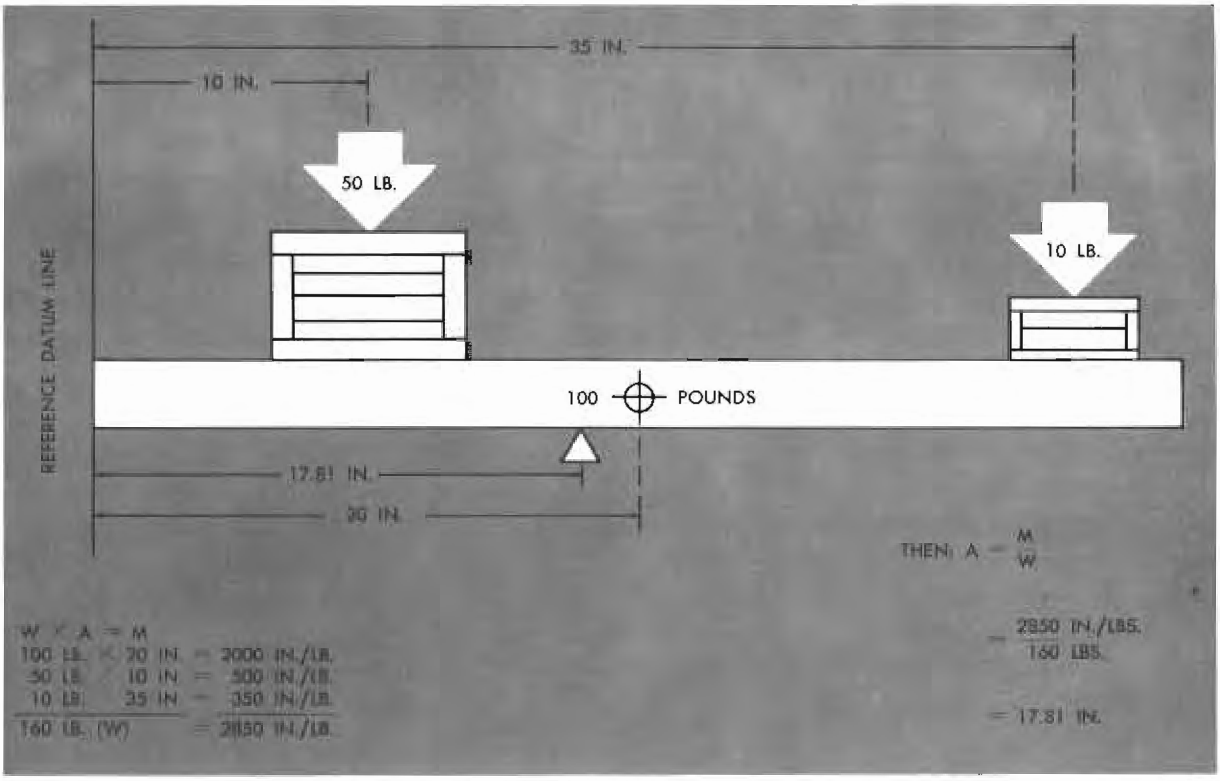


Figure 8-3. Balance Example Where Original Object Has Weight

When the weight, arm, and moment of the basic aircraft are known, it is not difficult to compute new CG locations on expendable items such as fuel, oil, crew, cargo, and the like, as they are added or removed. Using the longhand mathematical method, this is accomplished by adding all the moments of the additional items to the basic moment and dividing this by the sum of the weights of these items and the basic weight of the aircraft. This establishes the CG of the loaded aircraft in inches from the rd. The formula is

$$CG = \frac{\text{basic moment} + \text{additional moment}}{\text{aircraft basic weight} + \text{additional weight}} \quad (60)$$

LOAD FACTOR

The *load factor* of an aircraft is defined as an increase or decrease of normal weight as a result of maneuvers. It is expressed in units of normal weight, with the normal weight being one. If a 200-lb man were to stand on a set of scales in an elevator, he would see his weight increase on the scales as the elevator started to ascend. If the ascent began abruptly, the man might see the scales indicate as much as 400 pounds at the start. If this happened, his load factor at that moment would be 2.0. That is, the indicated weight equals 2.0 units of his normal weight.

An aircraft flying straight and level in still air has a load factor of 1.0. However, if it were to fly into a updraft, its weight would be increased in proportion to the violence of the updraft. If its weight at the time of entry into the updraft were to double, its load factor at that moment would be 2.0. Conversely, if the aircraft were to enter a downdraft, the load factor might be zero (0.0) or even negative. This depends upon the maneuver, whether it is induced by rough air or by the pilot's manipulation of the controls. The landing maneuver has a pronounced effect on the load factor, especially at the moment the wheels touch the ground, at which time the load factor may be as high as 3.0. For this reason, a limit is placed on the landing weight of an aircraft.

The Logistics Command has specified that all cargo aircraft must be built strong enough to withstand a load factor of 2.5. This figure is termed the

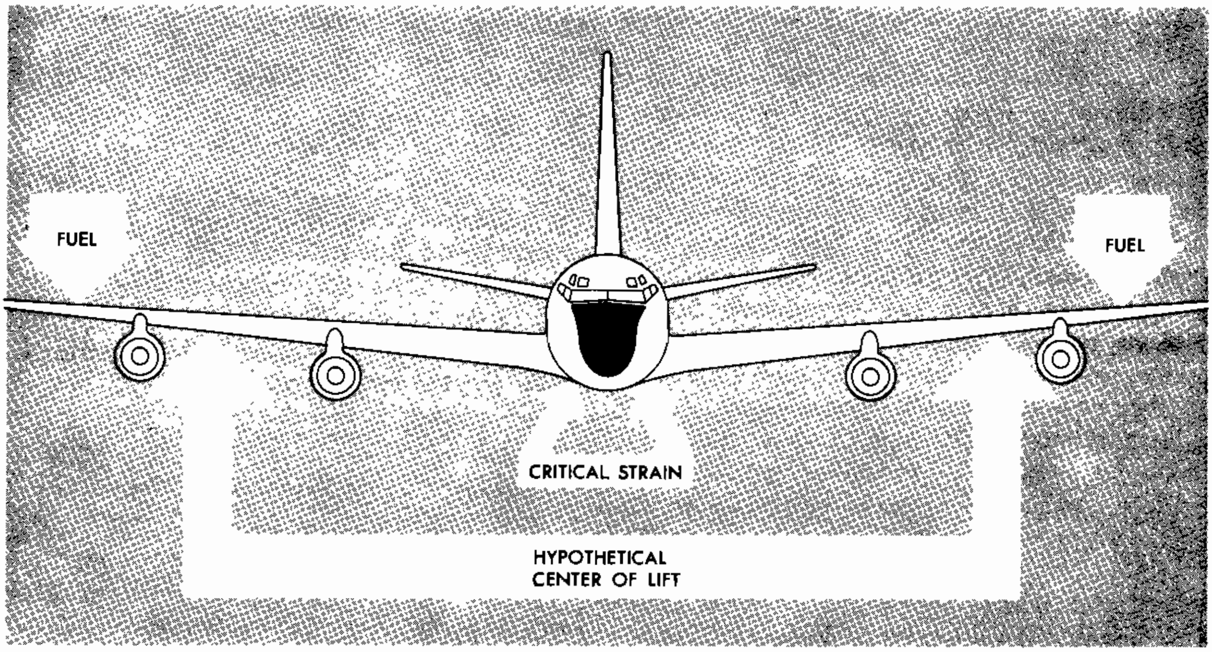


Figure 8-4. Effect of Fuel Loading in Wings

load limit factor. Since the fuselage and the weight of all its contents are supported in flight by the wings, it is apparent that the critical strain is on the wings, and specifically on the wing roots. (See figure 8-4.) An empty aircraft naturally has less strain on the wings during flight, and is able to withstand a load factor in excess of 2.5 with safety. An overloaded aircraft, however, may have such a strain on the wing roots that a load factor of 2.5 would damage the wing structure.

If all the fuel for an aircraft is contained within its fuselage, it contributes to the strain on the wings. This is one reason why the fuel is distributed to tanks located throughout the wings. This condition may be seen clearly in the illustration which shows the aircraft supported from two points representing center of lift on each wing. Supported in this manner, the aircraft has a vertical stress on the wings identical to the stress encountered in straight and level flight in still air. The fuel load is represented as weights near the tips. This placement of fuel does not strengthen the wing structure, but it does reduce the strain at the wing roots and spreads the stress throughout the length of the wings.

WEIGHT CONVERSIONS

When computing weight and balance, it is often necessary to convert measurements of capacity to measurements of weight. Following are some of the conversions most often made.

Fuel: Gasoline=6.0 lb per gallon; JP-4=6.5 per gallon (the weight of fuel varies with the temperature, but is usually considered at 6.0 lb per gallon for gasoline and 6.5 lb per gallon for JP-4.

Oil: 7.5 lb per gallon.

Water: 8.3 lb per gallon.

Alcohol: 6.8 lb per gallon.

ADI: 7.5 lb per gallon (50% water—50% alcohol).

CENTER OF GRAVITY CALCULATIONS

As explained previously, the basic CG represents the point of weight concentration of the basic aircraft before variables such as fuel, oil, crew, equipment, and cargo are loaded. As these variables are loaded and later removed from the aircraft the CG moves. Consequently, the fore and aft center of gravity limits, between which the CG may be positioned without dangerously affecting the flight characteristics of the aircraft, are established. CG calculations thus form a definite part of the flight planning for both cargo and bomber aircraft.

These calculations insure that the loading of these aircraft is correctly accomplished to maintain proper balance during takeoff, flight, and landing. Center of gravity calculations are required whenever the balance of an aircraft is changed by the addition, removal, or shifting of weight. Normally, such calculations are only concerned with the variable load. Occasionally, however, the basic CG must be recomputed, which involves weighing the aircraft. The procedures for weighing are discussed later.

There are three methods of calculating the CG position: *longhand, Chart E,* and the *load adjuster.* The longhand method takes additional time but is more accurate, and it is actually the basis for the other two methods. The Chart E method is usually used when a load adjuster is not available. The load adjuster method is most commonly used and makes rapid CG calculations possible.

Formulas for CG Calculations

There are six basic formulas used in making longhand weight and balance calculations.

Formula 1:

$$\text{Weight (lb)} \times \text{arm (in)} = \text{moment (in-lb)} \qquad (61)$$

The moment to be added or subtracted because of loading or unloading an object from an aircraft is found by multiplying the weight of the object by its arm (distance from the rd).

Formula 2:

$$\frac{\text{Total moment}}{\text{Total weight}} = \text{average arm} = \text{distance from rd to CG} \qquad (62)$$

In this formula, the total moment is the sum of the aircraft basic moment and the moments of items loaded in the aircraft. The total weight is the sum of the aircraft basic weight and the total weight of the loaded items. When the total moment is divided by the total weight, the result is the distance in inches that the CG position is from the rd.

Formulas 3, 4, and 5 are used for computing new CG locations as a result of adding, removing, or shifting weight. The term "original" as used in these formulas refers to the aircraft condition just prior to a change in load.

Formula 3 (Adding Weight):

$$\frac{\text{Original moment} + \text{added moment}}{\text{Original weight} + \text{added weight}} = \text{new CG} \qquad (63)$$

Formula 4 (Removing Weight):

$$\frac{\text{Original moment} - \text{moment removed}}{\text{Original weight} - \text{weight removed}} = \text{new CG} \qquad (64)$$

Formula 5 (Shifting Weight):

$$\frac{\text{Original moment} \pm \text{moment change}}{\text{Original weight}} = \text{new CG} \qquad (65)$$

The moment change is computed by multiplying a weight by the distance it is moved. If the weight is moved forward, the moment change is subtracted from the original moment to determine the new CG location by formula 5; if the weight is moved aft, the moment change is added to the original moment to find the new CG position by formula 5.

Formula 6:

$$\frac{\text{Change in moment}}{\text{Total weight}} = \text{CG change} \qquad (66)$$

This formula is, in effect, a simplified version of Formula 5; however, the result obtained is the amount of CG change which must be added to or subtracted from the old CG.

Problems in CG Calculations

The following sample problems are included as practical applications of the formulas presented previously.

The problem representing Formula 1 and Formula 2 is shown in figure 8-5. In this problem, it would be impossible for the takeoff or landing CG to exceed the specified limits, since the items are standard with a fixed location as determined by the design of the aircraft. In another problem, however, it will be shown how the disposition of expendables can cause the CG to fall outside the limits.

The following problem is an application of Formula 3 (Adding Weight).

Problem: Find the arm at which the added cargo in the following loading must be placed to maintain a predetermined CG location.

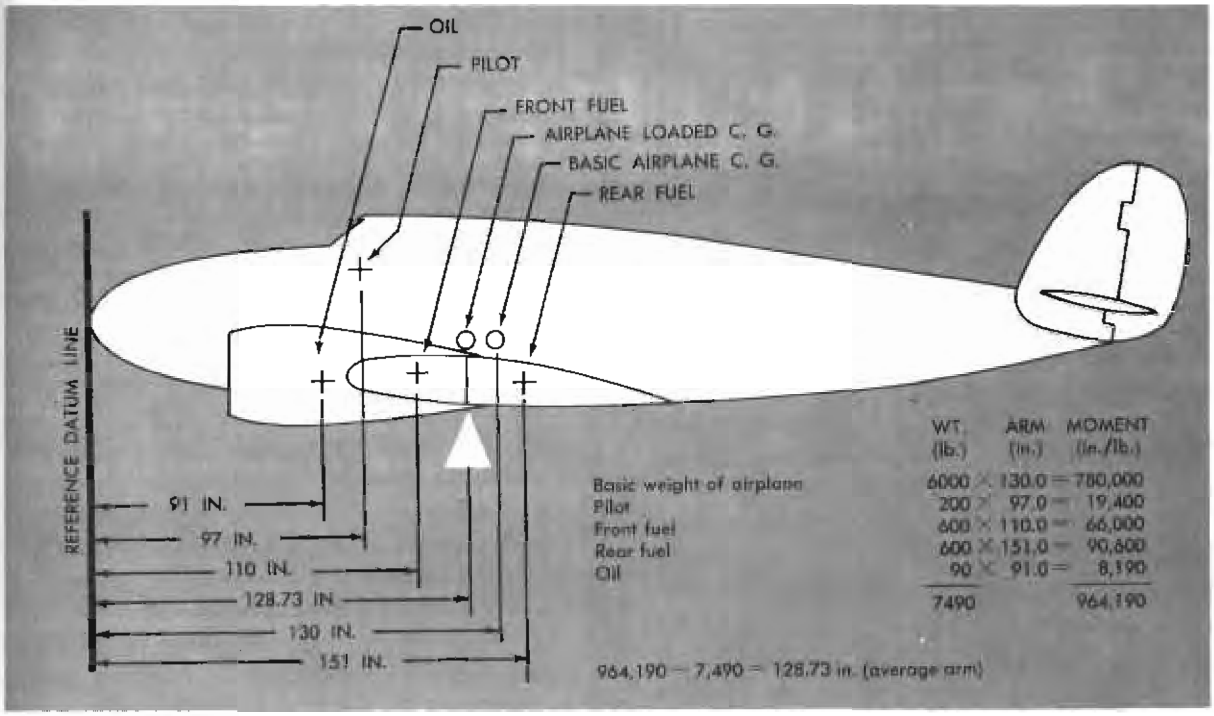
Original load	23,500 lb; CG 175 in
Cargo added	500 lb
CG after adding cargo	180 in

Solution:

$$\frac{\text{Original moment} + \text{added moment}}{\text{Original weight} + \text{added weight}} = \text{new CG}$$

$$\frac{23{,}500 \text{ lb} \times 175 \text{ in} + 500 \text{ lb} \times A \text{ in}}{23{,}500 \text{ lb} + 500 \text{ lb}} = 180 \text{ in}$$

$$\frac{4{,}112{,}500 + 500\,A}{24{,}000} = 180$$



	WT. (lb.)		ARM (in.)		MOMENT (in./lb.)
Basic weight of airplane	6000	×	130.0	=	780,000
Pilot	200	×	97.0	=	19,400
Front fuel	600	×	110.0	=	66,000
Rear fuel	600	×	151.0	=	90,600
Oil	90	×	91.0	=	8,190
	7490				964,190

964,190 ÷ 7,490 = 128.73 in. (average arm)

Figure 8-5. Center of Gravity Calculation

$$4{,}112{,}500 + 500\,A = 180 \times 24{,}000$$
$$500\,A = 4{,}320{,}000 - 4{,}112{,}500$$
$$500\,A = 207{,}500$$
$$A = 415 \text{ in (Arm of added load)}$$

The following problem is an application of Formula 4 (Removing Weight).

Problem: Find the CG of this aircraft after 500 gallons of fuel have been used.

Takeoff load	20,000 lb; CG 180 in
Fuel	500 gal; arm 190 in
(Fuel weight, 6 lb per gal)	

Solution:

$$\frac{\text{Original moment} - \text{moment removed}}{\text{Original weight} - \text{weight removed}} = \text{new CG}$$

$$\frac{(20{,}000 \text{ lb} \times 180 \text{ in}) - (3{,}000 \text{ lb} \times 190 \text{ in})}{20{,}000 \text{ lb} - 3{,}000 \text{ lb}} = \text{new CG}$$

$$\frac{3{,}600{,}000 - 570{,}000}{17{,}000} = 178.2 \text{ in (new CG)}$$

The following problem is an application of Formula 5 (Shifting Weight).

Problem: How far will the CG of this aircraft move when the landing gear retracts?

Gross weight 25,000 lb; CG 180 in
Main gear 860 lb; move 60 in aft
Nose gear 95 lb; move 14 in forward

Solution: Since the main gear moves aft, its moment is added to the original moment, from which amount the nose gear moment is subtracted, since the nose gear moves forward.

$$\frac{\text{Original moment} \pm \text{moment change}}{\text{Original weight}} = \text{new CG}$$

$$\frac{4{,}500{,}000 + 51{,}600 - 1{,}330}{25{,}000} = \text{new CG}$$

$$\frac{4{,}550{,}270}{25{,}000} = \text{new CG}$$

$$\text{New CG} = 182.01 \text{ in}$$

The following problem is an application of Formula 6.

Problem: How much will the CG shift as a result of the following crew changes? (Figure 200 pounds per man.)

Gross weight = 30,000 lb.
Copilot moves 110 in forward
Navigator moves 300 in aft

Solution:

Copilot moment = 22,000 in-lb forward
Navigator moment = 60,000 in-lb aft

$$\frac{\text{Change in moment}}{\text{Total weight}} = \text{CG change}$$

$$\frac{60{,}000 - 22{,}000}{30{,}000} = \text{CG change}$$

$$\text{CG change} = 1.27 \text{ in aft}$$

In the next problem, see if the CG of the aircraft will be within limits for landing after the bombs have been dropped and 700 gallons of fuel have been used.

Problem:

Takeoff load, 30,000 lb; CG	188 in
Bombs, 8 at 300 lb each	Arm 210 in
Arm of fuel	185 in
Forward limit of CG for landing	187 in
Aft limit of CG for landing	195 in

Solution:

$$\begin{aligned} \text{Fuel moment} &= 700 \text{ gal} \times 6 \text{ lb/gal} \times 185 \text{ in} \\ &= 4{,}200 \text{ lb} \times 185 \text{ in} \\ &= 777{,}000 \text{ in-lb} \\ \text{Bomb moment} &= 2{,}400 \text{ lb} \times 210 \text{ in} \\ &= 504{,}000 \text{ in/lb} \end{aligned}$$

$$\frac{\text{Original moment} - \text{moment removed}}{\text{Original weight} - \text{weight removed}} = \text{new CG}$$

$$\frac{(30{,}000 \text{ lb} \times 188 \text{ in}) - (777{,}000 \text{ in-lb} + 504{,}000 \text{ in-lb})}{30{,}000 - (4{,}200 \text{ lb} + 2{,}400 \text{ lb})} = \text{new CG}$$

$$\frac{4{,}359{,}000}{23{,}400} = \text{new CG}$$

$$\text{New CG} - 186.28 \text{ in}$$

The results of this problem show that the new CG is unsafe for landing, since the forward safe limit is 187 inches. In this case, it would be necessary to calculate a location for one or more members of the crew to take after disposition of the load to keep the CG within limits.

HANDBOOK OF WEIGHT AND BALANCE DATA

Every aircraft must have a perpetual weight and balance record. This is kept on a variety of charts and forms, contained in the *Handbook of Weight and Balance Data* (TO 1-1B-40), which also contains instructions for completing the forms. The following forms are used:

Record of Weight and Balance Personnel, DD Form 365

Chart A—Basic Weight Check List, DD Form 365A

Chart B—Airplane Weighing Record, DD Form 365B

Chart C—Basic Weight and Balance Record, DD Form 365C

Chart E—Loading Data Charts and Graphs

Weight and Balance Clearance Form F, DD Form 365F

Chart A (DD Form 365A)

Chart A (Basic Weight Check List) is the list of fixed and operating equipment. It is initiated by the manufacturer prior to delivery and contains items of equipment that are, or will be, installed in the aircraft. The equipment is itemized by compartment number, name, weight, arm, and moment of each item. These items are inventoried before delivery and checked off in the delivery column if installed. Chart A is used at in-between weighing times as a running inventory, and any changes in the inventory that affect the weight and balance of the aircraft are carried forward to Chart C.

Inventories should be made periodically, but are required specifically when:

- The aircraft undergoes modification, major overhaul, or repair.
- The aircraft is received at a new base.
- Changes of equipment are made for a different type of operation or mission.
- The aircraft is reweighed.
- The pilot reports noseheaviness or tail-heaviness in flight.

Chart B (DD Form 365B)

Form 365B (Aircraft Weighing Record) is the record of the actual weighing of the aircraft.

Chart C (DD Form 365C)

Chart C (Basic Weight and Balance Record) is a continuous history of the basic weight, moment, and balance computer index resulting from structural and equipment changes in service. The main purpose of the basic aircraft bookkeeping system is to keep this historical information up to date. Whenever these weight changes occur, they are immediately recorded on Chart C and the original basic weight and moment corrected to include the change. The new basic weight and moment is then used as basic data for subsequent loading calculations.

Chart E (Loading Data Charts and Graphs)

Chart E, consisting of several loading graphs and charts, uses the same basic process as the longhand method. However, the Chart E method is not as accurate as the longhand method because of the rounded off numbers and possible inaccuracies in reading the graphs, but it is sufficiently accurate for normal use.

Chart E data may be in graphic or tabular form. The recent type of Chart E is in tabular form and consists of the following items:

1. Complete fuselage diagrams
2. Location of leveling devices
3. Location of jig point
4. Location of reference datum, and distance from rd to the leading edge of MAC and to the centerline of wheels
5. Length of MAC
6. CG range, given in inches and also in percent of MAC
7. Fuel tables
8. Oil tables
9. Cargo and passenger tables
10. Crew change table
11. Bomb and ammunition data
12. Compartment centroids and limiting capacities
13. Landing gear moment change due to retraction
14. CG table (CG loading limits)
15. Design gross weight and compartment data
16. Miscellaneous data

All weights and moments for all variable load items are obtained from the loading graphs or tables. These are added arithmetically to the current basic weight and moment, which are entered on Chart C. The totals obtained are the gross weight and the total moment for the condition.

The tables are simplified by dividing all moments by a constant to reduce the number of digits in the total moment. This constant can be 100, 1000, or 10,000, depending on the size of the aircraft. For example, the constant for the C-124 is 10,000; thus the moment in inch-pounds is divided by 10,000.

The weight placed in each compartment is tabulated separately on Form F. The corresponding simplified moment is obtained from the table, and the gross weight versus simplified moment and the balance in percent of MAC can be found directly instead of by calculation.

LOAD ADJUSTER

The *load adjuster* (balance computer) is used by the engineer and loading personnel to direct the loading of an aircraft and thereby control the location of the final CG. With the load adjuster, the following information can be determined rapidly and accurately.

1. The CG location for any loading condition
2. The loading required to achieve a desired CG location
3. The effect of any change in weight or location of the load
4. The necessary shift of a movable load or a crew member during flight to maintain the CG location within the loading range

The load adjuster has the appearance of the widely used mathematical slide rule. (See figure 8-6.) The load adjuster, however, adds and subtracts moments. Each loading scale represents a combination of weight and moment or the effect of load (weight placed in a given location). The left end of the load adjuster represents the nose of the aircraft and the right end, the tail. Consequently, loading an item which causes the indicator hairline to move to the left tends toward a forward center of gravity position, and loading an item which causes the indicator hairline to move to the right tends toward an aft center of gravity position.

The parts of a load adjuster are: *base, slide, indicator,* and *carrying case.*

Base

The *base* of the load adjuster contains grooves in which the slide and the indicator move back and forth. The top side of the face shows the balance ranges; the bottom side shows the index scale. On the back of the base is a plan view of the fuselage showing the compartments and centroids with a corresponding reference scale in inches. On the

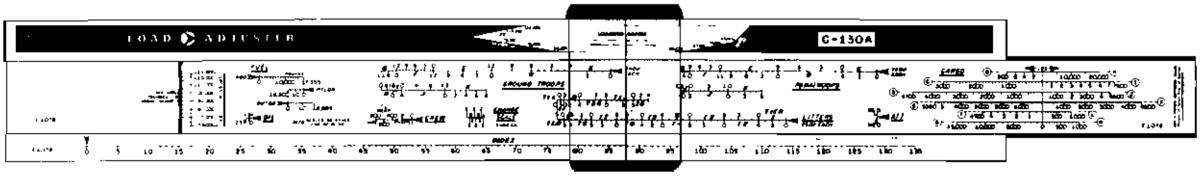


Figure 8-6. Load Adjuster

portion under the slide is a grid consisting of horizontal and sloping vertical lines. The horizontal lines represent gross weight and the sloping lines represent percent of MAC or inches from the reference datum.

Indicator

The *indicator* is used to make the load adjuster settings. It is a rectangular piece of transparent plastic with a hairline perpendicular to the scales. The hairline indicates a CG position in relation to the balance limits. The engineer uses the indicator hairline to line up the settings.

Slide

The top face of the *slide* has loading scales which are used to compute the effect on the CG when such items as crew, cargo, fuel, oil, and ammunition are loaded in various parts of the airplane. The reverse side of the slide usually shows scales with the weight plotted against simplified moments. These scales are used to determine the index for a particular basic condition of weight and moment.

Operation

All loading calculations start with the hairline over the basic index. From there on, only two operations are required to load each of the totals shown on the Form F.

1. Move the slide until the 0 vertical starting line of the scale being used is under the hairline.
2. Move the indicator until the hairline is over the weight being added. The new index is then read under the hairline on the index scale at the bottom of the rule. (The indexes are estimated to the nearest tenth.)

These two operations are repeated for each loading total that appears on the Form F. The computations are made in the order that the items appear on the form, and the resulting index reading is progressively entered in the index column. (These indexes are not added mathematically on the Form F as are the moments.) When moving the slide, *make sure that the indicator does not move and see that the slide remains in position.*

The effect of removal or redistribution of the load is determined by following the same two steps above, except that the hairline is not set over the 0 line of any given scale, but rather over the total weight to be removed and the last recorded index reading. The indicator is then moved to the 0 line of the scale or to an intermediate weight and the new index is read under the hairline on the index scale.

To read the CG position from the grid of the load adjuster, the hairline of the indicator is set at the takeoff index and the slide moved so that the gross weight figures on its left side are conveniently close to the indicator hairline. The point of intersection of the gross weight with the indicator hairline is dropped straight down into the grid to give the CG position with reference to the sloping percent MAC lines. Estimate to the nearest tenth.

FORM F

Form F is a summary of the actual disposition of the load in the aircraft. It records step by step, in an orderly manner, the balance status of the aircraft, and it serves as a work sheet on which the weight and balance technician or flight engineer can record the calculations and corrections. Two versions of the form are provided, one for transport and the other for tactical missions. Although the forms differ somewhat in detail, their general use and the end results are the same. Figure 8-7, shows the transport form.

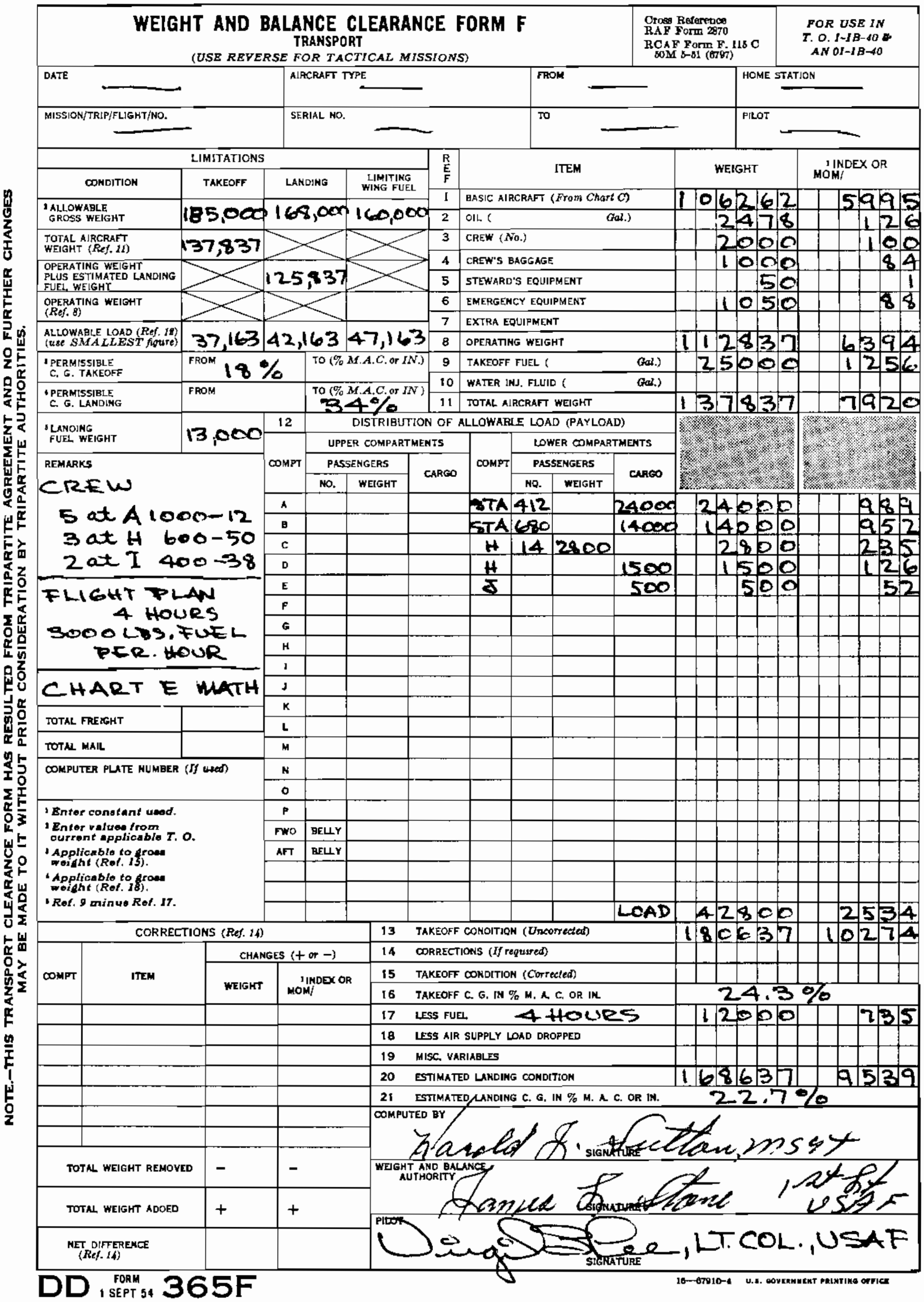
Form F comes in expendable pads or as separate sheets. The original and a carbon copy are prepared for each loading. The original, which has the signature of responsibility, serves as a certificate of proper weight and balance and has flight clearance purposes. The duplicate remains with the aircraft for the duration of the mission.

As outlined in TO 1-1B-40, the procedure for completing a Form F (with the aid of Chart E) for transport and cargo aircraft, is as follows:

1. Enter the necessary information at the top of the form.
2. In the limitations table, enter the gross weight and CG restrictions obtained from the latest applicable technical order.
3. Ref-1. Basic weight and index or moment. Obtain these figures from the latest entry on the Chart C.

NOTE: If the load adjuster is used, enter the index number obtained from Chart C opposite the basic weight of Ref-1. Enter the plate number of the load adjuster under the Remarks section.

4. Ref-2. Amount and weight of oil.



NOTE.—THIS TRANSPORT CLEARANCE FORM HAS RESULTED FROM TRIPARTITE AGREEMENT AND NO FURTHER CHANGES MAY BE MADE TO IT WITHOUT PRIOR CONSIDERATION BY TRIPARTITE AUTHORITIES.

WEIGHT AND BALANCE CLEARANCE FORM F
TRANSPORT
(USE REVERSE FOR TACTICAL MISSIONS)

Cross Reference
RAF Form 2870
RCAF Form F. 115 C
50M 5-51 (6797)

FOR USE IN T. O. 1-1B-40 & AN 01-1B-40

DATE	AIRCRAFT TYPE	FROM	HOME STATION
MISSION/TRIP/FLIGHT/NO.	SERIAL NO.	TO	PILOT

LIMITATIONS

CONDITION	TAKEOFF	LANDING	LIMITING WING FUEL
[2] ALLOWABLE GROSS WEIGHT	185,000	168,000	160,000
TOTAL AIRCRAFT WEIGHT (*Ref. 11*)	137,837		
OPERATING WEIGHT PLUS ESTIMATED LANDING FUEL WEIGHT		125,837	
OPERATING WEIGHT (*Ref. 8*)			
ALLOWABLE LOAD (*Ref. 18*) (*use SMALLEST figure*)	37,163	42,163	47,163
[3] PERMISSIBLE C. G. TAKEOFF	FROM 18 %	TO (*% M.A.C. or IN.*)	
[4] PERMISSIBLE C. G. LANDING	FROM	TO (*% M.A.C. or IN.*) 34%	
[5] LANDING FUEL WEIGHT	13,000		

REF	ITEM	WEIGHT	[1] INDEX OR MOM/
1	BASIC AIRCRAFT (*From Chart C*)	106262	5995
2	OIL (*Gal.*)	2478	126
3	CREW (*No.*)	2000	100
4	CREW'S BAGGAGE	1000	84
5	STEWARD'S EQUIPMENT	50	1
6	EMERGENCY EQUIPMENT	1050	88
7	EXTRA EQUIPMENT		
8	OPERATING WEIGHT	112837	6394
9	TAKEOFF FUEL (*Gal.*)	25000	1256
10	WATER INJ. FLUID (*Gal.*)		
11	TOTAL AIRCRAFT WEIGHT	137837	7920

12 DISTRIBUTION OF ALLOWABLE LOAD (PAYLOAD)

COMPT	UPPER COMPARTMENTS PASSENGERS NO.	UPPER PASSENGERS WEIGHT	UPPER CARGO	COMPT	LOWER COMPARTMENTS PASSENGERS NO.	LOWER PASSENGERS WEIGHT	LOWER CARGO	WEIGHT	INDEX OR MOM/
A				STA 412			24000	24000	989
B				STA 680			14000	14000	952
C				H	14	2800		2800	235
D				H			1500	1500	126
E				J			500	500	52
F									
G									
H									
I									
J									
K									
L									
M									
N									
O									
P									
FWD	BELLY								
AFT	BELLY								
							LOAD	42800	2534

REMARKS
CREW
5 at A 1000-12
3 at H 600-50
2 at I 400-38

FLIGHT PLAN
4 HOURS
3000 LBS. FUEL
PER. HOUR

CHART E MATH

TOTAL FREIGHT	
TOTAL MAIL	
COMPUTER PLATE NUMBER (*If used*)	

[1] *Enter constant used.*
[2] *Enter values from current applicable T. O.*
[3] *Applicable to gross weight (Ref. 15).*
[4] *Applicable to gross weight (Ref. 18).*
[5] *Ref. 9 minus Ref. 17.*

REF	ITEM	WEIGHT	INDEX OR MOM/
13	TAKEOFF CONDITION (*Uncorrected*)	180637	10274
14	CORRECTIONS (*If required*)		
15	TAKEOFF CONDITION (*Corrected*)		
16	TAKEOFF C. G. IN % M. A. C. OR IN.	24.3%	
17	LESS FUEL 4 HOURS	12000	735
18	LESS AIR SUPPLY LOAD DROPPED		
19	MISC. VARIABLES		
20	ESTIMATED LANDING CONDITION	168637	9539
21	ESTIMATED LANDING C. G. IN % M. A. C. OR IN.	22.7%	

CORRECTIONS (*Ref. 14*)

COMPT	ITEM	CHANGES (+ *or* −) WEIGHT	CHANGES (+ *or* −) [1] INDEX OR MOM/
TOTAL WEIGHT REMOVED		−	−
TOTAL WEIGHT ADDED		+	+
NET DIFFERENCE (*Ref. 14*)			

COMPUTED BY
Harold J. Suttan, MSgt
SIGNATURE

WEIGHT AND BALANCE AUTHORITY
James [illegible] Stone, 1st Lt USAF
SIGNATURE

PILOT
, LT. COL., USAF
SIGNATURE

DD FORM 1 SEPT 54 **365F**

16—67910-4 U.S. GOVERNMENT PRINTING OFFICE

Figure 8-7. Transport Form "F"

5. Ref-3. Number and weight of crew (use actual weights if available).
6. Ref-4. Weight of crew baggage.
7. Ref-5. Weight of steward's equipment.
8. Ref-6. Weight of emergency equipment.
9. Ref-7. Weight of extra equipment.
10. Ref-8. Enter the sum of the weights for Ref-1 thru Ref-7 inclusive to obtain the operating weight.
11. Ref-9. Number of gallons and weight of takeoff fuel. Do not include warmup and taxi fuel. (Under Remarks, the fuel tanks that were serviced are listed as the amount of fuel in each tank.)
12. Ref-10. Number of gallons and weight of the water injection (ADI) fluid.
13. Ref-11. Total aircraft and fuel weight.
14. Ref-12. Using the same compartment letter designation that appears on the Chart E, or on the back of the load adjuster, enter the number, weight, and moment index of the cargo. The sum of the compartment totals must not exceed the Allowable Load entry in the Limitations section.
15. Ref-13. Enter the sum of Ref-11 and the compartment totals, weight and moment index under Ref-12 opposite Takeoff Condition.
16. Check the weight figure, Ref-13, against the Gross Weight Takeoff in the Limits table. Check the simplified moment figure opposite Ref-13 against Chart E Gross Weight Center of Gravity table (or load adjuster) to ascertain that the indicated CG is within allowable limits.
17. If changes in amount or distribution of load are required, indicate the necessary adjustments by proper entries in the Corrections table in the lower left-hand corner of the form. Enter a brief description of the adjustment made in the column marked *Item.* Add all the weight and moment index decreases and insert the totals in the space opposite Total Weight Removed. Add all the weight and moment index increases and insert the totals in the space opposite Total Weight Added. Subtract the smaller from the larger of the two totals and enter the difference, with the applicable plus or minus sign, opposite the Net Difference. Transfer these net difference figures to the space opposite Ref-14.
18. Ref-15. If Ref-14 is a plus value, add it to Ref-13 and enter the sum. If Ref-14 is a minus value, subtract it from Ref-13 and enter the difference. Make sure that the value does not exceed allowable limits.
19. Ref-16. By referring to the CG table on the Chart E or to the CG grid on the load adjuster, determine the takeoff CG in percent MAC. Enter this figure in the space provided for Takeoff CG in Percent MAC.
20. Ref-17. Estimate the weight of fuel and other items that will be expended before landing. Enter the weights and moments indexes in the spaces provided. Do not consider reserve fuel as expended when determining estimated landing condition.
21. Ref-18. Enter the weight of Air Supply Load to be dropped before landing, with the index or moment/constant.
22. Ref-19. Enter the weight of Miscellaneous items to be expended before landing, such as water injection fluid, with the index or moment/constant, and enter the shift of the crew to their landing positions, with the index or moment/constant change due to the crew movement. Explain in Remarks, if necessary.
23. Ref-20. Enter the differences in weights and the index or moment/constant between Ref-15 and the total of Ref-17, 18, and 19.
24. Ref-21. By again referring to the CG table on Chart E, or the CG grid on the balance computer, determine the estimated landing CG position. Enter this figure opposite Estimated Landing CG.
25. The necessary signatures must appear at the bottom of the form.

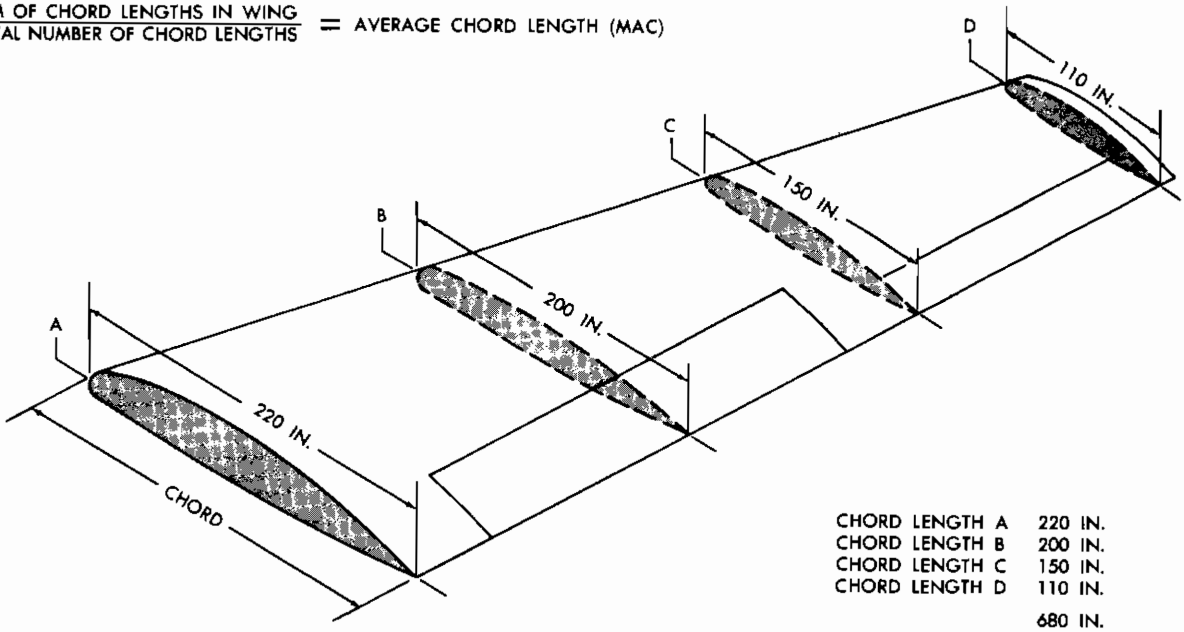
Percent MAC for CG Location

In step 19, using the balance computer (load adjuster), the indicated CG was checked for location within allowable limits. With the final index on the scale, the slide is removed and the gross weight is referenced with the hairline. Then, looking straight down on the grid, you can estimate a CG in percent of MAC.

In view of the relationship between the CG location and the moments produced by areodynamic forces, the greatest of which is lift, it is logical to express CG location with respect to the wing. This is done by specifying CG in percent of the mean aerodynamic chord (MAC) of the wing.

Although MAC was estimated for you on the load adjuster, it may be necessary for you to compute percent MAC. The Chart E will give you percent MAC if you are directly on the gross weight or arm of the chart. If not, you will have

$$\frac{\text{SUM OF CHORD LENGTHS IN WING}}{\text{TOTAL NUMBER OF CHORD LENGTHS}} = \text{AVERAGE CHORD LENGTH (MAC)}$$



CHORD LENGTH A	220 IN.
CHORD LENGTH B	200 IN.
CHORD LENGTH C	150 IN.
CHORD LENGTH D	110 IN.
	680 IN.

$$\frac{680\text{ IN.}}{4} = 170\text{ IN. (MAC)}$$

Figure 8-8. Percent of MAC Diagram

to interpolate in the chart, or compute percent MAC by formula. Figure 8-8 illustrates a typical problem.

Computing Percent MAC

To express the CG in percent MAC instead of in inches from the reference datum, it is necessary to know:

1. Weight (total weight)
2. Moment (total moment)
3. Length of MAC
4. Distance from rd to the leading edge of MAC

Let's examine the formula for CG, and substitute some known values of a C-141 aircraft into a problem to arrive at a percent MAC for takeoff.

$$\text{Arm} = \frac{\text{Total moments} \times 10{,}000}{\text{Total weight (GW)}}$$

$$\text{CG \% MAC} = \frac{\text{Arm-leading edge MAC} \times 100}{\text{Length of 100\% MAC}}$$

Example:

$$\frac{24{,}632 \times 10{,}000\text{ (moment)}}{263{,}473\text{ (GW)}} = 934.9\text{ (arm)}$$

$$\begin{array}{r} 934.9\text{ (arm)} \\ -858.9\text{ (LEMAC)} \\ \hline 76.0 \times 100 = 760.0 \end{array}$$

$$\frac{760\text{ (arm-LEMAC)}}{2657\text{ (Length of 100\% LEMAC)}} = .2860$$

Then:

$$2860 \times 100 = 28.6\%\text{ MAC takeoff CG.}$$

CHAPTER 9

Charts and Operational Data

The preceding chapters have presented background knowledge used to control aircraft and engine performance. In this chapter, the application of these controlling factors is shown through the presentation and explanation of operational data. We shall also explain how the charts are used by the engineer to extract the required data.

The charts are presented and discussed in the general order of their flight mission use: takeoff, climb, cruise, descent, landing, and taxi. The coverage of each chart includes the reasons why it is necessary, how the data is obtained, and in some instances, the development of the formula used in the data reduction (or reference to an earlier chapter where the formula has previously been explained). A typical example of a completed chart and an explanation of its use is illustrated for the jet engine and reciprocating engine aircraft. Remember that the charts selected here for illustrative purposes are specially prepared to eliminate unnecessary detail and to highlight the point being discussed.

The factors involved in the flying of a combat, cargo, or ferry mission are numerous and variable. As a flight engineer, you have to be aware of all these factors and provide for all of them in determining the amount of total fuel that is to be carried for a specific flight. How the variables are to be handled depends principally on the particular type of mission, the atmospheric conditions, and the time allocated for the flight.

The graphic presentation is used in illustrating these cruise control data in chart form since this has been proven to be the most efficient method of presentation. This type of presentation is accurate, leaves little doubt as to interpretation, and gives the user a quick means of interpreting aircraft and engine performance trends. The original charts were first set up by the manufacturers, who constructed them from predictions through the application of aerodynamic principles and wind tunnel tests of models, while the aircraft plans were still on the drawing board. Then, when the first new experimental models were flight-tested, the charts were modified wherever necessary.

A complete discussion of chart construction cannot be covered here; however, a detailed discussion of how some of the more fundamental ones are used is presented.

CHART CLASSIFICATION

The appendix of the aircraft flight manual presents complete performance and cruise control charts for normal and emergency operation. These charts give sufficient data for preflight and inflight planning of the entire mission.

Climb and cruise control charts are calculated for standard day conditions only, but sufficient information is included to cover the principles involved in adjusting for existing conditions. The charts used for normal operation show the expected performance of the aircraft during these conditions.

All charts are calculated for standard aircraft configuration. Any deviation from standard configuration must be compensated for before using the chart.

We shall now discuss the charts and operational data in five categories: takeoff, climb, cruise, descent, and landing and taxi, the latter two of which are combined.

TAKEOFF PERFORMANCE

Principles Involved in Takeoff

Takeoff performance is frequently the most critical of the phases involved in mission planning, since it is the *takeoff* which limits the load. An aircraft would be able to carry a considerably greater weight in flight than it can lift from the runway. Because of (1) variations in atmospheric conditions, (2) pilot technique, and (3) power available, it requires careful selection and use of available data to predict the takeoff performance accurately. In order to provide a reasonably accurate means of predicting this takeoff performance, it is necessary to establish a procedure that will allow for aircraft capability and its environment in the atmosphere, as well as the variations in pilot technique. Let us discuss how this is done.

Takeoff procedures are more or less standard in the following order. All takeoffs call for partially extended flaps. In initial stages of the takeoff roll, weight is usually kept on the nose gear until the airspeed approaches the recommended takeoff speed. This keeps the angle of attack of the wing at a minimum, thereby allowing the aircraft to accelerate rapidly. Then as the weight is eased off the nose gear by use of the elevator control, lift overcomes gravity while thrust overcomes drag and the aircraft becomes airborne.

From this you can see that the airspeed at which the wheels leave the ground is determined by the gross weight of the aircraft being overcome by lift. By using a standard takeoff procedure, the pilot can then make necessary corrections according to takeoff predictions from known and calculated variables. A knowledge of the formula used to construct the charts from which these variables are calculated will be helpful. This will better enable you to understand the relationship of lift to drag and friction.

Although there is only the one factor—gross weight—which determines an aircraft's takeoff speed for a given wing flap setting, there are several variables which determine the takeoff distance. Three of these variables relate to the aircraft itself and five variables involve related conditions. Three major variables relating to the aircraft are (1) rolling friction, (2) aerodynamic drag, and (3) thrust. Related conditions which also effect the takeoff distance are (1) type and slope of runway, (2) field elevation, (3) wind direction, (4) air temperature, and (5) humidity.

Let us now consider the three variables relating to the aircraft.

ROLLING FRICTION. Resistance created by rolling friction is equal to the reaction of the weight on the wheels multiplied by the coefficient of friction for the surface. This coefficient of friction is indicated by the Greek letter mu (μ). The value of μ for aircraft tires rolling on a hard surface is about .025. Rolling friction may be computed by the formula:

$$\text{Friction (F)} = \mu \times (\text{gross weight} - \text{lift})$$

AERODYNAMIC DRAG. Aerodynamic drag is that resistance created by an airfoil moving through the air. This resistance (drag) must be overcome by thrust as the airfoil is moved through the air before the aircraft can become airborne.

When an aircraft is moving down the runway at a given speed (V), lift is developed by the wing. The value of this lift is computed by the formula:

$$L = C_L S \frac{EASK^2}{295}$$

From these formulas for rolling friction and lift, we see that as the speed (V) increases, lift also increases which results in decreasing rolling friction.

Aerodynamic drag created by the moving of air over the airfoil increases with the increase in airspeed, expressed in the formula

$$D = C_D S \frac{EASK^2}{295} \quad (68)$$

These are the drag forces previously discussed in aerodynamics. We can now discuss the third major variable, thrust.

THRUST. Thrust is needed to overcome rolling friction and aerodynamic drag both of which tend to hold the moving aircraft back. Once the aircraft is moving, its rate of acceleration depends on how much the thrust exceeds these two retarding forces. In order to get the aircraft up to flying speed quickly and within the distance limits of a runway, it is essential that the engines quickly develop an abundance of power to create ample thrust. This brings the time element into the picture, and now we go from thrust horsepower (power) to thrust (force) which creates the energy needed for acceleration.

The greater the degree in which thrust exceeds the combined resistance, the more rapid is the acceleration. Resistance is increased if tires are too "soft" or if the wings are kept at a relatively high angle of attack. Thrust is reduced if engine output is below the specified value. Proper maintenance, the required power settings, and proper flying technique all contribute to the ability of the aircraft to meet its design specifications as they relate to performance. The flight engineer, of course, is primarily concerned with engine performance and mission accomplishment.

For reciprocating engine and turboprop engine aircraft, the power delivered to the propeller and the efficiency of the propeller determine how quickly the aircraft can reach flying speed. An engine developing 1000 bhp (torquemeter) delivers 1000 bhp to the propeller shaft to be converted to thrust. The propeller dissipates all this power with various degrees of efficiency. The actual efficiency of a propeller can be expressed by the relationship in the formula

$$\eta = \frac{\text{thp}}{\text{bhp}} \qquad (69)$$

The greek letter eta (η) the symbol for propeller efficiency, equals thrust horsepower divided by brake horsepower. Then, when we consider the actual output of the engine for useful work, the formula for thrust horsepower appears as

$$\text{thp} = \frac{D \times \text{TASK}^2}{325} \qquad (70)$$

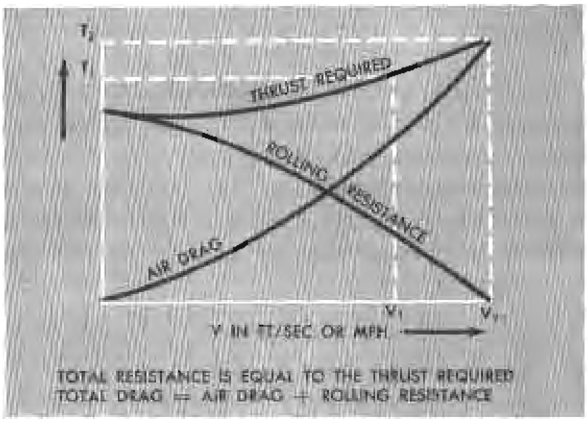
This formula relates thrust horsepower as overcoming drag at a rate which is equal to true airspeed. This formula can be combined with the formula relating thp and bhp with the formula for drag. Then we arrive at a formula which gives us a true picture of bhp required for any condition.

$$\text{bhp} = \frac{C_D S \times \text{EASK}^3 \times \frac{1}{\sqrt{\sigma}}}{95{,}875\,\eta} \qquad (71)$$

Knowing the takeoff EASK, we can find the bhp required to get the aircraft off the ground. Since most calculations are done in terms of power output of one engine, we can further modify the formula to

$$\text{bhp/eng} = \frac{C_D S \times \text{EASK}^3 \times \frac{1}{\sqrt{\sigma}}}{95{,}875\,\eta \times R} \qquad (72)$$

where R is the number of engines on the aircraft. This formula shows that for constant bhp, the available thrust decreases as the speed of the aircraft increases. Of course, the formula can be used to find the bhp/eng required for conditions other than takeoff as well. It is essential in all problems to know the required EASK and to substitute this value in the formula. The above equation is solved for us graphically in one or more of the curves in the appendix to the aircraft technical order.



TOTAL RESISTANCE IS EQUAL TO THE THRUST REQUIRED
TOTAL DRAG = AIR DRAG + ROLLING RESISTANCE

Figure 9-1. Total Resistance Curve

Figure 9-1 shows the thrust required to overcome the two resisting forces, rolling friction and drag. Figure 9-2 shows the relationship between thrust available and thrust required in respect to velocity.

Now let's review briefly the 5 conditions which have a tremendous effect on the takeoff distance.

TYPE OF RUNWAY (RCS). The rougher the surface of the runway, the higher the coefficient of friction is between the tires and the runway surface. As a result, the rolling resistance increases, making greater thrust necessary for takeoff. This, of course, causes the takeoff run to

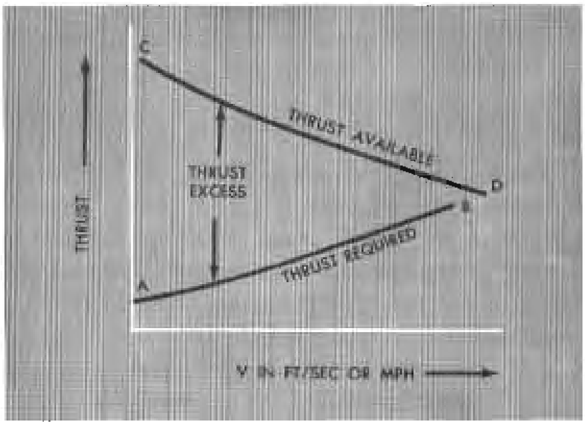


Figure 9-2. Thrust Available Curve

increase in proportion to the friction (resistance) created.

FIELD ELEVATION. The higher the altitude of the field, the less dense is the air, the higher the takeoff airspeed, and the greater the distance required to become airborne. The increased speed is necessary to achieve the required air pressure differential between the top and the bottom of the wing.

WIND DIRECTION. The effect of a headwind on an aircraft during takeoff shortens the takeoff run because the velocity of the wind is added to the groundspeed of the aircraft as the total velocity of the air mass passing the wing as lift. Conversely, a tailwind increases the takeoff run. In flight, however, a tailwind is more desirable, since it increases groundspeed in the amount of the wind velocity.

AIR TEMPERATURE. Since warm air is less dense than cool air, on a hot day an aircraft must travel at a greater than normal speed for any given angle of attack in order to become airborne. This is true for the same reason previously discussed under field elevation. The effect is the same as that of takeoff from a higher altitude.

HUMIDITY (RECIPROCATING ONLY). As a result of constant evaporation, the atmosphere always contains moisture in the form of water vapor. This moisture does not consist of tiny particles of liquid held in suspension in the air, as in fog, but is an invisible vapor as truly gaseous as the air with which it is mixed. However, the engine produces power in proportion to the amount of dry air it consumes. Since the water vapor displaces dry air, its presence causes loss of power. As the mixture of water vapor and air is drawn through the carburetor, fuel is metered into this mixture as though it were all dry air, thus creating, as we shall see, an excessively rich mixture.

The mixture of water vapor, air, and fuel enters the combustion chambers where it is then ignited. But since the water vapor is incombustible, it merely occupies space that would otherwise be occupied by dry air which, under dry conditions, would contribute to combustion. Since water vapor is incombustible, the engine operates on an excessively rich mixture. The resulting horsepower loss under such conditions can therefore be attributed to (1) a loss in effective volumetric efficiency due to dry air being displaced by water vapor, and (2) incomplete combustion caused by an excessively rich mixture.

In discussions of the effect of high humidity on engine operation, a question frequently asked is: If water injection cools an engine, enabling it to produce more power, why does water vapor cause a loss of power? The answer involves the difference between finely divided drops of water, as provided by water injection, and vaporized water, as in humidity. When liquid moistrue, as in water injection, vaporizes, it absorbs considerable heat. As the vapor expands, it cools the engine. Under high humidity conditions, on the other hand, this vaporization process has already taken place, and the water vapor exists at the same temperature as the air. Therefore, the water vapor absorbs no heat during combustion but merely replaces dry air. Since humidity in this manner deprives the engine of power, the takeoff distance is accordingly lengthened.

Takeoff Power and Gross Weight (Reciprocating Only)

Now, with the foregoing in mind, let's discuss the data used to compute the takeoff power of the engines. Takeoff bhp is based on sea level and standard atmospheric conditions. If the atmospheric conditions are standard and if pressure altitude is standard, there will be no bhp loss. However, if either of these factors is not standard—which is nearly always the case—there will be a loss in power. This loss results in the following four outcomes: (1) longer takeoff run, (2) longer acceleration time to safe three-engine takeoff speed, (3) reduced rate of climb, and (4) reduced ability to clear obstacles in the takeoff path. "Wet" takeoff power, with water injection (ADI), is more desirable than "dry" takeoff power because of the greater bhp available. The takeoff data used to compute maximum power for reciprocating and turbine engines will be reviewed in the discussion to follow.

COMPUTING MAXIMUM TAKEOFF POWER. When we predict maximum takeoff power available for reciprocating engine aircraft, two charts are used: the psychrometric chart shown in figure 9-3 and the maximum wet power available chart, figure 9-4. The psychrometric chart is used for obtaining any expression of water vapor (humidity) in the air.

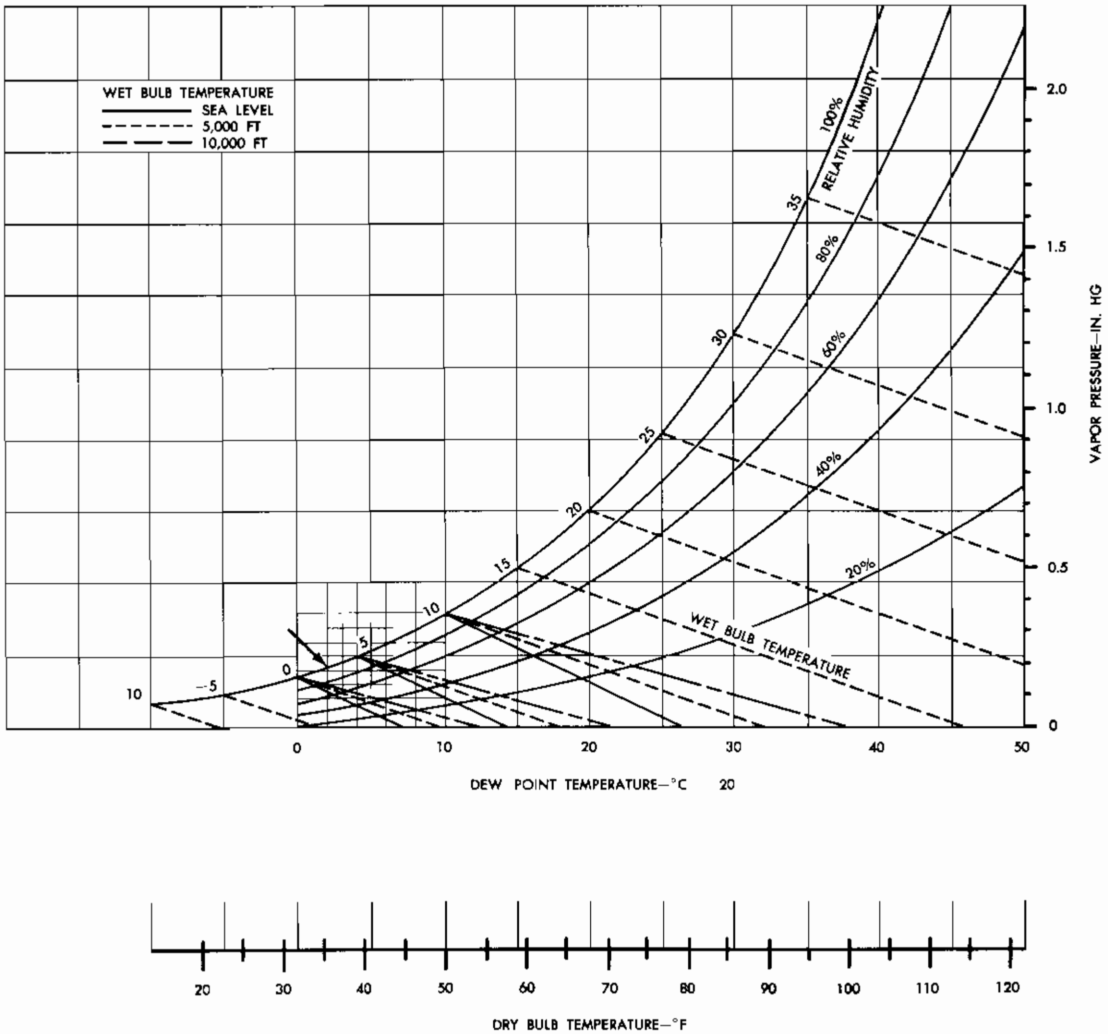


Figure 9-3. Psychrometric Chart

This water vapor may be expressed as relative humidity, specific humidity, vapor pressure or dewpoint. The value may be obtained from the psychrometric chart when the wet and dry bulb temperatures are known, or from OAT and relative humidity readings. In the event that a relative humidity or vapor pressure reading is not available, the dewpoint temperature corresponding to 80% relative humidity or a maximum vapor pressure of 1.0″ hg, whichever is less, is recommended as a conservative value. The flight engineer is responsible for compensating for power loss due to humidity by using data given by the control tower in conjunction with the psychrometric chart.

The following example illustrates the use of the two charts:

Determine the wet takeoff power available for the following conditions:

OAT	5° C (40° F)
Pressure Altitude	1500 feet
Relative Humidity	80%
Water Injection	Operative

The first step is to find the dewpoint, which is predicted from the psychrometric chart. At the intersection of the 5° C line and the 80% relative humidity line, read horizontally to the left and find the dewpoint to be approximately 2° C (35° F).

On the wet takeoff power available chart, figure

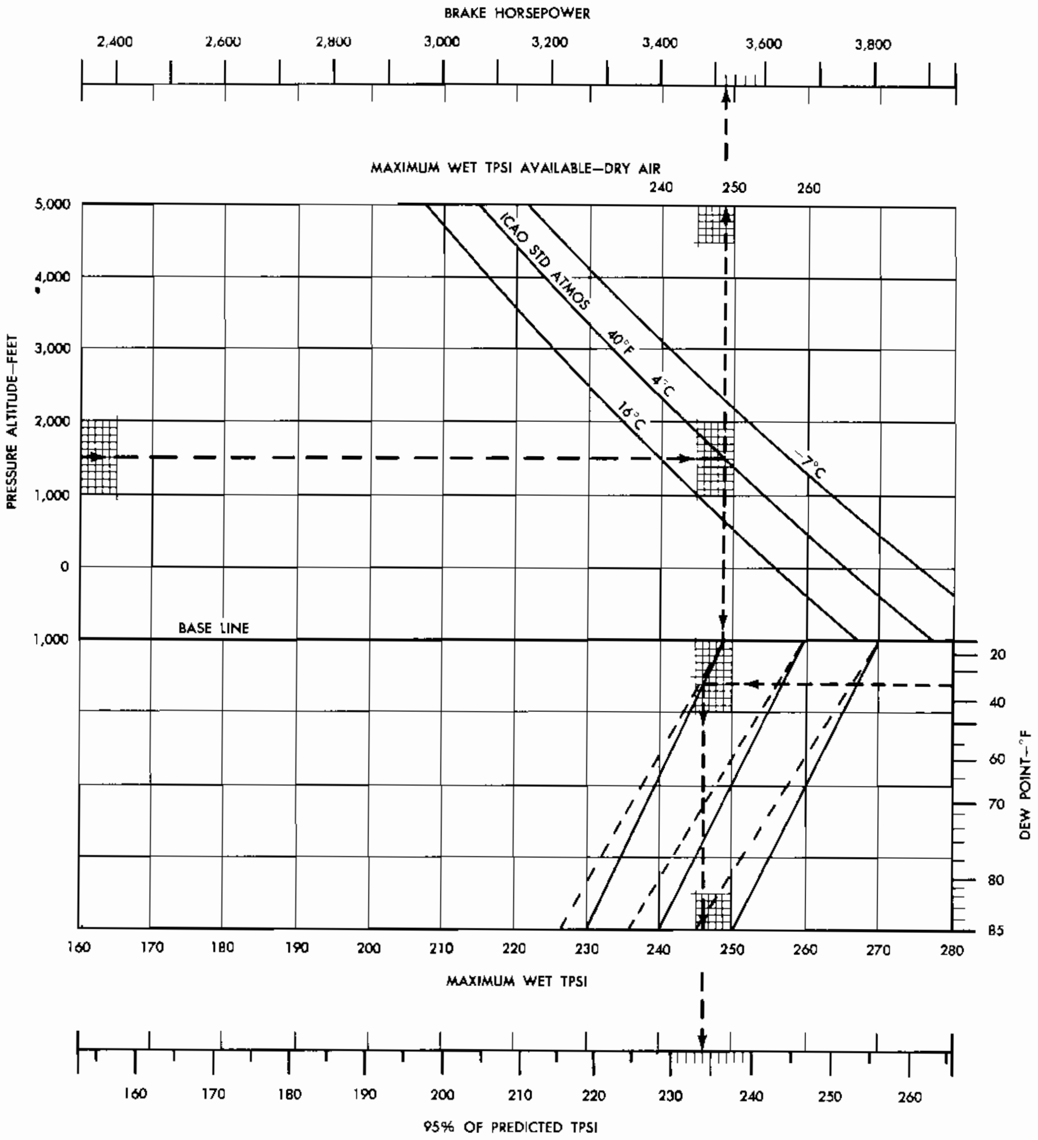


Figure 9-4. Maximum Wet Power Available Chart

9-4, locate the intersection of the 1500 foot pressure altitude line and the 40 ° F line. At this point, observe that the power available (corrected for altitude and temperature but not for dewpoint) is 249 TPSI (3520 bhp). By following this power line vertically down to the dewpoint base line, you account for the humidity by interpolating the dewpoint guideline at a reading of 35° F. (Interpolating involves the judgment of values represented by distances between lines.) Then follow the chart lines vertically to the maximum wet takeoff power available of 246 TPSI. Only 246 TPSI (3480 bhp), then, is available for takeoff under the indicated conditions.

Reject Power. Regardless of the accuracy used to determine actual bhp available for takeoff, minor discrepancies in engine conditioning must be presumed to exist. These discrepancies always cause less power to be produced than predicted. The engine deficiency must be computed correctly and does not include major maintenance discrepancies. During the takeoff, if the torque reading does not fully register predicted power, this should cause no great concern as long as a specified percentage of the predicted power is maintained. The power output is considered satisfactory as long as 95% of the predicted power is developed. This minimum performance power as indicated by the torque reading is called "reject power," and it represents the minimum power at which takeoff is permitted. This reject power can be predicted from the bottom scale of the power available chart as 234 TPSI (see figure 9-4). This figure is derived by taking 95% of the maximum wet takeoff power available of 246 TPSI.

At times you may wish to determine the reject power by slide rule computations, as you learned in Chapter 2. To do so, set up your slide rule in the following manner using A and B scales: The maximum wet power of 246 TPSI represents 100% power. Slide the *hairline* of your rule to 100% on A scale. One hundred percent is represented by the figure 1 at the extreme right on A scale. Locate the figure 246 on B scale (which represents the maximum power available). Slide this figure to aline under the hairline which you set on 100% on A scale. Now you have the maximum power of 246 TPSI set up as 100% on your slide rule. To determine 95% of 246, merely slide the hairline back to the left along A scale to the figure 95. Read 95% directly below this point as 234 on B scale.

Circular slide rules, because of their compactness, may come into widely accepted use in the future. These slide rules are calibrated on the same principles as the regular slide rule and, in their better grades, serve the same purpose. On the circular slide rule, the lines radiate as straight lines from the center, but the progressive widening of the radials cause no problems in interpolation.

Sometimes it is necessary to know the maximum power to expect without water injection. In that case, you need to compute a dry bhp for takeoff. This is accomplished by using a maximum dry power available chart.

The following example demonstrates the procedure for determining dry bhp and TPSI available: Determine the maximum dry power available for the following conditions:

OAT	40° F
Pressure Altitude	1000 feet
Dewpoint	20° F
Water Injection	Inoperative

1. First we go back into the maximum wet power available chart shown in figure 9-4, and read the available torque at OAT of 40° F and pressure altitude of 1000 feet as 253 TPSI.
2. Then enter the maximum dry power available chart, figure 9-5, with this reading of 253 TPSI wet and determine the maximum dry torque in dry air to be 236 TPSI, as illustrated by the dotted line. Follow the maximum dry power line downward to the dewpoint base line. Follow the dewpoint slope to a dewpoint of 20° F; then follow the chart lines on down to the torque available reading of 238 TPSI.
3. From the maximum allowable MP and TPSI chart, in the inset on the right hand side of the maximum dry power chart, read the maximum allowable torque for 40° F (3° C) carburetor air temperature of 235 TPSI.
4. To prevent damage to the engine, do not exceed 235 TPSI since the predicted torque of 238 TPSI exceeds this performance limit.
5. Then from the 95% scale at the bottom of the chart, read the minimum performance torque of 226 TPSI which is equal to 3200 bhp. Any TPSI of a lesser value is considered as reject power.

EQUIVALENT PERFORMANCE WEIGHT (RECIPROCATING ENGINES ONLY). Although, in most instances, a takeoff factor is used to determine the engine performance capability, the flight engineer should understand the principles of equivalent performance weight affecting takeoff. Just as atmospheric conditions affect the available horsepower, they also affect the apparent weight of the aircraft. Pressure altitude, outside air temperature, and maximum power available all affect performance as though the aircraft weighs more than it does. For any conditions of actual weight, altitude, temperature and power available, the airplane has takeoff acceleration and climbout angles equivalent to those for another weight at sea level standard atmospheric conditions and maximum allowable bhp per engine. This latter weight may be used as a reference for the comparison of takeoff performance and is called equivalent performance weight (EPW).

After determining the minimum performance torque, sometimes referred to as 95% of predicted TPSI or bhp available, the equivalent performance weight may be found by entering the chart shown in figure 9-6 with 40° outside temperature. Then proceed to the field pressure altitude and minimum performance TPSI and to the actual gross weight. Conversely, the actual

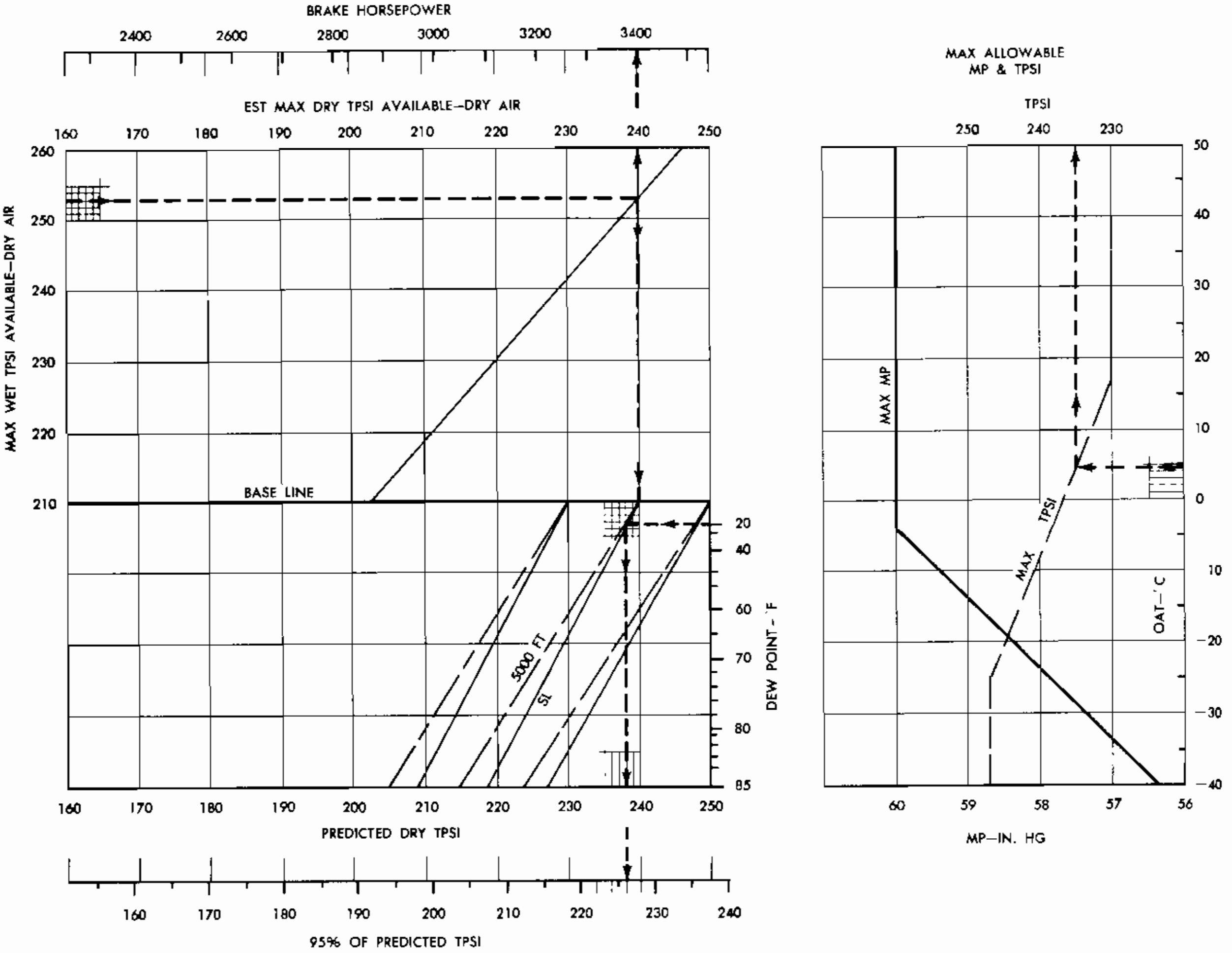


Figure 9-5. Maximum Dry Power Available Chart

gross weight corresponding to a limiting equivalent performance weight may be found. By choosing a constant EPW which represents the minimum desired level of takeoff performance, the maximum gross weight for any pressure altitude, outside air temperature, or power may be obtained to satisfy this condition.

Example: (Reciprocating Engine Aircraft) Determine an EPW from the conditions given in the last problem, using an actual gross weight of 175,000 pounds.

The initial step is to correct for the pressure altitude and the temperature by the succeeding steps beginning at the lower left hand side of the chart in figure 9-6. Enter the chart with 40° OAT F (which is the equivalent of 5° C) and proceed down until a point representing 1500 feet pressure altitude is found. At this point, compensation has

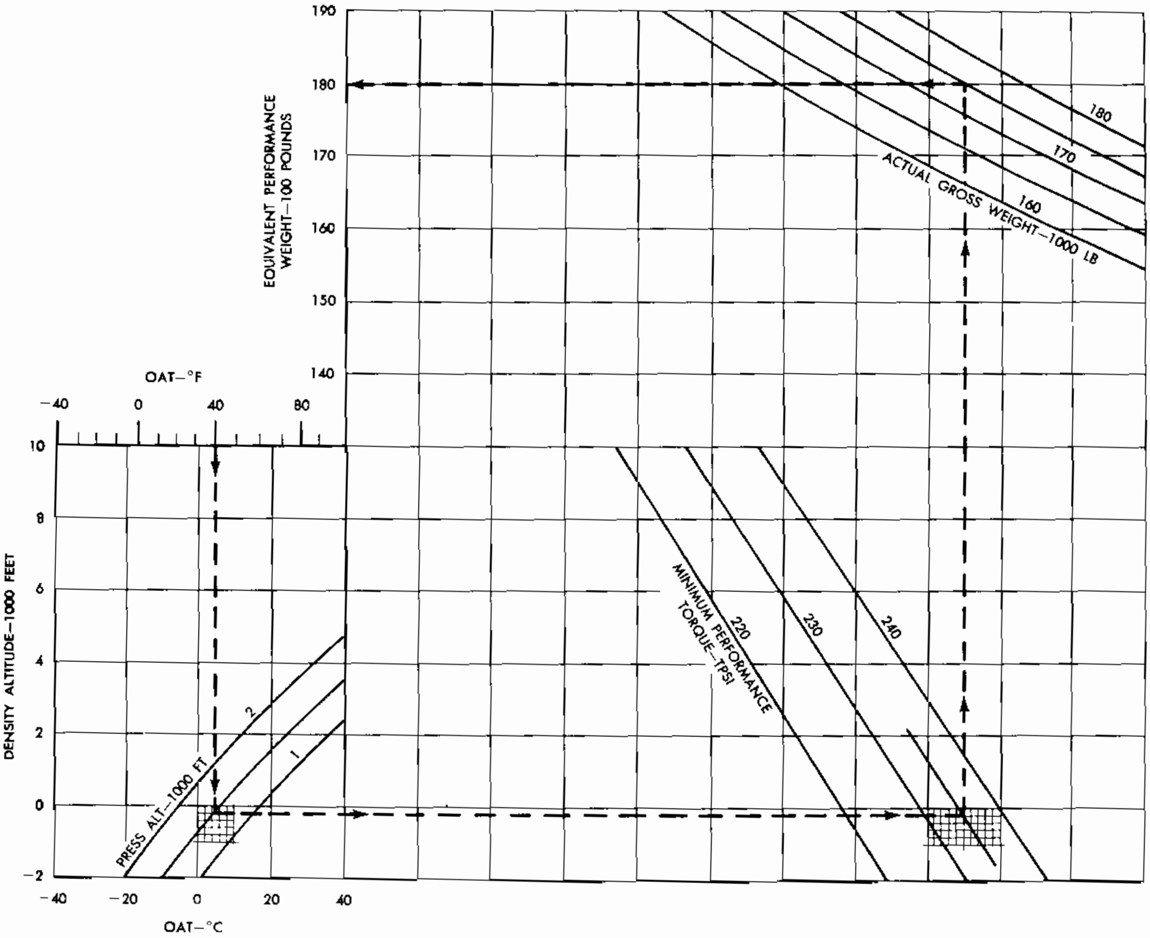


Figure 9-6. Equivalent Performance Weight Chart

been made for the density of the air. From there, proceed directly to the right to the point representing 235 TPSI (minimum performance torque) and then vertically to the actual gross weight line representing 175,000 pounds. Directly to the left you discover the EPW to be 180,000 pounds.

(Turbojet). On some aircraft this performance is reduced to a mathematical factor which is then applied to the charts concerning takeoff. This is particularly applicable to some jet powered aircraft. In addition to the losses of thrust reflected by the atmospheric corrections which must be made, jet aircraft have systems which are operated on engine bleed air, thus further reducing the amount of thrust which can be developed for takeoff. All these factors have a detrimental effect on takeoff performance.

Jet engine thrust is primarily affected by air temperature and pressure altitude. Relative humidity, which has an appreciable effect on reciprocating engine power, has very little effect on jet engine power and may be disregarded. The use of engine bleed air for systems operation, however, reduces thrust available for a given throttle setting under all conditions of takeoff. If an engine does not attain the required thrust setting, it is not providing rated thrust, and the takeoff should not be started. This decision is reached after the completion of a computation of the engine pressure ratio (EPR), to establish a thrust factor and a takeoff factor.

The EPR is the ratio of engine turbine exit pressure to compressor inlet pressure. This is a representative value of the thrust being developed at a given throttle setting and at a given set of atmospheric conditions.

Notice that performance gross weight is not mentioned in operation of jet engine aircraft as it is in the operation of reciprocating engine aircraft. In jet engine aircraft, performance at par-

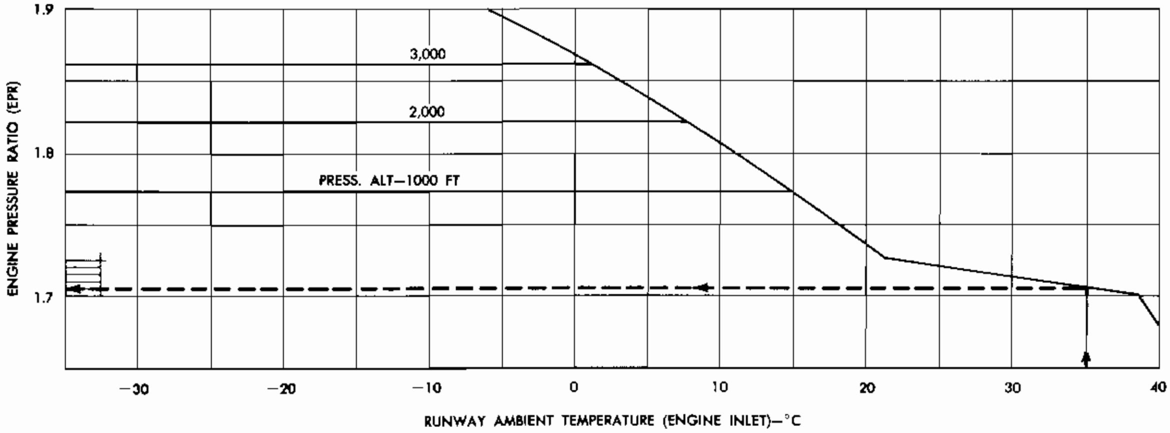


Figure 9-7. Takeoff Thrust, EPR

ticular atmospheric conditions is compensated for with a correction in engine pressure ratio illustrated in figure 9-7. This value is then converted to a thrust factor and a takeoff factor. In this instance, we are not concerned with reductions in EPR which would be necessary if airconditioning or rain removal equipment were being used.

Example: (Turbofan Engine Aircraft) Determine the maximum brake release gross weight for a turbofan engine powered aircraft under the following conditions:

4 Engine
Pressure Altitude = 3,000′
Runway Temperature = 35° C
Flaps = 20°
Runway Length = 12,000′
Runway Slope = 1.5% uphill
Runway Condition = Wet
Effective Headwind = 40 knots

To obtain EPR, enter the bottom of chart 9-7 with the runway temperature (35° C) and proceed upward until the altitude line (3,000′) is intersected. Notice that when it is not possible to intersect the given altitude as in this case, the connecting curve must be used which represents the point at which it is possible to overboost an engine at a given set of conditions. Directly to the left of this point an EPR of 1.705 is read. It is at this point that all corrections for bleed air being used must be made. The correct EPR is then converted to a thrust factor by entering the bottom of the chart shown in figure 9-8. Enter the chart with the corrected EPR (1.705) obtained from the chart in figure 9-7 and proceed upward until the given pressure altitude (3000 ft) is reached. Directly to the left a thrust factor of 1217 is indicated.

The thrust factor is then corrected to a takeoff factor by using the chart in figure 9-9. Enter the chart with the obtained thrust factor (1217) at the upper left margin. Proceed to the right and intersect the temperature (35° C), then proceed downward and intersect the pressure altitude (3,000′) and read the takeoff factor to the right as 271.

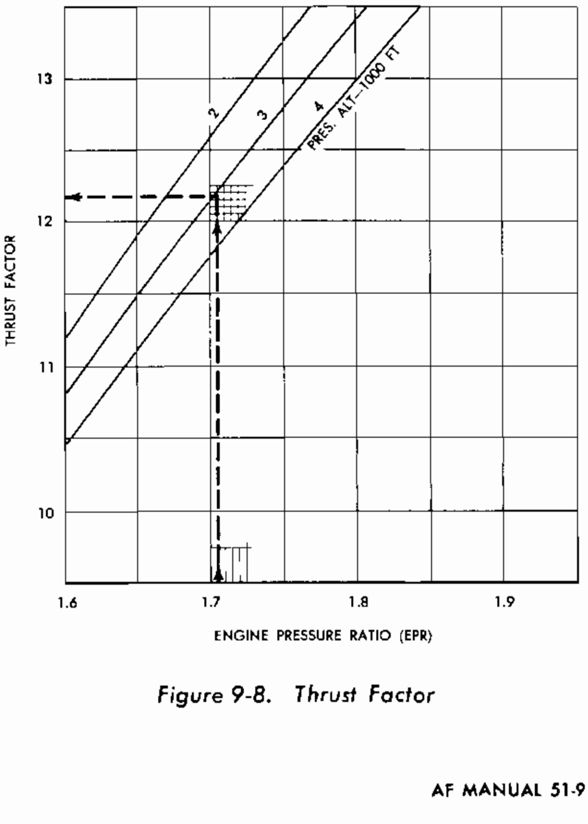


Figure 9-8. Thrust Factor

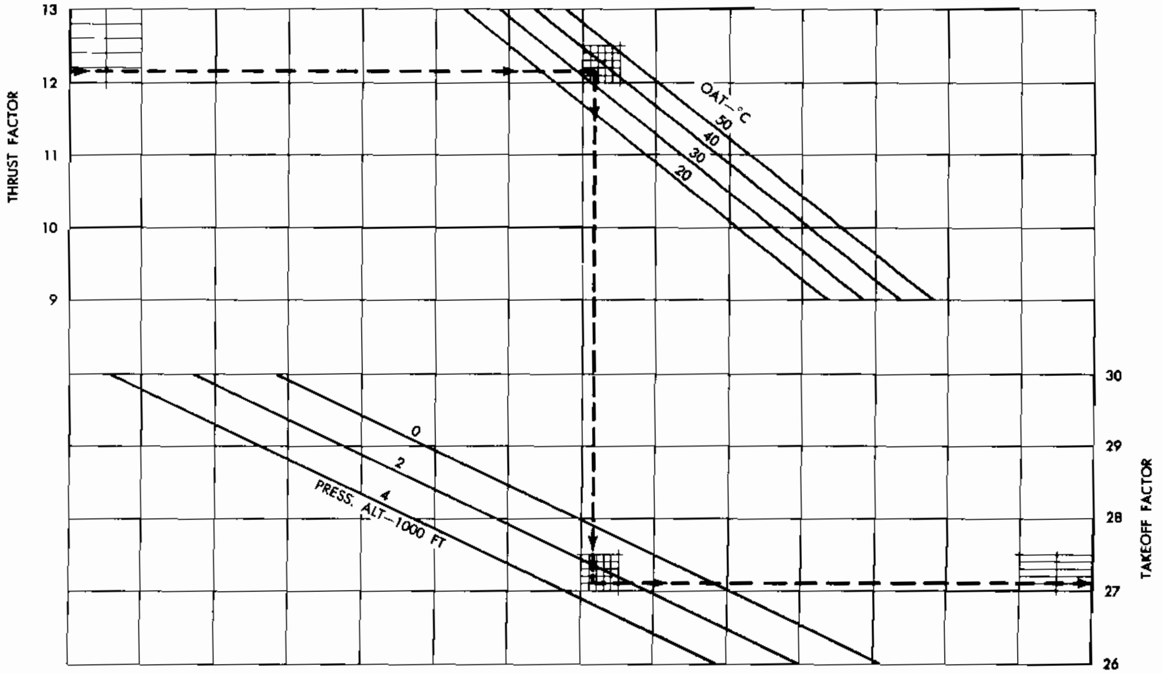


Figure 9-9. Takeoff Factor

Now we can determine the actual maximum gross weight at which brake release, takeoff run, and takeoff can be allowed. Two charts combined in figure 9-10 are needed for this computation. Enter figure 9-10 from the right with runway length (12,000 ft) and make the necessary corrections for runway surface condition (wet), and runway slope (+1.5%). At this point, enter the adjoining chart, and proceed to the intersection point from the takeoff factor (27.1) and read a brake release gross weight of 265,000 pounds.

In the preceding examples, it has been demon-

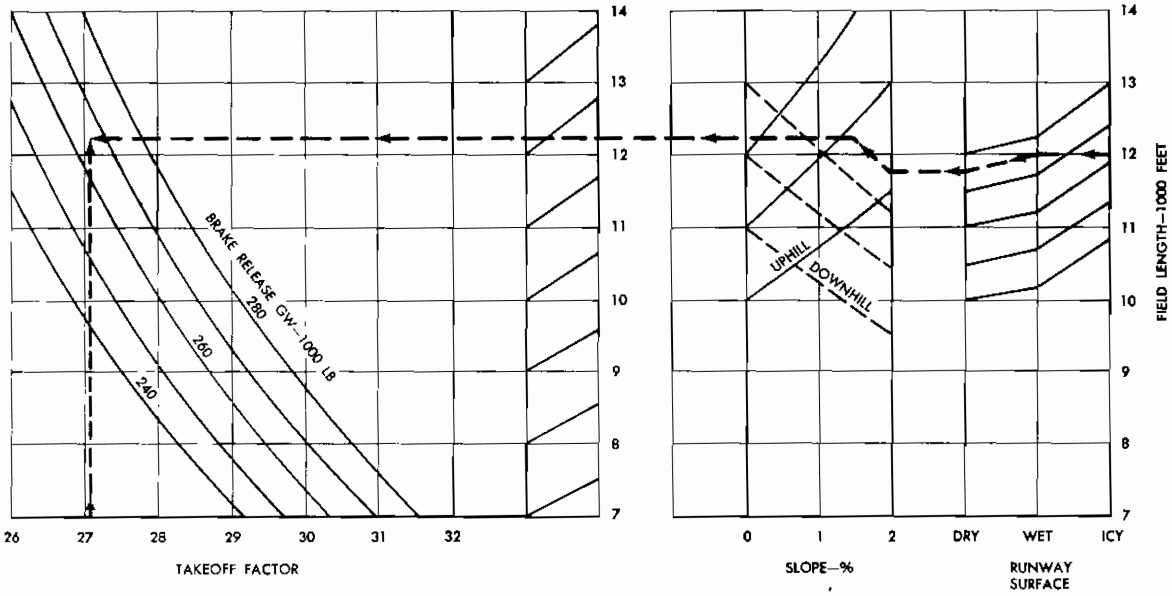


Figure 9-10. Critical Field Length

strated that takeoff will not be made unless thrust at least reaches a specified minimum for a given gross weight. On the other hand, a maximum gross weight is allowed for the maximum thrust which can be developed under a given set of conditions. To put it more simply; one set of conditions was concerned with the power required for a given takeoff gross weight and the other set of conditions was concerned with the maximum weight which can be lifted from the runway under existing conditions.

Example: (Turboprop Engine Aircraft) Predict the takeoff shaft horsepower or torque inch pounds for a turboprop engine aircraft under the following conditions:

Pressure Altitude	2500 feet
Temperature	+20° C
Gross Weight	130,000 lbs
Runway Length	9000 feet
TIT	971° C

The first consideration must be given to pressure altitude and temperature and their effect on available torque. This is done by entering a torque correction chart, figure 9-11, and predicting the amount of correction which must be made since the takeoff is for a day other than standard. The OAT of 20° C at 2500 pressure altitude is 10 degrees hotter than a standard day. The initial entry into the chart is made at the desired turbine inlet temperature (971° Military Power) and then proceeding vertically until a point is intersected representing 2500 feet pressure altitude. From this point, move directly to the right to the standard +10° C line and then straight downward to the bottom of the chart and read a torque factor of approximately 0.93. This value is a multiplier (torque correction factor) to be used later for correcting standard day torque to nonstandard day torque.

The next value to be predicted is the calibrated airspeed which must be used for takeoff. This is accomplished by plotting the indicated airspeed from the normal takeoff speed chart and correcting it for ground effect. Enter the normal takeoff

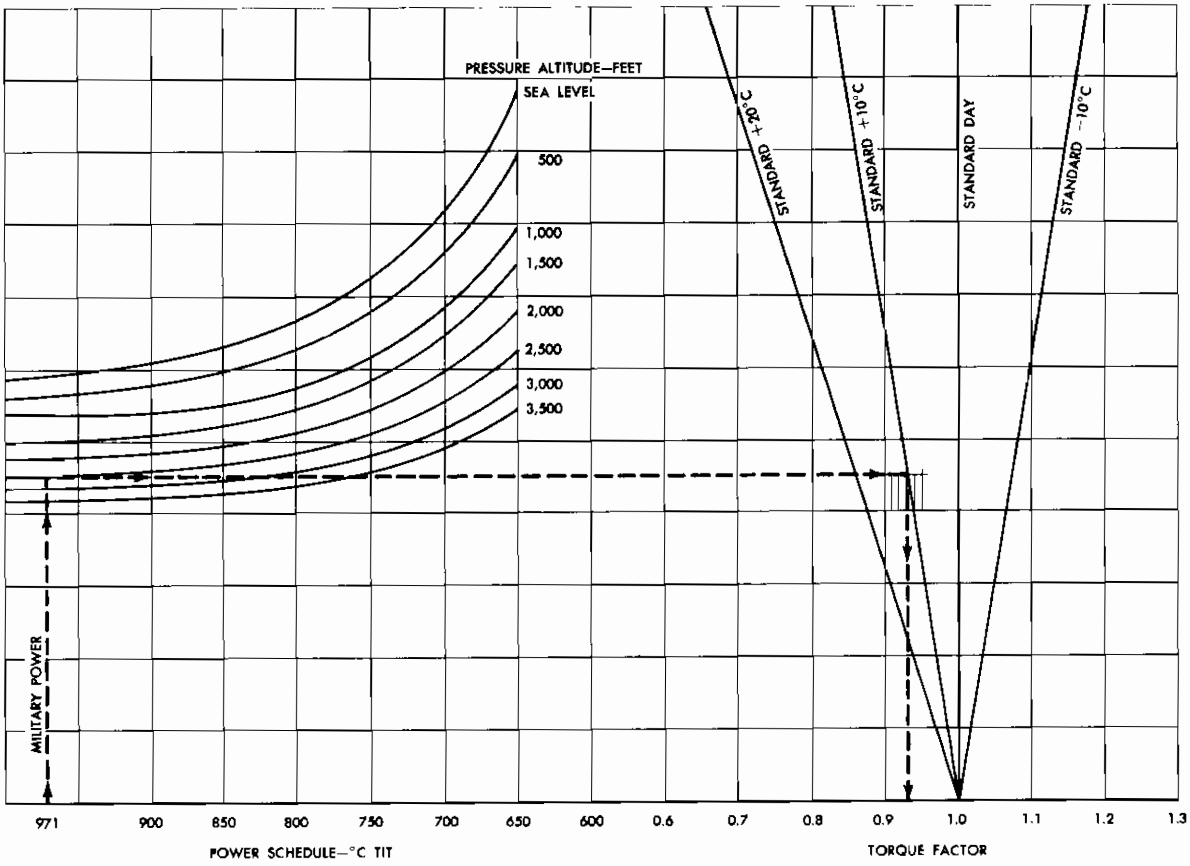


Figure 9-11. Torque-Correction Chart

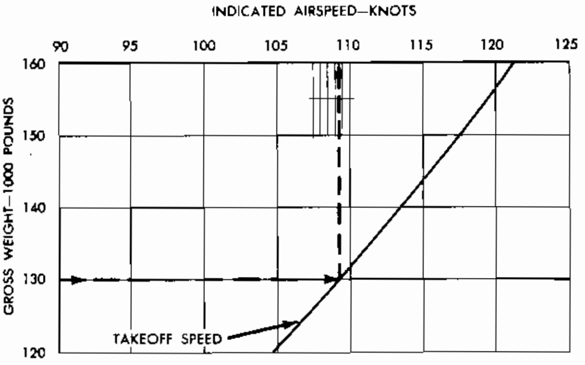


Figure 9-12. Normal Takeoff Speed

speed chart, figure 9-12, with 130,000 pound gross weight and move to the right to the takeoff line. Then read vertically to an indicated takeoff airspeed of 108.5 knots.

Now the shaft horsepower or torque inch pounds can be predicted for a standard day takeoff. Enter the takeoff power available chart, figure 9-13, with +20° C OAT and proceed vertically to the calibrated airspeed line of 100 knots. From this point, move directly to the right to the interpolated 2500 foot pressure altitude point and then proceed downward to the bottom of the chart and read the indicated torque as approximately 14,750 inch pounds.

It was noted in the first step of this procedure that a torque correction factor of 0.93 (chart 9-11) was applicable for the takeoff conditions as listed, since the temperature is 10° hotter than standard for the pressure altitude. The standard day torque available of 14,990 inch pounds is now multiplied by the torque correction factor of 0.93 and the actual takeoff power available is found to be 13,950 inch pounds. Using the conversion scale shown at the bottom of the chart in figure 9-13 to convert from indicated torque to shaft horsepower, you find that 13,950 inch pounds is equal to approximately 3200 shaft horsepower.

The foregoing examples have shown the computations required for maximum power and for gross weights. Now, let us consider the ground run which is equally as important for takeoff and which, also, must be accurately computed.

Length of Ground Run

When we compute the length of the ground run required to become airborne, several factors enter the picture. In addition to liftoff speed, we must also compute a speed at which we may safely stop, or continue the takeoff. Takeoff distance is that distance from the point of brake release to the point of liftoff. This distance, as we have seen from the previous discussion, is affected

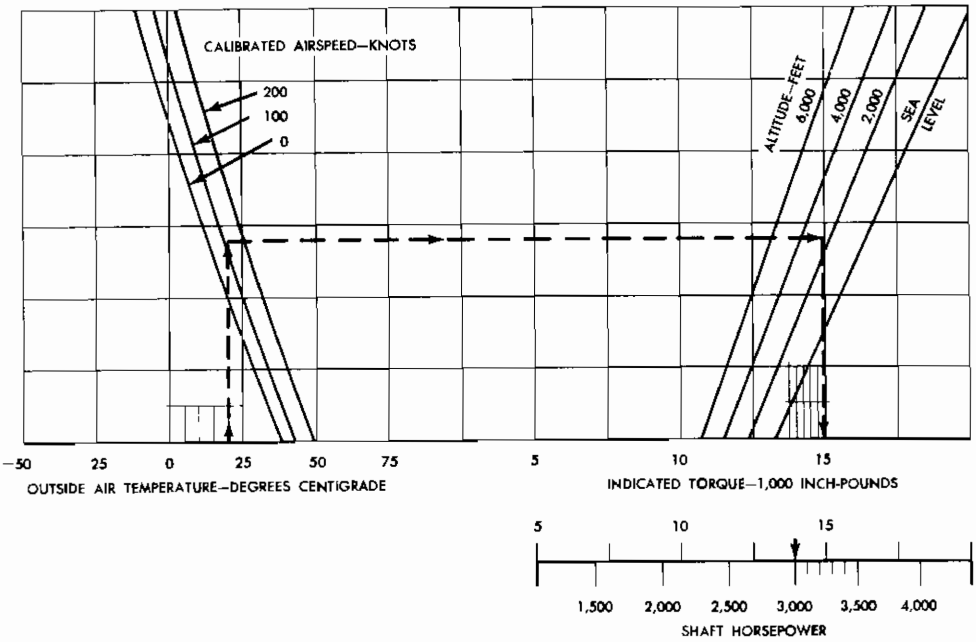


Figure 9-13. Takeoff Power Available

by thrust applied, gross weight, runway type, runway condition and slope, amount of wing flaps used, and effective winds.

When computing takeoff distance, the takeoff factor (for jet aircraft) or an equivalent performance weight (for reciprocating engine aircraft) must be predicted from the power available. The procedure for predicting the takeoff distance (ground run) is almost identical for both types of aircraft. After the takeoff factor of equivalent performance weight is established, corrections must be made for flap position, runway slope, runway condition, and effective winds. Each of these factors has its individual effect on the amount of runway required for the aircraft to accelerate to liftoff speed, and each factor must be given due consideration when planning a mission.

The takeoff distance, critical field length, and the distance to aecelerate and stop *versus* equivalent performance weight is shown on the takeoff distances chart. Corrections for runway gradient (slope), wind component, and slippery runway conditions are included. If the runway length available exceeds the critical field length, the takeoff may be safely scheduled. Also when the runway length exceeds the accelerate-stop distance, then refusal speed is equal to liftoff speed. Any time this condition arises, it is not necessary to predict a refusal speed.

If the available runway length is *shorter* than critical field length, then the chart must be read in reverse, starting with the runway length and reading the maximum allowable equivalent performance weight on the critical field length line.

Since runway slope affects aircraft acceleration and stopping segments in opposite manners, it is impossible to show a single slope correction that would be applicable to all distance lines on the chart. The slope correction is accurate for the critical field length and the 4-engine distance but tends to overcorrect the accelerate-stop distance. Thus, the refusal speed chart should be checked on downhill runways even when the runway length exceeds the slope-corrected accelerate-stop distance. Corrections for runway condition do not apply to the 4-engine takeoff distance since no stopping segment is involved.

Wind velocity has a major effect on takeoff distances. In the planning stages, no credit can be taken for performance benefits due to anticipated headwinds. Wind velocity and direction just before takeoff, however, must be accounted for in order to get the correct refusal speed. If the wind is measured at runway level, the actual velocities may be used. If, however, the wind is measured at control tower height, conservative practice is to use 50 percent of the headwind component or 150 percent of the tailwind component, as the effective wind for takeoff. The portion of the problem involving wind angle and velocity is shown for reciprocating engine aircraft in the following example.

Example: (Reciprocating Engine Aircraft) Use the equivalent performance weight of 182,500 lbs and predict the takeoff distance using the following conditions:

Wet Runway
1.5% Uphill slope
36 knot headwind at 70 degrees
Takeoff Runway 04
Altitude 1500 feet
Temperature 40° F
33% Flaps

In computing for the effective headwind or tailwind, it is necessary to predict the wind angle, that is the wind degrees in relation to runway degrees, so that its direct effect on the aircraft can be determined. For this computation, use the crosswind correction chart, figure 9-14. We enter the chart with the wind angle and velocity as indicated by the arrow.

Notice that the existing wind is coming from a 30° angle to the runway (70 — 40). Enter the chart on the wind angle line and read the desired answers in the lower and left hand margins. This has the effect on the aircraft of a 31 knot headwind and an 18 knot crosswind.

Skill in the reading of charts can be acquired very quickly through repetition of the processes, using a different set of values for each exercise. In this instance, you should set up a series of five or more problems involving (1) headwinds in knots and degrees, and (2) direction of the runway. After completing this exercise you should easily remember the procedure.

Example: (Turbojet Engine Aircraft) The same considerations must be given turbojet powered aircraft for computing takeoff data as for reciprocating engine powered aircraft. Some of the terminology may differ, but basically it has the same meaning. Some turbojet aircraft performance instructions recommend that takeoff be refused under definite circumstances. For instance,

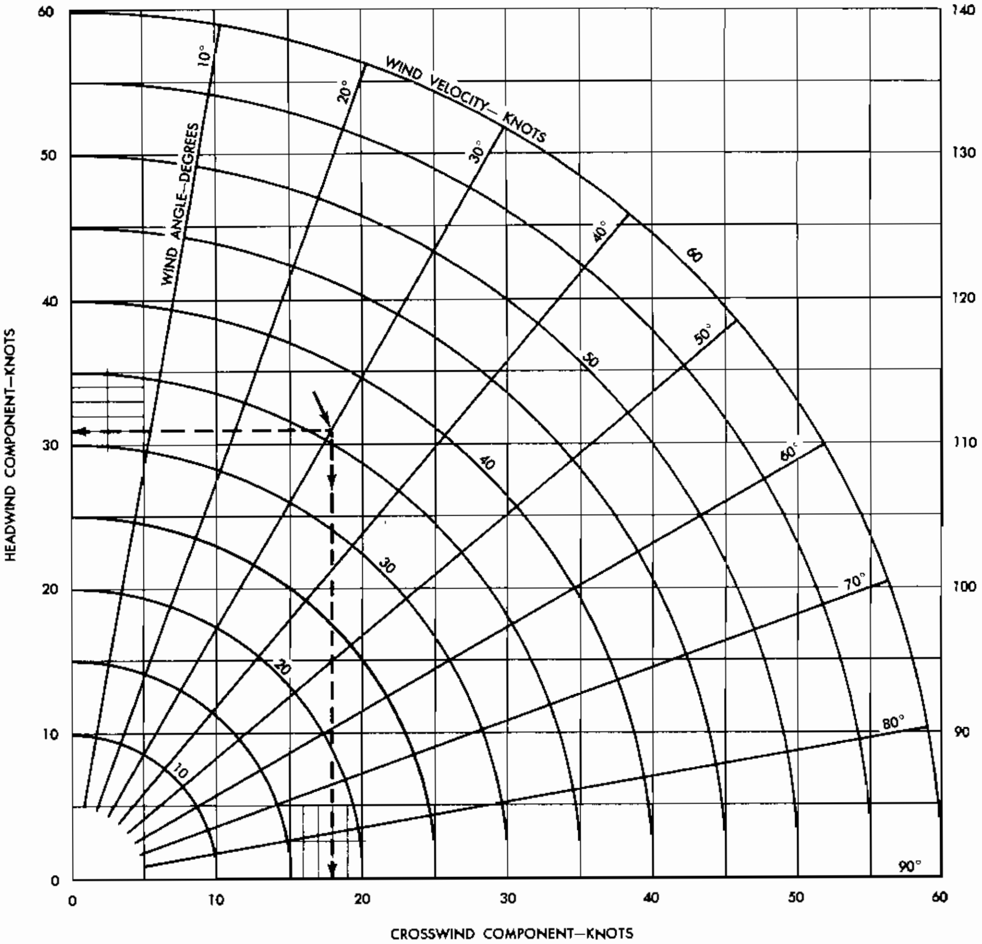


Figure 9-14. Crosswind Chart

it is recommended that takeoff not be attempted when slush and water puddles on the runway exceed ½ inch in depth. When slush or puddles are less than ½ inch deep, takeoff may be scheduled, but the distances may increase up to 15%. An instance has been recorded where puddles and running water of varying depth resulted in an increase of takeoff distance of 27%. Ground run time therefore increases proportionally, and the increase in acceleration check time must be accounted for. The retarding effect of slush and water puddles increases as the speed increases; therefore, the actual acceleration check may indicate better performance than predicted. Because of the increased retarding effect at higher speeds, this better performance should not be expected toward the higher speed end of the takeoff run.

To determine a takeoff ground run for jet engine powered aircraft, let us use the following conditions for demonstration:

Gross Weight	220,000 lbs
Takeoff Factor	27
Runway Conditions:	
Altitude	2800 ft
Temperature	20° C
Gradient	1.0% Uphill
Flap Setting	20°
42 Knot wind from	340°
Runway Heading	360°

In order to compute properly the amount of takeoff ground run, we must first determine the effect the wind is going to have on performance. In this instance the wind is blowing across the runway at a 20° angle (360 − 340). From the chart shown in figure 9-14, and using the procedure previously illustrated by the dotted line, you see that this creates a headwind component of approximately 39 knots and a crosswind component of approximately 14 knots. Following the stated rule for headwind computations, 50% of the effective wind will be considered for this

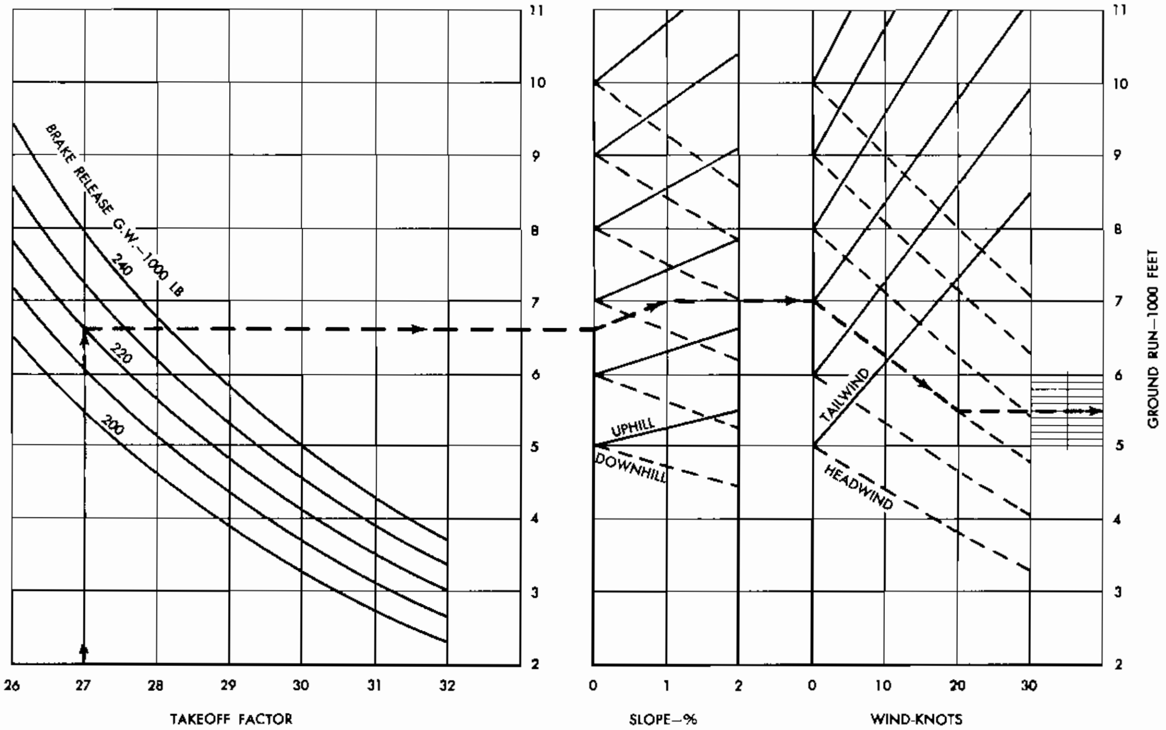


Figure 9-15. Ground Run—Uncorrected and Ground Run—Corrected

problem. This amounts to 19.5 knots correction. Enter the chart shown in figure 9-15 with the takeoff factor 27. Proceed upward to the gross weight, 220,000 pounds, and then to the right to the flap setting 20°. From this point continue to the right section of the chart and account for the runway gradient slope 1.0% uphill. From there, compute the effective headwind 20.0 knots. The resulting ground run required after all corrections have been made is shown at the right hand margin of the chart in figure 9-15 to be approximately 5500 feet.

After we determine the length of the ground run for takeoff, we compute the speed required for liftoff.

Takeoff Speed

The recommended takeoff, climbout, and flap retraction speeds represent the optimum compromise between shortest ground distance and best climbout performance. Climbout is that flight condition from the instant of liftoff until the flaps are retracted and climbing power is established. The climbout speeds are 15 to 20 percent above the power-off stall speeds for a wing flap setting, and slightly below the best angle of climb speed with one engine inoperative and the propeller feathered. The scheduled flap retraction speeds assure a safe margin above stall speed and a positive gain in climb performance. The takeoff procedure recommended with these speeds is to leave the weight on the nose wheel during the takeoff run until within 5 or 10 knots of the recommended takeoff speed; then ease the weight off the nose wheel and, holding constant attitude, allow the airplane to fly off at the speed shown. Due to changing ground effects on the airspeed static system, as the airplane leaves the runway, the indicated airspeed increases even though the airplane does not accelerate. While holding constant attitude, the indicated airspeed should be allowed to increase to the values shown for climbout by the time 50 to 100 feet of altitude has been reached. Then climb power may be established at the discretion of the pilot.

Example: (Reciprocating Engine Aircraft) Determine the takeoff, climbout, and flap retraction speed for the actual gross weight of 173,000 pounds at 33% flap position.

Using the takeoff, minimum climbout, and flap retraction speeds chart, figure 9-16, enter at the bottom with the actual gross weight of 173,000

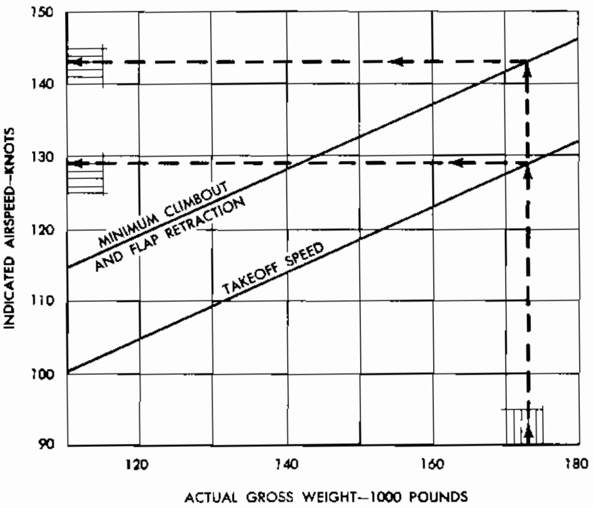


Figure 9-16. Takeoff, Climbout, and Flap Retraction Speeds

pounds. Proceed vertically to the takeoff speed line and read horizontally to the left to find the takeoff IAS, which is 129 knots. In rough air, the takeoff IAS should be increased 5 to 10 knots to provide the necessary safety margin.

Using the same procedure, proceed vertically to the minimum climbout and flap retraction line, and read horizontally to the left to find the flap retraction speed of 143 knots.

TAKEOFF ENGINE FAILURE. Under normal operating conditions, runways are usually long enough so that an aircraft can accelerate to takeoff speed and still brake to a stop within the length of the runway if an engine should fail before the aircraft leaves the ground.

In many instances, however, where maximum takeoff weights, high temperatures, high pressure altitudes, short runways, or a combination of these factors are involved, the available runway length may fall short of the accelerate-stop distance. When such is the case, a speed-distance relationship must be determined to find the maximum weight for which the runway length can be used, and a speed above which takeoff must be continued in case of engine failure. Various conditions of runway length and takeoff speeds are expressed in figure 9-17.

This relationship between takeoff speed and runway length is shown in the Takeoff Performance Graph no. 1. The graph is composed of a vertical speed axis, a horizontal distance (runway length) axis, and three curves labeled I, II, and III. Curve I is the normal 4-Engine Takeoff Curve, Curve II is the 3-Engine Stop Curve, and Curve III is the 3-Engine Takeoff Curve.

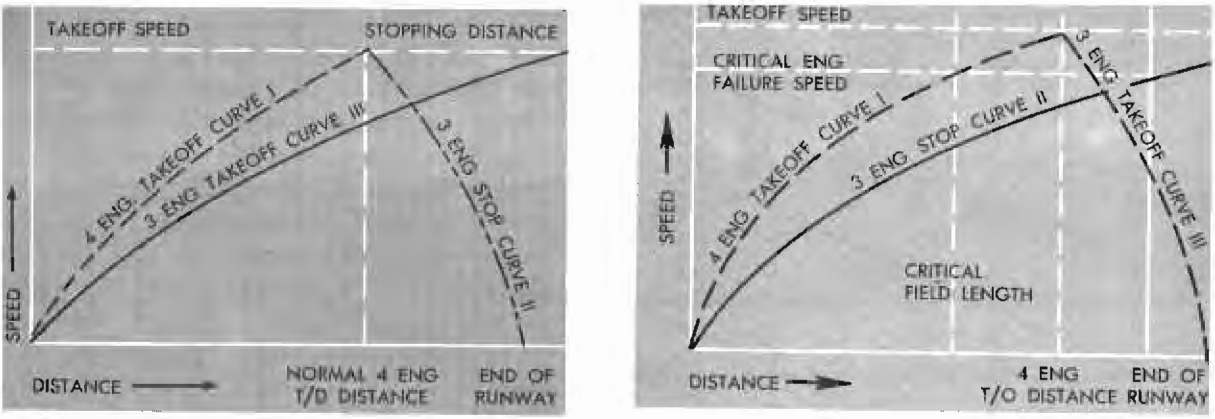
Curve I represents normal 4-engine acceleration up to takeoff speed. The end of the curve represents normal takeoff speed, which can be converted to linear runway distance by drawing a line down to the distance axis.

Curve II is used in conjunction with Curve I to show the required stopping distance from any point on Curve I where engine failure occurs. The horizontal distance between the two curves indicates stopping distance, as labeled in the illustration. In this case, engine failure occurred right at the takeoff point, and the graph shows that the aircraft could be stopped just within the limits of the runway.

Curve III is also used in conjunction with Curve I to show the distance required for takeoff if the takeoff run is continued after engine failure. Like stopping distance, 3-engine takeoff distance is indicated by the horizontal distance between any point on Curve I and Curve III. The graph shows that takeoff can be accomplished regardless of where engine failure occurs, because the end of Curve III is short of the end of the runway.

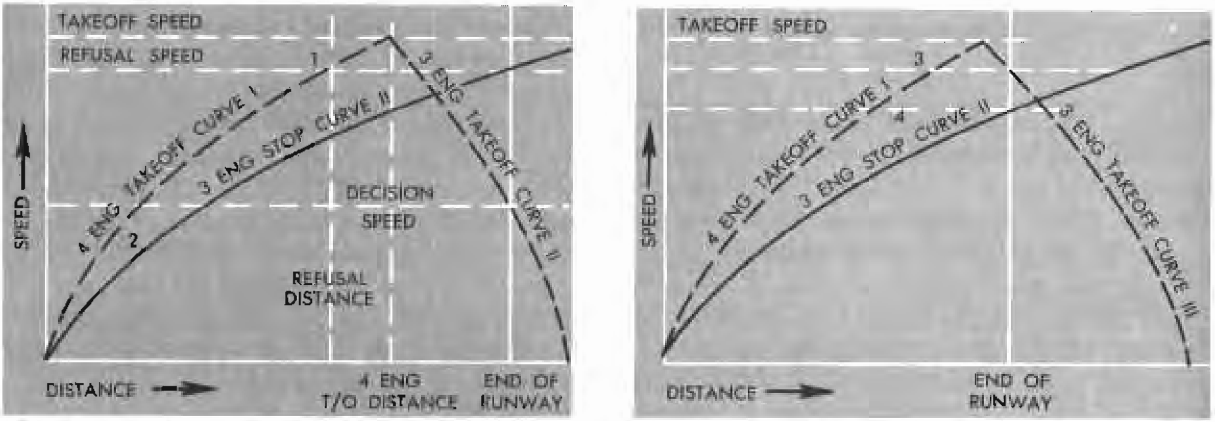
Now let us consider the effects of various runway lengths, using first the Takeoff Performance Graph no. 2. In this graph, the vertical end-of-runway line intersects Curve II at a point before normal takeoff speed has been reached. When this point is projected across to Curve I, it shows the point (1) beyond which the aircraft cannot be safely stopped if engine failure should occur. This speed is known as refusal speed. Point 2 of Curve I shows the minimum speed to which the aircraft can accelerate, lose an engine, and continue the takeoff run on three engines. This speed is known as decision speed. The conditions shown in graph no 2 represent a high level of safety, since the aircraft could either stop or continue anywhere between the decision speed (2) and refusal speed (1).

The Takeoff Performance Graph no 3 shows another situation in which the runway length is such that the refusal speed and the decision speed are at the same point. This point is called critical field length and also critical engine failure speed. If the engine failure occurs beyond this point, takeoff must be continued, because the 3-engine stop distance is beyond the end of the runway. If engine failure occurs before this point,



Takeoff Performance Graph #1

Takeoff Performance Graph #3



Takeoff Performance Graph #2

Takeoff Performance Graph #4

Figure 9-17. Takeoff Performance Graphs

the aircraft must be stopped, because 3-engine takeoff distance exceeds the length of the runway. Engine failure right at critical field length is of grave concern, for an almost instantaneous decision must be made whether to stop or go.

The Takeoff Performance Graph no 4 represents a situation that would probably occur only if an aircraft has made an emergency landing at an air base with a short runway, and then, after repairs, is to take off again. The runway is so short that, if engine failure should occur anywhere in the shaded area between points (3) and (4), the aircraft could neither stop within the runway length nor take off on three engines. Consequently, if engine failure should occur right at point (4), an immediate decision must be made to stop. Should engine failure occur beyond point (3), takeoff must be continued and can be continued safely because the aircraft has sufficient airspeed to become airborne within the runway length.

An alternate method of checking acceleration may be used when runway distance markers are available. This consists of establishing a speed-distance curve for normal 4-engine acceleration, the speeds which should be attained at distances corresponding to the runway marker positions.

REFUSAL SPEED (S_1). A study of the charts will reveal that when the available runway length is greater than the critical field length, there is a zone of engine failure speeds in which takeoff may be either aborted or continued. Since stopping is the desirable choice on a piston-engine airplane, the maximum speed from which a stop can be made in the remaining runway length is called the refusal or S_1 speed. This can vary between critical engine failure speed and the takeoff or S_2 speed. In some instances, takeoff might be scheduled on a runway shorter than the critical field length. In this case, there is a zone of engine failure speeds in which, with normal procedures, the airplane cannot become airborne or stop within the remaining runway length. The refusal speed (S_1) should be used with the knowledge that the airplane may overrun the runway if takeoff is continued when an engine failure occurs at or just after that speed. It is possible to become airborne, however, as much as 5 knots below recommended takeoff (S_2) speeds.

Refusal or S_1 speeds are obtained from the same chart as the takeoff speeds as illustrated in figure 9-18. Since refusal speeds generalize as a function of equivalent performance weight while takeoff speeds are a function of actual gross weight, the chart first solves for refusal speed in percent of takeoff speed, then the percent speed is converted to indicated airspeed using the constant percent lines on the takeoff speed chart. The input conditions are runway length and EPW, with corrections for runway condition, slope, and wind component. Notice in figure 9-18 that we enter the chart from the left with a runway length of 10,400 feet. Then we account for the runway condition, which is snow and ice. From there, an uphill runway slope of ½%, and a head wind of 5 knots is calculated on the chart. Thereafter, we move across the chart to the right to an EPW of 180,000 pounds then, directly beneath that point at the bottom of the chart, we read the refusal speed to be 92 percent of takeoff speed.

Speed-Time Relationship. The time to accelerate from 60 knots to 100 knots or 10 knots below S_1 speed, whichever is lower, is found on the speed-time relationship chart like the one shown in figure 9-19. The equivalent performance weight (180,000 pounds) and runway gradient (½%) determine a total acceleration time in the upper part of the chart. The intersection of this total time and the takeoff speed for actual weight establish the speed-time line on the lower part. Following this line down to 100 knots or S_1 minus 10, we read a time of 40 seconds directly below. Then, as we proceed on down the line to 60 knots, we read a time of 20 seconds. The difference between these times (20 seconds) is the acceleration check time. Although wind has a large

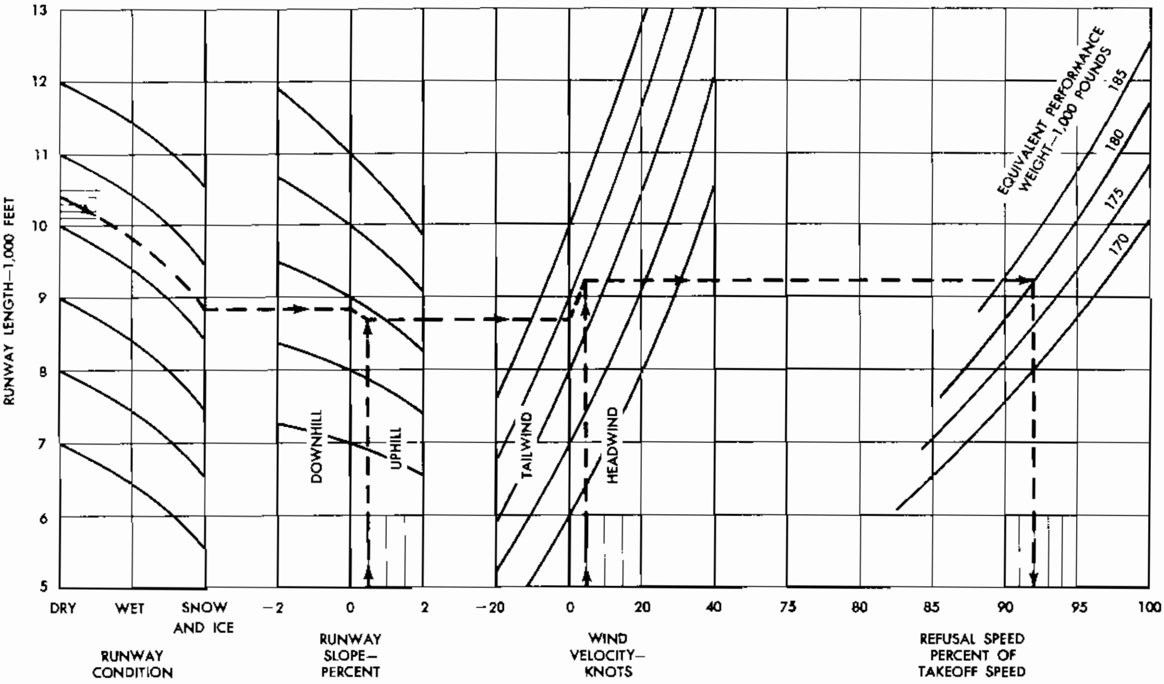


Figure 9-18. Refusal Speed

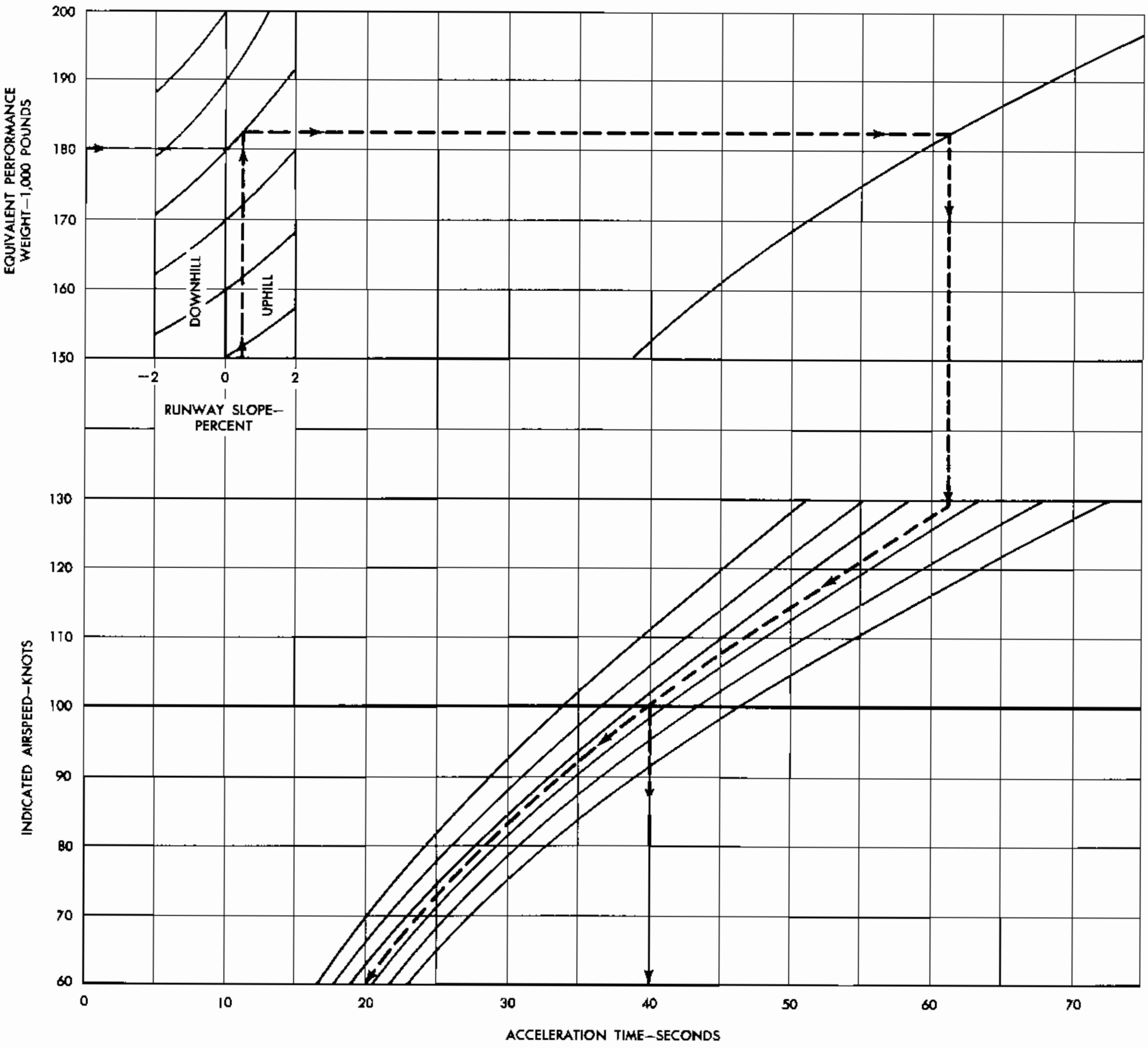


Figure 9-19. Speed-Time Relationship

effect on the total time from brake release to takeoff speed, it does not appreciably affect the shape of the speed-time curve; therefore no wind corrections are necessary in determining the net time to accelerate from one indicated airspeed to another.

SPEED-DISTANCE RELATIONSHIP. Runway distance markers are available at most established military bases and at many commercial airports. These are positioned and numbered to show runway length remaining as illustrated on the runway marker system chart, figure 9-20. Speed-distance relationships are shown for various takeoff flap positions on the speed-distance relationship chart such as the one in figure 9-21. By entering this chart with the takeoff distance corrected for slope, wind, and the takeoff speed, an acceleration line is established. The runway distance markers correspond to 1000 foot distance intervals along this line; therefore the predicted speed at any distance marker may be obtained, or conversely, the distance at which the S_1 speed should be reached can be predicted. The nearest marker ahead of the refusal speed distance is chosen as a "GO-NO-GO" marker. After passing this marker, if the airplane has attained predicted speed, it is committed to a takeoff. On the other hand, if the predicted speed has *not* been reached at this marker, takeoff may safely be aborted. An acceleration

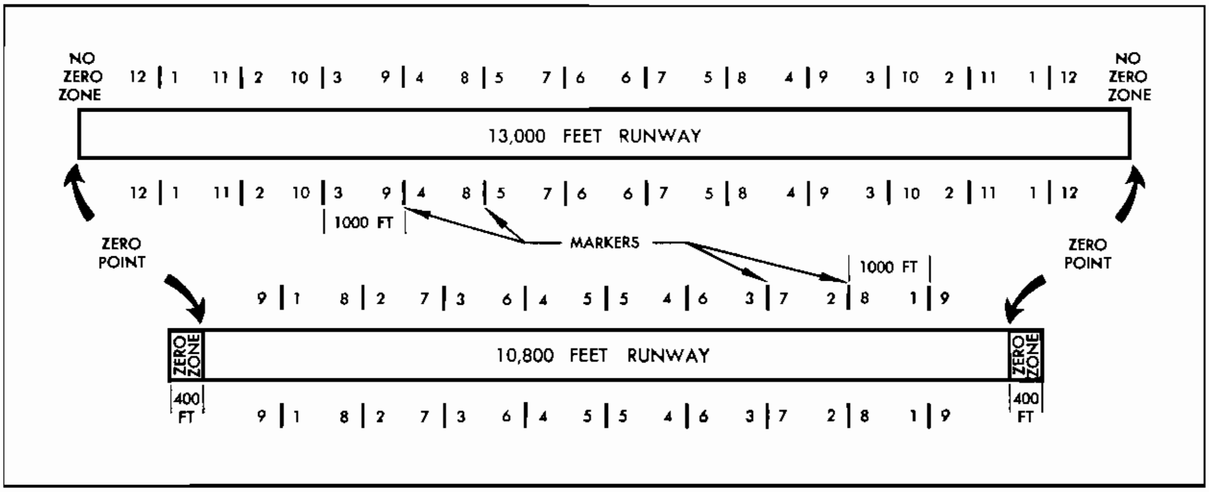


Figure 9-20. Runway Marker System

check speed is read for the distance 2000 feet, or two markers, ahead of the go-no-go marker. This check is used only to monitor takeoff performance and to alert the pilot for a possible abort at the go-no-go marker.

When runway length is insufficient for takeoff at the existing gross weight with normal takeoff flap setting, the use of greater flap setting reduces the runway length requirements by 8 to 16 percent. Likewise, in emergencies the takeoff speed may be reduced a maximum of 5 knots, which further shortens the ground distance approximately 10 percent. Greater speed reductions will, however, seriously impair the climbout performance. To assure adequate climbout performance when using reduced takeoff speeds, the airplane equivalent performance weight should be at least 5000 pounds less than the maximum allowed by command directive or obstacle clearance flight path. Recommended takeoff speeds should never be reduced when rough air prevails. In fact, added safety will result from increasing the takeoff speed 5 to 10 knots in rough air.

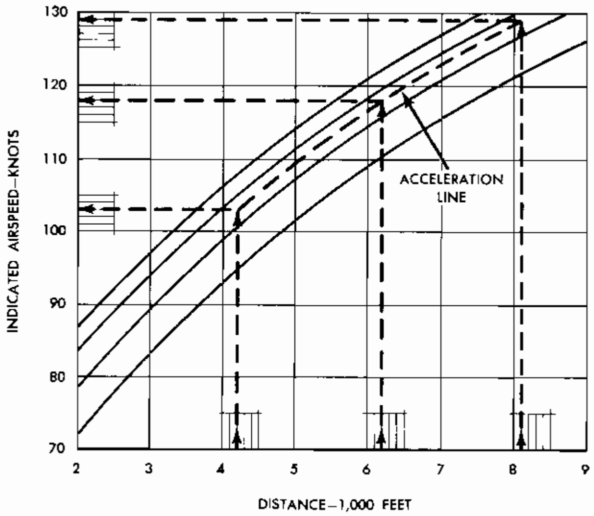


Figure 9-21. Speed-Distance Relationship

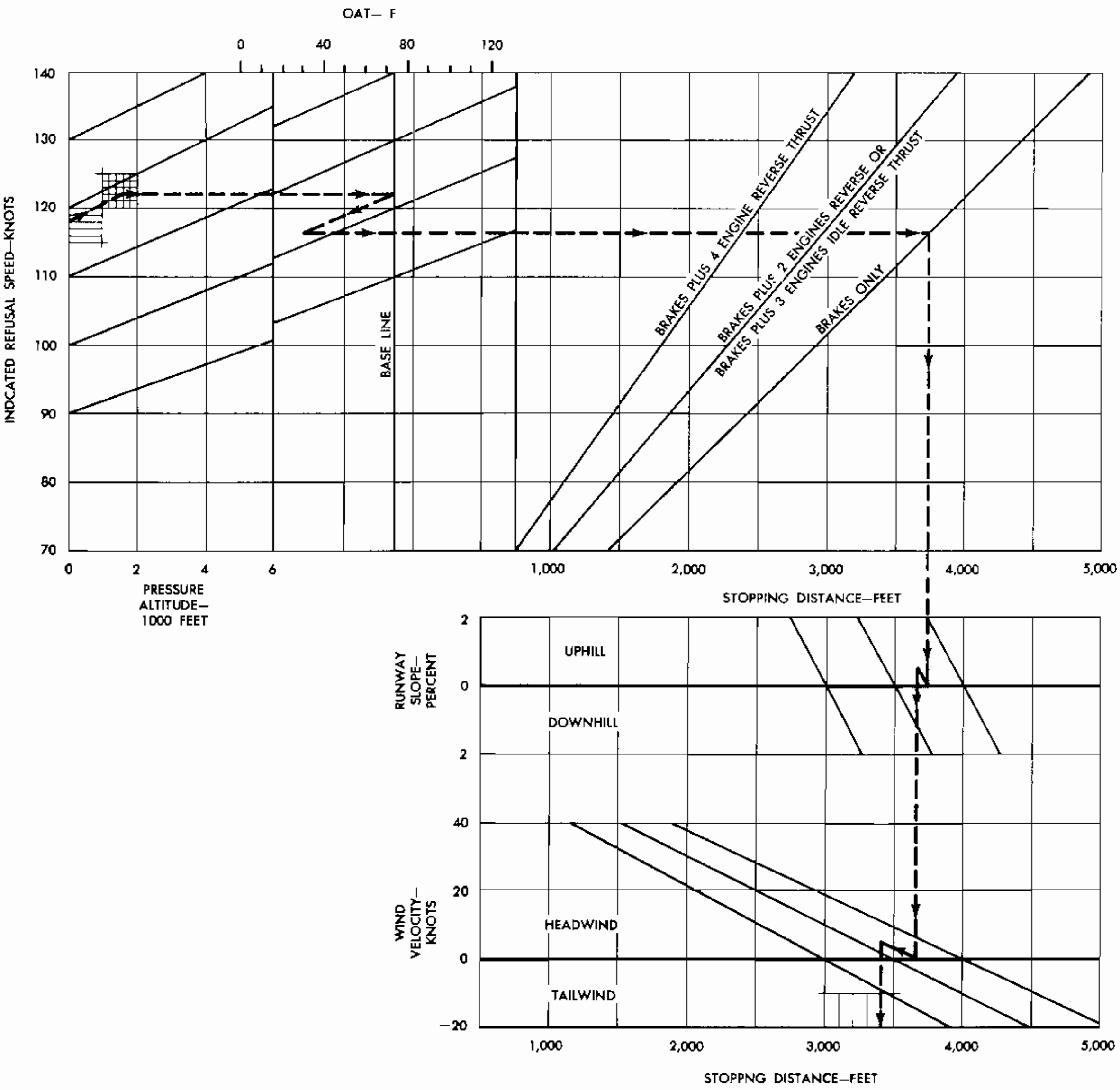


Figure 9-22. Stopping Distance Chart

Stopping Distance. The critical field lengths and accelerate-stop distances shown on the takeoff distances chart include stopping segments based on maximum use of wheel brakes plus 3 engines in idle reverse thrust. The stopping distance varies with the procedure used and runway conditions. For instance, wet and icy runway conditions are accounted for in the appropriate charts. The effects of procedure on stopping distance are shown on the stopping distance chart in figure 9-22. Although airplane weight and wing flap position do have a small effect on stopping distance, this has been disregarded for simplicity. To use the chart, enter with the refusal speed in the left margin. The illustration shows 118 knots.

Account for 1800 feet pressure altitude, and 30° temperature. After accounting for brakes only, runway slope, and effective wind, the stopping distance is illustrated as 3400 feet.

TAKEOFF CHECK POINTS. In order to assure that takeoff speed will be obtained in the length of runway required, it is necessary to check acceleration at various points before lift off. At a point between this acceleration check and lift off, the pilot must know whether he is committed to takeoff or whether he can stop on the existing runway. This point is known as the go-no-go distance, which is the distance at which the go-no-go speed must be reached to assure the accuracy of the predicted takeoff data. The first check is the accelerate-check distance which is 2000 feet less than the go-no-go distance. This information is obtained from the speed-distance relationship chart.

Acceleration check point is used to assure that the aircraft is accelerating as it should for the distance covered on the existing runway. The acceleration check, go-no-go distance and the refusal check are based on the takeoff distance and the airspeed needed to become airborne.

The last point along the runway for stopping the aircraft safely is known as the refusal distance or time. This is a specific distance before lift off which permits the pilot to safely reject the takeoff in the event of engine or systems failure.

The refusal speed, as earlier discussed, is determined by the length of runway available, whereas the acceleration check is dependent upon the airspeed required to lift off. When an acceleration check is made, it is a performance check of aircraft and engines before refusal speed, for a given set of conditions.

To check the performance of the aircraft, two charts are consolidated in figure 9-23. Enter the chart in figure 9-23 with the thrust factor, and compute the gross weight and acceleration check speed. The dotted line illustration shows a thrust factor of 9, a brake release gross weight of 190,000 lbs, and an acceleration check speed of 120 knots.

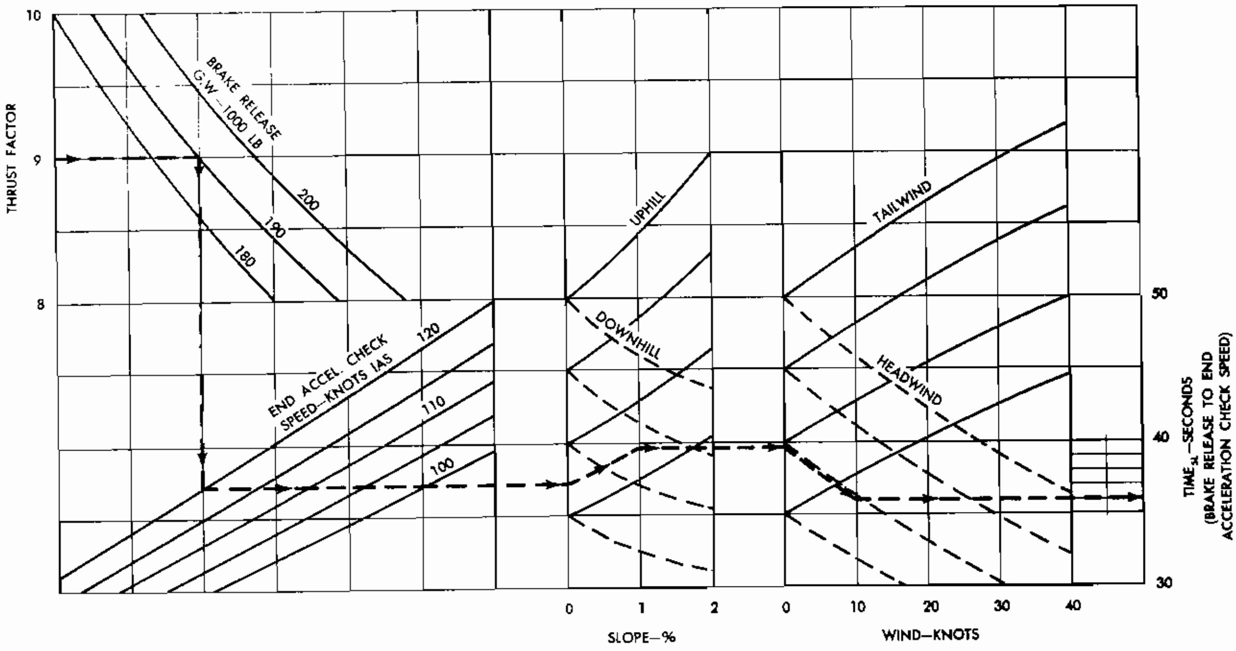


Figure 9-23. Acceleration Chart

From that point, enter the right-hand section of the chart to determine the acceleration check time. The dotted line illustration then shows the time as 36 seconds after accounting for the runway slope and effective wind.

TAKEOFF SPEED (V_{to}). Takeoff speed is that speed to which the airplane must be accelerated before lift off from the runway, and is computed from the chart shown in figure 9-24.

Example: (Turbofan Engine Aircraft) Enter this chart (figure 9-24) with the gross weight at the bottom. Move vertically to the flap setting line, and read the takeoff speed in the left margin. During the takeoff run, the indicated speed is different in the acceleration (3-point) attitude than in the rotated (2-point) attitude. This is due to the position change of airspeed indicating components which brings about an error of indication during takeoff. This error can be explained as follows: The pitot tube, being rigidly fixed to the aircraft structure, rotates from a direct position in the airstream, to a slightly upward tilt, which sets up a slight burble effect across the tube inlet. This causes an oscillation in the speed indication from a positive to a negative reading in respect to a stabilized IAS. This change may result in the indicated speed at lift off being no different than the indicated initial rotation speed. This creates the illusion that the airplane is not accelerating during the rotation. It is important for the pilot to understand these effects and to follow the recommended procedure so that the charted takeoff distances can be realized.

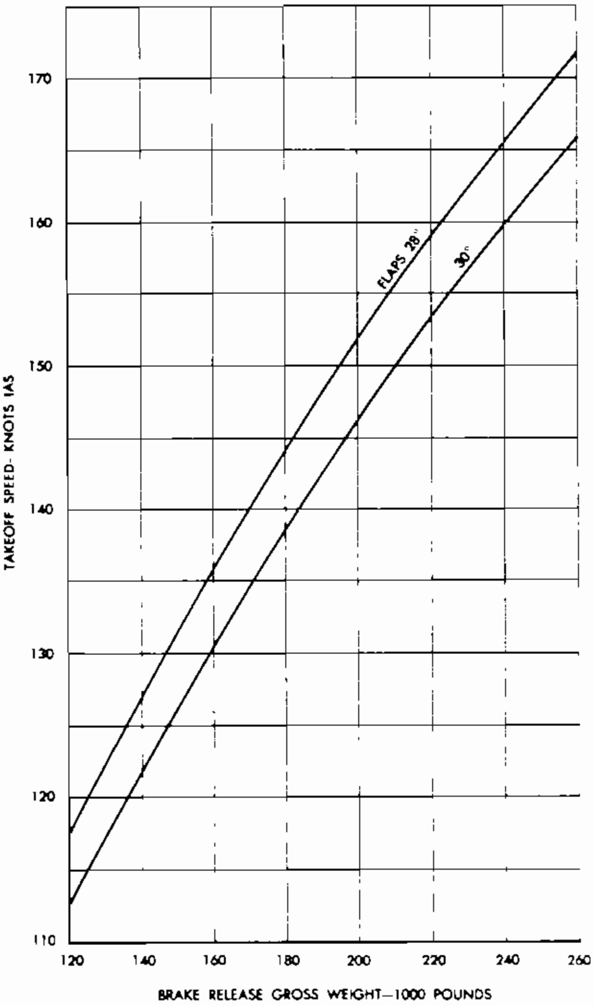


Figure 9-24. Takeoff Speed Chart

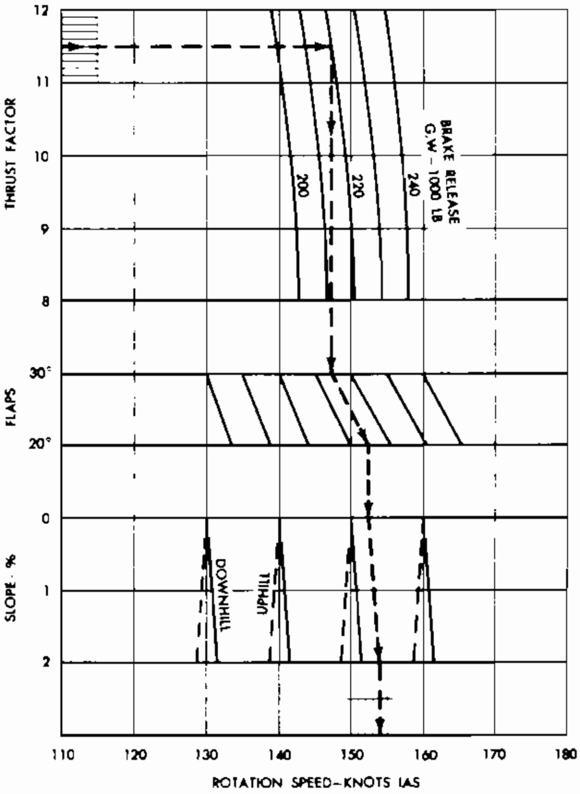


Figure 9-25. Rotation Speed Chart

ROTATION SPEED (V_{rot}). Rotation speed is that speed during the takeoff run at which rotation from the three point attitude to the takeoff attitude is initiated. This speed is reached approximately 3 seconds before liftoff speed, and varies with the gross weight of the aircraft as illustrated in figure 9-25. Enter the chart with the thrust factor in the left margin, and calculate the rotation speed at the bottom as illustrated by the dashed line.

Critical Engine Failure Speed (V_{cef}). Critical engine failure speed is that speed to which the airplane can be accelerated, lose an engine, and then either continue the takeoff with the remaining engines, or stop, in the same total runway distance. This speed is computed on two charts, consolidated into a single chart for illustration in figure 9-26 after determining the distance. Critical engine failure speed is used to determine decision speed except when it is exceeded by ground minimum control speed. First enter the chart with the takeoff factor, and follow the dashed line for the illustration of its use to obtain critical engine failure speed.

Ground Minimum Control Speed (V_{mcg}). Ground minimum control speed is the minimum airspeed at which the airplane, while on the ground, can lose an outboard engine during acceleration and allow the pilot to maintain directional control with the rudder. Compute this speed from the chart as illustrated by the dotted lines in figure 9-27. Ground minimum control speed is greatly affected by the condition of the runway and is compared, in takeoff planning, with critical engine failure speed, refusal speed, and sometimes with takeoff speed in determining decision speed.

Inflight Minimum Control Speed (V_{mca}). Inflight minimum control speed is the minimum speed at which an engine can be lost and directional control of the aircraft maintained using full rudder deflection and not more than 5 degrees of bank. Compute the trust factor for jet powered aircraft (figure 9-28), then enter the left margin with the thrust factor and move to the center base line. The inflight minimum control speed appears directly below that point on the indicated airspeed scale.

Refusal Speed (V_r). Refusal speed is compared, in takeoff planning, with ground minimum control speed, and is the maximum speed the airplane can attain under normal acceleration and then stop in the available runway.

Decision Speed (V_d). Decision speed is the minimum indicated airspeed at which an engine failure can be experienced and the takeoff safely continued. Remember that safe abort capability is assured if the takeoff is aborted before reaching this speed. Decision speed is critical engine failure speed or ground minimum control speed whichever is higher; however, it must *never* exceed refusal speed or takeoff speed.

Acceleration Check. A speed-time acceleration check is made from brake release to a predetermined speed during the takeoff run. A three-knot tolerance is usually applied to the end-check speed to determine the minimum acceptable airspeed. If the indicated airspeed is less than the minimum acceptable, the takeoff will be aborted.

Takeoff Flight Path

When obstacles beyond the field must be cleared after takeoff, the climbout performance becomes important. Three- and four-engine flight paths are shown in different charts for various wing flap settings and equivalent performance weights. However, the example shown in figure 9-29 is for three engine, 33% flaps, and distant obstacles. For safety, the three-engine flight paths should be used to determine the obstacle clearance. Considering the differences in takeoff ground run, a higher degree of flap setting gives better obstacle clearance at distances less than one mile beyond the runway, while a lesser degree of flaps permits better obstacle clearance at greater distances. These flight paths will be obtained provided (1) that takeoff and climbout are made using maximum power at the recommended speeds shown on the takeoff speed chart, (2) that the landing gear is fully retracted 15 seconds after takeoff, and (3) in case of engine failure, that the propeller is promptly feathered and the cooling flaps are closed on the dead engine.

In the example shown, we see that we can safely climb to an altitude of 1000 feet in a distance of 15,000 feet (2.8 miles) from the takeoff point. Any obstacle of lesser height could be safely cleared. Notice that we enter the chart at the bottom with the distance desired from takeoff point (15,000 feet). Then account for the effective wind on the wind section of the chart, and move vertically to the equivalent performance weight. From there we read the height we can attain in that distance above the runway level directly to the left as 1000 feet.

When using 33 percent wing flaps for takeoff, the climbout speed schedule is high enough to allow flap retraction without further acceleration. Thus, flaps may be retracted when obstacles have been cleared, usually at a minimum of 500 feet above the terrain. The angle of climb cannot be improved by raising the flaps because the aircraft converts the drag reduction into greater horizontal distance in a given time. However, better

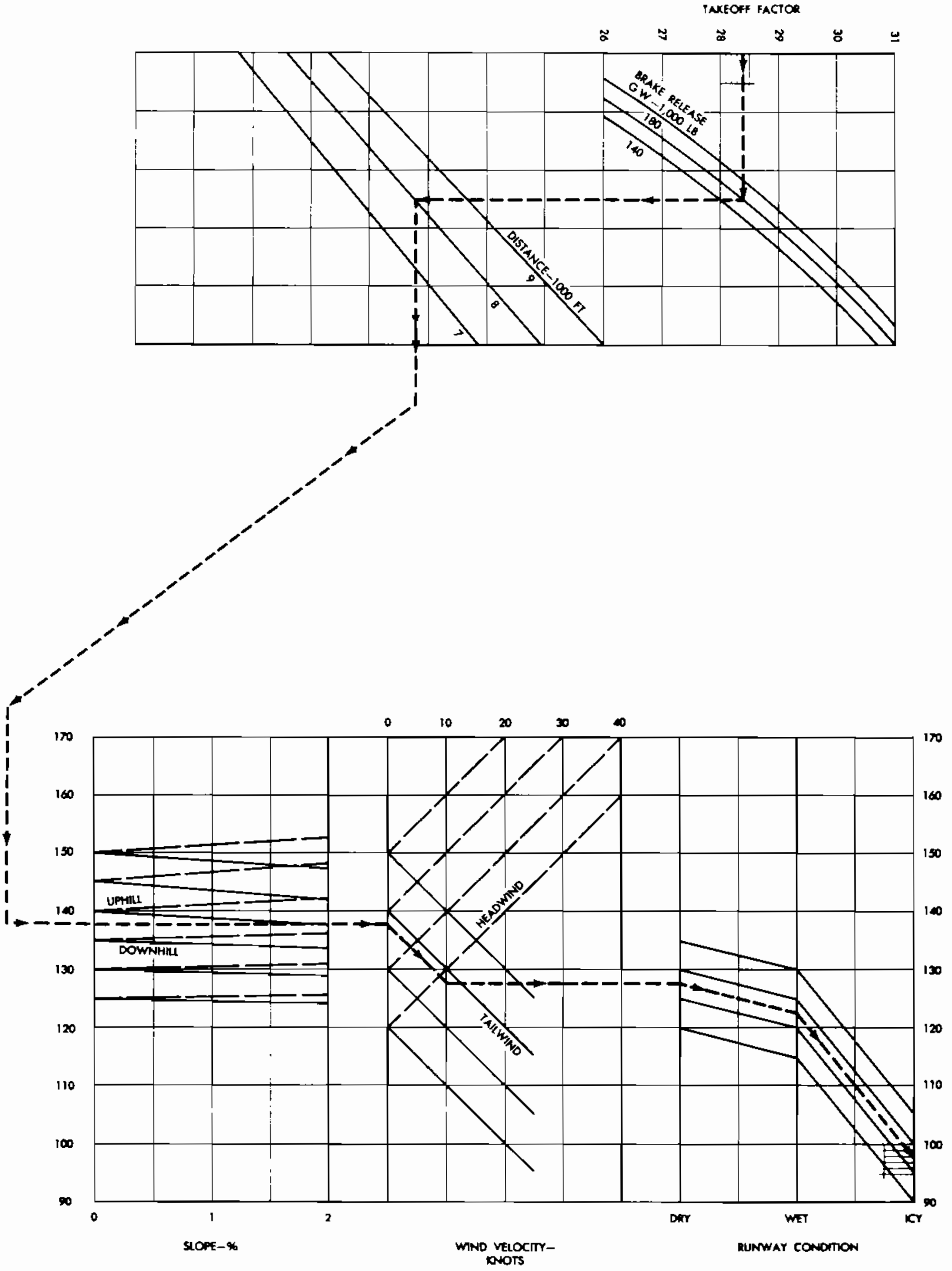


Figure 9-26. Critical Engine Failure Speed

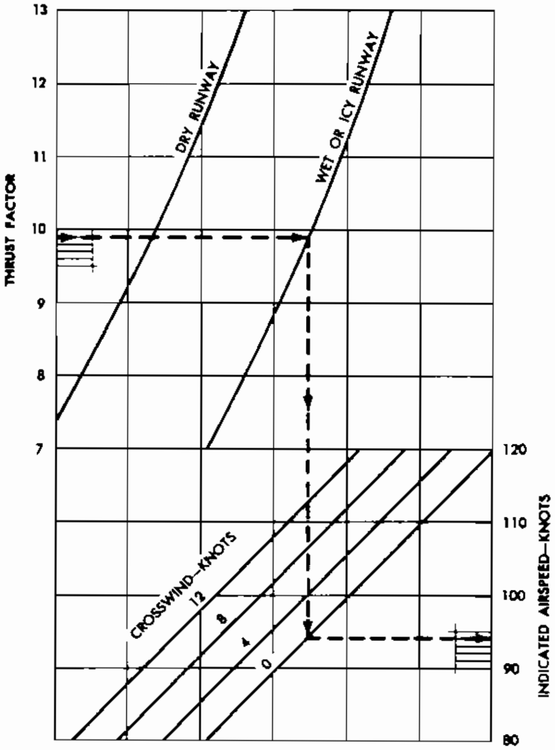


Figure 9-27. Ground Minimum Control Speed

airplane handling is obtained with the flaps down; so flap retraction and acceleration to flaps-up climb speed should be delayed until all obstacles are cleared. When using a high percent wing flaps for takeoff, however, the situation is somewhat different. The angle of climb with 33% flaps is so much better than with the higher percent that it usually pays to retract flaps to 33% as soon as the landing gear is retracted, and accelerate to the 33% flaps minimum climbout speed. Further acceleration and flap retraction should not be attempted until obstacles have been cleared, because the rate of climb that must be traded for this acceleration, about 7 to 8 fpm for each knot per minute acceleration, is excessive. The climbout factor for jet engine powered aircraft has the same effect on the takeoff flight path chart as the equivalent performance gross weight for reciprocating engine aircraft. Enter the flight path chart shown in figure 9-30 with the obstacle height and distance to the obstacle to find the climbout factor, as illustrated. Then with this climbout factor and thrust factor, enter the climbout factor chart shown in figure 9-31, to find the brake release gross weight as illustrated by the dashed line.

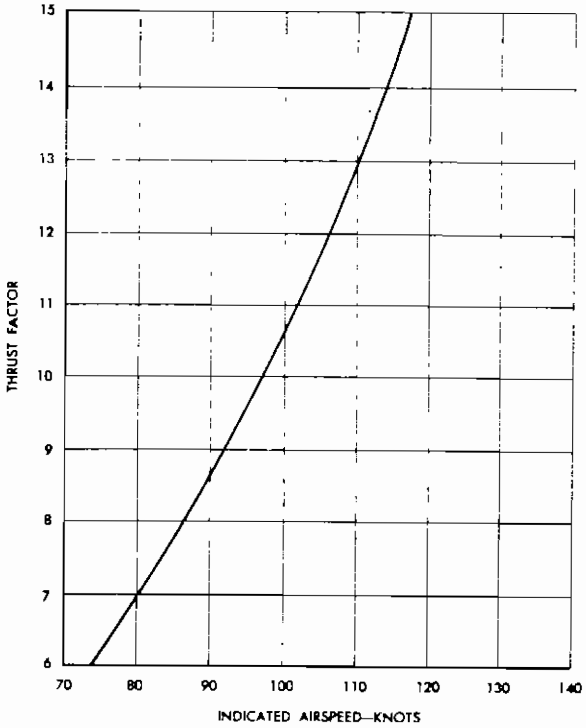


Figure 9-28. Air Minimum Control Speed

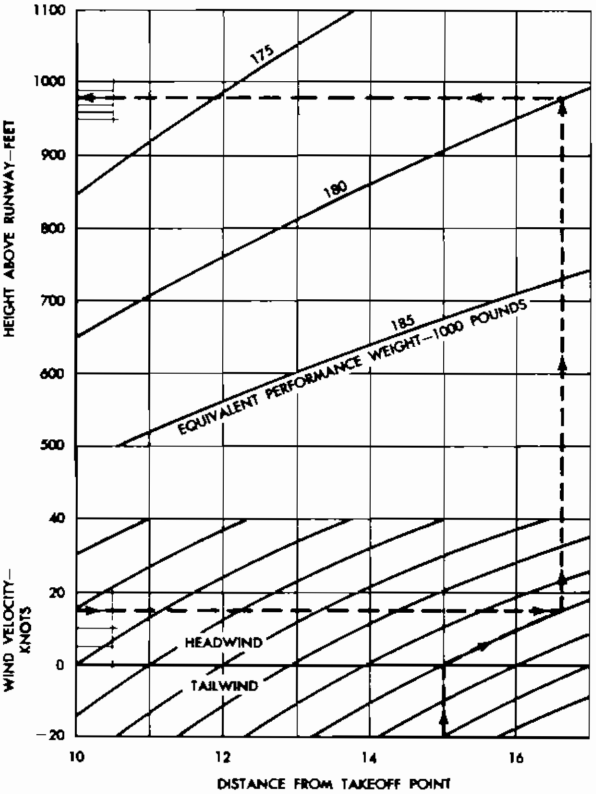


Figure 9-29. Takeoff Flight Path

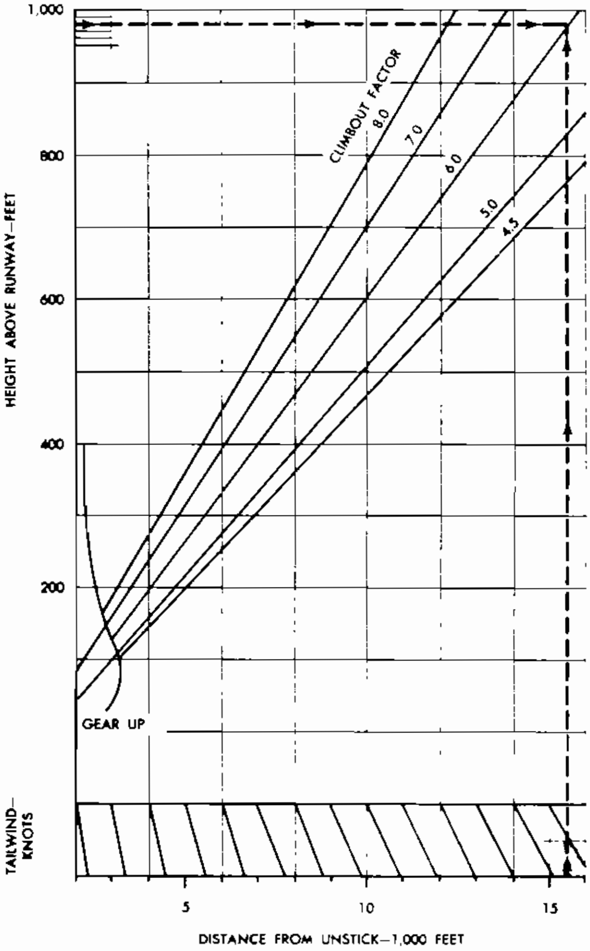


Figure 9-30. Climbout Flight Path (3 engines)

Takeoff Performance Data

Takeoff performance is of great importance in the operation of tanker and transport airplanes, since the amount of payload carried is a function of the maximum allowable takeoff weight under the existing operating conditions. When normal atmospheric conditions prevail, the maximum, normal, and overload takeoff weights are generally determined by structural limitations of the aircraft. At overload takeoff weights, care must be exercised in taxi and ground handling operations because great stress is imposed upon the landing gear and airplane structure. Smooth runways are essential and nonturbulent air is desirable if adequate margins of safety in flight are to be assured. For any particular mission, however, airplane performance considerations may limit the maximum takeoff weight. These limitations may be determined by:

- Length, condition, and slope of runway.
- Obstacles to be cleared after takeoff.
- Field pressure altitude.
- Air temperature, humidity, and wind conditions.
- Power output of engines.
- Standard operating procedures which determine minimum safety criteria.

The prediction of takeoff performance is further complicated by the fact that variations in pilot technique cause large differences in the resulting airplane performance. Technique variations may be minimized, if not eliminated, by outlining a recommended takeoff procedure and presenting performance charts based on adherence to this procedure. Thus the charts show how the airplane should actually perform with optimum pilot technique and predicted engine power output. Adequate safety margins must be incorporated in the procedures adopted by the using organization, with due regard to (1) the variables involved in the tactical situation, (2) the experience of the crew with the aircraft, and (3) the skill of the crew.

Now let us use the charts to solve a typical takeoff problem with all of the required entries, first using examples for the reciprocating engine aircraft, and then for the turbine engine aircraft. *Example:* (Reciprocating Engine Aircraft) From the performance charts, determine the power avail-

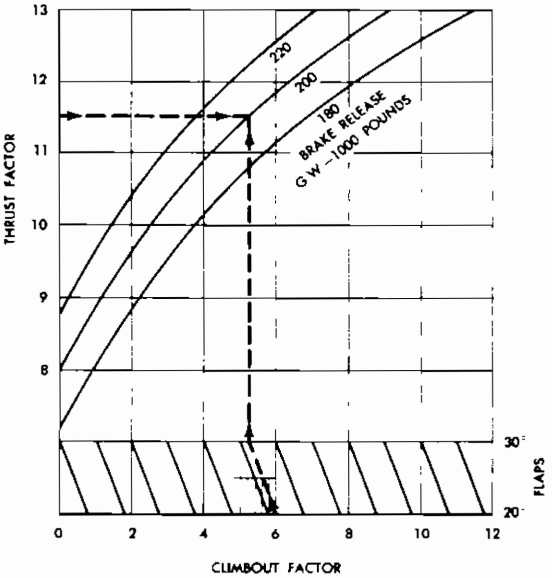


Figure 9-31. Climbout Factor (3 engines)

able and maximum gross weight for takeoff under the following conditions:

Runway Length	10.000 ft.
Field Pressure Altitude	1.000 ft.
Dry Bulb Temperature	16° C
Dewpoint	40° F
Obstacle Height	480 ft.
Distance to Obstacle	10 NM
Flap Position	33%

Use the charts to obtain the required data as follows:

1. Enter the takeoff distances chart (figure 9-15) with the takeoff factor, and determine the ground run as 5500 feet, as illustrated.
2. Enter the three-engine takeoff flight path chart (figure 9-29) with the ground distance from end of runway (10 NM) and proceed vertically to the obstacle height (480 ft) and interpolate the maximum allowable equivalent performance weight of 185.000 lbs. Since the equivalent performance weight of 181,500 lbs derived in our problem is less than 185,000 lbs, this maximum weight takeoff is limited only by the runway length.
3. From the maximum wet power available chart (figure 9-4), the maximum wet TPSI available is 242.
4. The minimum performance torque (95%) is 230.
5. Using the minimum performance torque (230) and the equivalent performance weight (181,500 lbs), enter the equivalent performance weight chart (figure 9-6) and interpolate for the maximum actual gross weight for takeoff of 170,750 lbs.

Using the equivalent performance weight of 181,500 lbs, determine the following:

1. Takeoff ground roll (figure 9-15)—8500 ft.
2. Critical Field Length (figure 9-10)—10,000 ft.

Anytime the takeoff is limited by the runway length, (1) the critical engine failure speed and the refusal speed will be the same, (2) the accelerate-stop distance will not be applicable, and (3) the critical field length will be the same as the runway length.

3. Refusal Speed (figure 9-18)—99% of Takeoff Speed.
4. Go-no-go Distance—6,000 ft.
5. Go-no-go Speed—114 knots.
6. Accel-Check Speed (figure 9-21)—99 knots.

Using the actual gross weight of 170,750 lbs determine the following:

1. Takeoff Speed (figure 9-24)—137 knots.
2. Climbout Speed (figure 9-32)—142 knots.
3. Flap Retraction (figure 9-16)—143 knots.

Example: (Turbofan Engine Aircraft) Determine the maximum brake release gross weight and necessary performance data for takeoff using the following conditions:

Runway Length	8500 ft.
Field Pressure Altitude	2000 ft.
Airplane Lineup Distance	200 ft.
Runway OAT° C	27°
Wind	16 knots at 30° to runway
Flap Position	30°
Obstacle Height	200 ft.
Distance to Obstacle	7000 ft.

1. Enter the takeoff thrust setting, EPR chart (figure 9-7) with OAT and Pressure Altitude and read an EPR of 1.735.
2. Enter the thrust factor chart (figure 9-8) with the EPR and pressure altitude and read a thrust factor of 13.
3. Enter the takeoff factor chart (figure 9-9) with the thrust factor. OAT° and Pressure Altitude and read a takeoff factor of 28.2.
4. Enter the crosswind component chart (figure 9-14) with 16 knots of 30 degrees and read a headwind component of 14 knots divided by 2 which is 7 knots.
5. For maximum weight takeoff, assume critical field length the same as runway length. Enter the critical field length chart (figure 9-10) with 8300 feet (8500 — 200), correct for 7 knot headwind, and interpolate at 28.2 takeoff factor to read the maximum brake release gross weight of approximately 252,000 lbs.
6. Enter the takeoff speed chart (figure 9-16) with brake release gross weight and 30° flap position to read a takeoff speed of 162.4 knots.
7. Enter the minimum climbout speed chart (figure 9-32) with the brake release gross weight and 30° flap position to read the minimum climbout speed of 166 knots.
8. Enter the climbout factor chart (figure 9-32) with the thrust factor and brake release gross weight to read the climbout factor of 3.4.
9. Enter the climbout flight path chart (figure 9-31) with the obstacle height and distance to the obstacle to find that the minimum climbout factor is 2.5. Since the 2.5 is less than 3.4, the maximum brake release gross weight of 252,000 lbs for takeoff can be made. The takeoff perform-

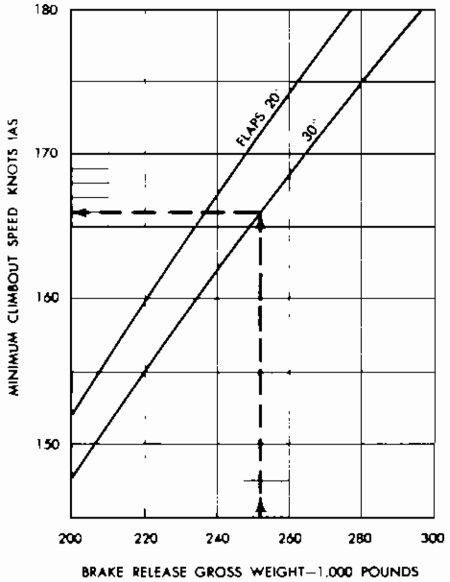


Figure 9-32. Minimum Climbout Speed

ance data predicted for turbojet aircraft is normally entered on a turbojet aircraft performance worksheet such as the one shown in figure 9-33.

Takeoff and Landing Data Card (TOLD)

It is the duty of the flight engineer to compute a takeoff and landing data card (TOLD card) before the takeoff. The front side of the TOLD card contains data necessary for the takeoff illustrated in figure 9-34. The reverse side of the card contains data pertinent to the landing. The landing data information is usually completed at the same time as the front section and is based on predicted landing conditions. The landing and emergency data card is discussed in detail later in this chapter. *Example:* (Reciprocating Engine Aircraft) Now as we proceed further with the data required for takeoff, use the charts to compute the information needed for a normal flap takeoff, using the following information:

Actual gross weight	150,000 pounds
Runway length	9,000 feet
Field pressure altitude	1,100 feet
Outside air temperature	68° F.
Dewpoint	20° F.

Terrain obstacle: 250-foot ridge four miles from end of runway.

From the wet takeoff power available chart, (figure 9-4) using 1100 feet pressure altitude and 68° F OAT, go vertically to the intersection of the dewpoint base line. Interpolate 20° F dewpoint, and then go vertically to the TPSI lines. In this case, we obtain 239 TPSI × .95 = 227 minimum performance torque. On the equivalent performance weight chart (figure 9-6), starting with the 227 TPSI, correct for pressure altitude and temperature. Then go vertically to the actual gross weight of 150,000 lbs and read the EPW at the left margin, which in this case is 162,000. Move horizontally to the right to a critical field length of 7,000 feet and proceed to the takeoff distance line to find a takeoff distance of 6,000 feet.

From the recommended speeds for takeoff and initial climbout chart (figure 9-16) for 150,000 pounds gross weight and 30% flaps, the recommended takeoff (T/O) speed is 149 knots. The recommended climbout and flaps up speed is 132.5 knots.

On the speed-distance chart (figure 9-21), the acceleration distance of 6,000 feet and the T/O speed of 116 knots shows the acceleration check at 4,000 feet to be 99 knots. The go or no-go speed is revealed as 128.5 knots. From this we see that, in this case, we may safely accelerate to takeoff speed and then stop within the length of the runway if the need arises. The minimum climbout and flap retraction speed of 125 knots was established on the recommended speed chart, figure 9-33. The 3- and 4-engine climb speeds required to complete the TOLD card are found on the go-around data chart explained later in this chapter.

To find whether or not the aircraft will clear the 250 foot ridge indicated in the problem, first subtract the critical field length (7,000) from the runway length (9,000), which is 2,000 feet. Convert this distance to 0.33 nautical miles and add to the 4 NM from the end of the runway to the obstacle to get the air distance to the obstacle of 4.33 NM.

By entering the takeoff flight path chart (figure 9-30) with 4.33 NM and intersecting the EPW of 162,000 lbs, note that the ridge will be cleared by several hundred feet.

The foregoing problems and examples should furnish you with sufficient review to properly manipulate the performance charts and to extract the required information for a safe takeoff under any condition. Now, in the order of logical sequence of a typical mission, let us review the procedure

JET AIRCRAFT PERFORMANCE WORKSHEET		
TEMPERATURE	TAKEOFF FACTOR	TAKEOFF GROUND RUN
PRESSURE ALTITUDE	TAKEOFF GROSS WEIGHT LIMIT 3 ENGINES	ACCELERATION TIME CHECK
TAKEOFF GROSS WEIGHT	CRITICAL FIELD LENGTH	TAKEOFF STABLIZER SETTING
WIND/VELOCITY	CRITICAL ENGINE FAILURE SPEED	INFLIGHT MINIMUM CONTROL SPEED
RUNWAY WIND COMPONENT/SLOPE	REFUSAL SPEED	CLIMBOUT SPEED/CLIMB FACTOR
CROSSWIND COMPONENT	GROUND MINIMUM CONTROL SPEED	FLAP RETRACTION SPEED
RUNWAY AVAILABLE/HEADING	DECISION SPEED	CLIMB EPR
TAKEOFF EPR	ROTATION SPEED	TOUCHDOWN SPEED/BRAKING SPEED
THRUST FACTOR	TAKEOFF SPEED	LANDING DISTANCE

Figure 9-33. Jet Aircraft Performance Worksheet

used to properly extract information from the performance charts for a safe and economical climb.

CLIMB PERFORMANCE

After a successful takeoff, the determination of time, distance, and fuel consumed are important in climbing to cruise altitude. Although charts are available for making these determinations, it is important for the flight engineer to be familiar with the principles involved in the climb and to be able to make the necessary computations.

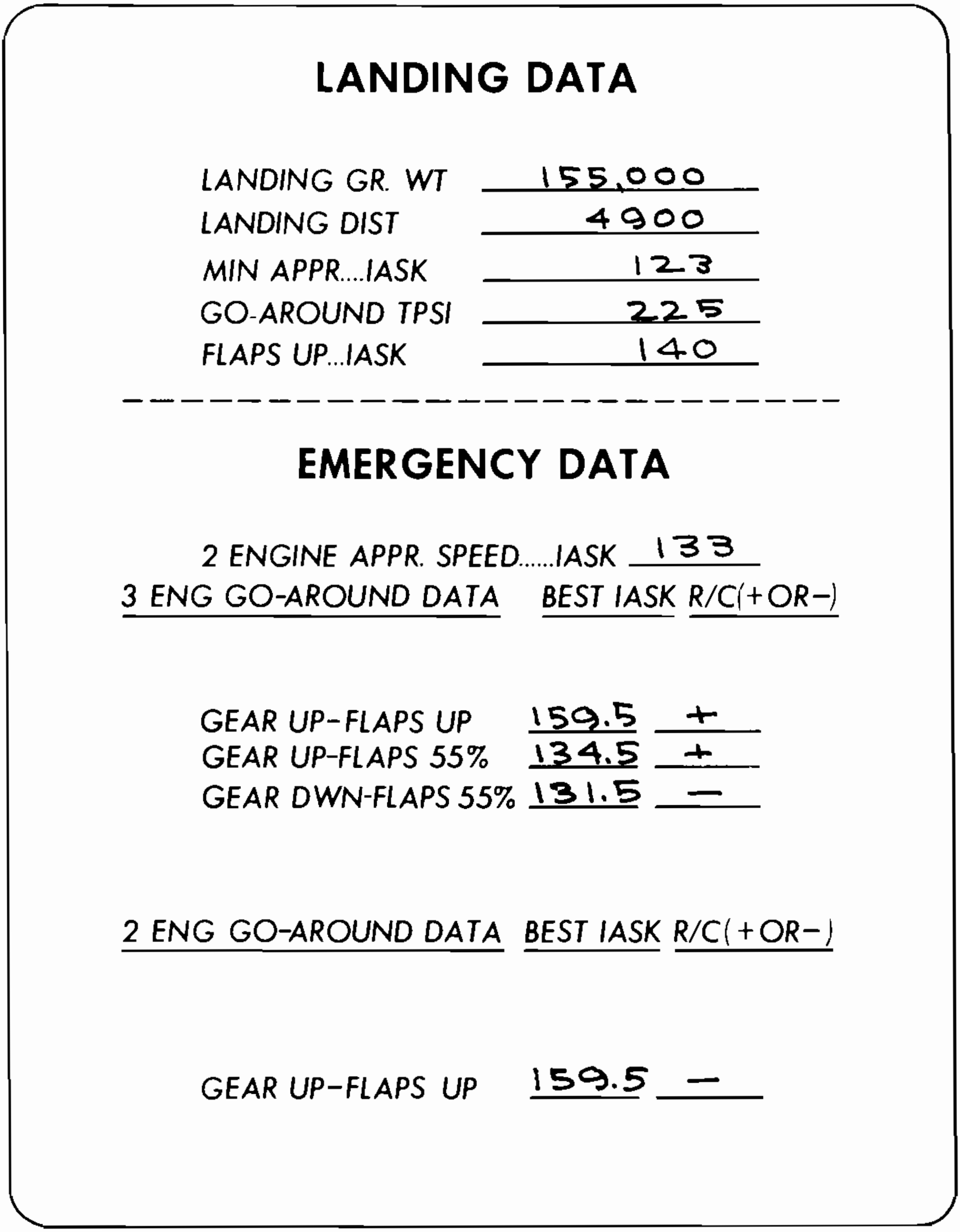
Principles Involved in Climb

When an aircraft is flying in straight, level, unaccelerated flight, the power output is just sufficient to maintain a stable thrust-drag condition. If power is increased and the flight attitude held constant, the aircraft at first begins to increase in speed, since thrust is greater than drag. With the increased airspeed, the aircraft has a tendency to climb unless the angle of attack is decreased by use of the elevators. If the aircraft is nosed up as power is increased, it is possible to climb, of course, without increasing airspeed, since P_{ex} is compensated for by the added reaction to gravity. P_a varies only slightly with airspeed and altitude. P_r, however, varies greatly with airspeed, gross weight, and altitude. The formula to determine the amount of power available which is in excess of power required is

$$P_{ex} = P_a - P_r \qquad (73)$$

EFFECTS OF VELOCITY ON POWER. In figure 9-35, note that P_r curve intersects the P_a curve at two points. The right-hand point of intersection is the point of maximum velocity, since P_a and P_r are equal. The vertical distance between the P_a and P_r lines represents power excess available during level flight. In level flight, the engine power is adjusted to a required setting with a reserve of excess power available for climb (P_{ex}).

Notice on the chart curve that excess power is greater at lower speeds than at higher speeds, except at speeds below 130 mph where the angle of attack of the wing is increased to a point where



LANDING DATA

LANDING GR. WT 155,000
LANDING DIST 4900
MIN APPR....IASK 123
GO-AROUND TPSI 225
FLAPS UP...IASK 140

EMERGENCY DATA

2 ENGINE APPR. SPEED......IASK 133

3 ENG GO-AROUND DATA	*BEST IASK*	*R/C(+OR−)*
GEAR UP−FLAPS UP	159.5	+
GEAR UP−FLAPS 55%	134.5	+
GEAR DWN-FLAPS 55%	131.5	−

2 ENG GO-AROUND DATA	*BEST IASK*	*R/C(+OR−)*
GEAR UP−FLAPS UP	159.5	−

Figure 9-34. TOLD Card (Front Side)

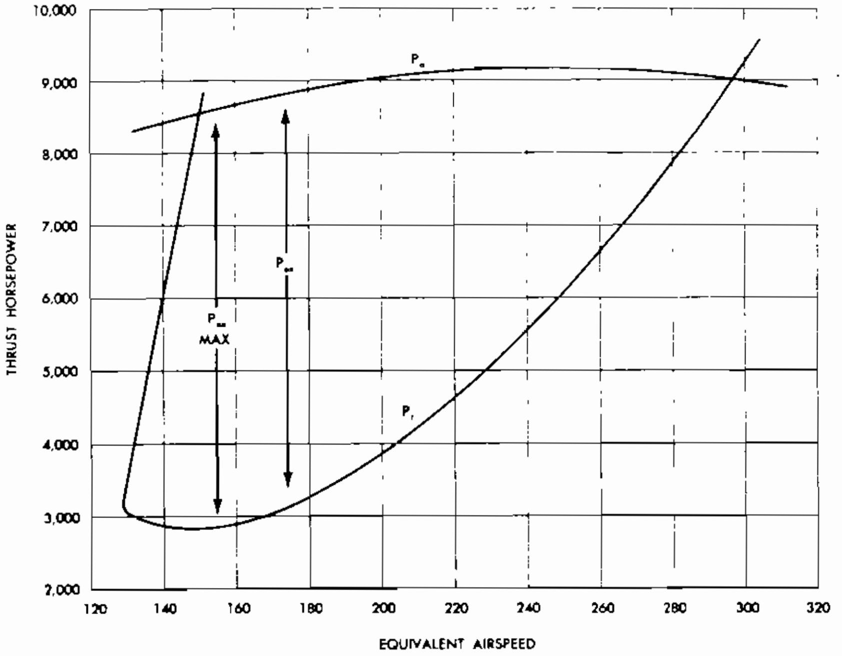


Figure 9-35. Variation of Power Required with Velocity

the P_r curve reverses direction and intersects the P_a curve. At this low-airspeed point of intersection, all the power available is necessary to maintain level flight. This point is very close to the stalling speed of the aircraft. This is a situation which approaches a condition of "getting behind the power curve" and is extremely dangerous for obvious reasons at low altitudes.

With changes in altitude, related changes in drag-thrust relationships take place. *In effect,* gravity, in a climb, hinders thrust and aids drag. In a lowering of altitude, on the other hand, gravity, in effect, assists thrust and hinders drag. This combination of relationships is particularly noticeable when we consider the difference between the ease with which an automobile accelerates while going down hill and the difficulty with which it accelerates when going up hill.

The fuel which the engines consume is affected, although not directly proportional, to the load. Since aerodynamic resistance is directly proportional to the square of the speed, it follows that the resistance and, in consequence, the requirement for power, increases very rapidly with the increase in speed. Since this is true, the aircraft, with an increase of 30% in speed in level flight consumes more fuel than the same aircraft while flying at the lower speed but at a significant increase in the rate of climb. The power required, then, is proportional to the total resistance (aerodynamic or gravity, or both) which is being met.

EFFECTS OF GROSS WEIGHT ON POWER. An increase in aircraft gross weight from 100,000 to 140,000 pounds, for example, changes the power required to maintain the same rate of climb and the same angle of attack. The additional power during climb provides the necessary increase in EAS to obtain the additional lift required. However, if the EAS is not increased with an increase in gross weight, the angle of attack must be increased to provide the necessary lift. This condition results in a wasteful increase in drag, which requires more power and reduces the rate of climb.

In actual practice, you will find that there is one combination of EAS and angle of attack for each different gross weight where P_r is at a minimum and P_{ex} is at the maximum. This is illustrated in figure 9-36. Notice that the best climb P_{ex} for 110,000 lbs occurs at an EAS of 157 and the THP of 2800. Notice the points at which power available meet the lines of gross weight. Maximum speeds increase progressively with weight reduction.

EFFECTS OF ALTITUDE ON POWER. The horsepower requirements also increase with increase in

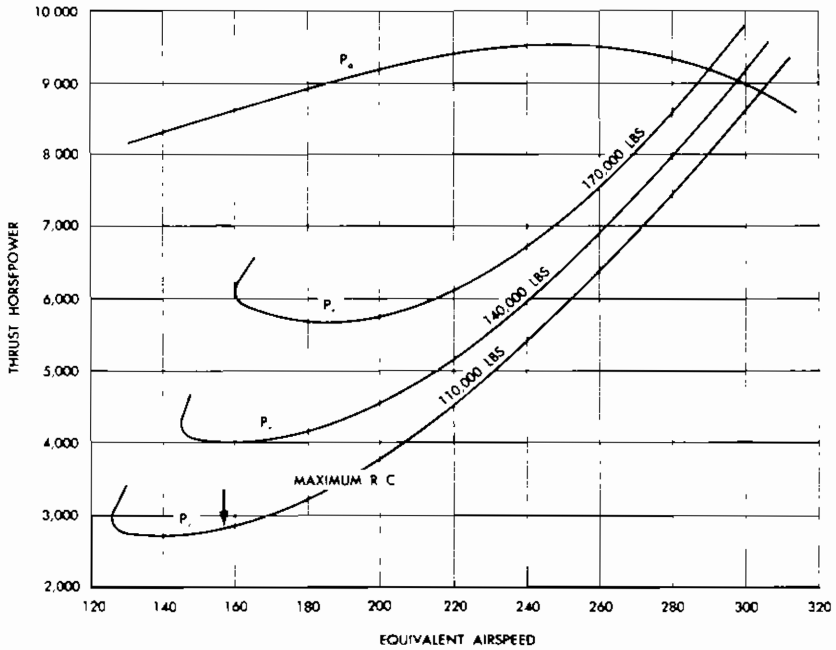


Figure 9-36. Variation of Power Required with Gross Weight

altitude. To restore the loss of lift at the same angle of attack, additional power must be applied to increase the EAS. According to the graph in figure 9-37, the P_r to maintain the maximum rate of climb for a given gross weight increases from 3400 thp at 20,000 feet. This is also illustrated by the decrease in P_{ex} from sea level to 20,000 feet.

You will notice on the power required with velocity gross weight, and altitude graphs that

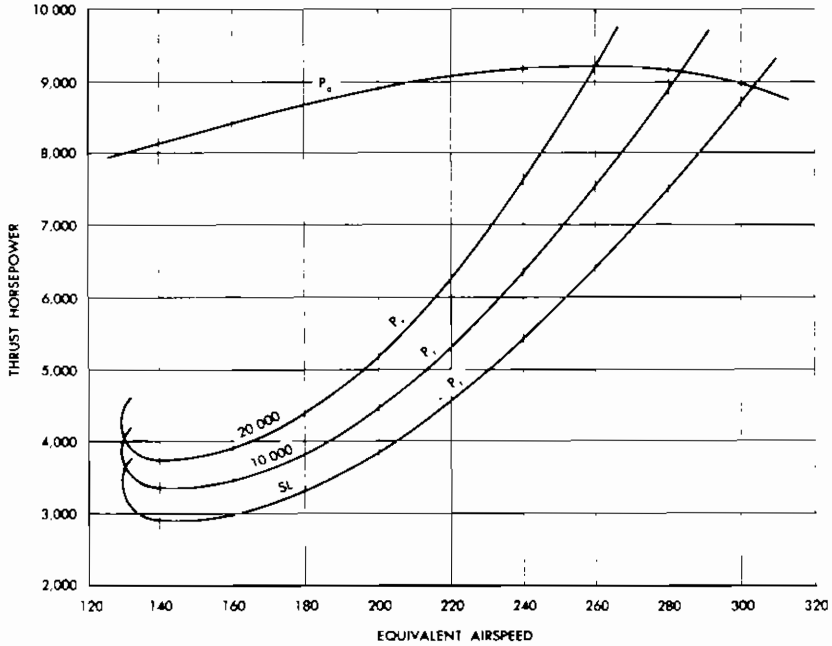


Figure 9-37. Variation of Power Required with Altitude