04.73 PERFORMANCE CHARACTERISTICS

INTRODUCTORY NOTE

This portion of ACM 04 contains material intended to interpret and explain the requirements of 6 CFR 04.73 and to present acceptable methods for showing compliance therewith. It is considered sufficiently specialized in the nature of its contents to warrant issuing it separately. Since there will be available a limited number of copies of this manual and of FLIGHT BRANCH REPORT No. 103 (to which reference is made herein), the distribution of both will be limited to those manufacturers of airplanes already in airline use and of airplanes for which application for certification as airline carriers is made.

It should be understood that any method which can be shown to be the equivalent of one set forth in this manual will be equally acceptable to the Secretary. Likewise, any interpretation herein shown to be inapplicable to a particular case will be suitably modified for such case on request. In either event such acceptance or modified interpretation will be effective as and when issued prior to subsequent incorporation in this manual which will be revised from time to time as equally acceptable methods, new interpretations, or the need for additional explanation or clarification are brought to the attention of the Bureau.

This manual supersedes EI-12 and all revisions thereto. It has been prepared in the same form as the remainder of ACM 04 and may thus be conveniently added thereto by those who receive it. On the reverse side of this page will be found a form for convenience in maintaining a record of subsequent revisions.

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.73 PERFORMANCE CHARACTERISTICS OF AIRLINE CARRIERS

1. The basic purpose of this requirement is to obtain sufficiently comprehensive information concerning take-off, climbing, gliding, landing, and one engine inoperative performance to enable the Airline Inspection Section to authorize weights at take-off suitable for the operation of the airplane over a given route. (See 6 CFR 40.12). The information should therefore be of such nature and in such form that a complete flight path for any of the above items of performance can be easily determined under any practicably possible combination of the numerous controllable and uncontrollable variables which affect such flight path. The controllable variables include weight, velocity, power, and piloting technique. The uncontrollable variables are temperature, atmospheric pressure, wind, and the surface and grade of the runway.

2. There are obviously various possible combinations of flight testing and calculation which will yield the required information. Any such combination, in which the method employed in the necessary calculations can be substantiated in a manner satisfactory to the Secretary, is acceptable. There are presented herein two acceptable methods for obtaining the required information. One is based, insofar as is possible, upon direct flight testing. The other is based upon certain basic flight testing from which the characteristics may be calculated, subject, at the discretion of the Secretary, to such check tests as may be necessary to establish the general validity of the method of calculation employed. The first method and the calculation in the second, are discussed under the heads "Direct Flight Testing" and "Alternate Method", respectively, in ACM 04.730 through 04.733. The basic flight testing for the alternate method is outlined immediately below.

3. Basic flight testing should be such as to furnish the data necessary to establish airplane polars (C_L vs C_D) corresponding to the following speed ranges and airplane conditions:

- a. V_S to V_L (all engines operating equally)
  - (1) With flaps and landing gear retracted
- b. V_{sf} to $1.6V_{sf}$ (all engines operating equally)
  - (1) With landing gear retracted
    - (a) With flaps 1/2 extended
    - (b) With flaps fully extended
  - (2) With landing gear extended
    - (a) With flaps 1/2 extended
    - (b) With flaps fully extended

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c. V^*_{min} to V^*_{max} (critical** engine inoperative, flaps and landing gear retracted)

(1) With inoperative engine idling, i.e. the throttle closed and the ignition switch on or shut off whichever is critical**.

(2) With critical** inoperative propeller braked or feathered if either is possible.

4. The flight testing outlined above can all be done by flying steadily at each required airspeed for each airplane condition and recording weight, airspeed, outside air temperature, propeller pitch unless constant speed, pressure altitude, manifold pressure, R.P.M., and carburetor air temperature as well as direct power if a torque meter or dynamometer is used. This should be done at a sufficient number of speeds in each of the ranges specified above (paragraph 3, items a, b and c) to define the particular polar involved. A minimum of six speeds for item a and four each for items b and c will be acceptable. From the above recorded data, the engine manufacturer's power curves and published propeller data, C_L and C_D may be calculated thus:

$$\rho = \frac{.0412\, p}{(t + 460)}$$ (p is "HG., t is °F.)

$$C_L = \frac{.93W}{\rho S\, V^2}$$ (V is actual airspeed* in mph)
(S is design wing area in ft^2; see 6 CFR 04.104)

$$D = T = \frac{375\, BHP\eta}{V}$$

$$C_D = \frac{.93D}{\rho S\, V^2}$$

* From airspeed calibration.

C_L may then be plotted against C_D as shown in Fig. 04.73-I

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* V_{min} and V_{max} are the minimum and maximum speeds in level flight which are possible for the given airplane condition.

** Critical with respect to the increased drag resulting. This can be determined by flying level at a given airspeed and trying each engine in turn and noting the power output of the operative engine(s). That condition requiring the greatest power to maintain the given airspeed is critical and should be used for the tests above.

.730 FLARE AND LANDING

A GENERAL

1. The nature of the landing flare from a steady glide (at some speed in excess of the stalling speed) to contact with the ground at the stalling speed and zero rate of descent, during which flare the speed and rate of descent are both continuously reduced so as to arrive at the stalling speed, zero rate of descent, and contact with the ground simultaneously, appears to be such that for a given steady glide speed there is only one height above the ground at which such flare can be started unless the thrust and/or drag characteristics (use of power, or change of flap or gear setting, respectively) are altered during the flare.

2. The foregoing conclusion has been reached as a result of the following reasoning. For a given steady glide speed, the flight path angle is an airplane characteristic and fixes vertical and horizontal components of velocity and of kinetic energy. The landing flare is the process of decelerating these two velocity components to the desired values at the ground. The forces available to accomplish this deceleration are the amount by which the lift exceeds the weight component perpendicular to the flight path and the amount by which the drag exceeds the weight component along the flight path. It should be noted, however, that the pilot cannot control these two forces separately since the relation of lift to drag is an airplane characteristic. For a given controlled deceleration of the rate of descent, for example, there will occur a given uncontrollable deceleration of flight path speed, which may or may not be that required to arrive at the desired speed simultaneously with arrival at the ground and zero rate of descent. The time history of the decelerating forces depends upon the height at which their application is started. It appears, therefore, that there is one height, and one only, from which these time histories of both forces bear the necessary relation, one to the other, to enable the airplane to simultaneously reach the ground, zero rate of descent, and the stalling speed. This height will be referred to as the critical height.

3. If a flare is started above the critical height, and if the speed and rate of descent are continuously reduced, the landing conditions are reached at some height above the ground. If such conditions are reached at the ground, the speed and/or the rate of descent cannot have been continuously reduced. If a flare is started below the critical height, and if the rate of descent is reduced to zero at, or somewhat above, the ground, the speed at which the zero rate is first reached will be in excess of the stalling speed and unless contact is simultaneously made, the airplane will float close to the ground while decelerating to the stalling speed. When the height at which the flare is started is successively further below the critical height, the speed at which zero rate of descent is first reached is further increased, until eventually a minimum starting height is found from which it is still possible to reduce the rate of descent to zero at the ground. Any fur-

ther reduction in such height results in contact with the ground at an unavoidable rate of descent. It also appears that, for a given steady glide speed, the minimum distance (along the ground), required to get down from a given height (necessarily in excess of that required for the flare) to the ground at the stalling speed and zero rate of descent, results from the execution of the gradual flare described at the beginning of paragraph 1. Such a flare is considered to be normal, and the flight path described by the airplane during its execution is believed to be a characteristic depending solely on the airplane. It should be noted that this definition of a normal flare applies to an airplane with conventional landing gear. In the case of a tricycle gear the definition should be altered to cover a specified rate of descent at contact for which the airplane has been designed.

B DIRECT FLIGHT TESTING

1. It follows from the apparent nature of a normal flare that, for a given height at which the flare is to be started, there is only one steady glide speed from which the normal flare can be executed. This is considered to be the optimum speed for such given height of flare. In the case of direct flight testing the selection of the optimum speed for a given flare must depend largely upon the experience of the pilot with the particular airplane. It also seems likely that it would be difficult to bring the airplane to a predetermined height over a barrier at the boundary of the field at a given speed and at the proper gliding attitude. It is therefore suggested that, if the flare and landing characteristics are to be determined by direct flight testing, the specified 50 ft. height (6 CFR 04.730 (a),(1)) be regarded as a minimum and the others as approximate, and that flares be made beginning as nearly as possible at each of three heights beginning with minimum and differing by 50 feet. For each such height the flare should be attempted at a sufficient number of glide speeds to determine the optimum. The height, speed and required distances (6 CFR 04.7320 (a), (1) and (2)) should be determined for each such attempt. If power is used to approach the starting point of the flare it is recommended that the speed in such approach be maintained as nearly as possible at that from which the flare is to be started, and that the throttles be slowly closed as the starting point is approached so that, when completely closed at the start of the flare, the minimum change in attitude of the airplane results. Tests should be conducted at each of three weights (light, maximum authorized, and one intermediate) and at each of two altitudes differing by approximately 3,000* feet (see paragraph C). In addition to the required distances, the following data should be recorded:

a. Temperature.
b. Local barometer reading, or pressure altitude.
c. Wind velocity and direction relative to flight path.
d. Propeller R.P.M.

* This applies to landplanes only.

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.731 CLIMB

A GENERAL

1. The climbing performance of an airplane depends upon the relation of thrust horsepower available to horsepower required for level flight. If the former exceed the latter the climb is positive, i.e., upward. If the latter exceeds the former the climb is negative, i.e., downward. For a given throttle setting and a given propeller, the thrust horsepower available is a function of airspeed and atmospheric conditions. For a given airplane at a given attitude, the horsepower required is proportional to the atmospheric density and the cube of the airspeed. The airplane drag characteristics are a function of attitude; the attitude is determined by the weight, density and airspeed, and the density by the atmospheric pressure and temperature. It may therefore be seen that all these things may and do affect the climbing performance.

2. The relation of thrust horsepower available and horsepower required for level flight to airspeed is such that there is, for a given set of the other conditioning variables, one airspeed at which $T\ HP_a - HP_r$ is a maximum if positive, or a minimum if negative. This airspeed is that at which the maximum rate of climb or the minimum rate of descent occurs. The rate of climb or descent may be expressed mathematically as follows:

$$C = \frac{33{,}000(T\ HP_a - HP_r)}{W}\ ;\ (\text{in fpm})$$

or, since

$$T\ HP_a = B\ HP\eta;\ (\eta = \text{propulsive efficiency})$$

and

$$HP_r = \frac{DV}{375} = \frac{WV}{375(L/D)}\ ;\ (V \text{ is in mph})$$

$$C = \frac{33{,}000B\ HP\eta - \dfrac{33{,}000WV}{375(L/D)}}{W}$$

$$= \frac{33{,}000B\ HP\eta}{W} - \frac{88V}{(L/D)}\ \ldots\ldots\ldots\ (1)$$

It should be noted that this is the rate of climb with respect to the air in which the climbing is done. It is the rate with respect to the ground only if the air is not moving vertically with respect to the ground.

3. An airplane climbing steadily in still air, or in air moving with uniform velocity, describes a flight path which is a straight line making an angle β with respect to the horizon. This is the angle of climb or of glide and is the angle whose tangent is the vertical velocity over the

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horizontal velocity. β is usually of the order of 10° or less and, in still air, is:

$$\beta = \frac{C}{88V} \text{ (radians)} \qquad (2)$$

or:

$$\beta = \frac{57.3C}{88V} = \frac{.647C}{V} \text{ (degrees)} \qquad (2a)$$

There is also, in still air, an airspeed at which β is a maximum for climb or a minimum for glide. Except at the absolute ceiling, this airspeed is less than the speed for maximum rate of climb and is greater than the speed for minimum rate of descent.

4. In general the determination of maximum or minimum rates and/or angles of climb or descent consists in obtaining, from direct flight tests or by calculation, rates of climb and/or descent at various airspeeds for each of a sufficient number of combinations of the other variables. These rates are then plotted versus airspeed. The maximum or minimum rate and corresponding speed may then be determined by inspection. The maximum or minimum angle and corresponding speed may be determined by the point of tangency of the radius vector drawn through the origin and tangent to the curve.

5. Another characteristic of climbing performance which is troublesome is the fact that all the instruments commonly used to indicate or measure it, with the exception of those used to measure time, are actuated in part or wholly by the actual pressure and/or temperature of the air in which the airplane is flying when the observation is made. Since these bear no fixed relation to altitude, the instruments read the actual values very rarely and, even then, fortuitously. Thus, e.g., the airspeed indicator measures an impact pressure which, if the instrument is accurate, actually exists. It indicates however, not that impact pressure but a fictitious speed called "true indicated airspeed" which would be necessary to produce the same impact pressure in sea level standard air. The altimeter or barograph measures an actual pressure but indicates not the pressure but a fictitious altitude called "pressure altitude" at which the actual pressure would occur in standard air. The rate at which this "pressure altitude" changes with time is actually a rate of change of pressure but is frequently called "indicated rate of climb". This situation requires corrections to be made to almost all climbing performance. If calculated it must, in order to be used by the pilot, be expressed in terms of the fictitious quantities indicated by his instruments. If determined by testing, the fictitious performance recorded must be converted into the actual in order to be able to determine what is the actual performance under any other set of circumstances than those which obtained during the test. These necessary corrections are further discussed below.

of climb at the standard altitude corresponding to the density, it is necessary to correct the actual rate for the effect of the difference in temperature upon the engine power.

d. From the observed power plant data and the engine power curves determine the actual bhp developed in the test. Then the bhp which would be developed at the same density in standard air is:

$$bhp_s = bhp \times \frac{p_s}{p} \times \sqrt{\frac{t + 460}{t_s + 460}}$$

and the change in C due to this change of bhp is:

$$\Delta C = \frac{33{,}000(bhp_s - bhp)\eta}{W}$$

where: W is the gross weight
η is propulsive efficiency. In the absence of more accurate data this may be assumed to be: $\eta = .75$

e. The observed speed V_i should be corrected for instrument error by means of the calibration curve giving true V_i. The actual airspeed at the standard altitude defined by ρ in item (b) above is:

$$V = \text{true } V_i \times \frac{1}{\sqrt{\sigma}}$$

and the rate of climb at the same standard altitude at this airspeed is:

$$C_s = C + \Delta C$$

3. Curves of C_s versus V should then be constructed, one for each standard altitude (as defined under item (c) above) at which tests have been made in order to determine the maximum rate of climb or minimum rate of descent and the corresponding speed as described in paragraph 04.731-A 4 above.

C ALTERNATE METHOD

1. The climbing performance may be calculated by means of equation (1) of paragraph 04.731-A 2 above by substituting therein appropriate values from Fig. 04.73-1, from the engine manufacturer's power curves, and from published data on propulsive efficiencies. The specified range (6 CFR 04.731) of weight and altitude should be covered at each of a sufficient number of values of V to determine the maximum angle and corresponding speed as described in paragraph 04.731-B 3 above.

.732 TAKE-OFF

A GENERAL

1. The general nature of the take-off flight path has been investigated in FLIGHT BRANCH REPORT No. 103* to which reference is made. Briefly summarized, it appears that the optimum technique consists in selecting a steady climbing speed, opening the throttles as rapidly as possible at the start of the take-off, unsticking at any convenient speed below the climbing speed and flaring gradually to steady climb at the selected speed. It also appears that, provided only that the speed does not exceed the selected climbing speed prior to the establishment of steady climb, the distance required to attain a given height above the ground depends entirely upon the steady climbing speed selected. This latter conclusion assumes, of course, the same airplane, weight, power, and ground and atmospheric conditions.

2. The selection of one-engine-inoperative best-angle-climb speed to be used in measuring the take-off characteristics of airline aircraft is somewhat arbitrary. The main consideration leading to its selection was that it is the speed which an operator would probably select as the minimum climb speed for clearing obstacles since if one engine fails the airplane will be at its best speed for clearing possible obstacles remaining in the flight path.

B DIRECT FLIGHT TESTING

1. To determine the take-off characteristics by direct flight testing, the specified test should be conducted at each of three weights (light, maximum authorized and one intermediate) at each of two altitudes differing by approximately 3,000** feet. Each such take-off should be made in a "normal" manner, i.e., the attitude of the airplane with respect to the ground should remain substantially constant after the tail comes up, the airplane should be flown off the ground at any comfortable speed below the climbing speed and flared gradually to steady climb at the specified climbing speed. Care should be exercised not to exceed this climbing airspeed prior to the establishment of steady climb and to maintain the steady climb at constant speed once it is established. It is desirable that take-off power be established before the airplane has moved very far from the start and it is suggested that brakes be used if necessary to prevent this distance exceeding 50 feet. The following data should be obtained:

a. Temperature (air)
b. Local Barometric Pressure
c. Wind Velocity and Direction Relative to Flight Path
d. Power (manifold pressure, rpm, carburetor air temperature)
e. Climbing Speed
f. Specified Distances (6 CFR 04.732 (a))
g. Specified Altitudes (6 CFR 04.732 (b))

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* See introductory note.

** This applies to landplanes only.

C ALTERNATE METHOD

1. Detail procedure for an acceptable method by means of which the required take-off characteristics may be calculated may be found in Appendix I of FLIGHT BRANCH REPORT No. 103*. The airplane L/D characteristics should be those determined in accordance with 04.73-3 above, the engine power characteristics should be obtained from the engine manufacturer's curves, and the propulsive efficiencies from published data such as that of the N. A. C. A.

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* See introductory note.

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.733 CEILING

A GENERAL

1. Ceiling is really a part of the climbing performance (see 04.731 above), i.e., it is the altitude at which a certain rate of climb occurs at full power. As may be seen by examining equation (1) of 04.731-A2, the rate of climb is the difference between two terms. The first of these represents the rate which would result if all the available power were used for climb. This is, of course, impossible since a portion of this power is necessary to maintain level flight and it is only the amount in excess of this which can actually be used for climb. The other of these terms represents the rate of descent of the airplane in the absence of any power. It is this descent which the power required to maintain level flight overcomes.

2. In a typical case the value of the first term may be 1.5 times that of the second at sea level. It follows that the value of rate of climb is then one third that of the first and one half that of the second. An error of 10% in the value of the first term results in 30% error in the rate of climb, and an error of 10% in the value of the second term results in 20% error in the climb. As the airplane gains altitude the value of the first term decreases while that of the second remains approximately constant so that at the altitude where, e.g., the first term is 1.1 times the second, an error of 10% in the first results in a 110% error in the climb, and an error of 10% in the second results in 100% error. As the absolute ceiling is approached the values of the two terms approach identity with the result that an infinitesimal error in either results in an infinitely great percentage error in the rate of climb.

3. It follows from the above that the ceiling is a marginal quantity very sensitive to slight variations in the magnitudes of the factors upon which it depends. For this reason it is recommended, whether the ceiling be determined by direct flight testing or by means of calculation, that rates of climb and descent be determined where these rates are of appreciable magnitude, i.e., as far as is practicable above and below the ceiling. Rates so determined are not so much subject to those errors associated with a marginal quantity and furnish fairly accurate data from which, subsequently, to predict those comparatively great variations in the ceiling which result from comparatively slight variations in weight, temperature, power, speed, etc.

B DIRECT FLIGHT TESTING

1. To determine the ceilings by direct flight testing, the procedure should be as outlined in 04.731-B1 above except that the sawtooths should be run at approximately 1,000 ft. intervals over the specified range of altitudes (6 CFR 04.733 (b)). The climb or descent data obtained should then be corrected to standard as described in 04.731-B2 above. The ceilings may then be determined by plotting, for each weight, maximum rate of

climb and minimum rate of descent versus standard altitude and reading the altitude at the specified rates of climb (zero for absolute and 50 ft/min. for usable ceiling.).

C ALTERNATE METHOD

1. The required information (6 CFR 04.733) may be determined by calculating rate of climb and descent versus airspeed as outlined in 04.731-C above and determining the ceilings by plotting results as in 04.733-B above.

APPENDIX I

PRESENTATION OF RESULTS

It is believed that the purpose of the requirement (see ACM 04.73-1) will be best served if the form in which the results are presented is the same for all cases. With this in view, it is requested that, so far as is possible, the following outline be used in preparing the necessary report. The outline is believed to be sufficiently general in form to accommodate the results obtained by means of direct flight testing, the alternate method, or any likely combination of them.

1. TITLE PAGE.
2. TABLE OF CONTENTS.
3. REFERENCES.
4. SYMBOLS.
5. INTRODUCTION.

   a. A small three-view drawing of the airplane, to scale, which should show overall dimensions, span and chord of each wing, flap and control surface, the normal ground wing incidence (to zero lift chord) the authorized range of C.G. position, and the location of the pitot-static head.

   b. A list of basic airplane data including at least light, standard, and maximum authorized weights; gross wing area; number and model of engines and propellers; airfoil section of wings; maximum deflection of flaps and control surfaces.

   c. A brief outline of the method used to obtain the required information.

6. SUMMARY OF RESULTS - The attached Figures 04.73-2 through-6 are recommended although any other forms of equal or greater convenience are acceptable.

7. TEST DATA - Under this item should be included all test data as recorded during any of the tests.

8. CALCULATIONS, ETC. - This item should include any calculations made to complete the report, such as corrections to recorded data in the case of direct flight testing, or calculation of the information of Fig.04.73-1 and of the required characteristics therefrom in case the alternate method is employed.

9. CONCLUSIONS AND/OR RECOMMENDATIONS.

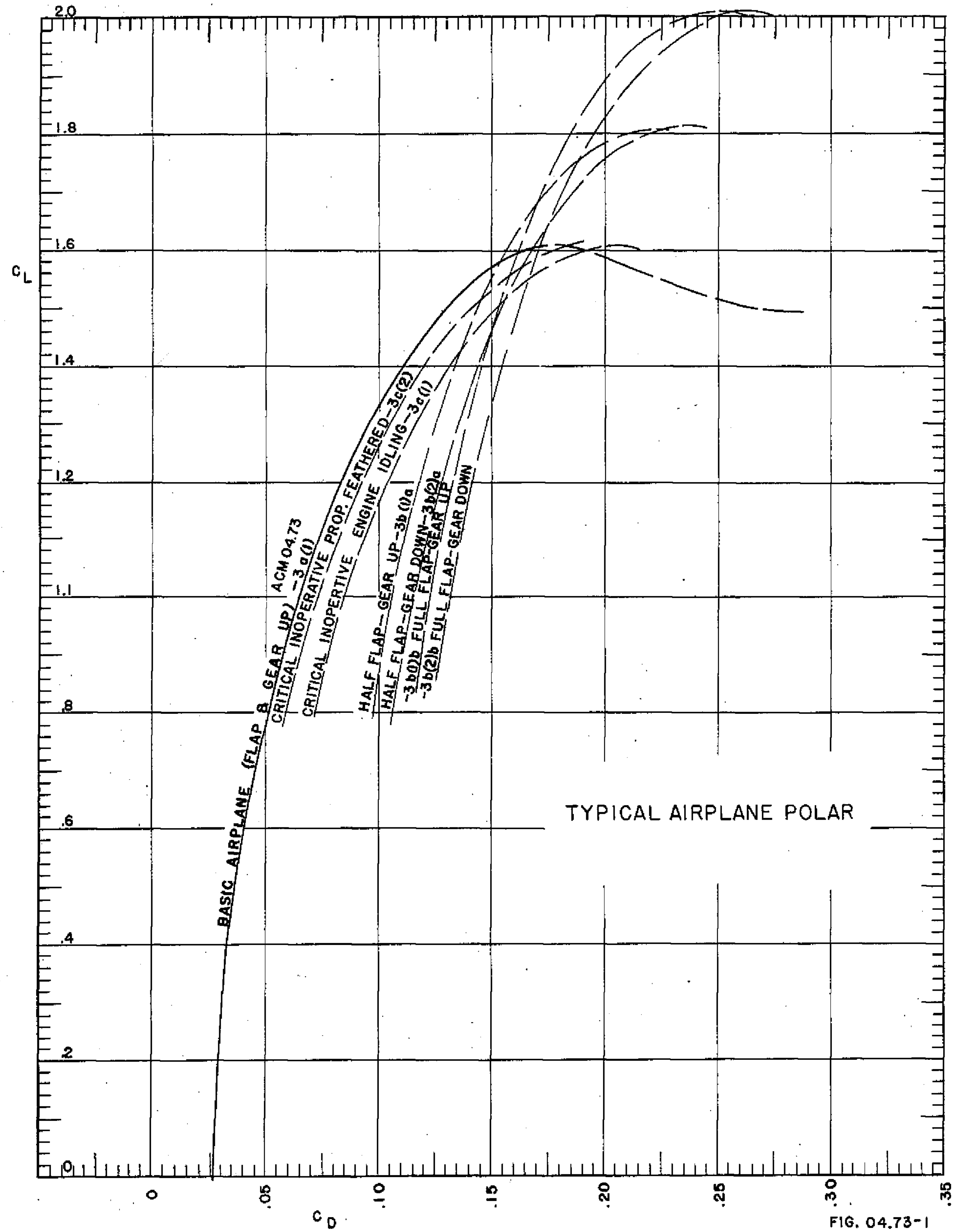

FIG. 04.73-1

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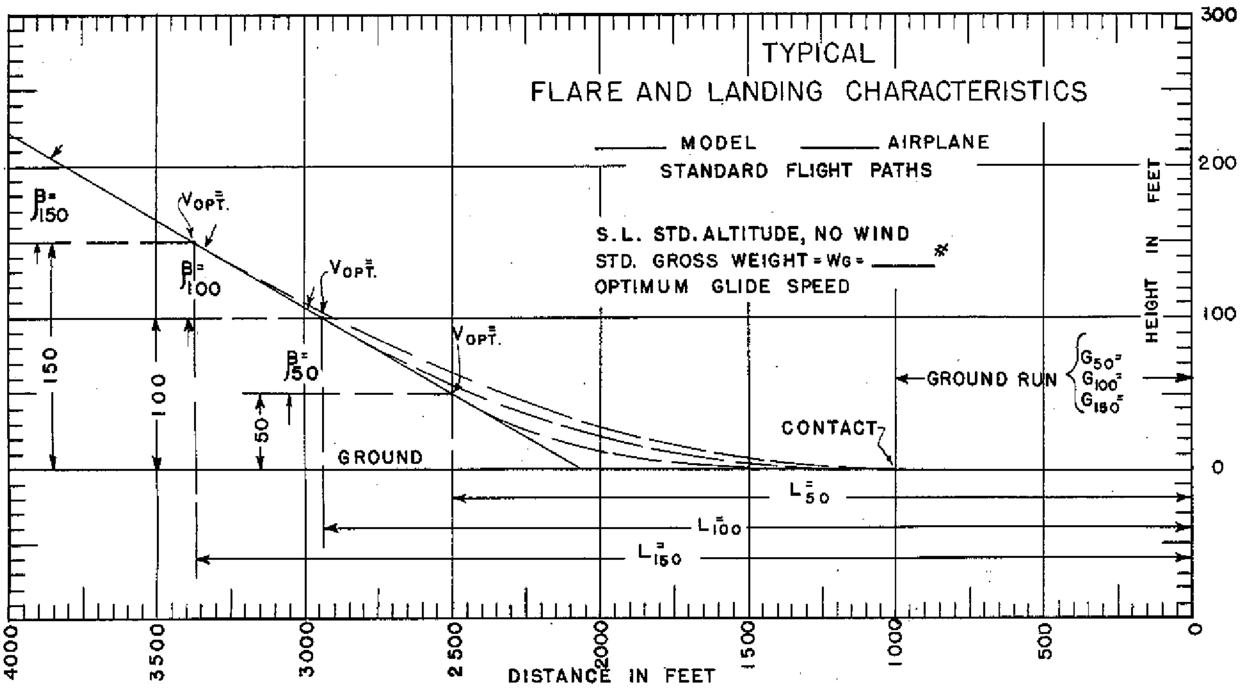

EFFECT OF DENSITY ALTITUDE

h_D	L/L_0			G/G_0			β/β_0		
	50	100	150	50	100	150	50	100	150
2,000	.9--	.9--	.9--						
0	1.000	1.000	1.000						
2,000	1.---	1.---	1.---						
4,000									
6,000									
8,000									
10,000									

EFFECT OF WEIGHT

W/W_G	L/L_0			G/G_0			β/β_0		
	50	100	150	50	100	150	50	100	150
1.2	1.---								
1.1	1.---								
1.0	1.000								
.9	.9--								
.8									
.7									
.6									

EFFECT OF GLIDE SPEED

V/V_s	L/L_0			G/G_0			β/β_0		
	50	100	150	50	100	150	50	100	150
1.5									
1.4									
1.3									
1.2									
1.1									

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FIG. 04.73-2

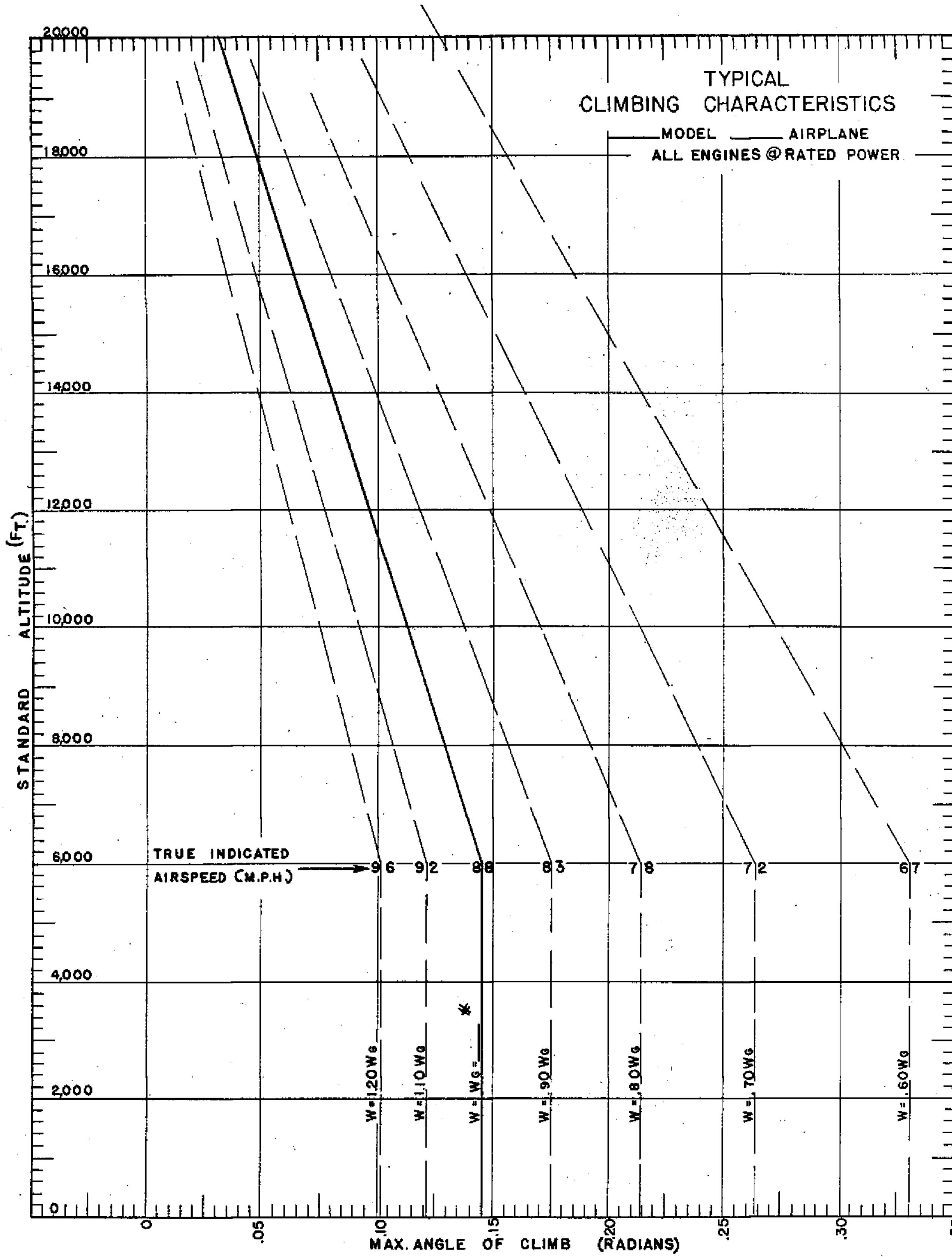

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FIG. 04.73-3

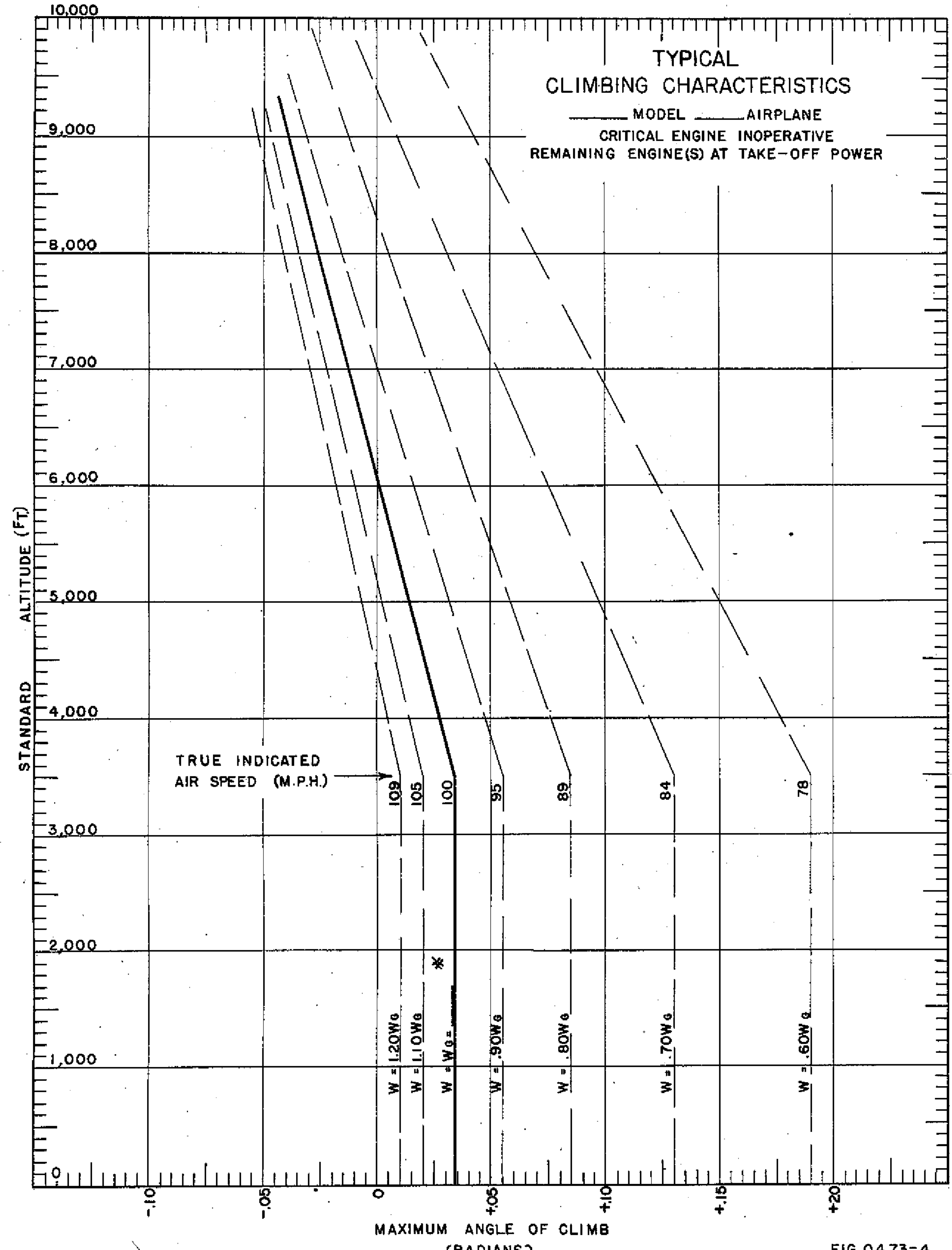

FIG. 04.73-4

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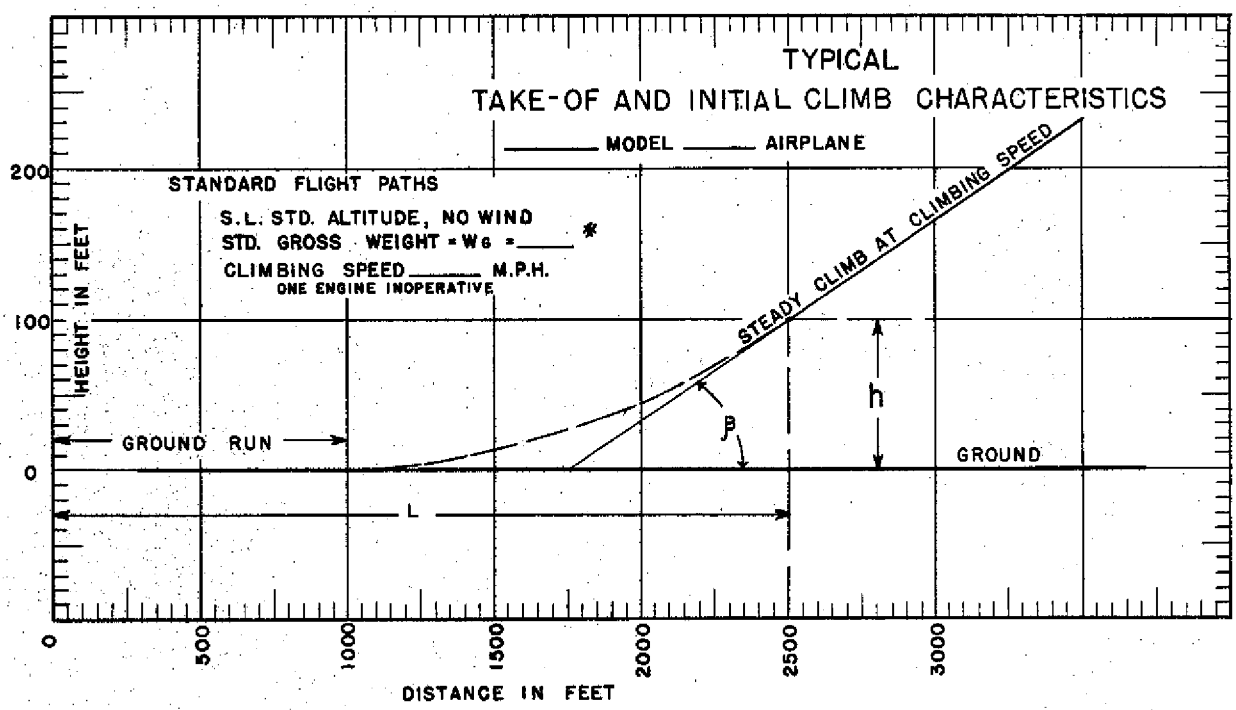

EFFECT OF ALTITUDE

h(FT)	L/Lo	h/ho	β/βo
-2.000	.9--	.9--	1.---
0	1.000	1.000	1.000
+2.000	1.---	1.---	.9--
4.000	1.---		
6.000			
8.000			
10.000			

EFFECT OF WEIGHT

W/Wo	L/Lo	h/ho	β/βo
1.2	1.---	1.---	
1.1	1.---	1.---	.9--
1.	1.000	1.000	1.000
.9	.9--	.9--	1.---
.8			
.7			
.6			

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FIG. 04.73-5

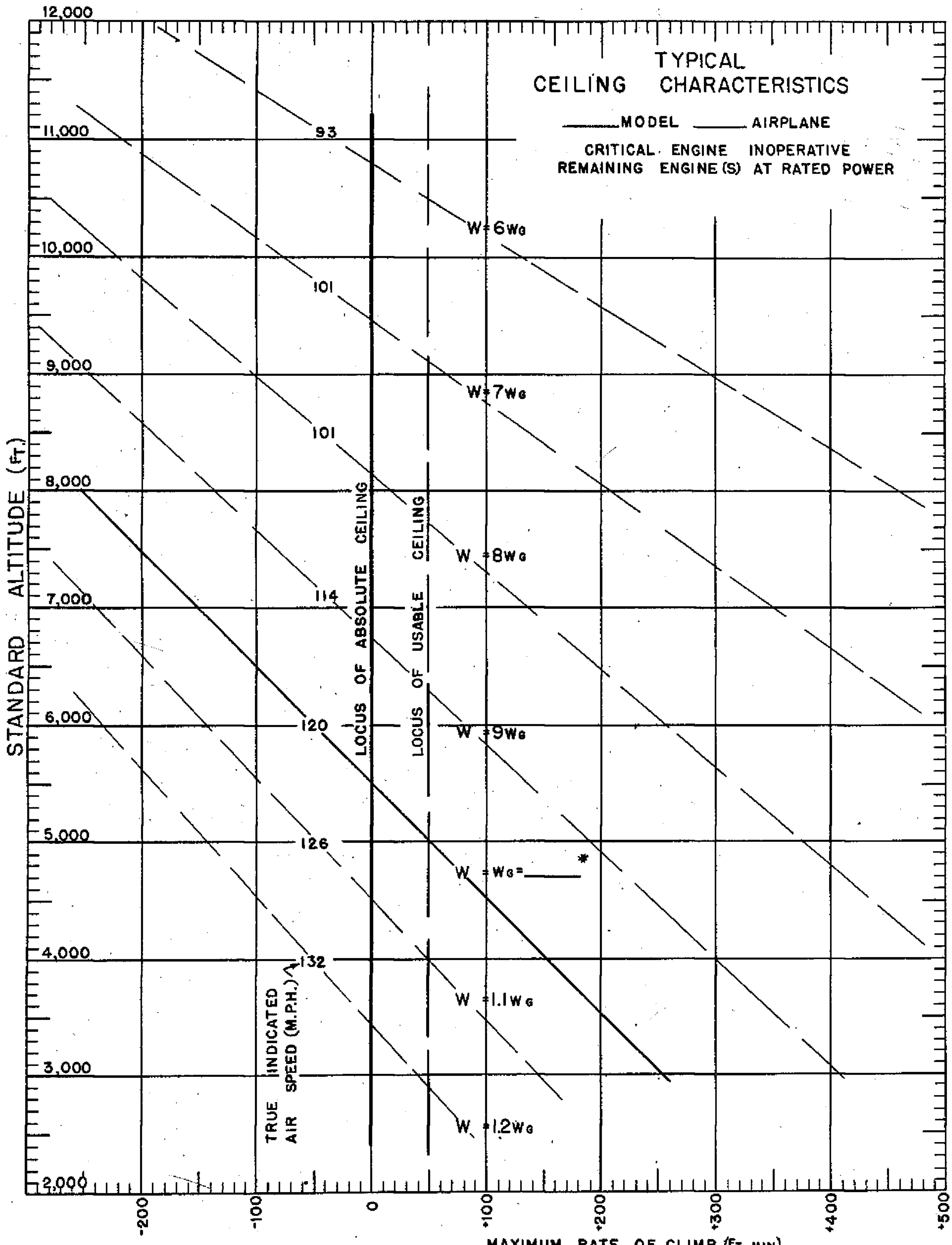

FIG. 04.73-6

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