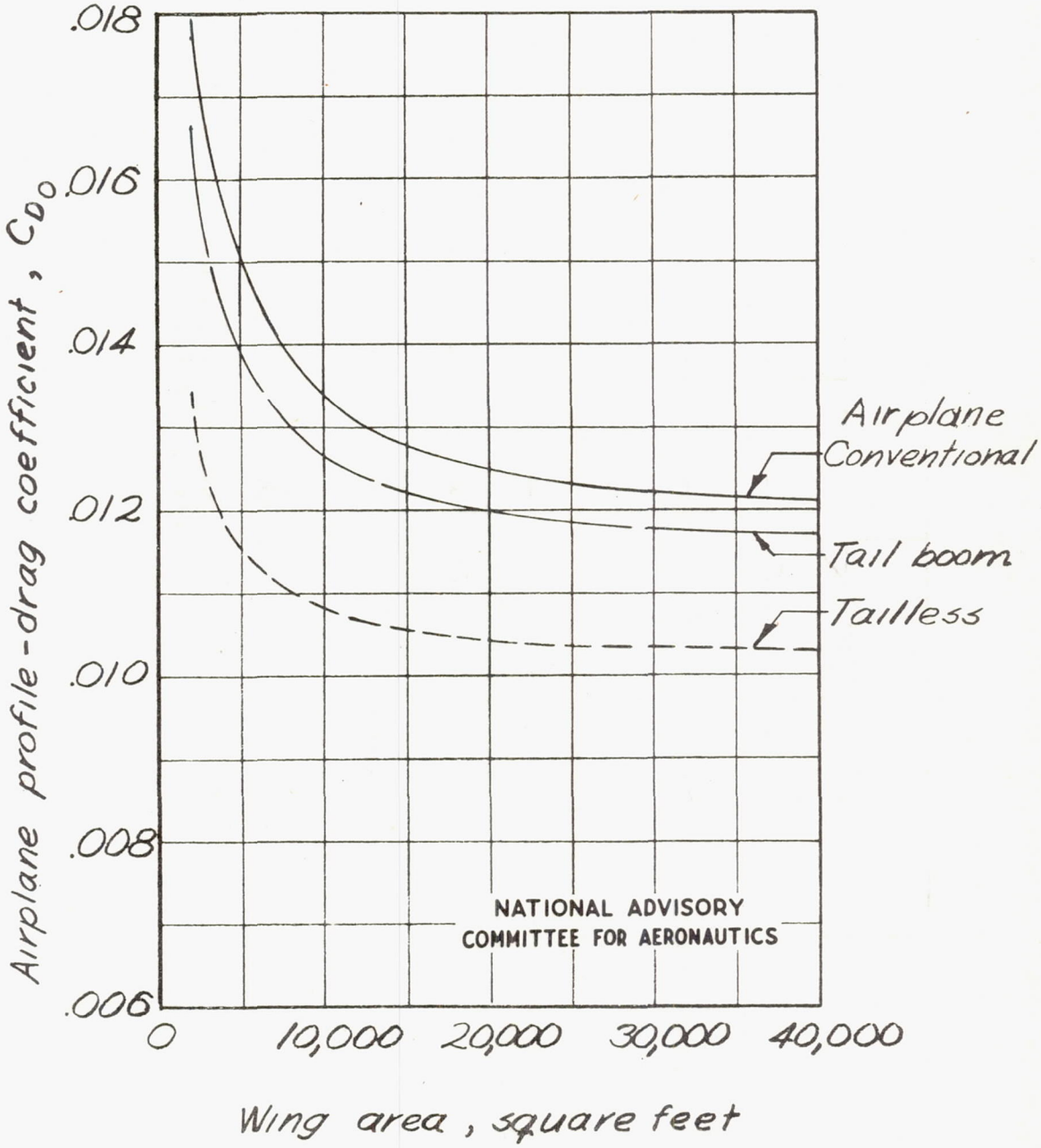


Figure 16.- Computed drag coefficients.

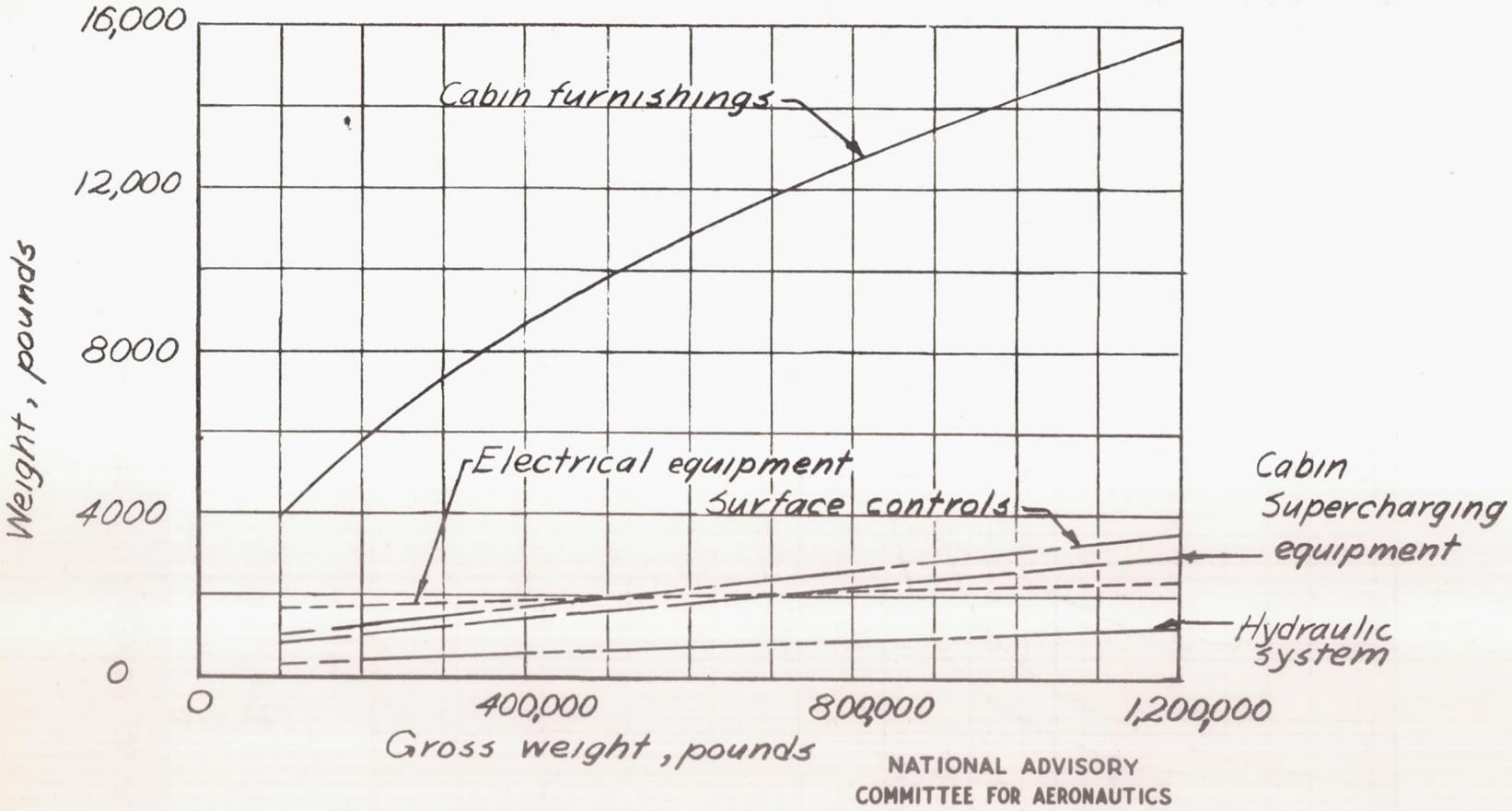
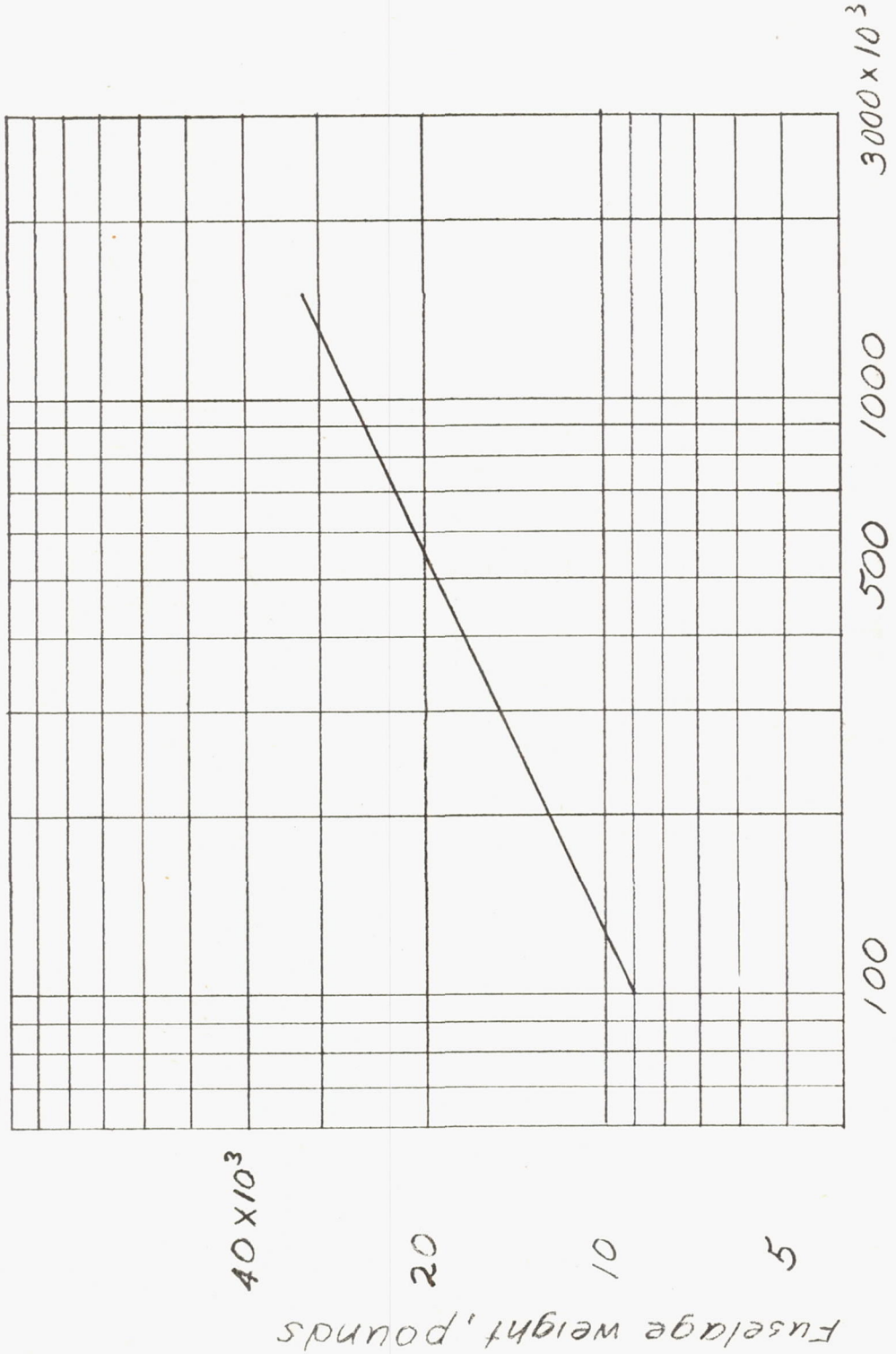
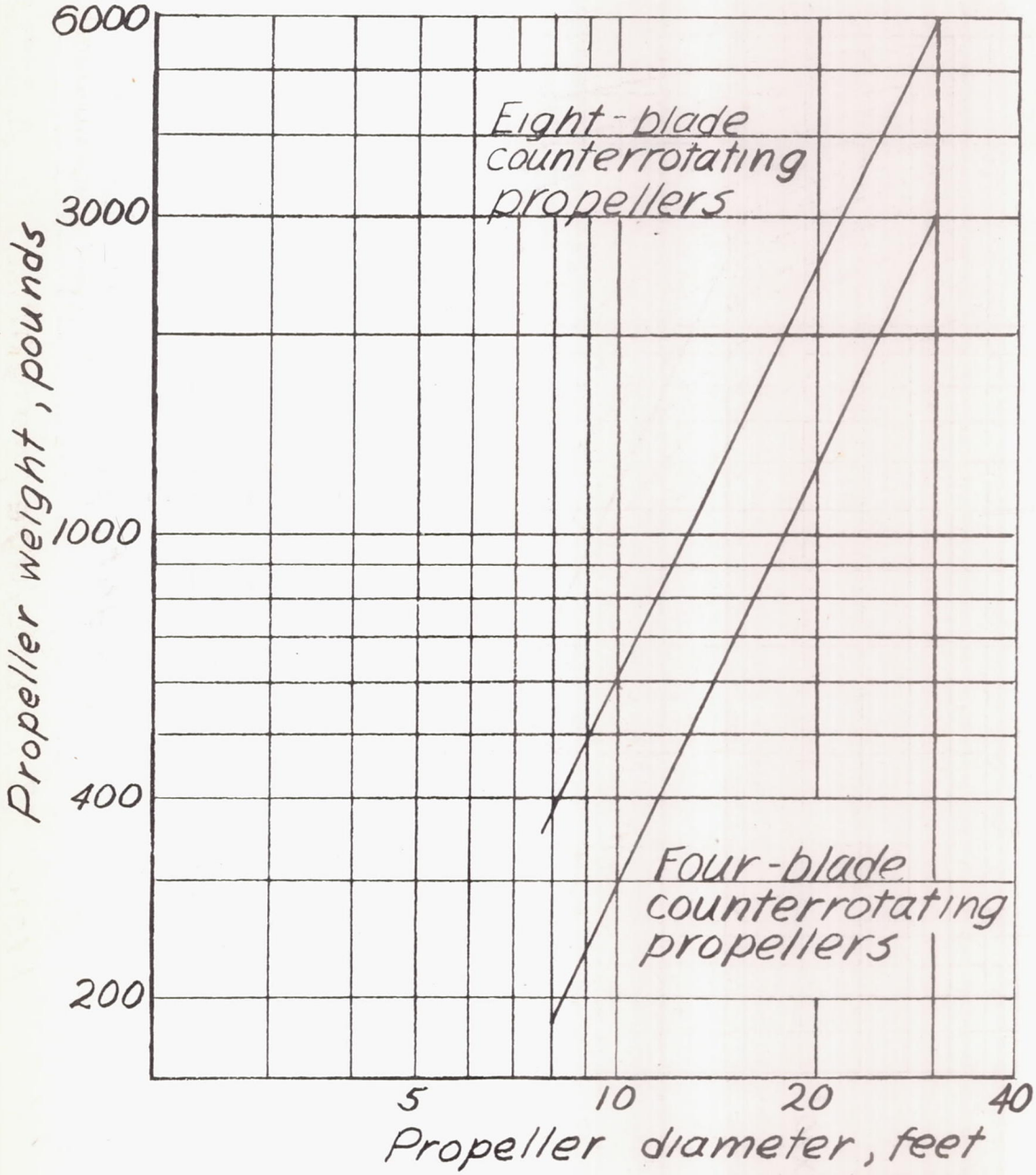


Figure 17.- Weights.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 18.- Fuselage weight.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 19.- Propeller weight.

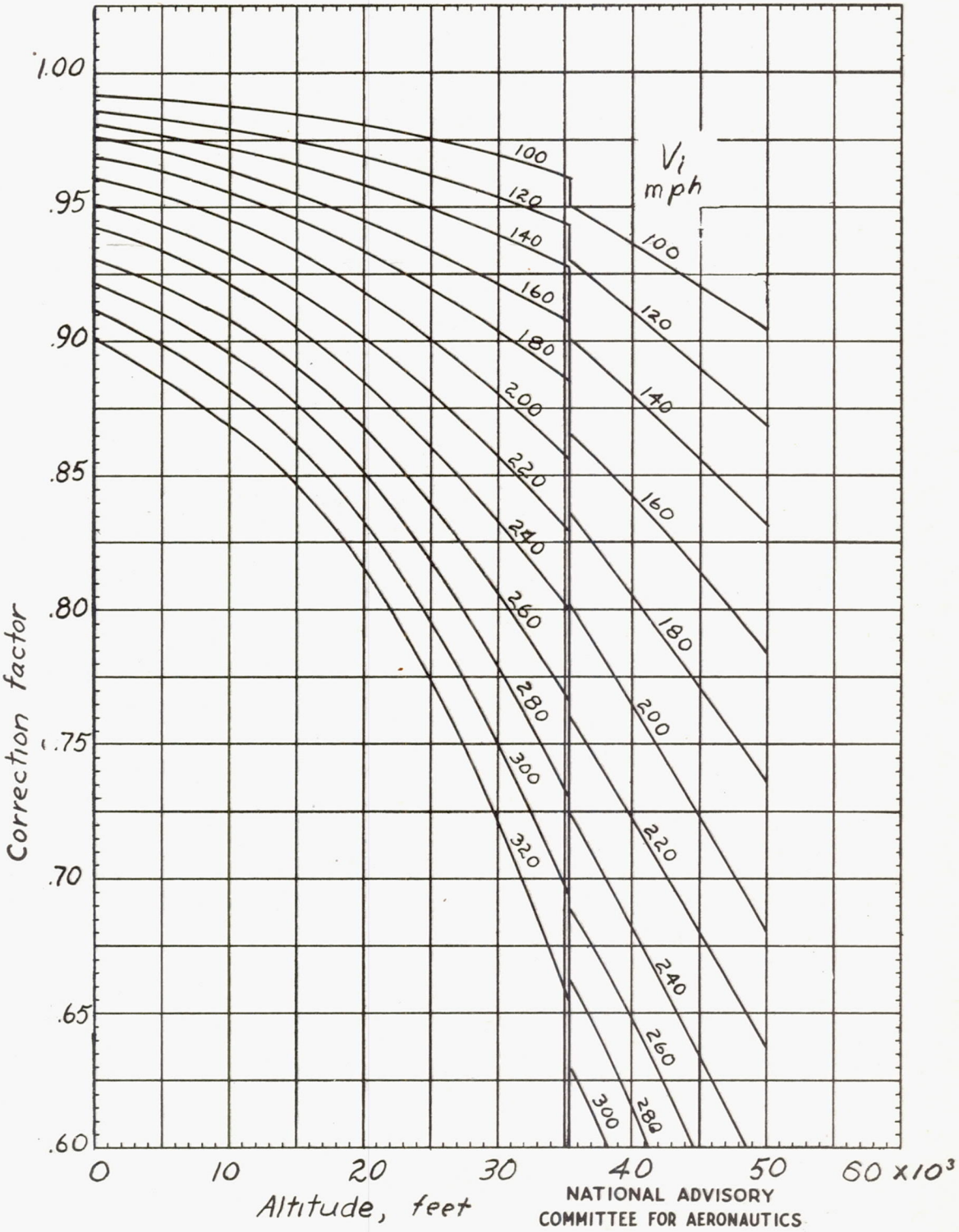


Figure 20.- Correction factor for acceleration in climb at constant indicated airspeed.