there is a definite EAS at which power excess is the greatest. The maximum rate of climb is reached at this speed.

Maximum Angle of Climb vs Maximum Rate of Climb

In the graph illustrated in figure 9-38, you see a plotted curve with the vertical axis calibrated for rate of climb in ft/sec and the horizontal axis for velocity in ft/sec or mph. The curve begins for a particular gross weight at the minimum speed for level flight. The first point on the curve represents the maximum *angle* of climb. The maximum angle of climb is the condition which results in the maximum altitude attained in the least horizontal distance covered. Because this angle of climb is steep and slow, the engines tend to overheat because of a reduction of airflow through the cowling. By lowering the nose of the aircraft slightly, the excessive drag induced by the high angle of attack is reduced and velocity increases to give better engine cooling and improved aircraft handling characteristics. A certain climb angle for each aircraft is called maximum rate of climb. Even though the climb angle in many instances is reduced, the aircraft flies faster and climbs higher per unit of time. This point is shown in the illustration at the apex of the curve. Notice also that if the climb angle is reduced from the maximum, the velocity increases but the rate of climb per unit of horizontal distances decreases.

Climb Speed

Airspeeds to be used in a climb are often a compromise between maximum rate of climb and an airspeed that produces adequate engine cooling. The EAS at which climb is most economically accomplished is near the EAS for maximum range. For some aircraft, a constant EAS is recommended for a normal climb. For others, the recommended airspeed differs with gross weight and power. High gross weights may necessitate a higher EAS in climb than one which is most economical. Where initial gross weights are high, it is desirable to stay at low altitude, if possible, until enough fuel has been consumed to decrease the weight.

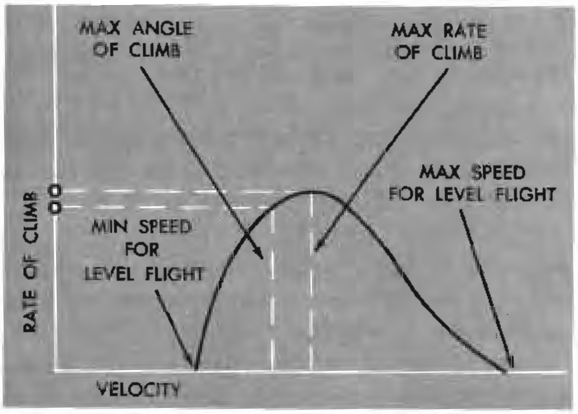


Figure 9-38. Maximum Angle of Climb vs Maximum Rate of Climb

Climb Computations

Several factors have to be calculated when climb computations are being made. The solution of the following sample problem illustrates such calculations.

Problem: An aircraft that weighs 140,000 pounds is to climb from sea level on a standard day to 15,000 H_p. The climb is to be made at an IAS of 170 knots. The bhp available in the climb is 2650. Compute the performance using two-thirds altitude, which represents an average altitude for the entire climb. From this given data, determine (1) the rate of climb, (2) distance and time, (3) power setting, and (4) fuel used in the climb.

RATE OF CLIMB. To solve the first step of the presented problem, enter the simplified climb prediction chart illustrated in figure 9-39. Using the data given in the problem, the R/C (Rate of Climb) can be found as follows. Locate the two-thirds climb altitude H_p (10,000 ft), the appropriate performance gross weight line (140,000) and interpolate the R/C at the intersection of these two lines as 750 ft/min. Proceed up this performance line to 1500 feet H_p, move horizontally to the left margin, and read the time for climb as 19 minutes.

DISTANCE IN CLIMB. The distance in climb calculation gives horizontal distance in miles as revealed in figure 9-40 by the dotted line. Enter the chart from the bottom with the gross weight (140,000 lbs). Move up the nearly vertical line to the pressure altitude line (15,000 H_p) and read the distance in climb directly to the left as 65 nautical miles.

POWER SETTING IN CLIMB. From the power schedule table, figure 9-41, find the power setting (rpm, MP, and TPSI) required to obtain 2650 bhp at the beginning climb altitude. The chart

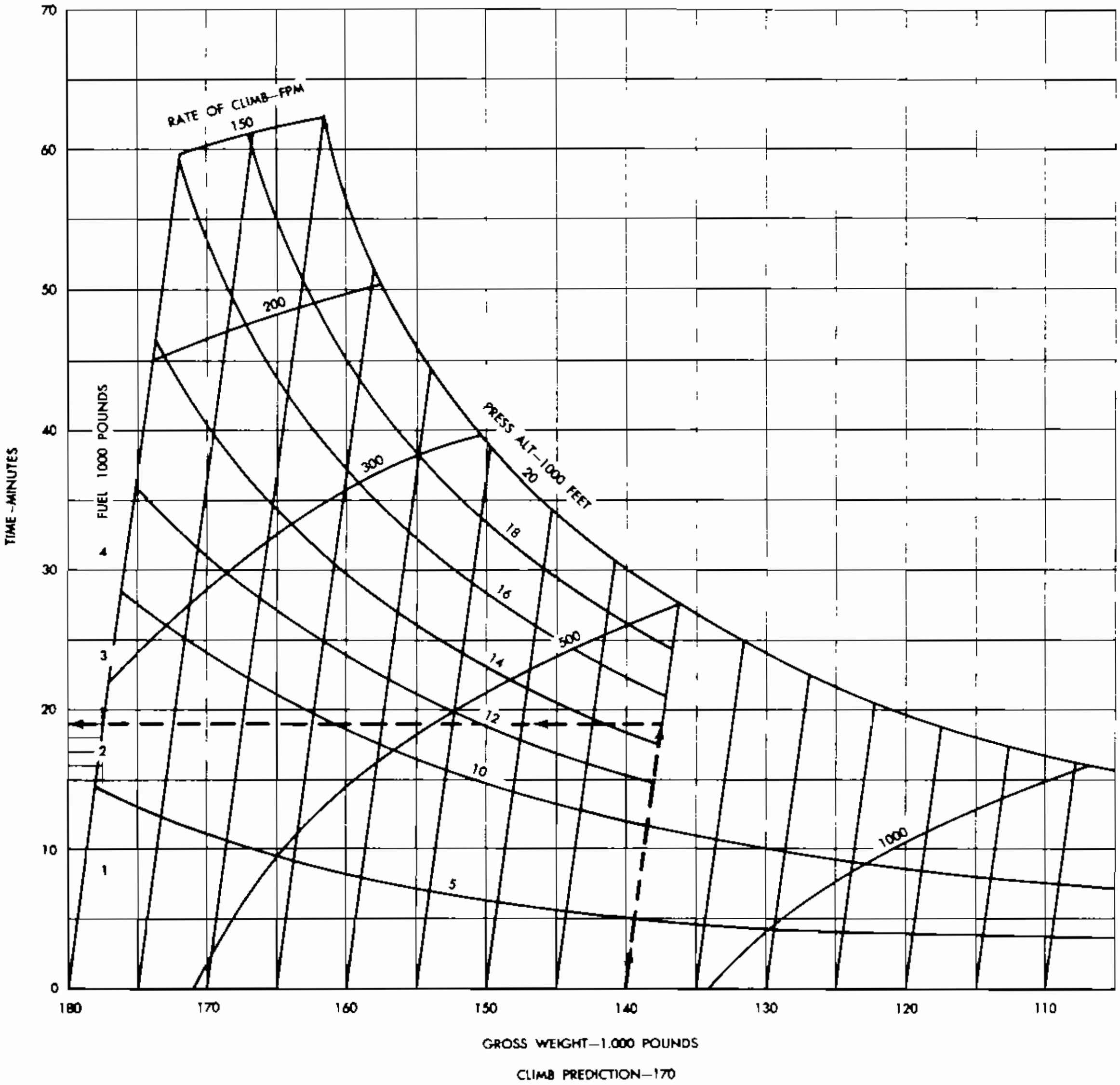


Figure 9-39. Climb Prediction Chart (Time and Fuel)

gives the following values: rpm 2550; MP 50.8 in Hg; TPSI 198

FUEL USED IN CLIMB. The fuel flow (total) for the climb can be determined by using the fuel flow curve. Observe that the fuel flow for four engines at 2650 bhp (1950 × 4) is 7800 lbs per hour, and $7800 \times \frac{19}{65} = 2470$ lbs of fuel used for climb.

Climb Prediction Charts

The climb prediction charts provide a method of finding time, distance, and fuel consumed during a climb. The chart permits rapid calculations, and is sufficiently accurate if interpolations are precise. Climb prediction charts are plots of gross weight versus range in nautical miles with various altitude lines crossing the range guide lines.

The factors involved in interpolation vary somewhat in any mission. However, the margins of safety are sufficient if interpolations are made with care.

Any deviations from standard conditions, whether they arise from small drag changes, changing atmospheric conditions, or loss of power, can be accounted for by adjusting the initial gross weight with a "*weight adjustment factor*" to obtain

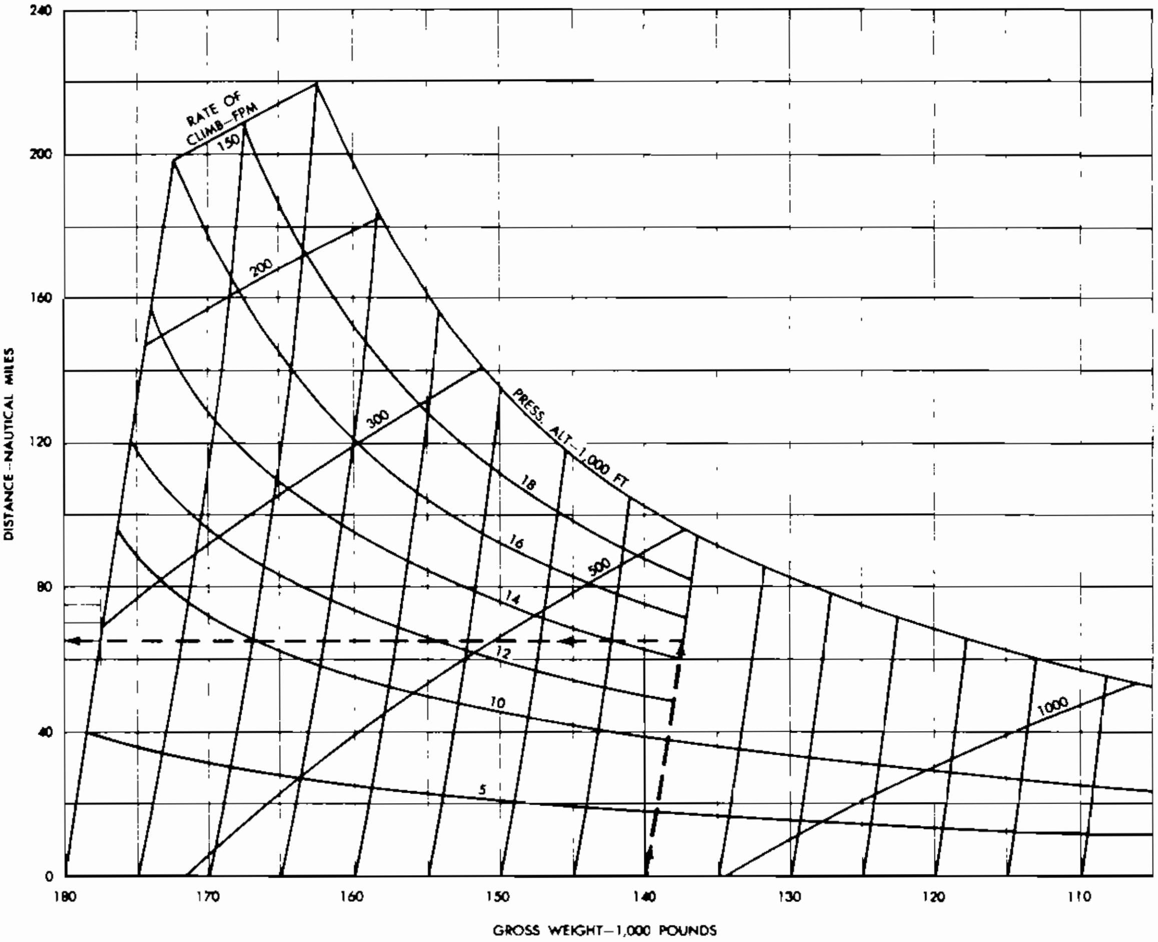


Figure 9-40. Climb Prediction Chart (Distance)

an *"effective weight"* to enter the charts. For example, increments of weight adjustment to be applied for several variations for a specific type of aircraft may be as follows:

Variation	*Weight Adjustment*
Drag Changes	Add 1,000 pounds for every square foot increase in drag area.
Engine Power Loss	Add 1250 pounds for each 100 bhp total reduction in power.
Outside Air Temperature	Add 550 pounds for each degree centigrade hotter than standard day.

The temperature-weight adjustment is necessary because as OAT increases, the density of the air decreases, thereby causing a decrease in the lifting effect of the aircraft wings. In other words, as the OAT increases, the aircraft behaves as though it weighs much more than its actual weight, thus the 550-pound addition for each degree of temperature increase.

Conversely, when the OAT is lower than standard day temperature, an increase in lift would result. However, in the interest of safety, climb predictions under such a condition are ordinarily based on standard day values.

The following example illustrates how the correction factors are applied with the prediction chart to find climb data required.

Example: (Reciprocating Engine Aircraft) Suppose that a climb is to be made from 5,000 feet to 20,000 feet at an initial (actual) gross weight of 145,000 pounds under the following conditions:

Climb speed 170 IASK.

External fuel tanks are removed.

Ambient temperatures average 12° C above standard.

Average engine power is expected to be 60 bhp below normal rated.

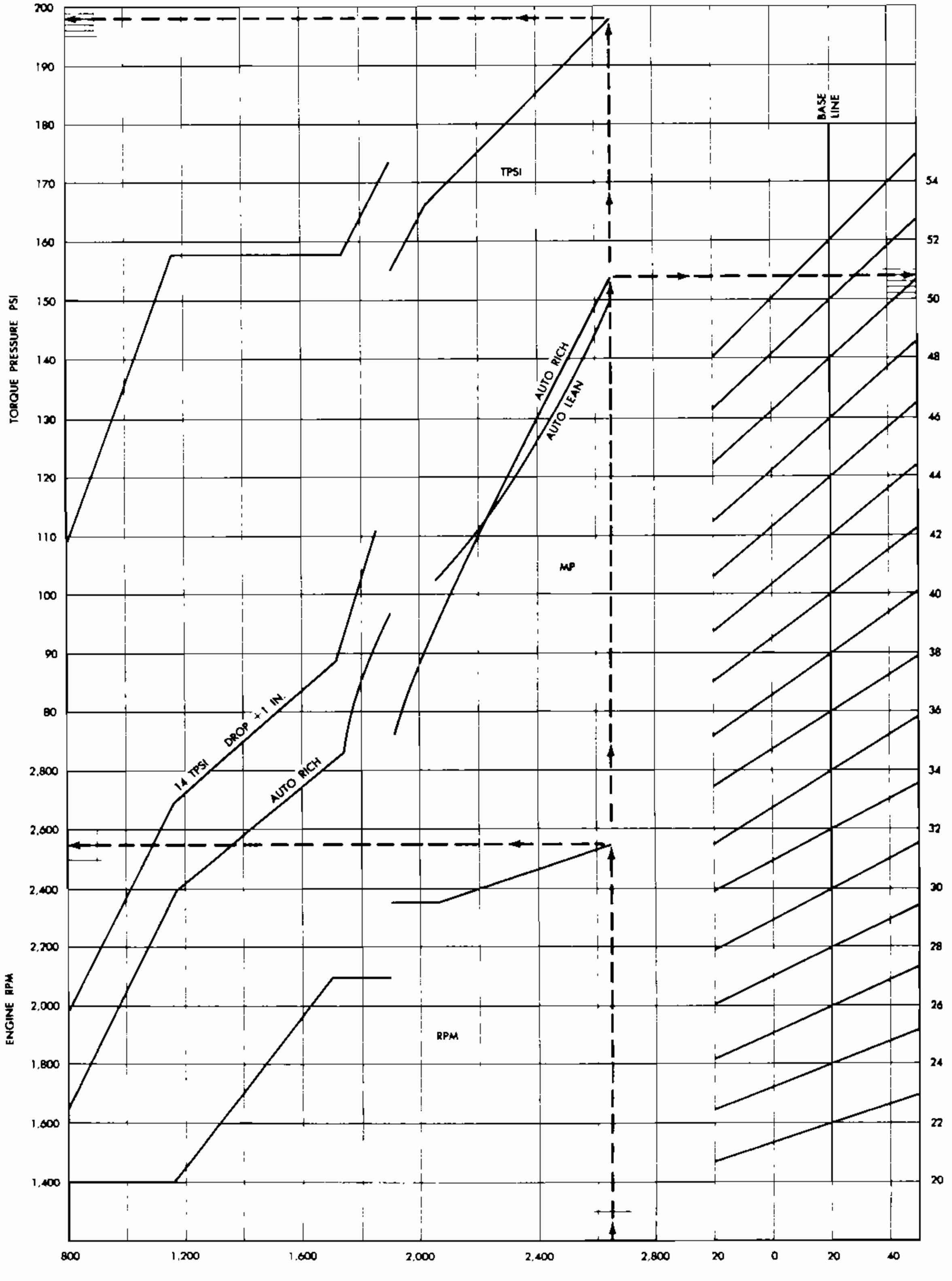


Figure 9-41. Power Schedule

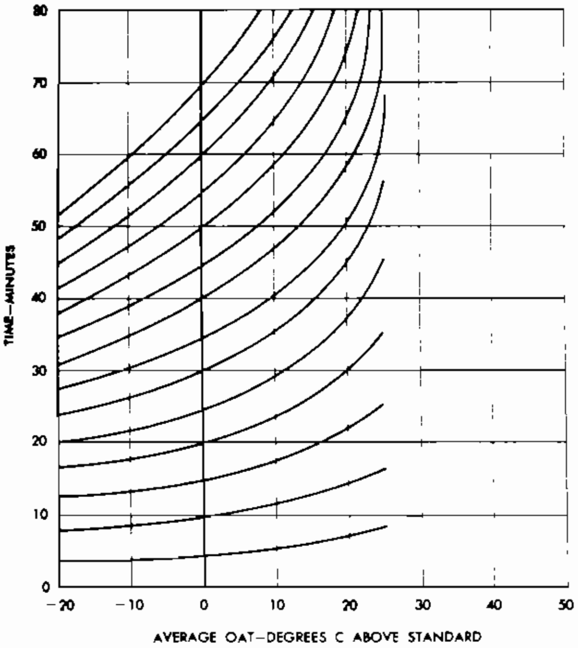


Figure 9-42. Climb Correction for Temperature

First determine the effective weight from the various weight adjustments. Removal of the external fuel tanks decreases the drag by 2.7 square feet of flat plate area. Therefore, 2.7 × 1,000 = 2700 pounds.

Power deficiency correction: Average power loss of 60 bhp per engine times 4 equals 240 times 1250 lbs for each 100 bhp loss equals 300,000 divided by 100 equals 3000 thusly, $\frac{4 \times 60 \times 1250}{100} = 3000$ pounds addition to compensate for power deficiency.

Ambient temperature correction: 550 lbs for each degree hotter than standard becomes 12 × 550 = 6600 pounds.

Total weight adjustment: Temperature 6600 lbs plus power deficiency 3000 lbs minus drag reduction from removal of tip tanks 2700 lbs equals 6900 lbs total. 6600 − 3000 − 2700 = 6900 pounds. Then the effective weight becomes 145,000 + 6900 = 151,900 pounds.

Distance in Climb. Enter the climb prediction chart for a specific aircraft at its gross weight, and follow vertically to the altitude line from which the climb begins. Follow parallel to the angled gross weight lines up to the 20,000-foot altitude line. The horizontal distance flown in nautical miles is obtained by reading horizontally to the left from this intersection to the nautical miles scale. However, since the computation is concerned only with the beginning of the climb to 20,000 feet, we must subtract the distance in nautical miles which would be flown from sea level to the altitude at which the climb started. By reading horizontally to the left from the intersection of the gross weight and the altitude line at which the climb started, you find the distance in nautical miles flown.

Time for Climb. To find the time required for the climb, use the chart for the specific aircraft and follow with the nearly vertical gross weight line to the 20,000 foot pressure altitude line. Then, follow horizontally to the left, and interpolate the time required for the climb. Here again the computation is concerned only with the time from the beginning of climb to 20,000 feet. So, we handle this problem in the same manner as we did for the climb distance. First, subtract the time in climb from sea level to, let us say, 5,000 feet. Enter the chart on the gross weight and follow it vertically to the 5,000-foot altitude line. Follow the horizontal line to the extreme left and interpolate the time.

Fuel Used in Climb. To determine the amount of fuel used for the climb, read the figure adjacent to the time scale labeled FUEL-1000 POUNDS. The figure corresponding to the minutes in climb indicates the fuel used for the climb.

Climb Speed. Finally, correct the IASK for position error and compressibility factor at the average pressure altitude of the climb. This correction reveals the EASK. Multiply this EASK by the average density altitude smoe to establish the average climb speed (TASK). To use the computer, smoe the EASK in the following manner: Set the average density altitude under the hairline in the DENSITY ALTITUDE window. Locate the figure 10 in the black box (labeled wind index) on the minute scale of the computer. Opposite this figure, under the pointer hairline, read the smoe on the miles scale. Now, with the computer correctly set up on the density altitude and smoe, locate the EASK on the minute scale. Directly opposite this figure, on the miles scale, read the TASK. Using this TASK and time to climb, the distance covered in the climb may also be predicted. A slight variation in distance may be noted due to the individual reader's interpolation on the climb prediction charts.

Figure 9-42 shows the average variation of

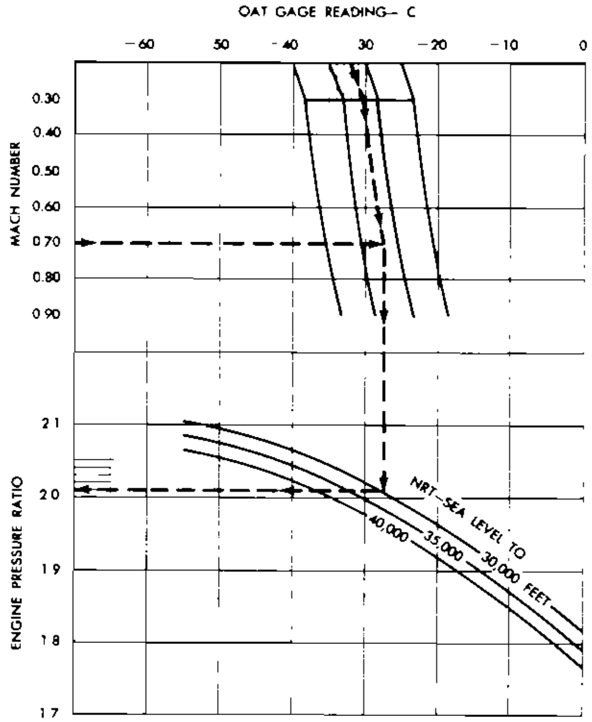


Figure 9-43. Engine Ratings, EPR

climb time with temperature changes. The following example illustrates the procedure.

Example: (Turbojet Engine Aircraft) A climb is to be made from sea level to 31,000 feet with an initial weight of 260,000 lbs minimum OAT gage reading —32° C. From these factors determine the (1) fuel used, (2) distance, (3) time, (4) speed, and (5) rate of climb.

First, an EPR factor for climb must be determined from the engine ratings (EPR) chart, figure 9-43. This subject is developed in Chapter 10.

Climb Fuel. Enter the en route climb fuel chart (figure 9-44) with 260,000 lbs at sea level. Read 6000 pounds of fuel consumed climbing to 31,000 ft. This chart may also be used to determine the fuel consumed climbing between any two intermediate altitudes.

Climb Distance. Enter the en route climb range chart (figure 9-45) with 260,000 lbs at sea level. Read 100 nautical air miles covered climbing to 31,000 ft. The time spent in the climb is equally as important as the range. For the climb time, consult the chart shown in figure 9-46.

Climb Time. Enter the en route climb time chart with 260,000 lbs at sea level. Read 16.4 minutes, time elapsed, climbing to 31,000 ft.

Flight engineers who are making the transition from reciprocating engine to turbine engine aircraft are frequently surprised by the efficiency of turbine engines at the higher altitudes. Although all types of aircraft benefit from the reduced aerodynamic drag encountered at high altitudes, only the turbine engines have the capacity to induct sufficient air to provide both cooling ability and combustion efficiency at high altitudes. These characteristics are reflected on the charts relating to climb speed, climb time, climb distance, and fuel used in climb, as well as in the charts which reflect flight in cruising condition at high altitudes.

The performance charts presented in this problem may be used to compute climb data for any en route or secondary climb as well as for the initial climb after takeoff.

Predicting Point of Secondary Climb

There will be times when you must predict a point along the course at which a secondary climb must begin to bring the aircraft to a predetermined altitude for the fulfillment of the mission. A good example is a rendezvous between a tanker and another aircraft, or in another case, an aircraft may have to climb to clear a mountain range.

To show how the point of secondary climb is calculated, suppose you are cruising at a pressure altitude of 5,000 feet (standard day) and want to

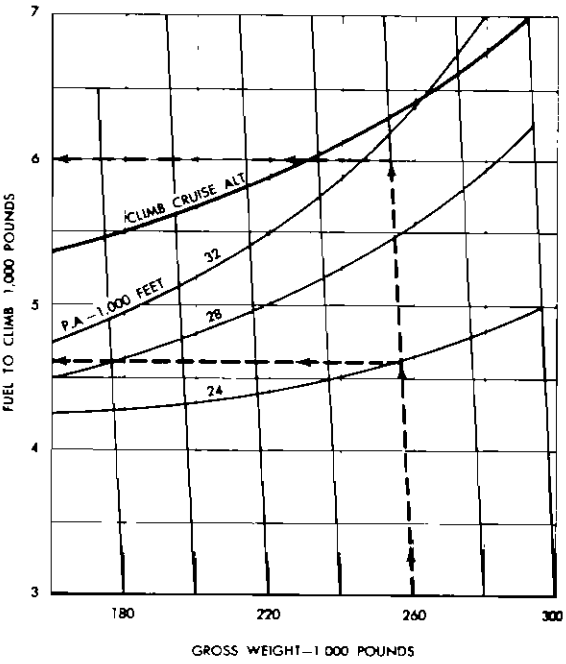


Figure 9-44. En Route Climb—Fuel

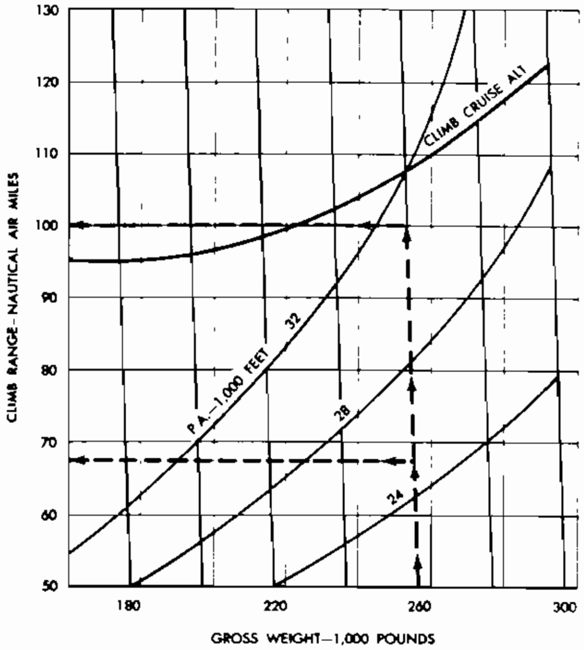


Figure 9-45. En Route Climb—Range

reach a pressure altitude of 15,000 feet (standard day) 900 NM from your takeoff point. This is a typical secondary climb situation, and is illustrated in figure 9-47.

Select an arbitrary point (A) along the 5000-foot cruising altitude that is 300 to 500 NM before point B (end of climb) at 15,000 feet (see illustration). From this ending weight point A, determine what your gross weight would be directly under the end of climb point B if you continued to cruise at this same altitude (5,000 feet) using the last recorded TASK and fuel flow. Change this weight obtained at point B to a performance weight by correcting the weight for temperature and drag configuration. Then take this performance weight into the appropriate climb prediction chart to obtain the time required to climb from 5,000 feet to 15,000 feet. When you get the time in minutes for the climb, multiply it by the cruise fuel flow in pounds per hour, and divide the product by 60 minutes to obtain the fuel weight lost in climb time. Now add this weight lost in climb to the performance weight obtained at point B. This supplies you with the performance weight at the starting point (C) of the secondary climb. Using this performance weight, re-enter the climb prediction chart to obtain a more accurate time to climb.

Since you have the time expended in climb, you must now find speed and distance in the climb so that a nautical mile point may be plotted on course up to which you will cruise and then begin the secondary climb. The airspeeds for climb at different actual gross weights are found in an inset on the climb prediction chart. Inasmuch as the weight at the start-to-climb point (C) is expressed as equivalent performance weight, we must now remove the weight correction for temperature and drag configuration to obtain the actual gross weight. When you obtain an actual gross weight, determine the IASK for climb. Then, using average pressure and density altitudes of the climb, convert this IASK to a TASK. With the TASK and time expended in climb you can obtain the forward distance traveled in the climb. Subtract this distance from the 900 nautical mile point (B) and you have the actual nautical mile point (C) at which the secondary climb is begun.

CRUISE DATA AND PERFORMANCE FACTORS

The cruise part of any mission is the most important from the fuel management viewpoint, since this is the time-consuming part. Cruise control technique must be understood, and the principles

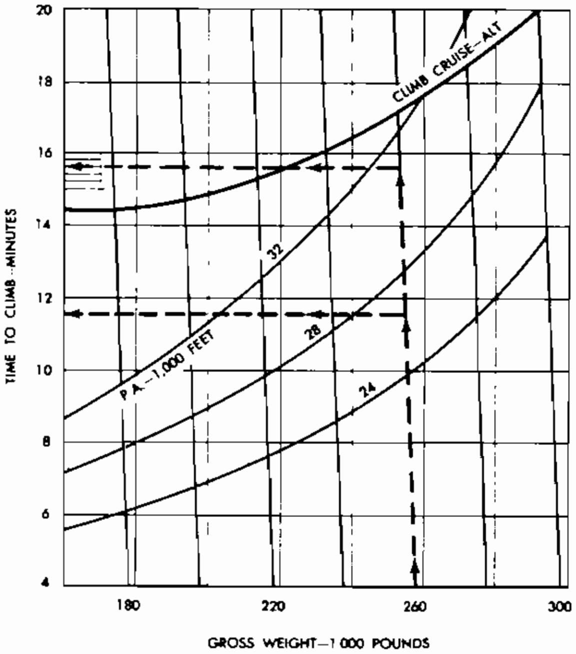
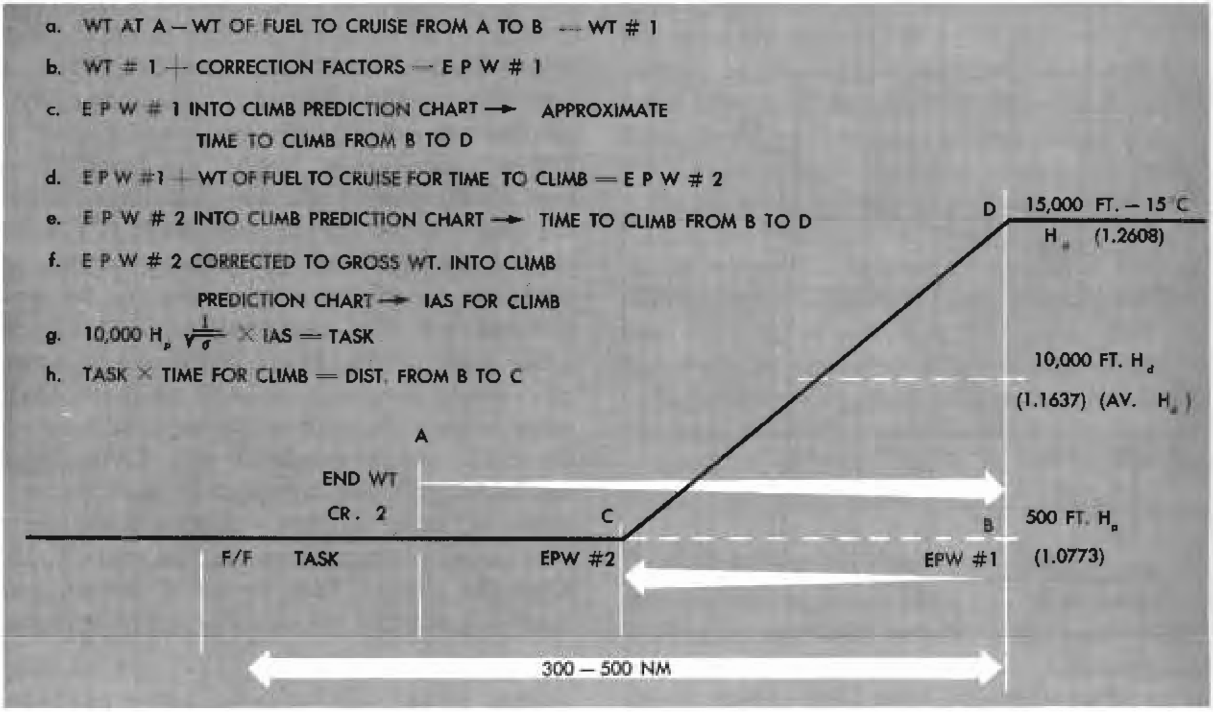


Figure 9-46. En Route Climb—Time



a. WT AT A — WT OF FUEL TO CRUISE FROM A TO B — WT # 1

b. WT # 1 + CORRECTION FACTORS = E P W # 1

c. E P W # 1 INTO CLIMB PREDICTION CHART → APPROXIMATE TIME TO CLIMB FROM B TO D

d. E P W #1 + WT OF FUEL TO CRUISE FOR TIME TO CLIMB = E P W # 2

e. E P W # 2 INTO CLIMB PREDICTION CHART → TIME TO CLIMB FROM B TO D

f. E P W # 2 CORRECTED TO GROSS WT. INTO CLIMB PREDICTION CHART → IAS FOR CLIMB

g. 10,000 H_p $\frac{1}{\sqrt{\sigma}} \times$ IAS = TASK

h. TASK × TIME FOR CLIMB = DIST. FROM B TO C

Figure 9-47. Secondary Climb

closely followed to obtain the best performance from the aircraft and engines.

During the past years, the effective range of long-range aircraft has increased appreciably. This increased range has been largely due to the improvement of performance techniques for cruising. The application of these techniques requires the skill and knowledge of both the flight engineer technician and the pilot, and proper coordination between them.

Among other things, the flight engineer must always be aware of ways to conserve fuel during flight. This consciousness of the need for economy insures that he uses constantly his ability to read and interpret cruise performance charts. In an emergency, his knowledge of factors which contribute to economy will have a definite effect on mission accomplishment, and perhaps on the safety of the aircraft and crew.

There are five types of cruise for reciprocating engine aircraft: (1) constant power, (2) constant speed, (3) maximum range, (4) long range, and (5) maximum endurance.

Cruise conditions for turbine engine aircraft, however, are confined to three categories, (1) best range, (2) maximum range, and (3) maximum endurance. We shall discuss these types of cruise in the order named.

Constant Power Cruise

Constant power cruise consists of establishing a power setting and flying a mission or a part of a mission at that power. This is the simplest of cruise techniques. Constant power can be advantageous under certain emergencies. For example, if a crew member were injured, the pilot might request the engineer to determine and set up the highest power that could be maintained and still enable the aircraft to reach the destination or an alternate base without running out of fuel.

When constant power is maintained, high fuel consumption results. Also spark plugs have a greater tendency to become fouled under long periods of constant power than when power changes are made frequently. Therefore, constant power cruising should be employed only when high speed rather than economy is required.

Constant Speed Cruise

A constant speed cruise consists of periodic reductions in power as gross weight decreases to maintain a constant airspeed. Its principal advantage is that it simplifies the problem of being at a rendezvous point at a particular time. The degree of fuel economy obtained in constant speed cruise varies sharply with the speed that is chosen. Constant speed cruise at a low airspeed results in a fair degree of fuel economy, but low airspeeds with high gross weights cause difficulty in aircraft control and contribute to crew fatigue on long missions. Conversely, constant speed cruise at a high airspeed is uneconomical.

Maximum Range Cruise

Maximum range cruise is employed when maximum economy is desired. This procedure consists of making periodic power reductions to keep the airspeed down to the most economical for the particular gross weight and altitude.

As demonstrated in figure 9-48, there are three variable factors—(1) angle of attack, (2) specific fuel consumption, and (3) propeller efficiency—which together determine maximum range airspeed for a given set of conditions.

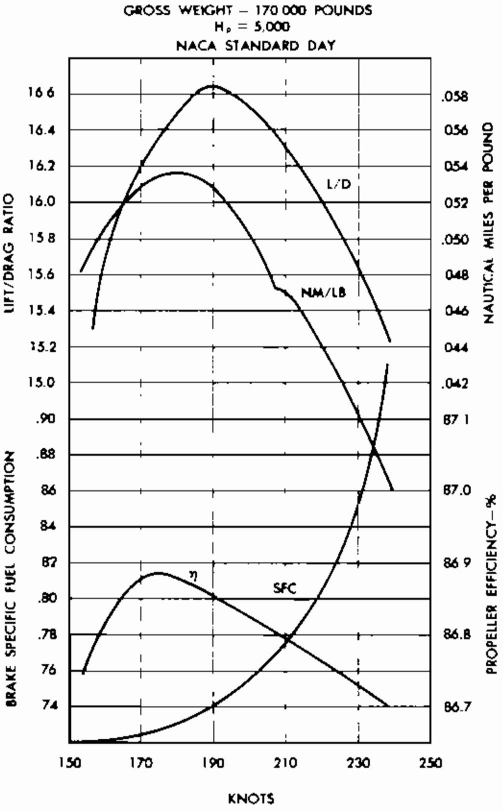


Figure 9-48. Variables Affecting Economy in Flight

ANGLE OF ATTACK. At some particular angle of attack, an aircraft wing is most efficient; that is, when the L/D (lift-drag ratio) is at a maximum value. When an aircraft flies in level flight at this angle of attack, the drag is less than it is at any other angle of attack. Accordingly, it is most desirable for the purpose of economy to fly at this angle of attack. Since L/D is a function of gross weight and airspeed, it is necessary to decrease airspeed with a decrease in gross weight in order to maintain this angle of attack in continuous flight.

SPECIFIC FUEL CONSUMPTION. Power requirements vary with airspeed for a given gross weight and altitude. Since SFC (specific fuel consumption) is a function of bhp, it becomes a function of airspeed. At some particular airspeed, SFC reaches a minimum value. If this airspeed differs from that at which the L/D is maximum, maximum range airspeed falls between these two speeds.

PROPELLER EFFICIENCY. It is desirable, for the sake of economy, to convert as high a percentage of engine horsepower to thrust horsepower as possible. The amount of bhp that is converted to thp depends on propeller efficiency which is, in turn, a function of airspeed, bhp, and other variables. Thus, at some particular airspeed, propeller efficiency (η) reaches a maximum value. If the speed at which this maximum propeller efficiency occurs is different than those for maximum L/D and SFC, then the actual maximum range airspeed must be a compromise among these three speeds.

When we compare the effects of the three above described variables, the airspeed at which the product of $\frac{L/D \times \eta}{SFC}$ reaches a maximum value is the airspeed for maximum range. This is demonstrated in the accompanying graph in which all three variables are plotted against airspeed, together with the actual nautical miles per pound of fuel (NMPP) at each EAS. The peak NMPP is obtained at the airspeed at which $\frac{L/D \times \eta}{SFC}$ is at a maximum.

So far, we have considered economy factors at a single altitude. We see that altitude is another variable that has an important influence on economy and range. The best altitude for economy, disregarding winds, depends on the type of aircraft, the gross weight, and the type of mission. Generally, it may be said that best economy is

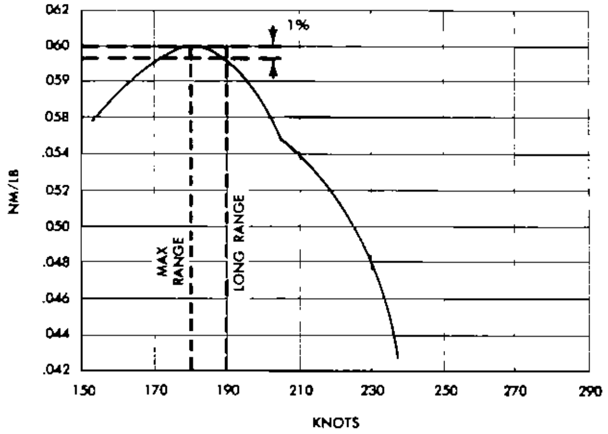


Figure 9-49. Relationship Between Max Range and Long Range

obtained at low altitude with a high gross weight and a high altitude with a low gross weight. For this reason, maximum range is usually realized by remaining at a low altitude while gross weight is high; then, after gross weight decreases, by climbing to higher cruising altitudes.

Long Range Cruise

Besides maximum range cruise, another type of desired operation is long range cruise. The relationship between these two cruises is shown in figure 9-49. Long range cruise gives approximately 99% of the range obtainable under maximum range conditions. At a lower power setting, the small increase in range is gained at the cost of a material loss in time and with increased crew fatigue.

The efficiency with which the aircraft flies depends, in large measure, on its flight attitude,—that is, with the manner in which it meets the relative air mass. Usually, an aircraft uses less fuel when operating with four engines than when operating with three engines. Let us assume that an aircraft is operating on engines 1, 2, and 4, and that all engines are operating at the same power settings. Under these conditions, because of the much greater thrust on the left side, the aircraft would require a great amount of rudder and aileron trim in order to remain on course. The outcomes of the trims would be that extra drag would be encountered, reducing thereby, the aerodynamic efficiency of the aircraft. The aircraft engines would consume more fuel in proportion to the distance flown for the same basic reason that an automobile engine would consume more fuel for a given distance of travel if the brakes were left on.

Best Range Cruise

Best range cruise for turbine engine aircraft is defined as the longest range obtainable while flying at a constant altitude.

When flying at a constant altitude, and less than normal rated thrust is required, temperature deviations from standard have no effect on the cruise range. However, when cruising at the limit of normal rated thrust, an increase in temperature reduces the maximum allowable gross weight and MACH number which can be flown at that altitude. This type of cruise is usually flown at an increasing MACH number.

The performance charts are constructed to give us the values for a specific range that we may expect from a given set of conditions. Figure 9-50 illustrates a condition for MACH, true airspeed, and fuel flow.

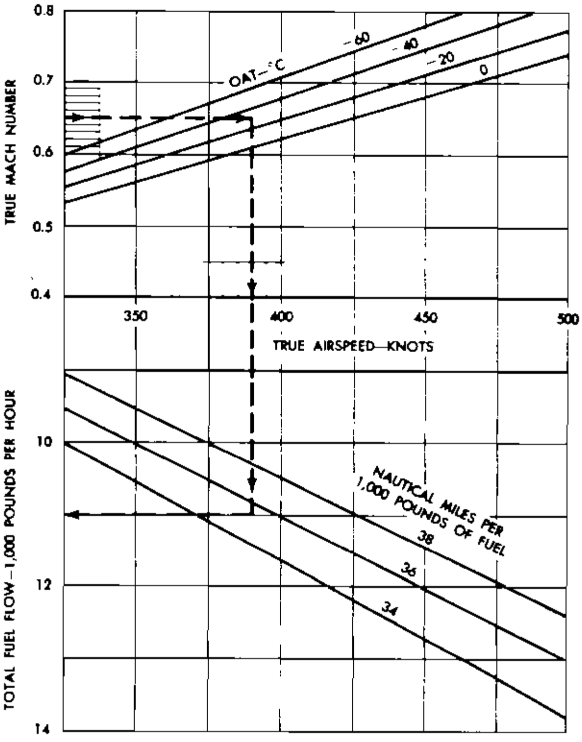


Figure 9-50. Specific Range (Best Range)

Factors Which Affect Aircraft Performance

Before we discuss the performance charts of turbine engine aircraft, let us consider the variables which affect aircraft performance. In our previous studies of aircraft performance in this manual, we discussed the performance factors individually, then added each factor to the problems on a step-by-step basis. We are now ready to consider the interrelationships of the performance factors after which we will use the charts to solve specific flight problems.

Difficult missions which tax the capability of both aircraft and crew are seldom encountered in routine situations. Command decisions which must exploit the full capability of the aircraft and crew, on the other hand, bring about the necessity for preflight planning and the careful use and consideration of fuel reserves. Because of the existence of many variables, the actual performance usually varies in some degree from the flight plan. These variables, in part, are as follows: (1) aerodynamic condition of the aircraft in flight as reflected by cleanliness, freedom from structural defects, and effectiveness of the trim; (2) items of external equipment which affect drag; (3) engine efficiency; (4) gross weight; (5) altitude; (6) temperature; and (7) speed. Unlike reciprocation engines, turbine engines have few problems relating to fuel-air ratio and to ignition.

The engineer of a turbine engine aircraft is primarily concerned with the relationship between anticipated fuel consumption and the actual fuel consumption. Assuming that a perfect job had been done in anticipating the fuel which should be used, we could assume that the actual consumption would correspond to this figure only if the seven or more factors were without variation from normal or that certain of these factors, while varying from normal, had cancelled each other out. As you can see, the engineer is needed to evaluate constantly, through his use of instruments and charts, the actual performance of the aircraft.

Maximum Range Cruise

Maximum range operation of turbine engine aircraft demands that the most economical altitudes and speed be flown at all times. This requires that the cruise altitude and speed be varied periodically during a maximum range mission to obtain the peak efficiency of the engines. To achieve this end, a cruise-climb procedure is flown to result in the optimum altitude. We refer to this procedure as the OPTIMUM STEP CLIMB. The optimum step climb cruise is a compromise between constant altitude cruise and variable altitude cruise. The step climbs are based on a constant MACH number, and are accomplished as soon as the gross weight reduction from fuel burnoff is sufficient to allow a climb of 400 feet per minute without any loss of speed. Normally, the step climbs are made in 4000 foot increments until optimum cruise altitude is reached. The range summary chart, figure 9-51, illustrates the optimum cruise-climb speed, altitude, and fuel flow for various gross weights. Let us here use differing gross weights of 220,000 pounds and 280,000 pounds to demonstrate the spreading effect of fuel flow and optimum cruise climb altitude with the increase of weight. First, enter the chart at the bottom with 220,000 pounds. Proceed vertically to the temperature line, selected as standard + 10° C for this problem. Read the fuel flow for 4 engines as 9800 pounds per hour in the left-hand margin. This figure represents the optimum cruise climb fuel flow. Next, enter the top section of the chart with 220,000 pounds, and continue upward to the optimum cruise climb altitude. Notice that for this weight, the optimum altitude is indicated in the left-hand margin as 41,000 feet pressure altitude. Continue upward on the gross weight graph line, until you encounter the optimum cruise-climb speed line, and read the speed as MACH 0.75.

The peak efficiency of the engines is that condition at which the maximum thrust is developed in relation to the amount of fuel being consumed. For each combination of altitude and speed, there will be a setting at which the peak efficiency of the engines can be realized. If the absolute maximum of efficiency were to be achieved, there would be a constant adjustment of power with each change of altitude and speed. However, the constant change is impractical and the optimum step climb procedure is considered the practical and appropriate method of insuring satisfactory efficiency.

Since, in this manual, we discuss both turbine and reciprocating engines, it is important that we distinguish between the principles which apply to these two types. In this chapter, we have indicated a somewhat less critical standard for power application for turbine engines than would be safe for reciprocating engines. Remember that, with reciprocating engines, the cylinder head temperature

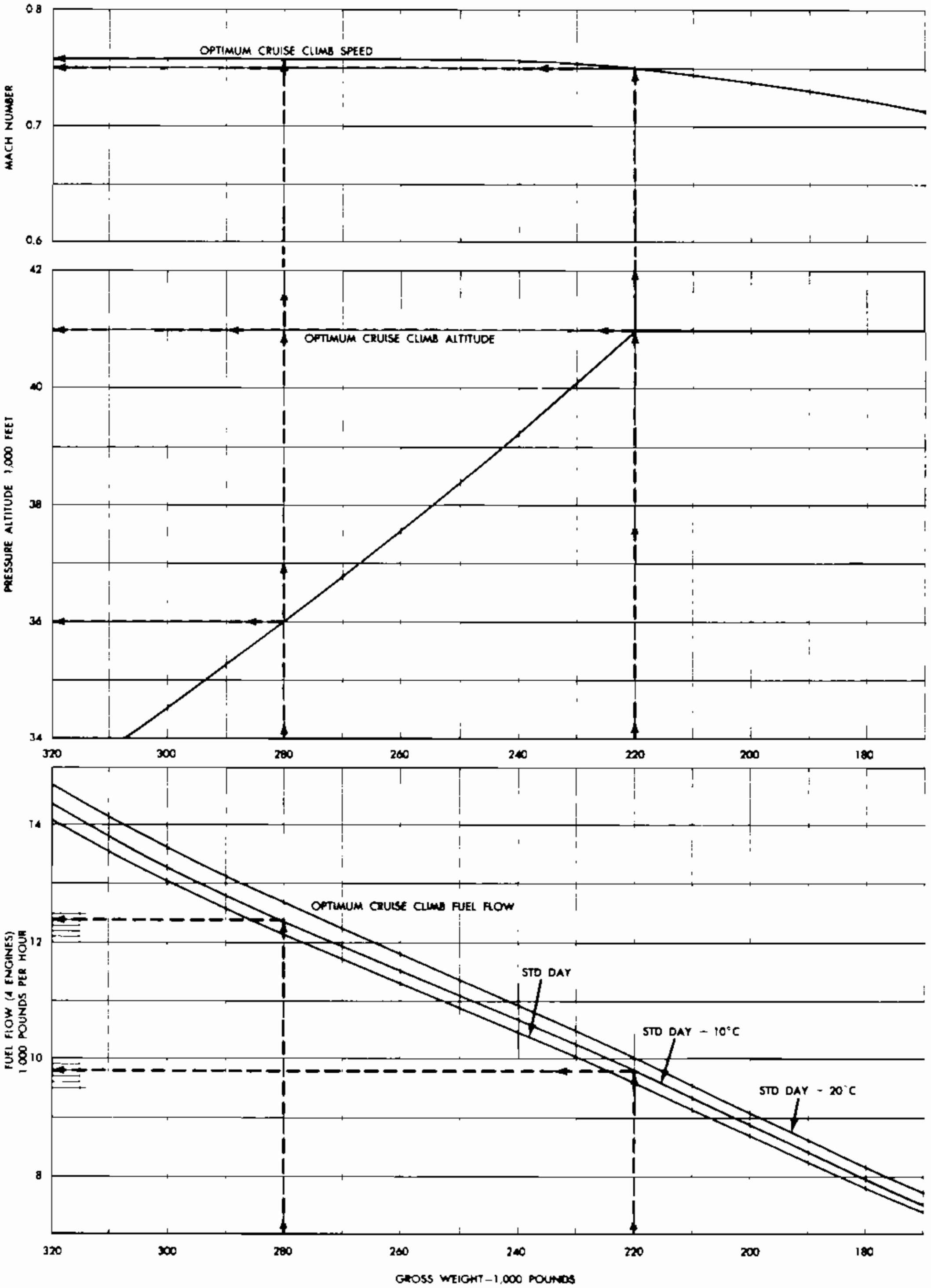


Figure 9-51. Range Summary

and, to a lesser degree, the oil temperature must be considered when seeking to gain maximum power from the fuel consumed. You are not concerned with these factors with turbine engines.

Maximum Endurance Cruise

Maximum endurance operation is accomplished by flying at a speed which results in a minimum of fuel consumption. The speed, therefore, is of no consequence other than in respect to its relation to the stalling speed. Since flying at a speed near the stalling speed is tiring to the pilot and since it reduces the margin of safety, maximum endurance cruise is properly flown at a speed from 10 to 15 knots above stalling speed, thus providing a significantly greater margin of safety.

The main disadvantage of maximum endurance cruise is that the EASK so closely approaches the stalling speed that the aircraft becomes difficult to fly. Maximum endurance is best obtained at the lower altitudes.

Comparison of Types of Cruise

The relative advantages and disadvantages of the various cruising techniques are demonstrated on the comparison of cruising techniques in figure 9-52. The conditions for which the data were computed are given on the graph. The available range of each cruising technique is represented by the nose position of each aircraft.

Two constant power missions are shown: 1450 bhp/eng and 1900 bhp/eng. The one flown at a constant 1450 bhp/eng is the most economical mission that could be flown at a single constant power. A lower power would be too low to permit stable flight at the initial cruising gross weight after the aircraft has climbed to 10.000 fcet pressure altitude. The mission flown at 1900 bhp/eng indicates the effect a higher power would have on economy, and hence on range.

Two constant speed missions are shown—one flown at 180 EASK, the other at 195 EASK. The mission flown at 180 EASK represents the most economical constant speed mission that could be flown under these conditions, for the aircraft would be unstable at lower airspeeds at the initial cruising gross weight. The mission flown at 195 EASK shows the effect of a higher constant speed on the range.

It is the opinion of some flight engineers that constant speed missions can be both faster and more economical than the long range missions. Note, however, that while both of the constant speed missions which we have illustrated are faster, they are less economical and shorter in range than the long range mission.

Despite the similarity in distance between the long range and the maximum range missions, the *long* range cruise shows a saving of more than

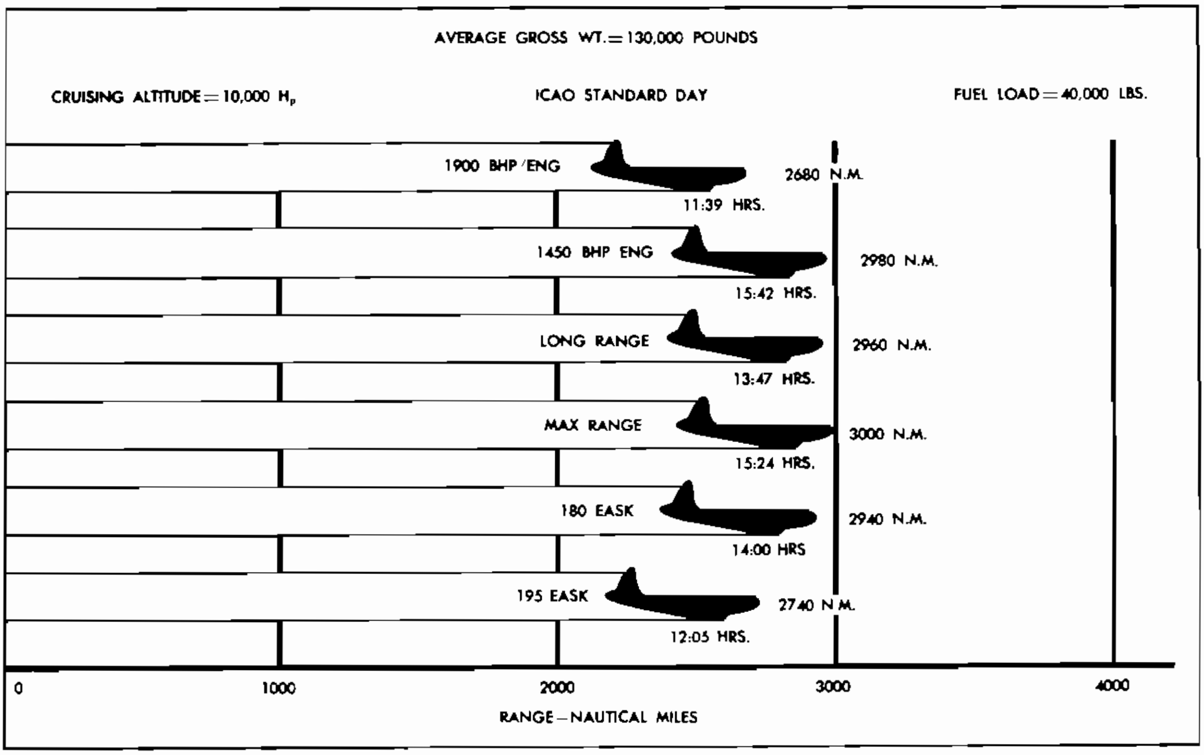


Figure 9-52. Comparison of Cruising Techniques

1½ hours of flying time. Thus, crew fatigue is greatly reduced, and *long* range operation is therefore preferred over ***maximum*** range operation.

A maximum endurance mission (not shown) would result in the longest flying time (16:35) and in covering only 2800 nautical miles for the 40,000 pounds of fuel consumed.

Techniques of Cruise

Good cruise control technique requires that the aircraft be flown at specified airspeeds for the prevailing flight conditions. Consequently, as conditions change during the flight, the airspeed must be changed accordingly. An airspeed schedule for optimum cruise conditions is established, taking into account economy, time, ease of aircraft handling, and atmospheric conditions including wind. The required power is then determined by the speed schedule. It is of prime importance in achieving optimum range to cruise at a speed recommended for a particular cruise condition, even when required power settings vary from those predicted. When maintaining cruising speed, power should be adjusted as required to hold the desired altitude.

Cruise Periods

When the airspeeds are determined for a mission plan, the cruising periods should be divided into parts sufficiently small that a constant airspeed may be held for each period. These periods should be treated as increments of gross weight and selected so that they represent approximately 1-hour periods. When the airspeed varies above or below a tolerance of ±2 knots during the period, a new cruise period should be started, based on the new average weight. The speeds selected for the plan should be the average speeds for these periods.

Speed and Altitude Control

Accurate cruise control requires that during each cruise period the selected speed be held within ±2 knots, with as few exceptions as possible. This tolerance may appear rather small, but normally it is not too difficult to maintain if the proper system of control is used. Remember that the elevator is basically the speed control, and power is basically the altitude control. With this in mind, it should not take an excessive amount of attention for the pilot to hold airspeed within limits with the elevator. Altitude can then be controlled, without upsetting the established speed, by making minor adjustments in power as the flight progresses. These power adjustments, however, must be made in accordance with the manual leaning procedures.

Maintaining precise cruising speeds at the expense of small and gradual changes in altitude will not adversely affect range, and will make the flight engineer's and navigator's jobs easier. The center of gravity of the airplane shifts due to crew movements, or other causes, and these shifts tend to alter the trim speed appreciably; therefore, frequent retrimming and a slight nudging of the control column may be necessary when flying on autopilot. Although a mere 20-foot altitude loss in one minute causes an increase of 1 knot in speed for average weights, about 28 bhp per engine increase is required to accelerate 1 knot in 1 minute. Thus, frequent power adjustments may be necessary when altitude must be maintained within small limits, such as ±100 foot. Average power settings and fuel flows for each cruise period are used as entries in the aircraft performance log/plan.

Cruise Procedure

Maintaining the recommended speeds and the minimum fuel flow results in the most economical cruise, regardless of whether or not the actual power settings and fuel flows are exactly as predicted. The following is a general procedure for setting up long range cruise conditions.

1. After reaching the desired cruise altitude, level the aircraft, allowing the speed to increase somewhat above expected cruising speed, and reduce power to approximately the expected (charted) cruise power.
2. As soon as cylinder head temperatures have stabilized below cruise power limits, establish and maintain long range cruising airspeed as given on the mission plan.
3. Adjust power as necessary to maintain the required altitude.
4. Set up torque pressures for the normal operating schedule in auto lean mixture, or if manual mixture adjustment is employed, follow procedures outlined in the engine operation section of the -1 technical order.
5. Adjust cooling flaps, as necessary, to maintain the cylinder head and carburetor air temperatures within the maximum limitations.

6. Adjust power to compensate for any mixture or cooling flap adjustment. Then adjust power as necessary during cruise to maintain altitude within limits.

Performance Correction Factors

Cruise control charts are based on standard external aircraft configuration. Any variation from this configuration causes a change in the drag of the aircraft and thus changes the performance from that shown on the charts. That is, normal power requirements must be modified to compensate for these changes in configuration so that the desired airspeed can be maintained. The two main performance correction factors are the weight correction factor and the Delta F correction factor.

WEIGHT CORRECTION FACTOR. The weight correction factor is an indication of the difference between the actual performance of the aircraft and the standard charted performance. Weight correction will be either a plus (+) correction factor or a minus (—) correction factor. When aircraft performance is better than charted performance, the weight correction is subtracted and is called a minus correction factor. On the other hand, if aircraft performance falls below charted value, the weight correction is added and is called a plus correction factor.

The weight correction factor may be either of the *known* type or of the *calculated* type.

Known Type Weight Correction Factors. These factors are listed in the -1 technical order and include structural changes that affect the configuration of the aircraft. For example, if an aircraft, normally equipped with tip tanks, has the tanks removed, the aircraft has less drag and performs better than the chart indicates it should. Therefore, a minus correction must be made; that is, the weight correction factor of the tip tanks is subtracted from the actual gross weight of the aircraft. If, on the other hand, equipment is added to the aircraft and the drag is thereby increased, the aircraft does not perform as well as the chart indicates, and a plus correction must be made and added to the actual gross weight.

Calculated Type Weight Correction Factor. If an aircraft has been flown and the aircraft performance analyzed previously by an engineer, a total weight correction factor will have been determined. The procedure for determining a total weight correction factor is discussed in Chapter 10. After the total correction factor has been calculated, it is used in place of the known type used in mission planning. Since accurate calculations in cruise control depend largely upon close weight tolerance, the weight correction factor must be taken into account when the following charts are used:

Nautical Miles Per Pound Fuel
Long Range Distance Prediction
Long Range Time Prediction
Long Range Summary

DELTA F CORRECTION FACTOR. To compensate for the increase or decrease in drag caused by changes in external airplane configuration for other than long range airspeeds, a correction factor known as Delta F is computed. The Delta F factor is measured in terms of equivalent flat plate area, and the Delta F value is found in the technical order for the particular aircraft. The bhp per engine required to overcome this extra drag produced by the Delta F factor may be computed with the formula:

$$\Delta F\ \text{bhp/eng} = \frac{\Delta F \times \text{EASK}^3 \times \text{smoe}}{\underset{(326{,}000)}{325 \times 295 \times R \times \eta}} \qquad (74)$$

Example: An aircraft is to fly at 10,000 feet H_p and at standard temperature at a constant airspeed of 180 EASK which is to be obtained with a chartered 1885 bhp/eng. Determine the additional bhp required if an additional drag item of +2.4 ΔF exists.

$$\Delta F\ \text{bhp}_{\text{req}}/\text{engine} = \frac{+2.4 \times 1803 \times 1.164}{326{,}000} = 50$$

Therefore,

1885 + 50 = 1935 bhp/eng required to maintain an EASK of 180.

Effect of Wind on Optimum Cruise Speeds

We have described how a headwind decreases ground range and tailwind increases it. Not quite so apparent is the fact that operating in headwinds may require airspeeds greater than zero wind cruise speeds, if loss of range is to be avoided. The effect of wind on range for a given airspeed can be stated in the following equation:

$$\text{Ground NMPP} = \text{Air NMPP} \times \frac{V - V_w}{V} \qquad (75)$$

where V is aircraft speed and V_w is wind speed, headwinds being considered positive values.

Figure 9-53 shows why airspeeds must sometimes be increased in headwinds to realize maximum ground miles per pound of fuel consumed. It

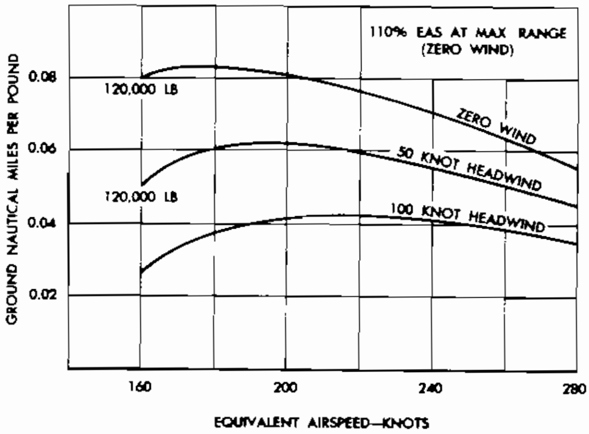


Figure 9-53. Nautical Miles per Pound Fuel

also illustrates a set of rules for operating in headwinds or tailwinds.

For a certain set of conditions, flying at speeds recommended for 99% maximum range results maximum range for 50-knot headwind operation during manual lean operation.

Flying at speeds recommended for 110% of zero wind maximum range speeds results in maximum range for operation in 100-knot headwinds.

No change in speed from recommended zero wind cruise speeds is required for operation in tailwinds.

Where winds must be accounted for in cruise predictions, the ground distance changes in proportion to the effect of the wind during the cruise.

Specific Range Curves

Figure 9-54 provides a graphic presentation of the performance of an aircraft under varying conditions of gross weight, airspeed, and power. The purpose of these charts is to present information for predicting fuel consumption versus distance and time of travel as the aircraft gross weight changes due to fuel used in cruise.

Separate NMPP fuel curve charts, similar to the one illustrated here, are prepared for four-, three-, and two-engine operation. For each combination of engines, separate standard day curve charts are presented for each 5,000 feet H_p, from sea level to 20,000 or 30,000 feet H_p, depending on the type of aircraft. The curves plotted on the charts are for operation in either auto lean, manual lean with spark advance, or auto rich. Lines of constant cowl flap gap are shown on all NMPP charts to help you maintain maximum permissible cylinder head temperatures. Also shown are recommended speed schedules for cruising at 99% of maximum range. On four-engine curves, an additional schedule for 50 knot headwind is included which is useful when strong headwinds prevail.

Different types of cruises may be worked on the NMPP charts. Cruises are normally predicted for one hour duration; however, the maximum time allowed in one cruise using one power setting is one hour and 29 minutes (1:29). When a cruise of 29 minutes or less is predicted, no average gross weight need be computed because of the small change in gross weight that will occur in the short time. For a cruise of 30 minutes or longer, an average weight must be computed.

The NMPP curves show that as the cruise progresses and fuel is consumed, the weight decreases and the airspeed increases for constant power output. If power output is reduced so that the EASK is kept on the 99% maximum range line, the airspeed decreases, but range is extended. When predicting cruise power for a time interval of 30 minutes to one hour and 29 minutes, an average weight is used to find the bhp and EASK for the particular period of time.

Now, let us see a sample cruise problem to demonstrate the use of the NMPP fuel chart and the foregoing information. Assume that a long range cruise is to be accomplished at a density altitude of 10,000 feet for one hour, with a beginning gross weight of 120,000 pounds, and with not more than 50 knot headwinds. The problem is to find the fuel flow, EASK, and bhp/engine for a 4-engine cruise, using manual lean mixture setting.

To obtain these factors, enter the nautical miles per pound fuel chart on the EAS for 99% maximum range line and follow this line upward to 120,000 pounds. At the intersection, read diagonally toward the right and parallel to the bhp guide lines to obtain approximately 1420 bhp. Using this bhp, enter the fuel flow per engine chart shown in figure 9-55 on the 1420 bhp/engine line and ascend vertically to the manual lean line. At the intersection, read horizontally to the left to obtain a fuel flow per engine of 720 pounds per hour.

Now that you know approximately how much fuel is required to produce 1420 bhp for one engine for one hour, you can obtain the total fuel

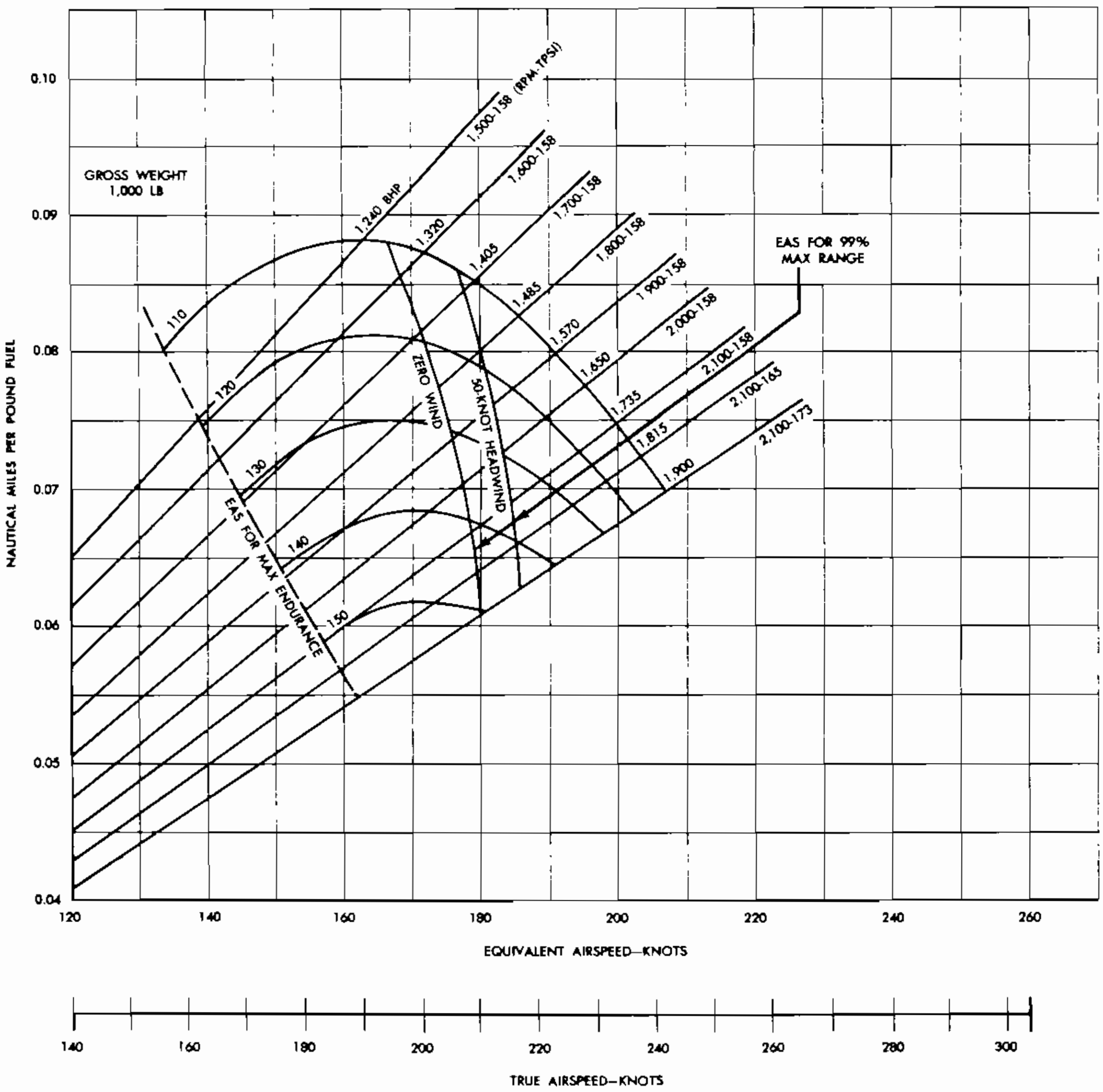


Figure 9-54. Specific Range

flow for the one-hour cruise by multiplying this fuel flow by four. Thus, 720 pounds/hr × 4 engines = 2880 lbs/hr. By taking one-half of the weight lost during the cruise and subtracting it from the beginning gross weight, you can obtain the average gross weight during the cruise. Using this average gross weight (120,000 — 1310 = 118,690) on the NMPP fuel chart, you obtain a more accurate EASK and bhp for the cruise increment. Enter the NMPP fuel chart (figure 9-54) on the EASK for 99% maximum range line and ascend along this line to the average gross weight of 118,690 pounds. At the intersection read straight down for an EASK of 180, and diagonally upward to the right to obtain a bhp of 1475.

EASK is commonly used as the primary variable in expressing aircraft performance. EASK corrected for density altitude equals TASK. A comparison between the EASK and TASK scales on the bottom of the 10,000-foot standard day NMPP chart shows the variation between EASK and TASK at a 10,000-foot altitude on a standard day. On the sea level NMPP charts, the scales read differently from charts for other altitudes.

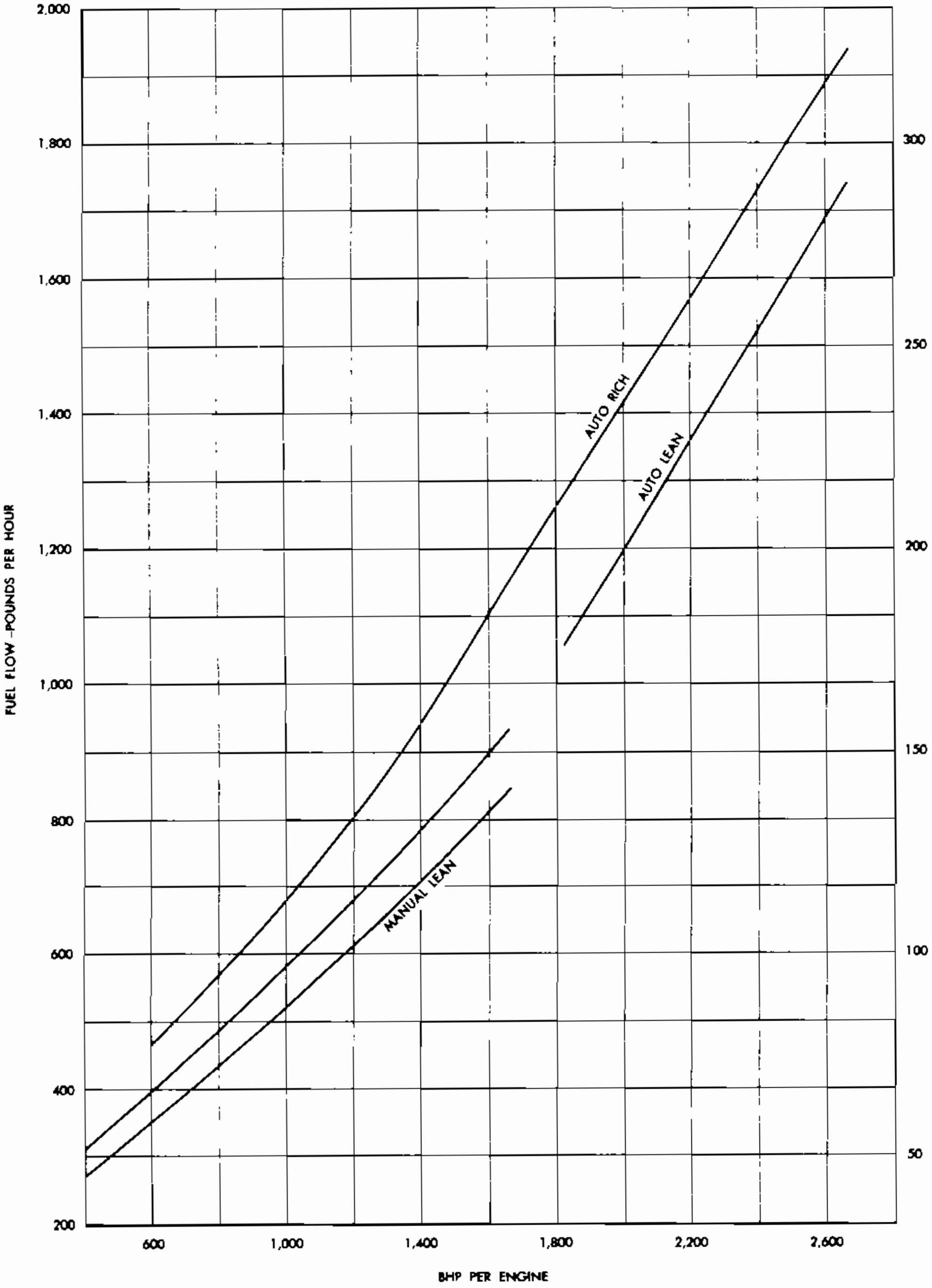


Figure 9-55. Fuel Flow per Engine

Thus, the relation between EASK and TASK changes with altitude and temperature.

Remember that the airspeeds on NMPP curves are usually EASK and the aircraft instruments read indicated airspeed (IAS). Therefore, the airspeed appearing on the charts must be changed to the indicated airspeed at which the aircraft should fly. This is the reverse of the procedure used in making an indicated airspeed correction. This procedure requires extreme care in the use of plus and minus signs. To change EAS to IAS, reverse the corrections for compressibility, pitot position, and instrument error. In starting with EAS to obtain an IAS, a negligible error is introduced. This procedure was explained in Chapter 5.

Air temperatures used on the NMPP charts are free air temperatures from outside the aircraft corrected for instrument and compressibility errors.

Many times it is necessary to determine which NMPP chart to use, especially when cruise altitude differs from the altitude and temperatures upon which the charts are based. For example: determine long range EASK and bhp/engine for a 4-engine auto lean, normal spark cruise at 7,000 feet H_p, outside air temperature +10° C, and an average gross weight of 130,000 pounds for the cruise period. From the density altitude chart, 7,000 feet H_p and outside air temperature of 10° C are equivalent to 8,000 feet H_d.

As a training exercise for use of the computer, determine the density altitude in the following manner:

In the Standard Atmosphere Altitude window, set the H_p of 7,000 feet directly under the outside air temperature of 10° C. Read the density altitude of 8,000 feet in the Density Altitude window.

In the rare instance in which a charted aircraft operates at long range and at a charted altitude, the procedure is to select the closest NMPP fuel chart to the cruise density altitude. Then, since bhp required at altitude varies as the reciprocal of the square root of sigma ($\frac{1}{\sqrt{\sigma}}$), the bhp/eng at the charted H_d divided by $\frac{1}{\sqrt{\sigma}}$ for the charted H_d equals the bhp/eng. A substitution of the known values in the formula discloses the required bhp/eng.

The above procedure is used for long range cruise with a charted aircraft operating at charted altitude, which seldom happens. Usually a Delta F Weight correction factor is necessary. These corrections are always made along the 99% EASK for maximum range line.

For other types of cruise you must have the average gross weight to determine:

- Constant power—Intersection of average gross weight and bhp lines for the given airspeed.
- Constant airspeed—Intersection of average gross weight and EASK lines for the bhp required.

Two factors are always required to compute the third factor.

Remember that these charts are designed for standard day conditions and standard aircraft configuration. Any deviation from standard must be corrected while using these charts.

BMEP Power Schedules

In conjunction with the NMPP charts, a set of power schedules is included in the -1 technical order. These schedules include:

Power Schedule Chart
Power Schedule Table
Fuel Flow Chart

After determining from the NMPP chart what power (bhp) is necessary to fly the aircraft, it is possible to obtain this power output (bhp) at any one of a variety of conditions. For example, almost any given bhp can be produced with various combinations of rpm and MP. The particular combination of rpm and MP that is used depends on three major factors that must be taken into consideration. First, required power; second, safe operating limits; and third, maximum economy consistent with the required power and safe operating limits. Since it would be impractical for you, the flight engineer, to have to think in terms of these requirements each time you change power settings, the brake mean effective pressure (bmep) power schedules have been designed to help you choose power settings that will satisfy the above conditions of power, safety, and economy.

POWER SCHEDULE CHARTS. The power schedule charts are made up for altitudes from sea level to 30,000 feet in increments of 5,000 feet. The number of charts vary with the type of aircraft, depending on whether or not it is a high-altitude or low-altitude aircraft.

The power schedule illustration chosen is the 5000-foot chart, figure 9-41. In order to use the chart, enter the brake horsepower required at the bottom of the chart. Reading vertically to the respective curves and then horizontally, the engine rpm, MP, and TPSI that corresponds to this power can be determined.

Rpm. The first information derived from the chart is the rpm. To determine rpm, enter the chart with the bhp, go vertically to the rpm curve, and then horizontally to the left to the rpm scale. The portion of the rpm curve between 1400 and 2100 rpm indicates the most desirable cruising range. Reading vertically upward to the TPSI curve, you find that the torque pressure remains constant at 158 within this rpm range.

From 2300 rpm to maximum rpm the propeller blades are theoretically against the low pitch stops and are therefore in fixed pitch. The power output is therefore proportional to the rpm in this range.

Manifold Pressure. To establish the manifold pressure for the specified bhp, continue vertically from the bhp base line through the rpm line to the fuel mixture lines. Where this vertical line intersects the auto rich or auto lean curve (for your particular condition), go horizontally to the right to the carburetor air temperature (cat) base line which, for this aircraft, is at −20° C. If the operating cat is 20° C, continue horizontally to the MP scale. If the cat is not 20° C, make the necessary correction by following the diagonal lines to the temperature and then read horizontally to the MP scale.

TPSI. After the input power (MP) has been determined, the output power (expected TPSI) is determined. Continue vertically on the bhp line until it intersects the TPSI line and read horizontally to the left to determine the torque pressure.

POWER SCHEDULE TABLE. The power schedule table presents in tabular form numerical data extracted from the power schedule charts. The rpm, MP, and TPSI for a bhp in between tabulated values must be calculated by interpolation (ratio and proportion on a slide rule) or by use of the power schedule chart.

If you use your slide rule for the calculation, remember that each engine has a constant number assigned by the manufacturer for use in the determination of bhp problems. Since this calculation involves ratio and proportion, scales C and D of the slide rule are used. The known values of bhp, rpm, and the engine constant number are used to solve for a TPSI. For the selected illustrative problem, we use a representative constant number of 191. Let's solve for the desired TPSI for 2650 bhp at 2550 rpm. First, set the slide rule hairline over the bhp (2650) on D scale. Next, position the rpm (2550) on C scale under the hairline. Now you have the rpm value on C scale positioned directly over the bhp on D scale. Next, move the hairline back to the left and align it over the constant number 191 on C scale. Read the TPSI directly under the hairline on D scale as 198.

FUEL FLOW CHART. A fuel flow per engine chart is included in the flight manual to provide the flight engineer with an inflight reference to fuel flow values. The fuel flow curves for specific conditions may be found either on the power schedule chart or a separate chart, as illustrated in figure 9-55. Fuel flow charts should *not* be used for accurate long range planning calculations.

FUEL MILEAGE CHARTS (TURBOFAN ENGINES). At the bottom of the chart, figure 9-56, note that MACH number and calibrated airspeed in knots are used rather than EASK and TASK. Nautical air miles/pound is read on the left hand scale for the relationship of an airspeed and gross weight. The two speed lines are noted as Best Range and 99% Best Range. A one percent loss in fuel mileage is noted for the gain in airspeed or an increase in MACH number.

When compromises are to be made involving fuel mileage and airspeed or involving airspeed and crew fatigue, the tactical situation or mission characteristics will determine the choice which the pilot will make.

Best range is the longest range obtainable while flying at a constant altitude, while *maximum* range is the longest range of which the airplane is capable.

Temperature deviations from the ICAO standard day have no effect on range when less than rated power is required. However, cruise time and fuel flow will be modified slightly because true airspeed and engine specific fuel consumption vary with temperature at a given MACH number. These relationships are true whether cruising at maximum range (climbing flight path) or constant altitude. For maximum range cruise where rated power is required (such as for 3- or 2-engine operation), an increase in temperature means a reduction in range, altitude, MACH number, and time, and an increase in the rate of fuel flow. For constant altitude cruise at rated power, an increase in temperature reduces the maximum allowable weight and MACH number that can be flown at that altitude. The effect of temperature on cruise range, altitude, and miles per pound is shown as curves of specified temperature departure from the ICAO standard day. Fuel flow data are plotted as a function of gage OAT.

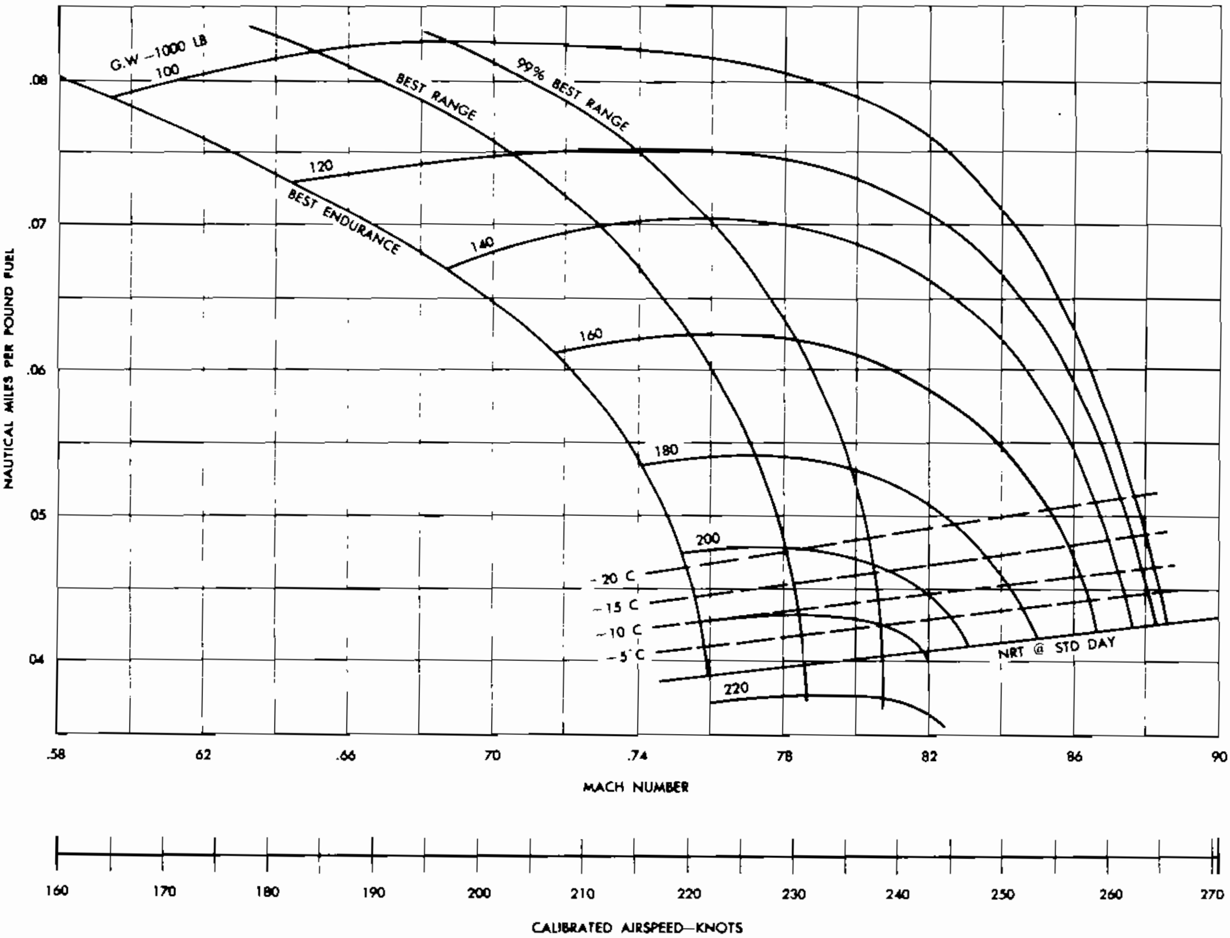


Figure 9-56. Fuel Mileage

Charts of 4- and 3-engine nautical air miles per pound of fuel are shown versus MACH number and for a range of gross weights. Data are shown for a wide range of altitudes, including those normally flown while under Air Traffic Control. Temperature has no significant effect on nautical air miles per pound of fuel since the temperature effect on fuel flow and on true airspeed for a given MACH number approximately offset one another. For cruise at the NRT limit, an increase in temperature reduces the maximum allowable gross weight and MACH number that can be flown at that altitude.

Included on the fuel mileage chart at a constant altitude are the data for the optimum step climb with the applicable temperature effects. In order to simplify flight planning, range and time data at a constant MACH of 0.78 are presented. Temperature effects are shown on the chart where applicable.

A cruise time chart for 99% best range and 99% max range, figure 9-57, is provided for all gross weights at altitudes of 25,000 feet and for 35,000 feet and above, operating on four engines. Whenever headwinds or tailwinds are involved, a chart, figure 9-58, is provided to show the increase or decrease in range or time. For any one condition, this effect in percent may be applied to either time or distance, but not to both.

Generalized fuel flow chart is provided in figure 9-59 to express the amount of fuel pounds/hour for one engine pressure ratio, MACH number, gage OAT and pressure altitude from sea level to 45,000 feet. These two charts are used in conjunction with one another, as illustrated by the dotted lines, to accurately determine a fuel flow for a given MACH number and altitude.

Cruise performance data may also be predicated for a constant airspeed or a constant MACH number. Normally, when cruising at a constant MACH

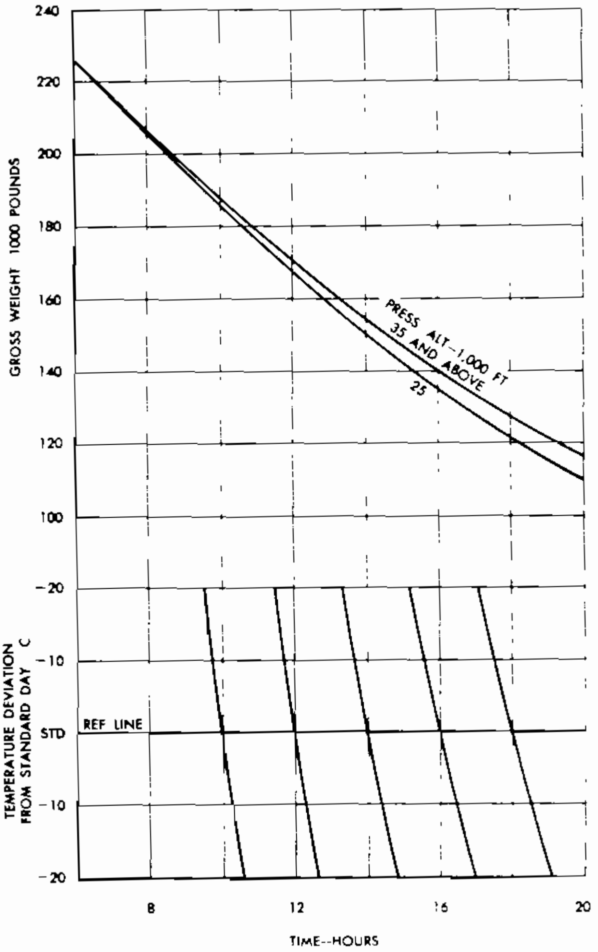


Figure 9-57. Cruise Time Chart

number, 0.78 is used. The interpolation on the fuel mileage charts will be identical to that as explained for the specific range charts.

Long Range Summary Curves

The long range summary curves, shown in figure 9-60, are used to obtain cruise control information for flight planning, and are especially useful for inflight reference. These curves, constructed directly from the NMPP curves, show the following information for a variety of gross weights and altitudes: fuel mileage in nautical air miles per pound fuel, cruising TPSI, engine (cruising) RPM, and cruising speeds in terms of indicated airspeed. The indicated airspeeds shown are corrected from EAS for 99% maximum range. The summary curves are useful for mission planning and inflight references when long range cruise procedures are used, due to the ease of interpolation between altitudes and gross weights, and the fact that cruising speeds have been converted to indicated airspeeds. These long range airspeeds are from 5 to 15 knots higher than those for maximum range. Advantages of these higher airspeeds are (1) decreased time to fly a mission, (2) greater ease of aircraft handling (especially in rough air), and (3) automatic speed correction for headwinds up to approximately 50 knots.

Abrupt interruptions in the curves occur as indicated by the dashed lines for various reasons such as (1) changes in mixture procedure, (2) CHT limits, and (3) engine operating schedules. One of the most important things to observe is the effect of mixture or CHT limit changes on power required. For instance, when cruising at weights requiring AUTO RICH powers, it is necessary to consume sufficient fuel so as to require well under 1850 bhp in the rich mixture before the engines can be permitted to operate at 1850 bhp in manual lean mixture. This is due to the presence of more cooling drag in the lean mixture condition.

RANGE SUMMARY (TURBOJET ENGINE AIRCRAFT). Summary charts of range data are prepared for 4-, 3-, and 2-engine operation. Figure 9-61, Range Summary—Turbofan Engine, is for the 4-engine configuration. For this type of cruise, the altitude is increased at a rate which is proportional to the airplane weight decrease due to the consumption of fuel. During this period, the distance flown per pound of fuel consumed is at the maximum value for the rate of speed. Cruise MACH number is shown on the cruise altitude charts. Maximum range data for both the 3- and 2-engine conditions assume the most critical engine out configurations. An outboard engine loss is assumed for the 3-engine condition and the loss of 2 engines on one side is assumed for the 2-engine condition. Less critical engine losses yield slightly longer ranges.

Long Range Prediction Curves

There are two kinds of long range prediction curves—distance and time. The distance chart, figure 9-62, is used to predict rapidly the distance traveled or fuel used as aircraft gross weight changes while fuel is consumed in long range cruise. The time chart, figure 9-63 is used to predict time elapsed or fuel used. Both charts are

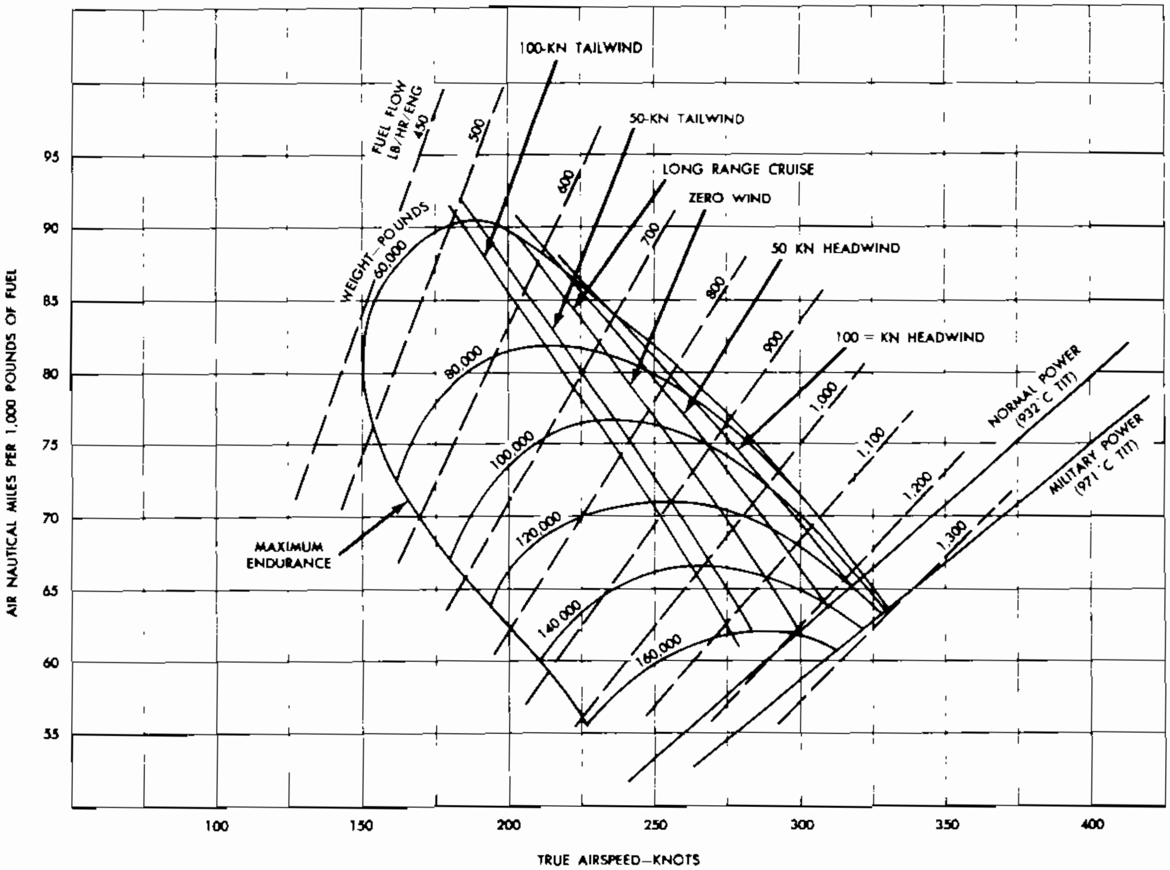


Figure 9-58. Effect of Wind on Range

prepared from information contained in the aircraft NMPP charts.

The following problem illustrates how the charts are used to predict fuel consumed and time required for a cruise.

Problem:

4-engine long range cruise
Beginning gross weight—130,000 lbs.
Altitude of cruise—25,000 feet
Distance of cruise—1400 NM
Find pounds of fuel consumed and time required for flight.

Solution: To find the amount of fuel consumed, enter the long range prediction—distance chart at 130,000 pounds and proceed vertically to the 25,000 foot density altitude line. Move horizontally to the left and read 2200 nautical miles at altitude. Due to the construction of the chart, the 2300 is used as a reference number. Add cruise distance of 1400 NM to the 2300 to obtain a new reference number (3600) which is used to re-enter the chart at the left. Move horizontally to the right along the 3700 nautical mile line to the 25,000 foot altitude line. At this point, proceed vertically to the gross weight scale and read 108,000 pounds. Thus, the fuel used for the 1400 nautical miles is: 130,000 minus 108,000 equals 22,000 pounds.

To find the time for the overall cruise distance (2100 NM), enter the long range prediction-time chart at 130,000 pounds beginning gross weight and proceed vertically to the 25,000 foot density altitude line. Move horizontally to the left and read time at altitude of 6.9 hours. Enter the chart again at 108,000 pounds ending gross weight and proceed vertically to the 25,000 foot altitude line. Move to the left and read time for the 25,000 foot altitude of 12.7 hours. Then the time required for the cruise distance of 1400 NM is found as follows: 12.3 hours minus 6.4 hours equals 5.9 hours flying time.

DESCENT CONTROL

The procedure for making a descent has long been a subject of controversy. Some engineers prefer to remain as long as possible at an altitude where best economy is obtained before beginning descent to the landing field. On the other hand, many engineers advocate a long gradual descent

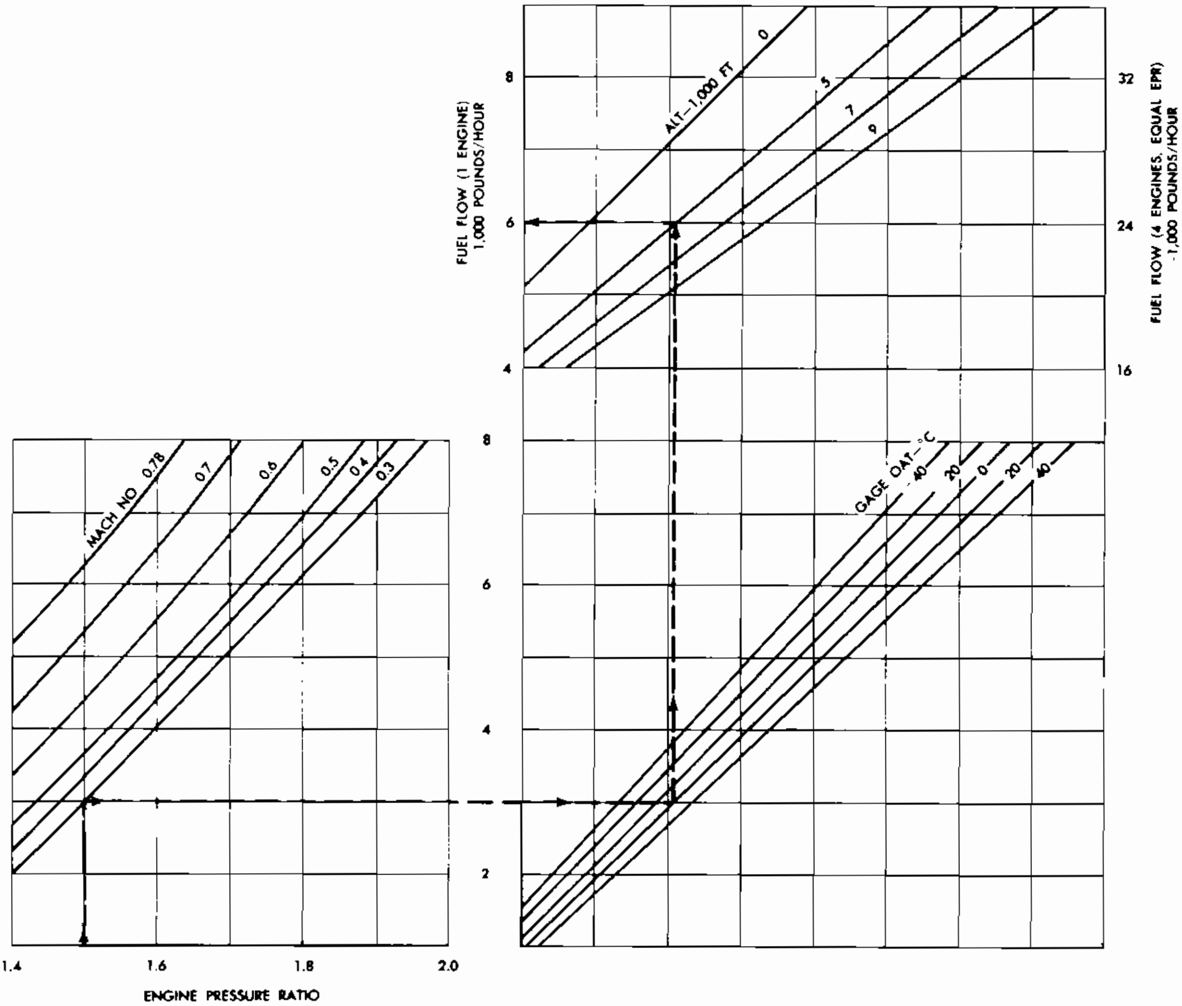


Figure 9-59. Generalized Fuel Flow

at a constant rate to the landing field. So you need to know the advantage and disadvantage of each method of descent.

To begin with, economy is just as important in descent as it is in cruise. By descending at long range cruising airspeeds, the most efficient angle of attack is obtained and the NMPP value remains near maximum. Since the bhp/engine required to maintain long range airspeed decreases as the rate of descent increases, engine cooling becomes less of a problem. At sufficiently low powers, adequate cooling can be maintained even with all cooling flaps closed (or in the trail position). This condition results in additional range available in descent, since drag is decreased. Therefore, a rate of descent should be chosen which permits closed cooling flaps at long range cruising airspeeds. If high rates of descent are used, power required will be so small that it will be necessary to operate in the constant rpm range. The power settings in this range result in low bmep and a low NMPP value. From the foregoing analysis, it appears that the most economical descent is one which is made at long range cruising airspeed and at a rate of descent that is high enough to permit adequate cooling of the engines with closed cooling flaps but not so high as to require reduced power settings which are undesirable.

Unfortunately, it is not always possible to avoid undesirable power settings. On some aircraft, the power requirements for controlled descents necessitate the use of power settings in the constant rpm range. On other aircraft, it is often necessary

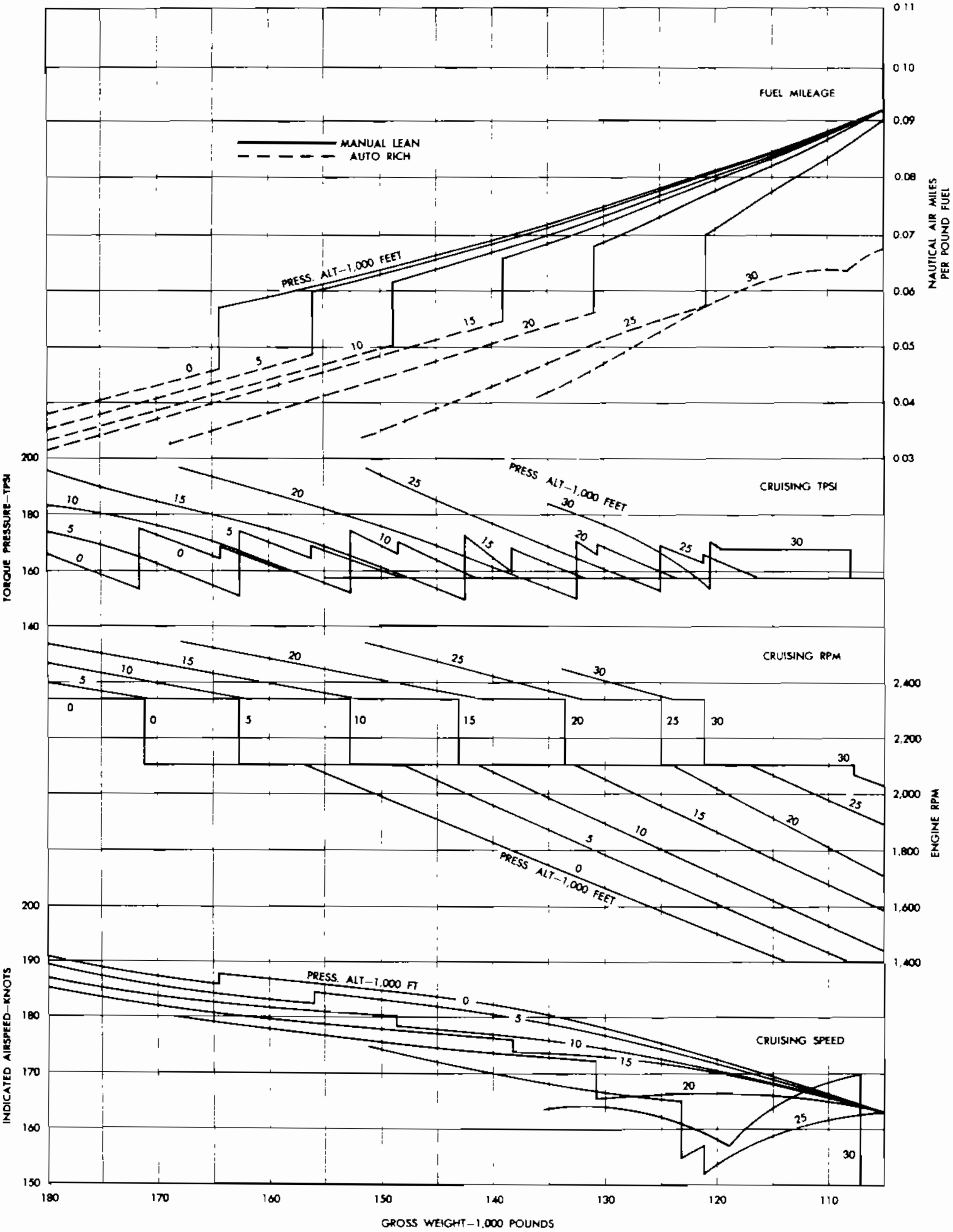


Figure 9-60. Long Range Summary Curves

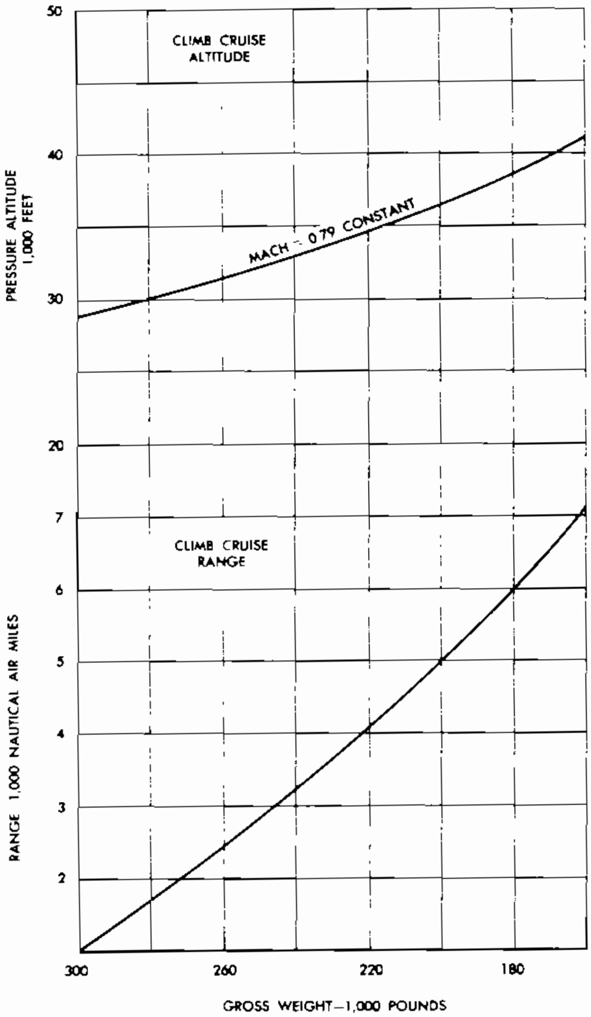


Figure 9-61. Range Summary (Turbofan Engines)

to use split powers. Split powers are necessary when the bhp/engine requirements call for special settings which cannot be used on inboard engines when the cabin is pressurized.

In general, we may conclude, that there is no one best technique to use for descent. The point at which to begin descent and the rate of descent may often be indicated by operational restrictions. The nature of the mission, surface topography, or local policy often determines the technique to be used.

Computed Data for Controlled Long Range Descents

There are several methods for computing descent data. For some aircraft, the descent data are computed from the curves used to obtain cruising data. The methods for obtaining these data may vary from command to command, but an acceptable method is usually given in the -1 technical order for the applicable aircraft.

Several terms and formulas, which will be used in most of the methods for computing descent data, are given here.

RATE OF DESCENT. Rate of descent is the rate in feet per minute at which an aircraft decreases altitude.

TIME DURING DESCENT. Time during descent is expressed by the formula:

$$\text{Time (minutes)} = \frac{\text{change in altitude (feet)}}{\text{rate of descent (feet/min)}} \qquad (76)$$

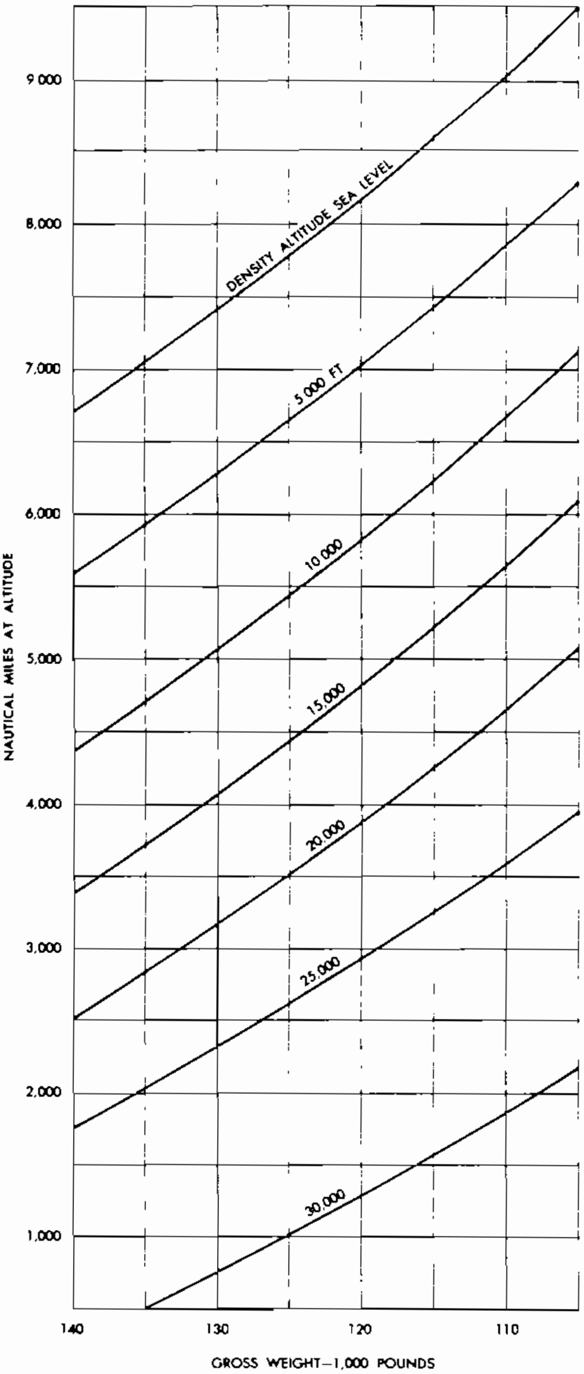


Figure 9-62. Long Range Prediction—Distance

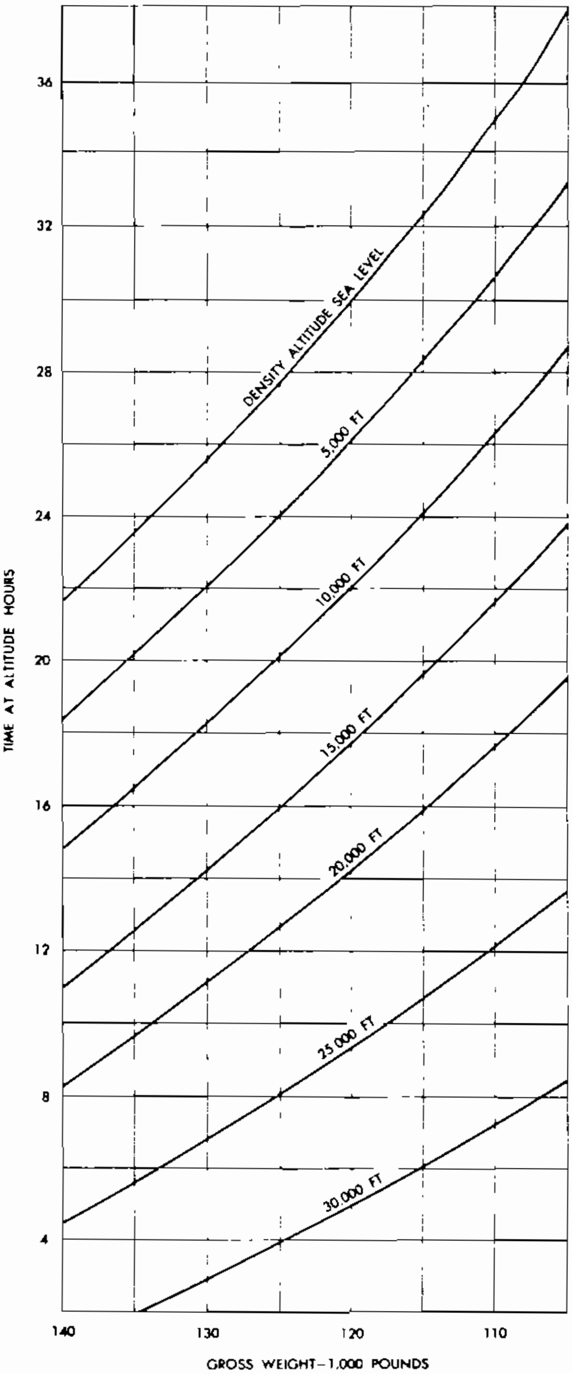


Figure 9-63. Long Range Prediction—Time

RANGE GAINED. When an aircraft climbs to cruising altitude, much work is required merely to lift the aircraft against the force of gravity. When the aircraft reaches cruising altitude, it possesses an amount of potential energy equal to the work expended in lifting it to that altitude. As the aircraft descends, this potential energy is transformed into kinetic energy. This kinetic energy (from falling speed) is converted into forward motion by the aerodynamic forces and these, in turn, permit reduction of bhp without decreasing airspeed.

Analyses of flight tests have shown that the energy derived from descent, while maintaining long range airspeeds, provides an additional 2.2 nautical miles range for every 1,000 feet of decrease in altitude. This additional range is virtually independent of the rate of descent used, provided long range airspeeds are maintained. This means that a close approximation of aircraft range in descent may be determined by finding the level flight range at cruising altitude and adding 2.2 nautical miles to this range for every 1,000 feet of descent from cruising altitude. This additional range is often called range gained. Descent at other than long range airspeeds reduces this range gained factor.

For example, an aircraft cruising at an altitude of 15,000 feet with a supply of fuel adequate for 400 nautical miles at this altitude could reach a landing field 433 nautical miles distant. This range is determined as follows:

$$\text{Range gained} = 2.2\ \text{NM}/1000' \times 15{,}000' = 33\text{NM}$$

and

$$400 + 33 = 433\ \text{NM}$$

Bhp Gain. The bhp/eng required to maintain a given airspeed in descent is obviously less than would be required for level flight at the same airspeed. Since the required bhp/eng is often determined from charts made for level flight, it is necessary to correct this bhp. This correction, called bhp gain, is determined by a formula. Its development is as follows:

The energy per minute gained in descent = gross weight × rate of descent = pounds × ft/min = ft-lbs/min

$$\text{thp gain}\ \frac{\text{gross weight} \times \text{rate of descent}}{33{,}000} \qquad (77)$$

Therefore, the horsepower consumed by the propellers in moving the aircraft forward is the horsepower required for level flight minus the bhp gain in descent. To find how much reduction in bhp/eng can be made, this quantity must be divided by propeller efficiency and by the number of engines. Thus:

$$\text{bhp}_{\text{gain eng}} = \frac{\text{gross weight} \times \text{rate of descent}}{33{,}000\ R\eta} \qquad (78)$$

where R = number of engines, and η = propeller efficiency.

For 4-engine aircraft that have a propeller efficiency of .85 in cruise, the three factors in the denominator of the formula may be combined into a single constant. Since $R = 4$ and $\eta = .85$ (approximately), the constant is $33{,}000 \times 4 \times .85 = 112{,}200$.

Therefore the formula for bhp gain for most 4-engine aircraft is:

$$\text{bhp}_{\text{gain eng}} = \frac{\text{gross weight} \times \text{rate of descent}}{112{,}200}$$

Example: Find bhp gain for a 4-engine aircraft with a gross weight of 113,000 pounds descending at a rate of 200 ft/min. Assume $\eta = .85$

$$\text{bhp}_{\text{gain eng}} = \frac{\text{gw} \times \text{r/d}}{112{,}200}$$

$$= \frac{113{,}000 \times 200}{112{,}200}$$

$$= 201\ \text{bhp}_{\text{gain eng}}$$

Controlled Descent Problem: An aircraft weighing 113,000 pounds is to descend from 20,000 ft H_p where the OAT is −10°C to 2,000 ft H_p where the OAT is −20°C at a rate of descent of 200 feet per minute with 0° cowl flaps. The airspeed will be long range EAS. Find the time, average TASK, distance, bhp required for descent, bhp gained, and fuel required. Since the bhp required to maintain long airspeeds will decrease with a decrease in altitude, descents are computed in increments of 5000 feet, except for the last descent increment which can be as large as 7500 feet but no less than 2500 feet.

The time for the first descent increment is:

$$\text{Time} = \frac{20{,}000 - 15{,}000}{200} = 25\ \text{minutes}$$

To find the average TASK you must first obtain an EAS from the sea level, standard day NMPP chart for 113,000 pounds, using the EAS for 99% max range line. The EAS determined to be 170 knots. Then multiply the EASK (170) by the smoe at the average density altitude of the descent increment (19,000 feet). This average density altitude is obtained by first plotting an "actual temperature" line on the density altitude chart and then determining the average density altitude (19,000 ft) by reading horizontally to the left from the actual day pressure altitude of 17,500 feet (one-half the distance between 20,000 feet and 15,000 feet). From the standard altitude and smoe table, read the average smoe of 1.347 for the average density altitude of 19,000 feet.

$$\text{TASK} = 170 \times 1.347 = 229\ \text{knots.}$$

The horizontal distance covered in the descent from 20,000 feet to 15,000 feet is computed as follows:

$$\frac{229\ \text{knots} \times 25\ \text{minutes}}{60\ \text{minutes}} = 95\ \text{NM}$$

The first step in finding the required bhp for descent is the process of extracting a bhp from the sea level NMPP chart and correcting it for altitude. Enter this chart on the EAS for 99% max range line and follow the line up to the beginning gross weight of 113,000 pounds. At this intersection, follow parallel with the bhp lines upward to the right to find 115 bhp. To corect this bhp for operation at 20,000 feet H_p where the OAT is −10° C, multiply the 1155 bhp by the smoe factor obtained from the density altitude chart. The smoe factor for 20,000 feet H_p at $-10°$ C OAT is 1.41. Therefore, an aircraft that would require 1155 bhp per engine for level flight at sea level would require $1155 \times 1.41 = 1630$ bhp for level flight at 20,000 feet H_p and $-10°$C OAT.

Brake horsepower gained during a descent is computed according to the procedure described previously in this chapter.

$$\text{bhp}_{\text{gain}} = \frac{\text{gross weight} \times \text{rate of descent}}{112{,}200}$$

$$= \frac{113{,}000 \times 200}{112{,}200} = 201$$

Thus, if 1630 bhp per engine is required in level flight at 20,000 feet, a power reduction of 201 bhp per engine would permit the aircraft to assume a rate of descent of 200 feet per minute at no increase in speed. The power per engine for this descent increment is $1630 - 201 = 1429$ bhp.

The fuel required for this descent increment is obtained from the illustrated fuel flow per engine chart. Enter the chart on the interpolated 1429 bhp eng line and ascend vertically to the manual lean curve. At the intersection, read horizontally to the left to obtain 630 pounds of fuel per hour. To obtain the total fuel flow for four engines, multiply 630×4 to get 2520. Then calculate the total amount of fuel consumed for the period of 25 minutes in the descent from 20,000 feet to 15,000 feet.

$$\frac{2520 \text{ lbs F F} \times 25 \text{ minutes}}{60 \text{ minutes}} = 1050 \text{ lbs of fuel}$$

The power settings to be used for 1429 bhp are extracted from the 20,000-foot power schedule chart which was illustrated and discussed earlier in this chapter. The power settings would be 1740 rpm, 34.6" Hg, and 158 TPSI.

For the remaining descent to traffic altitude over the field, break the descent into 5000-foot increments and repeat the preceding steps for each increment.

Planning the Point of Descent on Course

When planning a descent with an unknown point of beginning, plan your cruise to a point 300 to 500 nautical miles from your destination. From this point, determine what your gross weight would be directly over your destination if you were to continue cruising at this same altitude with the same TASK and fuel flow. If the aircraft weighed 105,000 lbs at a distance of 500 nautical miles from destination and the last recorded four-engine fuel flow was 2,000 lbs/hr and the TASK was 200, the gross weight directly over your destination (Wt no. 1) would be

$$\text{Time} = \frac{500 \text{ NM}}{200 \text{ TASK}} = 2.5 \text{ hours}$$

$$\text{Weight lost} = 2.5 \text{ hours} \times 2{,}000 \text{ lb hr} = 5{,}000 \text{ lbs}$$

$$\text{Weight } \#1 = 105{,}000 \text{ lbs} - 5{,}000 \text{ lbs}$$

$$= 100{,}000 \text{ lbs}$$

Next, you must approximate how much time is to be spent in descent in order to determine how much fuel to add to weight no. 1. This information is necessary to obtain the approximate weight at the point of descent (Wt no. 2). It is important to note that this descent is considered to end 1,000 feet over the destination. Thus, if we are to descend at a rate of 500 feet/min from 20,000 feet, the time expended in the 19,000 foot descent will be 38 minutes.

Fuel used in descent =

$$\frac{38 \text{ minutes} \times 200 \text{ lbs hr}}{60 \text{ minutes}} = 1266 \text{ lbs}$$

$$\text{Wt no. } 2 = \text{Wt no. } 1 + 1266 \text{ lbs}$$

$$= 100{,}000 \text{ lbs} + 1266 \text{ lbs}$$

$$= 101{,}266 \text{ lbs}$$

Weight no. 2 is then used on the standard day, sea-level NMPP chart to obtain an EAS for the descent. Enter the chart on the EAS for 99% max range line and follow the line up to 101,266 lbs (wt no. 2). At this intersection read straight down to obtain an EAS of 163 knots. To correct this airspeed to an average TASK, multiply the 163 EASK by the average smoe. The average smoe for a 19,000-foot descent occurs at a pressure altitude of 10,500 feet. This figure of 10,500 feet is 20,000 minus one-half of 19,000 feet. The smoe for this altitude is obtained by entering the standard altitude and smoe table with 10,500 feet and reading 1.1729 as the average smoe.

The average smoe may also be determined from your computer in the following manner: The use of the standard altitude chart mentioned above indicates to us that standard temperature exists at 10,500 feet. From this, we determine that the density altitude is the same as the pressure altitude. Since this is the case, merely position 10,500 feet under the hairline in the DENSITY ALTITUDE window of the computer. From there, locate the black box on the minute scale, and read the average standard smoe under the reference hairline on the wind scale. This, as you see, indicates the average standard smoe for 10,500 feet as 1.1729. To determine the average TASK, locate the EASK of 163 knots on the minute scale. Directly above that point, read the average TASK on the wind scale as 191 knots.

Although the computer, being constructed of thin, durable materials, does not contribute to "parallax error," it is well to hold this device in a position such that the eye is directly perpendicular to the figure being read to insure maximum accuracy. This method applies to the reading of all instruments.

Normal Type Descent

Usually a normal descent consists of coming down in one or more steps to specified control altitudes in the vicinity of the intended destination, when it is desirable to descend as rapidly as possible from one level to another. Lowering the landing gear and extending the wing flaps to 55% is the optimum procedure for fast descents. Minimum time and distance for descent are shown on the chart in figure 9-64, flying at the flap placard speed of 190 knots (IAS) with minimum power to maintain cabin pressurization. Enter this chart at the initial weight and altitude of 140,000 pounds and 20,000 feet respectively. On the time and mileage scales on the left, you will find that 5.7 minutes are used to 31 miles in the descent to 5,000 feet pressure altitude. The fuel consumed is only about 25 pounds per minute, so a negligible error is introduced by using the same gross weight for the beginning and ending altitudes of the descent.

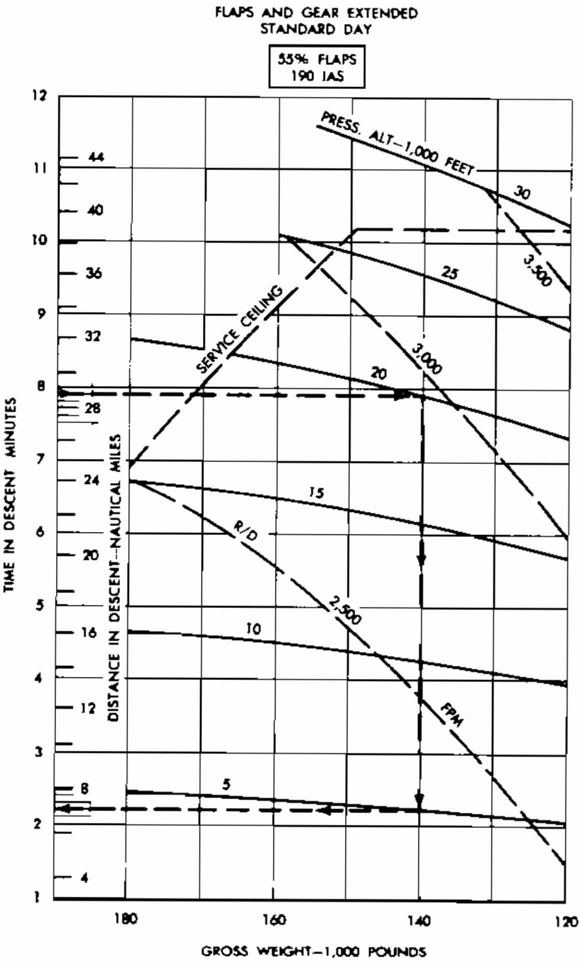


Figure 9-64. Minimum Time Normal Descent

Cruising Type Descent

No charts are furnished to predict distance, time, and fuel consumed in a cruising descent because present air traffic control procedures seldom permit use of a maximum fuel economy long range descent procedure. Furthermore, the small amount of time and fuel involved are hardly worth consideration in the mission plan since, in these instances, safety is not jeopardized. The many variables involved in cruising descent such as airplane weight, speed, power, and altitude, would make a chart presentation very complicated as compared with climb prediction, where power is constant and a fixed speed schedule is used. In these instances, when flight control procedures permit a cruising descent, maximum nautical miles per pound of fuel is obtained by holding sea level long range cruise speeds and reducing power to attain the desired rate of descent. Using this procedure, the energy derived from descent is equivalent to a free range allowance of 2.2 nautical miles per 1000 feet of descent. The rate of descent used must not be so high that power below the minimum required for maintaining cabin pressurization is used. By using full turbo, part throttle, and differential powers on the inboard and outboard engines, an average as low as 700 bhp per engine can be achieved while still maintaining adequate cabin pressure. Higher rates of descent per unit of time are available by increasing the descent speed, and the range gain will be affected a very small amount by moderate speed increases up to 30 or 40 knots above long range cruise. Even with speed increases, the rate of descent will usually be less than 1,000 feet per minute.

Example: Assume that permission has been obtained for air traffic control to make a cruising descent from 24,000 feet to 3,000 feet upon reaching a point 150 nautical miles from destination. The beginning gross weight is 120,000 pounds. Find the speed, time, rate of descent, fuel, and power required.

1. Enter the sea level NMPP chart with 120,000 pounds on the zero wind line and read the EAS as 174 knots.

2. Compute the average altitude of the descent as 13.500 feet and read the average smoe of 1.2305 from the standard altitude and smoe table.

3. Multiply the EASK (173) by the average smoe (1.2305) to determine the average TASK of 213 knots.

4. Compute the time elapsed for descent by dividing the distance (150) by the TASK (213)

$$\text{Time} = \frac{150 \times 60}{213} = 42 \text{ minutes}$$

5. Compute the rate of descent as follows:

$$\text{Rate of descent} = \frac{24.000 - 3000}{42} = 500 \text{ fpm}$$

6. Determine the NMPP value of .0805 from the sea level NMPP chart for the beginning gross weight of 120.000 lbs.

7. Compute the range gained for the 21.000 feet of descent

$$21 \times 2.2 = 46 \text{ NM}$$

8. Compute the fuel consumed for the descent as follows:

$$\text{Fuel} = \frac{150 \text{ NM} - 46 \text{ NM}}{.0805 \text{ NMPP}} = 1290 \text{ lbs}$$

Descent power is the level flight cruise power less the bhp gain generated by the rate of descent. The bhp gain for 120,000 lbs (beginning) and 118.710 lbs (ending) is 535 and 528 respectively.

9. Using the appropriate cruise power chart, enter with the beginning gross weight of 120.000 at 24.000 feet density altitude and read 1755 level flight bhp. Re-enter the chart with the ending gross weight of 118.710 at 3.000 feet density altitude and read 1280 level flight bhp. The initial and final powers for the cruising descent from 24,000 to 3.000 feet are as follows:

$$\text{Initial Power} = 1755 - 535 = 1220$$

$$\text{Final Power} = 1280 - 528 = 752$$

Since these powers are above 700 bhp, it will be possible to maintain adequate cabin pressurization by application of the proper rpm, throttle, and boost control settings.

En Route Descent (Turbojet)

The performance charts for en route descent show the relationship of altitude, gross weight, rate of descent, airspeed, nautical air miles, fuel consumed and the time elapsed. Rate of descent will increase with an increase in airspeed. It is possible to reach extremely high speeds in descent. However, speeds that can result in high speed buffet must not be used at high altitudes, and the structural limits must be observed at the lower altitudes.

The following procedures result in relatively low rates of descent.

1. Contact established with approach control sometime during the descent, since descent is started some distance from the landing base.
2. Cruise altitude maintained until approximately 220 nautical air miles from the landing base.
3. Two outboard engines retarded to idle and the two inboard engines at the power schedule required to maintain cabin pressurization.
4. Speed schedule of 0.78 MACH from cruise altitude to approximately 32,500 feet on a standard day, then 280 knots CAS from 32,500 feet to sea level.

LANDING AND TAXI

The landing and taxi operation begins at the end of the descent, at traffic altitude over the destination. The time for the landing and taxi operation may vary, depending on traffic conditions and weather; however, 20 minutes is considered as the average landing and taxi time.

Since the power setting during landing and taxi varies considerably, no rpm, MP, or bhp are recorded for these operations on the predicted flight plan. A standard rate of fuel flow per minute (pounds per hour) is used during landing and taxi. No airspeed is recorded on the predicted flight plan for landing and taxi; and since the operation normally takes place as the aircraft circles the destination in the traffic pattern, no distance along the course is predicted.

Chart computations, however, become necessary when the aircraft touches down on landing.

Landing and stopping distances, using either brakes alone or brakes and propellers in reverse pitch, are plotted on a landing ground roll chart, figure 9-65. The distances are applicable to all gross weights. Directly, wing flaps have little effect on aircraft stopping distances *after touchdown,* but indirectly they reduce the roll appreciably, since high wing flap angle materially reduces landing speeds and the consequent distance of roll. The effect of intercooler and cooling flaps positions at the speed range in which the stopping maneuvers are performed is very little. Speeds shown on the chart are true ground speeds, thus, the pilot's indicated airspeed must have the appropriate corrections applied. In general, the ground effect errors are small.

The curves of the chart are based on maximum wheel braking effectiveness. Theoretically, maximum braking is realized at just under the pressure at which wheel skidding can be caused. The use

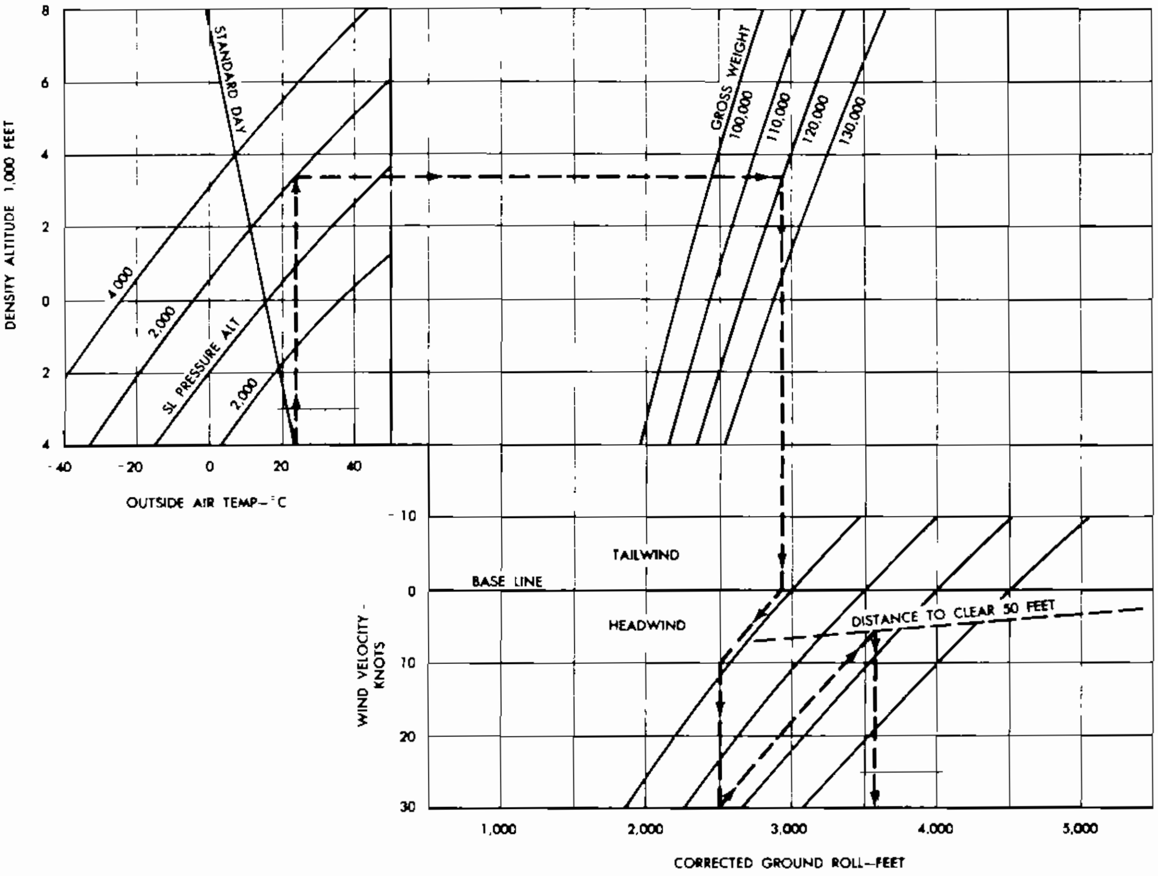


Figure 9-65. Landing Ground Roll

of reverse thrust during a landing aids considerably in stopping the aircraft. For instance, an aircraft using both wheel braking and two reversed propellers, traveling at 120 mph, decelerates to zero speed in a ground distance approximately 500 feet shorter than an aircraft employing wheel braking alone. Raising of wing flaps as soon as possible after landing also aids in the braking efficiency, because the weight of the aircraft settles faster and thereby is transferred more rapidly to the wheels. If flaps are left extended, on the other hand, some lift is developed, thus taking some weight off the wheels and limiting the braking effectiveness. Under these conditions, a normal braking effort tends to induce skidding.

Landing Distance Chart

Straight-in landing distances, or the distances over a 50-foot obstacle using brakes only to stop, are shown in the landing ground roll chart, figure 9-65. With two engines in reverse thrust in addition to brakes, the distances are approximately 75% of those shown or they can be computed on the specific chart for that condition. These distances are given, with variations due to different atmospheric and wind conditions, for various gross weights. Approach and landing speeds in terms of pilot's indicated airspeed (assuming no instrument error) are tabulated opposite the gross weights to which they apply. The distances are based on these speeds at approach and touchdown. In gusty air or strong crosswinds, add 10 mph to the speeds shown. Landing can then be made within distances shown if two engines are in reverse and brakes are used.

Example for use of landing ground roll chart is as follows: Find landing ground roll and total distance from a 50-foot height at 120,000 pounds gross weight, 2000-foot pressure altitude, 25°C OAT, and 10-knot headwind, using brakes only.

Enter the chart at 25°C and proceed vertically to the 2000-foot pressure altitude. Go across to the right to the 120,000-pound line and down to the base line. Follow the guide lines to the 10-knot headwind and read down to the ground roll of 2500 feet. Follow the guide line back up to the 50-foot obstacle line and read down to a total distance of 3570 feet.

CROSSWIND LANDING. Figure 9-66 is a convenient chart for resolving the wind into its components. This chart indicates the minimum recommended touchdown speed for the crosswind component. The example given on the chart explains its use. However, the indicated touchdown speed should be compared to the speed on the touchdown speeds chart. If the 50 degree flap touchdown speed should fall in the "caution" zone, determine touchdown speed using 40 degree flaps. The caution zone falls between the "Minimum Recommended Touchdown Speed" line and the diagonal line to the right. The area to the right of the caution area is progressively more hazardous. Notice in the illustration that the indicated values for runway wind component and the crosswind component fall in the caution area in one instance; in the other instance, these values appear at the beginning of the caution area, which is less critical. If this speed still falls in the yellow zone, predict the touchdown speed for 30 degree flaps. As a final step, 5 knots may be added to

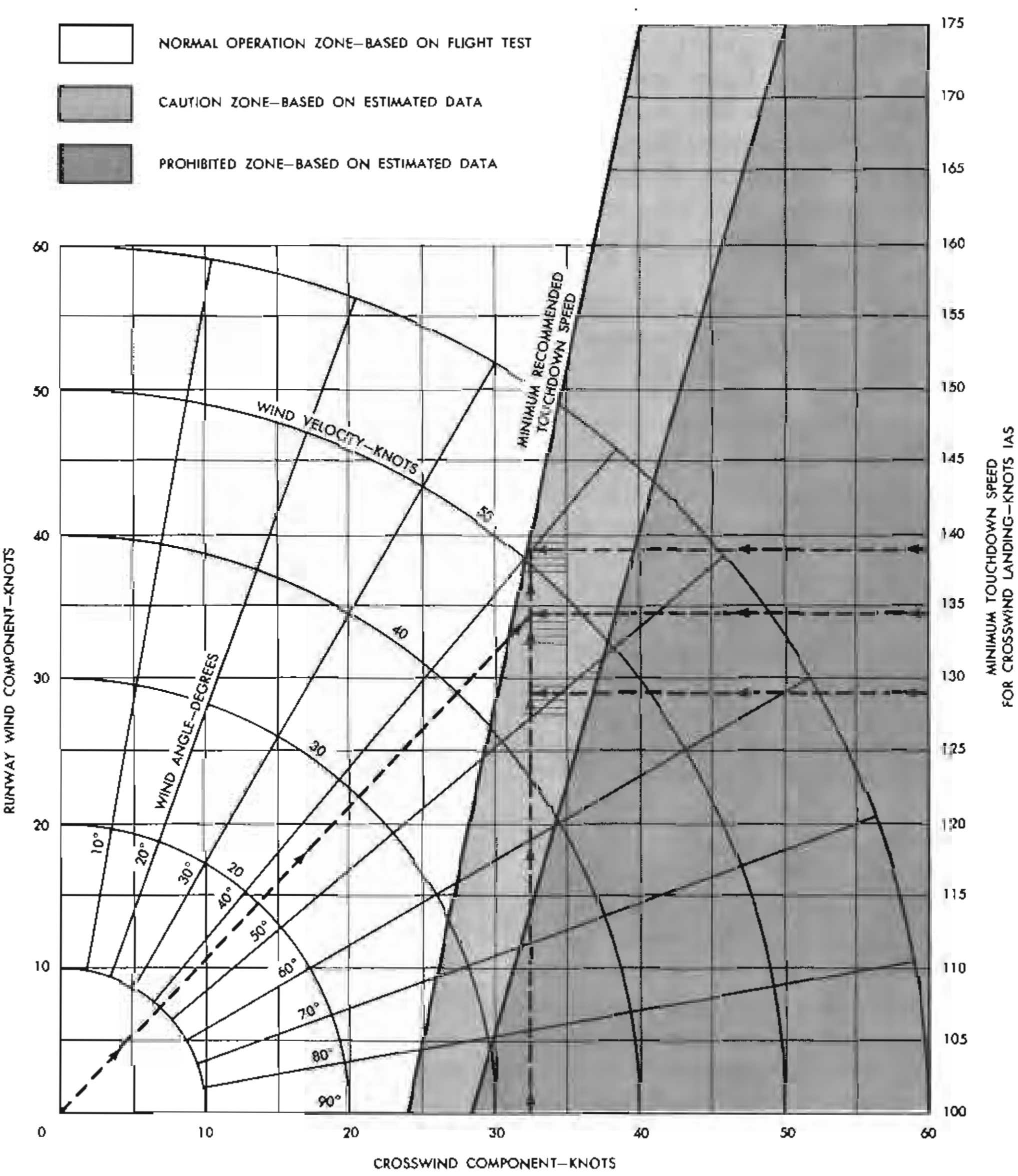


Figure 9-66. Runway and Crosswind Component

the 30 degree flap touchdown speed, unless this speed still falls in the yellow zone. In this latter instance, landing should be made at an alternate airport. Landing is *never* attempted if the predicted touchdown speed falls in the red "prohibited" zone.

Touchdown Speeds

Touchdown speeds in relation to gross weight and flaps position are shown in figure 9-67. Some aircraft will include approach speeds and touchdown speeds on the landing ground roll chart. The touchdown speed also serves as the "base" speed to which increments of speed are added in determining the recommended speeds throughout the landing pattern. In gusty air, it is better to touchdown at a slightly higher speed. Gusts seldom exceed plus or minus fifty percent of the average wind velocity and a speed increase equal to the reported gust increment should be accounted for. For example, if the wind velocity is 25 knots with gusts to 35 knots, the speed increase should be 10 knots.

Notice the IASK values at which the flap position lines cross the 200,000 pound vertical lines. Touchdown at 139 knots is indicated with 50° flaps, whereas touchdown must be made at 175 knots with flaps up.

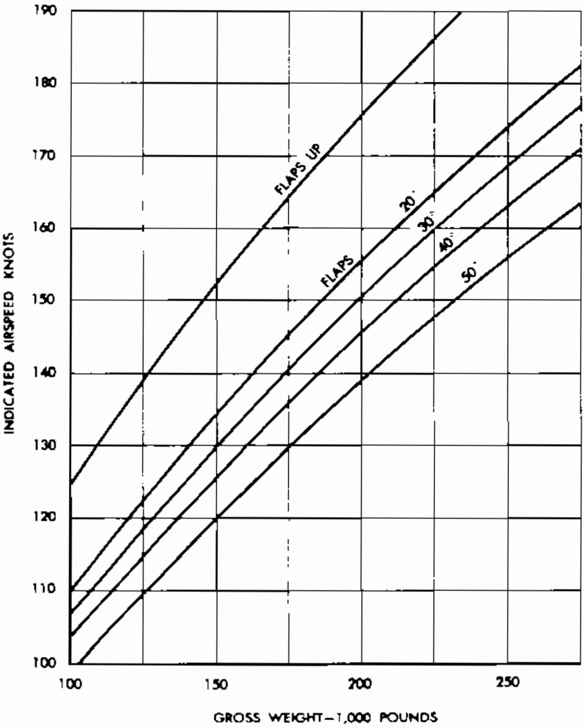


Figure 9-67. Touchdown Speeds

Delayed Braking

Tire and brake wear is accelerated by maximum effort stops and high landing weights. Tire and brake life can be increased by delaying the start of braking when runway lengths permit. Whenever possible, delay in start of braking to approximately 80 percent of touchdown speed is recommended. The one-stop brake limit is determined by the total amount of energy a brake is capable of absorbing before failure. The total brake energy is a function of gross weight and true speed. Since the indicated touchdown speed for any gross weight remains constant with altitude and temperature, the corresponding true airspeed increases with an increase in altitude and temperature.

To determine when landing conditions may be critical, obtain a maximum braking speed from figure 9-68. Notice the illustrated effect of flap position, runway slope and headwind on the braking speed, and compare it with the touchdown speed. When maximum braking speed is less than touchdown speed, use the following procedure.

1. Determine a ratio of braking speed to touchdown speed.

$$\frac{\text{Touchdown Speed} \quad 100\%}{\text{Braking Speed} \quad X\ \%} \tag{79}$$

$$\frac{\text{TS } 150 \quad 100\%}{\text{BS } 141 \quad 94\%}$$

2. Obtain a delayed braking factor from the delayed braking factors chart, figure 9-69.
3. Adjust the landing ground roll by applying the delayed braking factor.

Notice on the illustration that the product of the chart ground roll and the delayed braking factor produces the ground roll with delayed braking.

Flare Distance

The amount of flare distance to be used depends upon various factors including flap degrees and braking applications. In figure 9-70, assume an uncorrected landing ground roll of 7,150 feet, 50° flaps, the use of wheel brakes only, and the indicated tailwind component. Observe that the flare distance should be 2,850 feet.

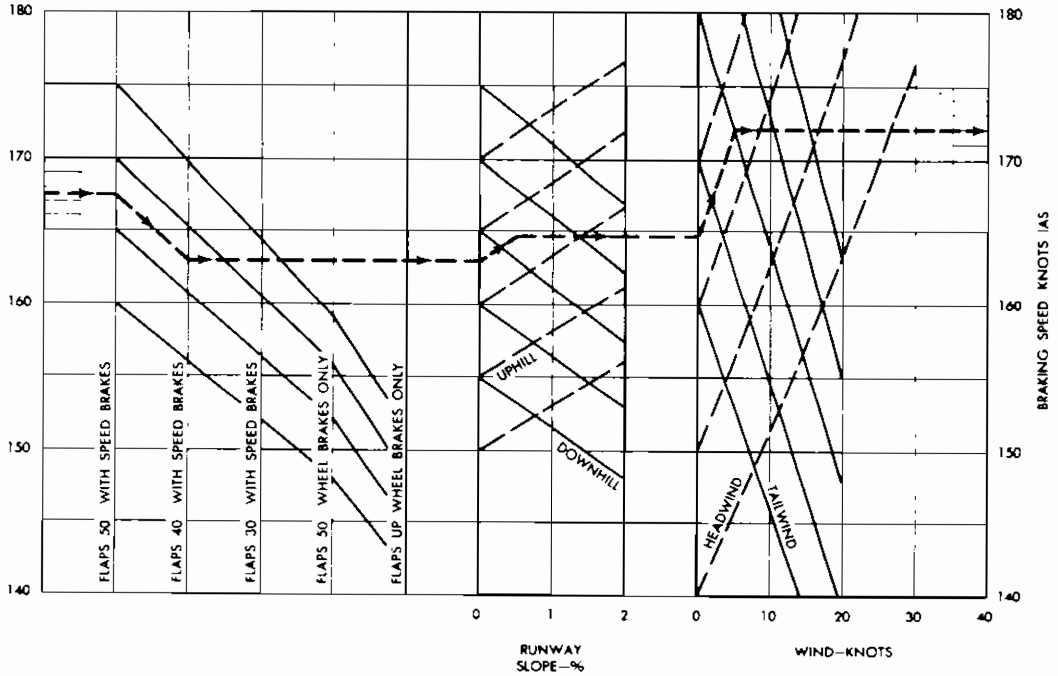


Figure 9-68. Maximum Braking Speed

Go-Around Performance (Reciprocating Engine Aircraft)

Go-around in the event of a refused landing may be performance limited, especially if one engine is inoperative. Generally a go-around on four engines will not be limited by performance unless the aircraft is at a low speed and nearing touchdown. However, the assumption that four engines will continue operating in go-around is not considered a sound procedure. That one engine will quit is a safer assumption. Before a go-around decision is made during an approach with one engine inoperative, careful consideration must be given the situation at the point where go-around would be initiated. Speed, height, existence of obstacles, weather and atmospheric conditions, gross weight, and expected power available should enter into the decision.

The following items should be considered carefully before attempting a three-engine go-around.

- Never attempt to go-around when airspeed is below the minimum approach speeds, even on four engines.
- At the moment a go-around decision is made, maximum power should be applied, wing flaps started up, and gear started up.
- Anti-detonant injection should be used, if available, and cowl flaps should be adjusted.
- The aircraft should be "cleaned up" as soon as possible before attempting another approach.

In computing go-around data, 3-engine data are used to provide the necessary safety factor. Two computations are needed: the best speed for go-around, and the best R/C. This requires the use of two charts: the *go-around data* chart for speed, and the *emergency climb* chart (3-engine) for rate of climb (figures 9-71 and 9-72).

Go-Around Data Chart (Reciprocating Engine Aircraft)

The best speeds for the aircraft configuration described on the takeoff and landing data chart are obtained from the go-around data chart. In using the chart, first determine whether the aircraft performance weight falls below the maximum PGW for 100 ft/min R/C under given conditions. The equivalent performance weight must be less than the one shown on the chart for the given conditions in order to have a successful go-around. Next, enter the chart with the actual gross weight. For example, filling out the TOLD card would require information based on an aircraft weighing 120,000 pounds.

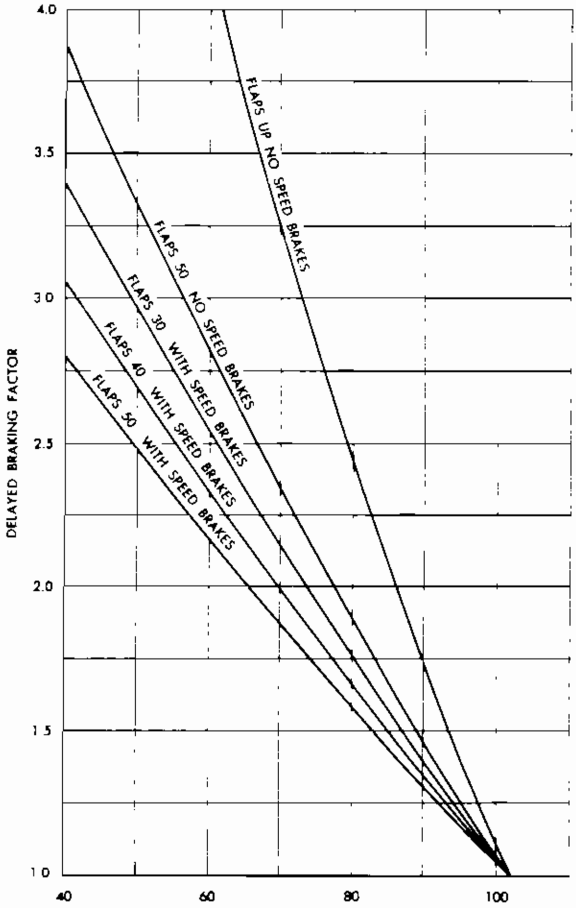


Figure 9-69. Delayed Braking Factors

Under conditions of 3-engine-gear-up-flaps-up, we have a choice of two lines, either line 1 or 2. The intersection of the 120,000-pound line and line 2 shows a minimum climb speed of 135 knots (IAS). However, flying at this slow speed may cause overheating of the engines. By going to line 1, the IAS would be 146 knots (max climb rate speed). Therefore, this faster speed should be used to prevent engine overheating.

Emergency Climb Chart (Reciprocating Engine Aircraft)

The emergency climb chart, figure 9-72, is based on 3-engine, wet power (3500) and standard day conditions and a weight of 150,000 pounds.

Both sea level and standard day rates of climb are shown, and each curve represents a condition as stated in the configuration box at the bottom of the chart. The effects of a windmilling propeller, cowl flap position, and small changes in power are also shown as increments in rate of climb. The purpose of these curves is not to present an absolute performance of the aircraft, since changes in altitude, temperature and engine power all affect the rate of climb, but rather to compare the relative performance in various configurations. Thus, the effects of lowering the landing gear, extending wing flaps, and changing airspeed can be quickly determined in an emergency situation.

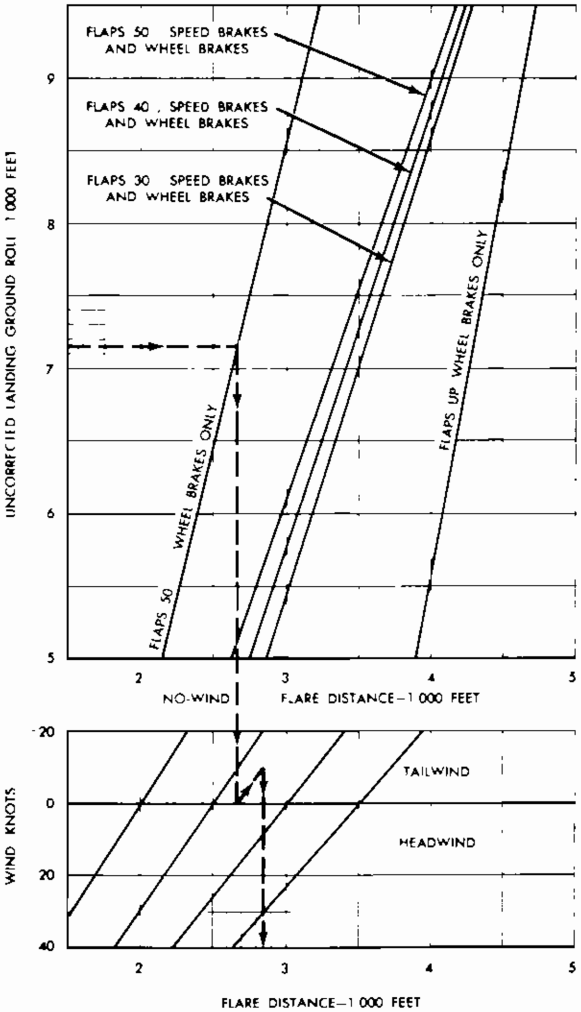


Figure 9-70. Flare Distance

Landing Data Side of TOLD Card

The landing data side of the takeoff and landing data card includes the following information.

Landing Gross Weight. The actual gross weight of the aircraft at the time of takeoff

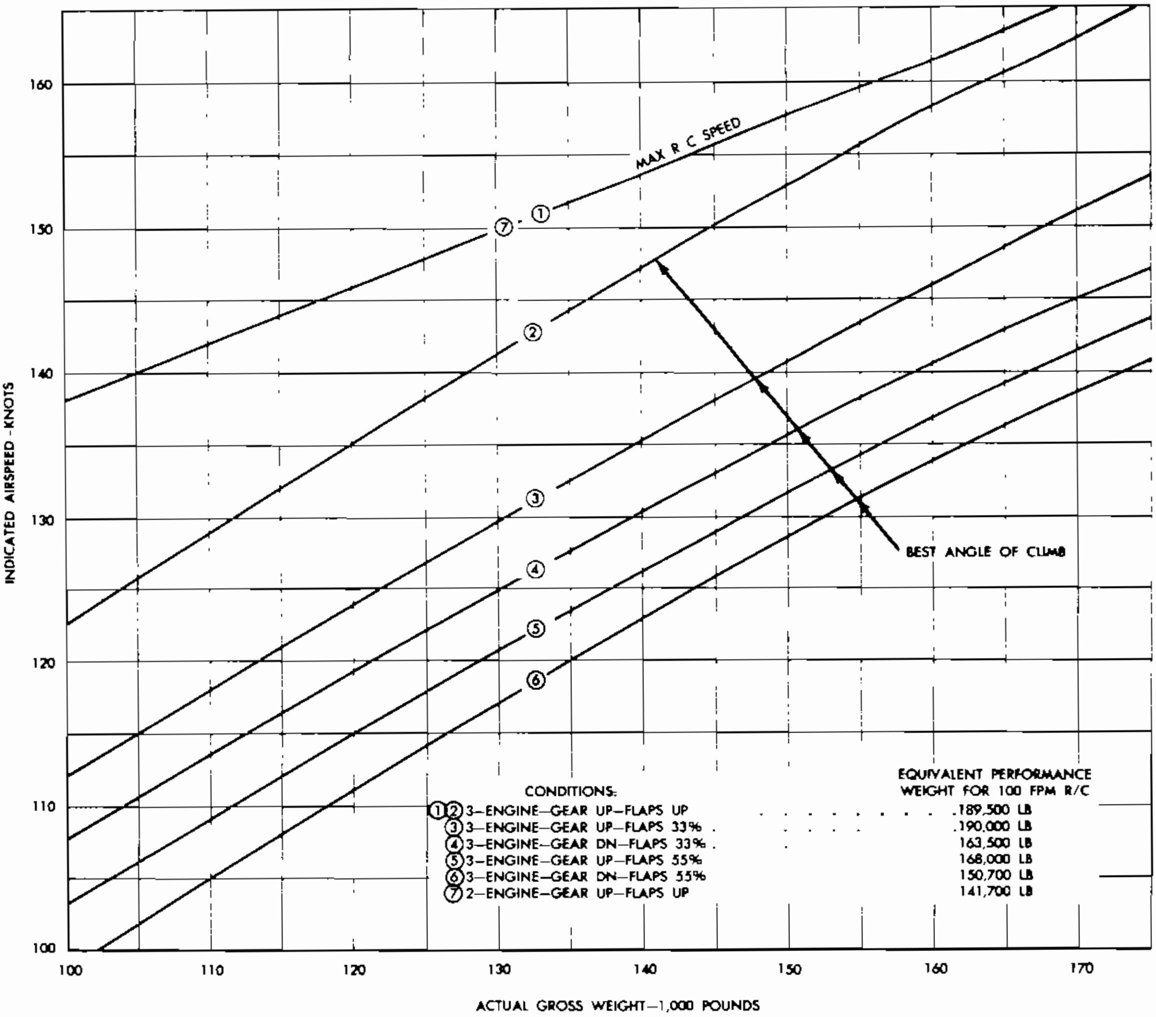


Figure 9-71. Go-Around Data

applies for computations of TOLD card if a landing were required immediately after takeoff. The remaining data are computed for this weight and recommended for each 5000-pound decrease of aircraft gross weight. When making these computations for each 5000-pound loss of weight, the existing atmospheric conditions and height of the terrain must be taken into account.

LANDING DISTANCE. The horizontal distance traveled, in feet, from the point where the aircraft clears a 50-foot obstacle at the approach end of the runway to where the aircraft comes to a full stop using brakes only.

MINIMUM APPROACH-IASK. Minimum indicated airspeed at which the aircraft is flown on final approach (125% of power-off stall speed with flaps fully extended).

GO-AROUND TPSI. Maximum torque reading available in pounds per square inch for go-around.

FLAPS UP-IASK. Indicated airspeed for raising flaps to 0° in the event go-around is required.

2-ENGINE APPROACH SPEED. Indicated airspeed for final approach with two engines operating. Normally recorded as 10 knots above minimum approach speed.

3-ENGINE GO-AROUND DATA. Indicated airspeed for go-around on three engines for the maximum rate of climb or the best angle of climb.

3-Eng Gear Up-Flaps Up. Indicated airspeed for best climb rate.

3-Eng Gear Up-Flaps 55%. Indicated airspeed for best angle of climb.

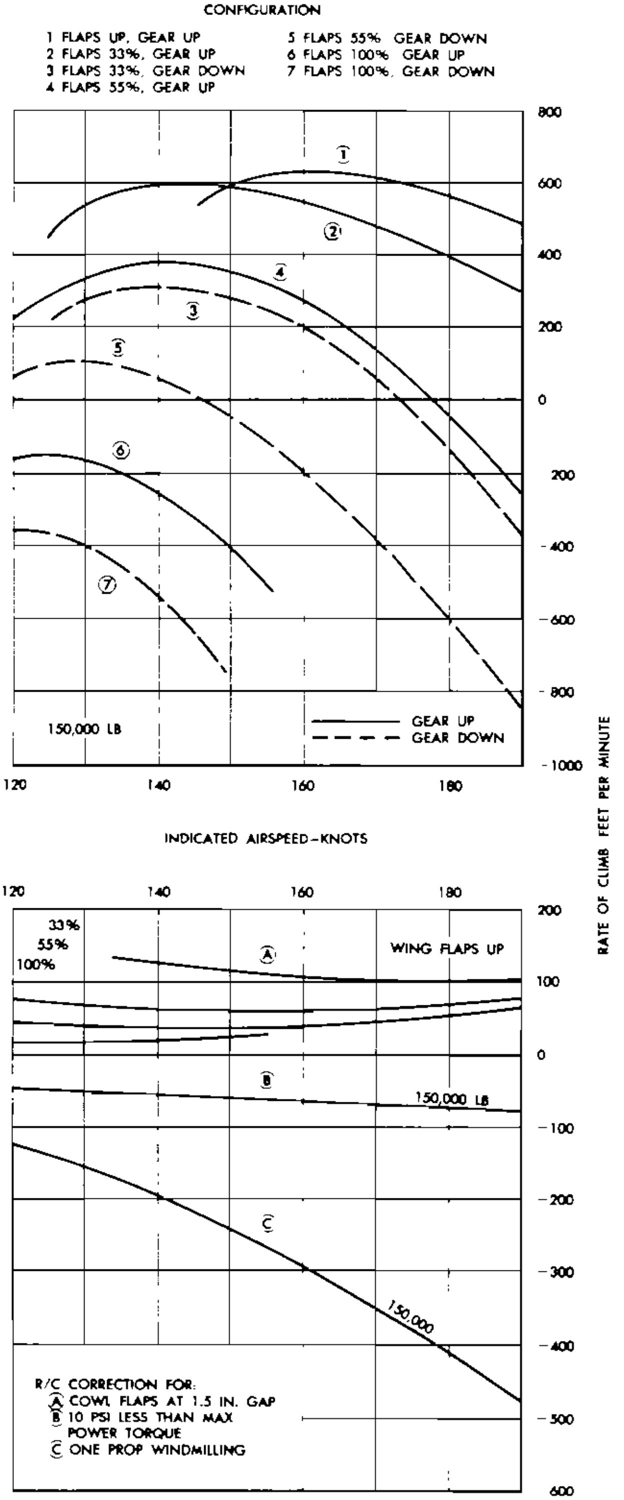


Figure 9-72. Emergency Climb

3-Eng Gear Dn-Flaps 55%. Indicated airspeed for best angle of climb.

2-ENGINE GO-AROUND DATA. Indicated airspeed for go-around on two engines with flaps and gear up for the maximum rate of climb.

NOTE: The airspeeds recorded on the landing card are obtained from the go-around data chart for the existing conditions.

R/C (+ or —). The R/C (+ or —) symbols denote that the equivalent performance weight limits shown on the go-around data chart are greater or less than the aircraft's equivalent performance weight, based on minimum performance torque. If the aircraft EPW is less than the EPW for the condition on the chart, a plus (+) sign is noted on the landing data card for that condition, and if the aircraft EPW is greater than the charted EPW, a minus (—) sign is noted on the landing data card for that condition. Do not attempt a go-around in configuration bearing a minus (—) sign.

FUEL RESERVES

Fuel reserves are additional quantities of fuel, above normal predicted requirements, that provide for abnormal operations such as against headwinds (wind reserve), three-engine operation (three-engine reserve), or unpredicted operation over a destination which causes additional flight time (endurance reserve). After the amount needed for each reserve is predicted, the amounts are added together to obtain the total fuel reserve. This total is included in the gross weight for the entire mission. This is done because, if reserves are not required, they will have to be carried the entire distance of the mission.

When calculating gross weight over destination, the fuel reserve weight must be added to the landing gross weight because the total fuel reserve makes the entire trip. The landing gross weight is the sum of the aircraft basic weight, crew, oil, miscellaneous and trapped fuel, and fuel for landing and taxi. The sum of aircraft gross weight and total fuel reserve gives the predicted ramp gross weight with which the rest of the mission is projected backward to the takeoff.

There is a definite procedure for calculating each reserve in relation to the order in which it is used. For a maximum load mission with a headwind after the equidistant point (EDP), the endurance reserve is calculated first. The three-engine reserve can be figured next, and then the wind reserve can be calculated with the wind reserve formula. If the headwind condition occurs before the EDP, the same order is used except the wind reserve is calculated with the zero wind fuel requirement for the distance the wind is effective.

Endurance Reserve

Unpredicted weather or the need for unusual landing procedure may make it undesirable for an aircraft to land immediately upon arrival at the destination. Therefore, a quantity of fuel which will provide an additional period of flight time at the end of the mission is added to the predicted fuel requirements. This additional quantity of fuel is known as the endurance reserve. Several methods for computing the endurance reserve may be used.

Endurance reserve can be computed from the applicable NMPP chart by using the fuel flow for the power required to maintain the landing gross weight at hovering airspeed for a specified period of time. The time is variable and may be based on a distance to be flown or on a period of time, depending on local policy.

Another method is based on the approximate fuel flow at the final predicted long range power for a specified period of time.

In some cases, the endurance reserve is considered to be the quantity of fuel above predicted requirements (including wind reserve and three-engine reserve) that the permanent fuel tanks are capable of holding. This reserve will vary greatly, depending on the mission, and in many instances will be somewhat in excess of a practical amount, for the purpose of safety.

Local field policy often specifies a given amount of fuel for an endurance reserve. If the home station is equipped with GCA, an additional amount of fuel will have to be added as a part of the endurance reserve. The amount is determined by local policy, which is governed by the number of approaches deemed necessary for each aircraft.

Three-Engine Reserve

Three-engine reserve is the additional quantity of fuel required for three-engine operation that would not be required for four-engine operation for the same distance. In computing three-engine reserve, the EDP is the key point. The justification behind the policy of computing three-engine reserve from the EDP is:

If an engine is lost before the EDP, it is advisable to return to the point of origin. In regard to fuel consumption, the most dangerous point at which to lose an engine is the EDP. If an engine is lost at the EDP, the aircraft has farther to fly on three engines to return to the destination than from any other point. In the event the loss of an engine occurs at or near EDP, the deciding factors as to whether to return to the starting point or to continue to the destination are wind direction and velocity.

To determine three-engine reserve, the fuel required from the EDP to destination on three and four engines must be compared. In comparing the three-engine and four-engine fuel requirements, if it is found that it takes more fuel to fly with three engines than with four engines, a three-engine reserve will be necessary. If it is found that three-engine requirement is less, then there is no additional fuel required for three-engine operation; consequently, no three-engine reserve is required. This condition is possible if the mission or part of the mission from EDP to destination has been predicted for high-speed, high-power, or high-altitude cruises. The three-engine long range fuel requirement may then be less than the four-engine fuel requirement.

When computing the three-engine reserve, analysis is required to determine the most desirable altitude for three-engine operation. By referring to the appropriate three-engine summary curve, a review of the values for various altitudes can be made. It is advisable to calculate the three-engine fuel requirements for an altitude of 10,000 H_p or below, provided terrain and weather conditions permit.

When computing the three- and four-engine fuel requirements from EDP to destination, the three- and four-engine distance prediction curves are used. Although the long range summary curves may be used, the *prediction* curves are more accurate when predicting data for the distances involved from the EDP to the destination. The difference between the actual gross weight at the EDP and the landing gross weight 1,000 feet over the destination will be the fuel required for either three or four engine operation from the EDP to destination. The difference between these equivalent performance weights at the EDP and destination will be the fuel required for three- or four-engine operation from EDP to destination.

For missions that project backwards, such as maximum cargo load or maximum off-load, the EDP gross weight is not known. In such cases, the procedure is to use the predicted landing gross weight at 1,000 H_p (plus endurance reserve) and project backwards on the three-engine prediction curves the distance to the EDP and get the approximate gross weight at the EDP. The difference between the two gross weights is the three-engine fuel requirement. To get the three-engine reserve, the four-engine fuel requirement must also be known. This can be computed in the same manner as given above by using the appropriate four-engine prediction curve at the altitude at which most of the return flights to be flown. The three-engine fuel requirement must exceed the four-engine fuel requirement in order to require a three-engine reserve.

Wind Reserve

Wind reserve is the amount of fuel above zero wind fuel requirements deemed necessary to overcome the effects of headwind conditions which may be encountered during any part of a mission. The effect of tailwind conditions is not considered, because fuel is saved due to the increased ground speed, thereby increasing the ground speed, and consequently increasing the NMPP values. Predicted wind conditions (obtained from the weather office) and the predicted amount of fuel required to cruise a given distance with zero wind conditions provide the basis for computing wind reserve.

True airspeeds are equal to true ground speeds with zero wind conditions; therefore the air miles flown and the ground miles covered during a cruise are equal when there is no wind. When headwind conditions are encountered, true airspeeds are higher than true ground speeds; therefore, more air miles are flown than ground miles. The required time for a cruise in this instance, is based on the air distance at a given true airspeed against a headwind. Thus, more fuel is needed since the fuel requirement for an aircraft is based on fuel flow and flight time. There is a definite relationship between the time required to fly a certain ground distance with zero wind conditions and the additional air distance flown due to wind conditions. This relationship also exists between fuel required to fly the air distance with zero wind and the additional fuel (wind reserve) needed to fly against a headwind. For practical application, this is expressed in the wind reserve formula:

$$\text{Wind Reserve} = \frac{\text{V of HW}_k}{(\text{Avg TASK}) - (\text{V of HW}_k)} \times \text{lbs of fuel (no wind)} \qquad (80)$$

The following predicted data are required to determine a wind reserve for a specified flight distance. (These values are only for the portion of the mission during which the headwind is encountered.)

- Average TASK, zero wind
- Fuel required, zero wind
- Velocity of the wind (speed and direction)
- Distance headwind is effective

The first and second items of the required data may be obtained from information contained in the predicted flight plan, or they may be computed from prediction curves. The third and fourth items are derived from information obtainable at the weather office.

The wind reserve for a mission may be found by calculating a reserve for each climb, cruise, and descent flown against a headwind and totaling those reserves. The average predicted headwind and the average true airspeed with zero wind conditions for each leg are substituted in the wind reserve formula. This average true airspeed is determined from the time and distance data recorded on a flight plan for the mission, provided the mission is not projected backward. The predicted weight of fuel required for each leg of the mission is obtained from the same source.

If the headwind is to be encountered after the EDP and the mission is being predicted backwards, the landing gross weight at traffic altitude and the time and distance prediction curves are used. The landing gross weight at traffic altitude includes a three-engine and an endurance reserve.

Using the time and distance prediction curves, a zero wind fuel requirement and average TAS are found for the distance the headwind is effective. With this fuel requirement, average TASK, headwind in knots, and a wind reserve is found by using the wind reserve formula. If the three-engine reserve is not too great and the headwind is effective from the EDP, the four-engine fuel requirements, found when working the three-engine reserve, can be used as the zero wind fuel requirements in the wind reserve formula. This fuel requirement is used with the time prediction curve to obtain an average TASK. When the headwind is encountered *ahead* of the target, the appropriate fuel requirement and average TASK from the predicted flight plan are used in the formula for the distance the headwind is effective.

Example: (Reciprocating Engine Aircraft) Assume that a maximum refueling mission is being predicted. The mission has been predicted to the refueling point, and now the problem is to predict backwards from the refueling point to the destination. In order to do this, we must know the "ON THE RAMP GROSS WEIGHT." This weight is determined by the sum of the aircraft basic weight, crew, oil, miscellaneous, and the *TOTAL FUEL RESERVE*. Of the above items, all are known except the TOTAL FUEL RESERVE. The problem, then, is to compute the reserves in order to obtain the "ON THE RAMP GROSS WEIGHT" with which the rest of the mission is predicted. Destination is 4,000′ H_p NACA DAY.

From the predicted flight plan, the known items for this mission such as aircraft basic weight, crew, oil, and miscellaneous, are obtained. The following information for this mission is given for computing the reserves: (1) hovering airspeed at 5000′ NACA Day for 1 hour duration, (2) distance from refueling point to destination is 1200 nautical miles, (3) 15 knot headwind encountered from refueling point to destination, and (4) the landing and taxi time is 20 minutes. The altitude at which most of the 4-engine operation is predicted to be flown, from the refueling point to the destination, is 15,000′ NACA Day.

The first reserve to be computed is the endurance reserve which is computed at maximum endurance airspeed and at the landing gross weight (no reserves) 1,000 feet over the destination. This condition is to be maintained for one hour.

Aircraft basic weight	100,000
Crew (5)	1,000
Oil (196 gal)	1,470
Miscellaneous	630
Ramp Weight (no reserves)	103,100
Landing & Taxi Fuel (45/min)	900
Landing GW (no reserves)	104,000

1. Enter the 5,000 foot NMPP chart with 104,000 lbs on the EAS for max endurance line and interpolate for the bhp of 935.

2. Enter the fuel flow per engine chart with 936 bhp on the manual lean line to find 415 lbs/engine and 1660 lbs for the aircraft for one hour.

3. Since the endurance reserve is for one hour, divide 1660 by two to give 830 to one-half the fuel for the period, and add this 830 lbs to 104,000 lbs to obtain the average gross weight for the period.

4. Re-enter the 5,000 foot NMPP chart with 104,830 lbs on the EAS for max endurance line and interpolate for the bhp of 945.

5. Enter the fuel flow per engine chart with 945 bhp to find 420 lbs/engine on the manual lean line and 1680 lbs for the aircraft for one hour. The endurance reserve is 1680 lbs.

The next reserve to be computed is the three engine reserve from the EDP to the destination which is 1200 NM. The landing gross weight 1,000 feet over the destination plus the endurance reserve (104,000 + 1680 = 105,680 lbs) will be used on three- and four-engine distance prediction curves.

1. Enter the four engine distance prediction curve with 105,680 lbs and the 15,000 foot altitude line and project backwards 1200 NM to the refueling point (EDP) to obtain the EDP gross weight of 119,700 lbs.

2. Subtract the 105,680 lbs from the 119,700 lbs to obtain 14,020 lbs, the four-engine fuel required from EDP to the destination.

3. Enter the three engine distance prediction curve with 105,680 lbs and the 10,000 foot altitude line, and project backwards 1200 NM to the refueling point (EDP) to obtain the EDP gross weight of 122,000 lbs.

4. Subtract the 105,680 lbs from the 122,000 lbs to obtain 16,320 lbs. This is the three-engine fuel required from EDP to destination.

5. Determine the three-engine reserve fuel, using the three-engine reserve formula as follows:

3-engine required fuel	16,320
−4-engine required fuel	14,020
3-engine reserve fuel	2,300

The last reserve to be computed is the wind reserve from EDP to destination which is 1200 NM. The landing gross weight 1,000 feet over the destination plus the endurance and three-engine reserves (104,000 + 1680 + 2300 = 107,980 lbs) will be used.

1. The four-engine fuel requirement of 14,020 lbs from the three-engine reserve formula will be used as fuel for "zero" wind in the wind reserve

formula since the winds are in effect for the same distance as the three-engine reserve.

2. Divide 14.020 lbs by two and add the quotient, 7,010 lbs, to 107,980 lbs to obtain the average gross weight of 114,990 lbs.

3. Enter the four-engine summary curve with 114.990 lbs at the 15,000 foot altitude line and obtain an IASK and correct to EASK, or enter the 15.000 foot NMPP chart and obtain an EASK of 170 knots.

4. Multiply this EASK of 170 by the smoe 1.261 at 15.000 feet to obtain the average TASK of 214 knots.

5. Substitute the known values into the wind reserve as follows:

Wind Reserve = headwind in knots divided by the average TASK minus the headwind in knots times the fuel "zero" wind.

$$WR = \frac{15}{214 - 15} \times 14.020$$

Wind Reserve = 1.057 lbs

Now that the three reserves have been computed, the on ramp gross weight may be determined. Add the total of the reserve fuel to the aircraft loading data as follows:

Aircraft Basic Weight	100.000
Crew (5)	1.000
Oil (196 gal)	1.470
Miscellaneous	630
Total Fuel Reserves	5.038
On Ramp Gross Weight	108,138

Note: Local policy may prescribe reserve fuel for heaters, for auxiliary power units, and for possible flight to alternate airports.

Maximum Endurance

Maximum endurance is frequently desired during operations such as rendezvous or instrument holding, or to provide time to check or correct the functioning of aircraft equipment. Maximum endurance charts to establish an EPR for less than 4-engine operation, such as the one shown in figure 9-73, are presented for endurance capabilities of the aircraft at optimum endurance altitudes. Constant altitude endurance data can be obtained from the specific range charts. The endurance summaries can be obtained from the recommended maximum endurance lines shown on the specific range or fuel mileage charts. The charts provide information and data which are required to plan and execute either maximum endurance or best endurance flight for given conditions for two-, three-, or four-engine operation.

Rules For Obtaining Maximum Endurance (Turbofan Engine Aircraft).

1. Fly the altitude specified for the prevailing gross weight and number of engines. These are optimum altitudes for obtaining maximum endurance. However, variations within ±4000 feet will not appreciably affect the overall endurance

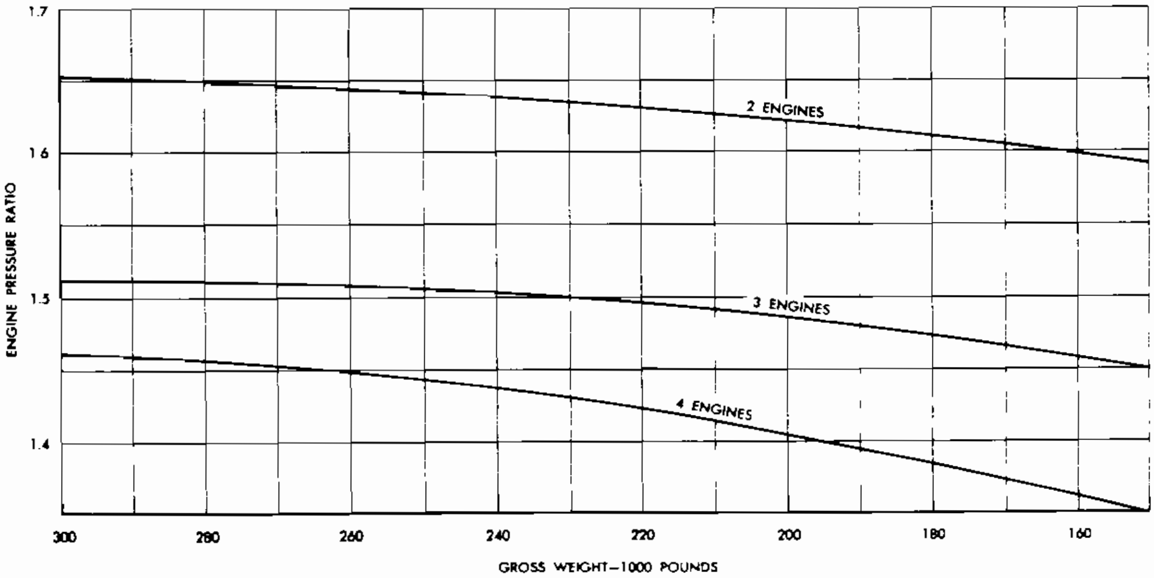


Figure 9-73. Maximum Endurance

time obtained. The effects of flying at an altitude other than that recommended are more critical at high altitudes.

2. Maintain the airspeed specified for the altitude and gross weight. Variations of ±10 knots will not appreciably affect the overall endurance time.

3. Use the engine thrust setting chart (4-, 3-, and 2-engines EPR) to aid in establishing the optimum engine settings for the particular speed and altitude.

4. Keep airplane drag at a minimum by keeping flaps and gear retracted.

5. If it is desired to continue the mission at a high altitude after the endurance operation has been completed, it will be advantageous to conduct the endurance as close to cruise altitude as possible. This will reduce the amount of fuel required to return to cruise speed and altitude. When a decision is to be made regarding whether or not to descend for the purpose of obtaining maximum endurance, the fuel required to descend, to sustain level flight for a given period, and to climb back to cruise altitude must be considered in order to reduce to a minimum the fuel consumed for the overall operation.

Example: (Turbojet Engine)

An aircraft, in clean configuration, operating with four engines is holding for one hour at 10 knots above the chart best endurance speed. The pressure altitude is 24,000 feet; gross weight is 240,000 pounds; temperature equals standard day + 10° C. Find (1) the holding speed and (2) the rate of fuel flow.

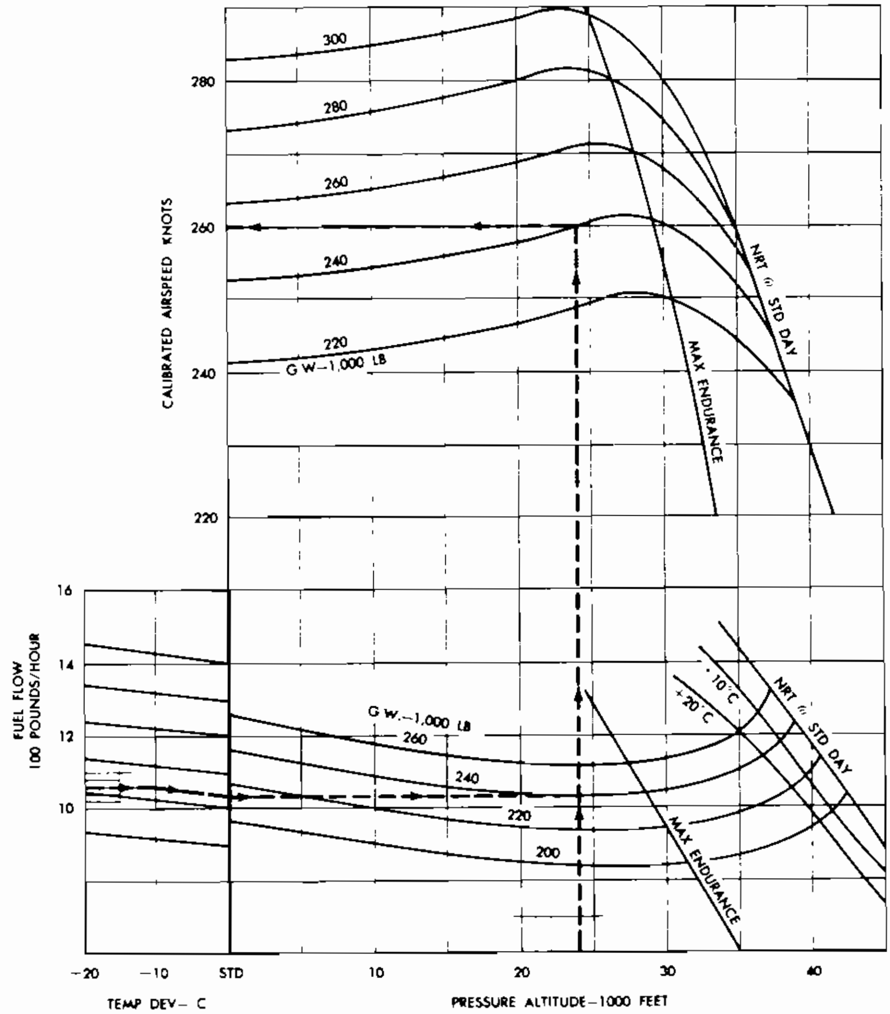


Figure 9-74. 4-Engine Endurance (Turbofan)

For the solution of the problem given, use the chart shown in figure 9-74, Four Engine Endurance, Turbofan.

1. Enter the chart at the bottom with 24,000 feet and proceed vertically to 240,000 lbs on the fuel flow grid. Read to the left and observe the temperature correction to provide 10,300 pounds per hour. Since the aircraft is flying at 10 knots above the best endurance speed, add 200 pounds per hour to the rate of fuel flow above noted. This addition totals 10,500 pounds per hour.

2. Continue up the speed grid at 24,000 feet to 240,000 pounds and read best endurance speed as 259.8 knots and find the speed to be 270.0 knots.

LANDING AND TAXI. The landing and taxi operation commences at the end of the descent, 1,000 feet over the destination. The time for the landing and taxi operation may vary depending on traffic conditions and weather. However, 20 minutes is considered as the average landing and taxi time, and the fuel flow will be predetermined for flight planning purposes. Command requirements or local policy may be in effect.

Since the power setting during landing and taxi will vary considerably, no rpm, MP or bhp are recorded on the predicted flight plan. For each aircraft, a specified average fuel consumption, based on experience, will be assumed as needed for landing and taxi operations. No airspeed is recorded on the predicted flight plan for landing and taxi, and since the operation normally takes place as the airplane circles the destination in the traffic pattern, no distance along course is predicted. *The time for landing and taxiing will be included in the total flight time,* and the fuel required for these conditions will be included as part of the estimated fuel required for the mission. The fuel for landing and taxiing will be added to the "On the Ramp Gross Weight" to give the "Landing Gross Weight" 1,000′ over the destination.

The fuel flows used for turboprop and turbofan aircraft for landing and taxi condition will be obtained from the appropriate flight manual for the aircraft. Special problems relating to the C-141 aircraft are discussed in Chapter 10.