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Flying Training

AIRCRAFT PERFORMANCE

This manual outlines required material for all phases of aircraft performance. It is a source document for the basic flight engineer course. It directs new flight engineers in learning the technical language and practical application related to flight. It furnishes the experienced flight engineers with background and review information. The aircraft performance technology presented in this manual is not limited to one specific airframe. For the most part, the technical language, performance charts, and procedures are common to all transport aircraft. There are two major factors that are responsible for the differences. These are a specific aircraft's design and the way different aircraft manufacturers construct performance charts and procedures to support that design. These factors may make a given performance limitation critical for one aircraft and insignificant for another. The material contained in this manual provides information relative to the duties of the flight engineer, the atmosphere, aerodynamics, power plants, weight and balance, and aircraft flight performance. It also includes guidelines for mission planning. This manual applies to the Air National Guard and the US Air Force Reserve units and members.

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Chapter 1

DUTIES OF THE FLIGHT ENGINEER

1-1. The Flight Engineer's Role and Skill. The flight engineer is vital to the operation of the larger, more complicated aircraft. The qualified flight engineer should have a wide mechanical background to perform the duties for this operation. The flight engineer must understand engines thoroughly, from both a theoretical and operational standpoint. The flight engineer must understand how the instruments and gauges of an aircraft work and know the limitations. He or she must be familiar with each of the complicated auxiliary systems and know the limitation of each. Accordingly, this manual addresses aircraft performance and flight engineer duties.

1-2. Ground Duties:

a. The flight engineer's ground duties are many and varied due to rank and position assignment. Although squadron and command level duties vary, it is a universal and continuous requirement to stay current on directives, technical orders, operational policies and procedures. The qualified flight engineer must maintain proficiency in the aircraft simulator and attend ground schools and refresher courses; perform numerous ground duties before takeoff, and continue these duties once the aircraft is back on the ground.

b. The flight engineer's ground duties before each mission begin with premission planning. These duties consist of flight plan preparation or computerized flight plan coordination, and computing takeoff and emergency landing data. The engineer coordinates with maintenance personnel on aircraft status and with aircraft loading personnel on load and center of gravity. The engineer performs a power "on" and power "off" preflight or thruflight.

c. On the ground, the flight engineer's main responsibility is to check aircraft condition and to perform systems operational checks. Also to bring to the attention of maintenance personnel any irregularities in systems operations for adjustment and repair. Negligence in performing any of these very important duties could jeopardize the mission and even result in the loss of the aircraft and crew.

1-3. Flight Duties:

a. Flight duties are similar, or even the same in some cases, to ground duties. But, ground emergency procedures are generally different from flight procedures. Flight duties begin once the condition of the aircraft is determined and the crew has accepted the aircraft. Normally, and in most aircraft, the engineer position must be occupied during all phases of ground and air operations.

b. Crew coordination is always very important. The engineer must be able to handle any system malfunction and assist the pilot in making any decision that could have an effect on the accomplishment of the mission.

c. Before engine start, the engineer must calculate and the pilot must check aircraft performance data. Each crewmember must be in their primary flight position. If there are two flight engineers, one may be on the ground for engine start and the other at the systems panel.

d. The pilot starts the engines in accordance with flight manual (-1) procedures, and the engineer observes each engine for irregularities. Normally, as the last engine starts, the engineer records this time and other information in his or her command performance log. When there are two engineers, the engineer on the ground clears each engine for engine start and checks to see that everything on the ground is clear before boarding the aircraft.

e. Taxi and operating time before lineup on the runway is critical. The engineers uses this time to perform any last-minute operation or to make any decision before takeoff roll.

f. The flight engineer must be extremely alert during takeoff and must take appropriate action should an emergency arise. With the takeoff a success, the flight engineer will continue to monitor systems operation and engine power, and update performance data throughout the climb to the assigned cruise altitude.

g. The duties continue during cruise: updating performance data, logging data, monitoring system operation, and before descent, computing landing data based on current conditions. The landing conditions could be critical and often require extensive performance computations. The aircraft commander and crew will base their decision to land or fly to their alternate on the engineer's computations.

h. The flight engineer must perform extensive flight duties in a professional manner. These duties are not complete until the aircraft is safely on the ground and maintenance personnel are briefed on the aircraft conditions and any discrepancies.

1-4. Maintenance Knowledge:

a. The competent flight engineer has good working knowledge of maintenance procedures. This knowledge can save hours of maintenance crews' time by diagnosing trouble as it occurs and reporting it to maintenance personnel on landing. The engineer has a technical background which enables him or her to recognize the probable cause of trouble much more readily than the pilot. The engineer can give a more detailed report of the symptoms. At times, by radioing this report ahead, parts will be ready, and work can start immediately after the aircraft lands.

b. The requirement to make inflight repairs still exists, and sometimes an engineer can make a temporary repair or isolate the malfunction. The flight engineer does not perform extensive maintenance; that is for specialists. Maintenance knowledge helps the flight engineer coordinate with maintenance personnel and in making emergency repairs.

c. The flight engineer uses maintenance and system knowledge during ground and flight duties. The safety and welfare of the aircraft and the crew often depend directly on the engineer's knowledge, experience, and the skill with which he or she discharges his or her duties.

1-5. Terminology. Since the flight engineer records much of the flight data in the form of symbols, abbreviations, formulas, and special terms, he or she must master this terminology. He or she must do so to thoroughly understand the publications and reports about aircraft operations and maintenance. Attachment 1 contains terminology, which is standard for most aircraft and used throughout the remainder of this manual.

Chapter 2
FLIGHT ENGINEER MATHEMATICS

2–1. What This Chapter Covers. This chapter covers only the areas of math a flight engineer might use during daily duties. It gives a brief explanation of each procedure accompanied by a typical "word problem" and a longhand form for study.

2–2. Math and the Flight Engineer. Numbers play an important part in the everyday duties of a flight engineer. Almost daily in a flight engineer's normal transactions and without giving the matter much thought he or she must add, subtract, multiply, divide, use decimals, and percentages. And most often he or she does it better than realized! Further, math is important to the flight engineer because ever since the beginning of "crew" flight, pilots have been asking; how much, how many, how far, how long, and so on. This required a flight engineer to deal with numbers accurately and quickly, in order to answer these questions properly. To do so, many flight engineers employ the use of calculators, as they are very fast and, if used correctly, very accurate. However, their answers depend on two very important points. The flight engineer must:

(1) "Plug in" the correct numbers.

(2) Mentally convert the results into a usable form. Both points require understanding of the task, and this chapter will increase that understanding.

2–3. Working with Whole Numbers:

a. Very large numbers are not needed in our daily work, but inflight performance manuals we often find large numbers that should be easy to read and understand. These numbers are in Arabic Notation, which we use exclusively in our calculations.

b. Arabic Notation involves the following ten figures, digits, or symbols; whichever term you may want to use to represent their names:

0 1 2 3 4 5 6 7 8 9

or

zero one two three four five six seven eight nine

c. One can use these ten digits in any combination, using one or more at a time as may be necessary to represent a given number of items. Express all numbers using the above ten digits, including zero which has no "value" alone, but merely fills vacant places within a number.

d. A digit has different values depending upon the location or "place" it occupies in a number. The word "place" in numbers has a special meaning shown in figure 2-1, which gives the names of the different places in numbers.

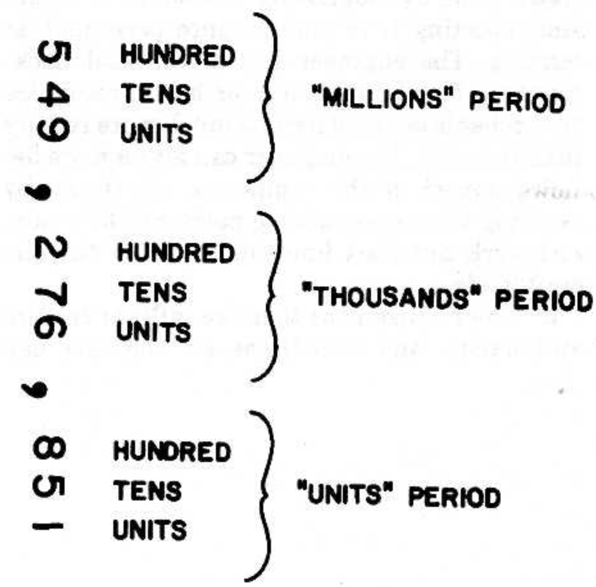


Figure 2-1. Working with Whole Numbers.

e. In figure 2-1, each group of three figures is called a "period" and each period is separated from the other periods by a comma. This structure enables us to read very large numbers. The number in figure 2-1 reads as follows: "five hundred forty-nine million, two hundred seventy-six thousand, eight hundred fifty-one." Carefully review this so you understand it thoroughly.

f. In figure 2-1, the period at the right end (851) is the "units period" while the second period (276) is the "thousands period" and the third period from the right (549) is the "millions period." This figure does not show the higher numbers because flight engineers rarely work with numbers larger than millions.

g. It's always helpful to read each figure in a period according to its position within the group, then look at the name of that "period" at the end of the group. Period names indicate the location of the digits in regard to the units place. For instance, the number 125,000,001 reads, "one hundred twenty-five million, one." Zeros merely fill vacant spaces, but do locate the digits 125 in the million period. The following are examples of numbers and how they are read:

1,003,500 = One million, three thousand, five hundred
800,010 = Eight hundred thousand, ten
87,109 = Eighty-seven thousand, one hundred nine
6,000 = Six thousand
4,120 = Four thousand, one hundred twenty

2–4. Addition:

a. Recall that uniting two or more numbers to make one number is addition. The result obtained by adding two or more numbers is the "sum." The sign "+" (read "plus") shows addition.

b. Note that addition is the most common operation in mathematics. Almost everyone knows how to add money.

EXAMPLE: If you have $17 and earn $7 more, and add them together, you find the total amount (sum) is $24.

c. Only add quantities of the same kind. Do not add dollars and gallons or automobiles and airplanes together by simply adding the numbers. The addition of 205 dollars and 110 gallons would give the sum of 315, but this would be neither dollars or gallons. The answer is a worthless sum that has no real meaning.

d. To avoid making serious mistakes when adding longhand, write the figures in straight, vertical columns. Place all the units in each of the numbers in the units column, all the tens in the tens column, all the hundreds in the hundreds column, and so on. This is one-time neatness counts!

e. When adding real things, remember the answer should contain the name of the things added. Thus, 10 pounds + 8 pounds = 18 pounds (10 lbs +8 lbs = 18 lbs.); 7 miles + 5 miles = 12 miles (7 mi+5 mi = 12 mi). Follow this rule to the letter to avoid errors in addition, subtraction, multiplication, and division.

f. Learn to check answers to make sure your problems are correct. This is important, especially in practical work. A good way to "prove" an answer in addition is first add the numbers upward and then recheck the sum by adding the numbers downward. The work is probably correct if the two sums agree. Adding downward simply changes the order of the digits. Any error in the first addition you would likely find in the second.

g. Remember, it is not difficult to add when you have the numbers. A flight engineer seldom has this situation. Most of the time the problem is in the form of a question. This requires deciding on the process to find the answer. Quite simply, solving "word problems" is the primary mathematical task of the flight engineer.

EXAMPLE: How much will a 148,461 pound aircraft weigh after being loaded with 77,500 pounds of fuel and 46,172 pounds of cargo?

(148,461 + 77,500 + 46,172 = ?)

OR:

```
  148,461 pounds
   77,500 pounds
 + 46,172 pounds
 ---------------
  272,133 pounds
```

2–5. Subtraction. Subtraction is simply the opposite of addition. Instead of combining numbers, we take one number away from another. If we have $24 and spend $7, we have $17 left. This is the process of subtraction. As in addition, the quantities of the numbers being subtracted must be of the same kind. Remember:

a. The number from which you subtract is the "minuend".

b. The number being subtracted is the "subtrahend".

c. The result or the answer is the "difference" or"remainder".

d. The sign " - " (read "minus") shows subtraction.

EXAMPLE: An aircraft uses only 3,640 feet of a 10,000-foot-long runway during take off roll. How much runway was not needed?

(10,000 - 3,640 =?)

OR:

```
  10,000 feet
 - 3,640 feet
 ------------
   6,360 feet
```

2–6. Adding and Subtracting Positive and Negative Numbers:

a. In a few instances the flight engineer must deal with positive and negative numbers. The more common situations are: when computing the temperature deviation from standard day and when computing the effects of negative field elevation to total distance to climb.

b. Numbers that have a value because of their distance from a given starting point (usually "zero") are positive and negative numbers. The Centigrade thermometer in figure 2-2 is an excellent illustration of positive and negative numbers. Those values above the "zero" point are positive and values below "zero" are negative.

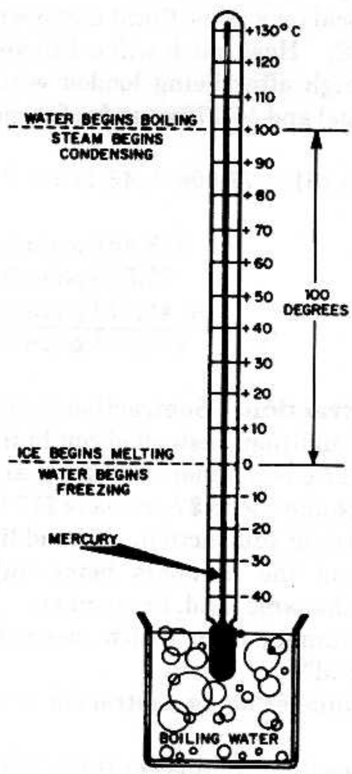


Figure 2-2. Celsius (Centigrade) Temperature Scale.

c. The difference between a positive and negative value on the scale will equal the total units between them. To avoid having to graphically find these differences, remember the following procedural rules:

Rules for adding positive and negative numbers are:

1. The sum of positive numbers is positive.

2. The sum of negative numbers is negative.

3. To add a positive and negative number; find the difference in their actual values and give the difference the sign (+ or -) of the larger number.

d. The rule for subtracting a positive and negative number is: *Change the sign of the subtrahend (the number subtracted from another), then proceed with the rules of addition.*

EXAMPLE: The actual outside air temperature (OAT) is -40 degrees C (actual OAT: -40° C). The International Civil Aviation Organization (ICAO) chart shows -57° C as the standard day temperature for our altitude. What is the current deviation from standard day temperature?

NOTE: In any temperature deviation math problem, the standard day temperature is subtracted from the outside air temperature.

FIRST:

(minuend) -40 Actual Outside Air Temperature
(subtrahend) (-) -57 Standard Day Temperature

THEN:

-40
+ 57 (following subtraction rule)
+ 17 (following rule 3 of addition)

e. The amount the outside air temperature varies from the standard day temperature (deviation) is + 17° C. In other words, it is 17 degrees "warmer" than it would be on a standard day.

EXAMPLE: Field elevation is -980 feet Mean Sea Level. After takeoff we are going to climb to an altitude of 35,000 feet, what will be the total distance we will climb?

NOTE: In climb distance problems field elevation is subtracted from the final altitude.

FIRST:

+ 35,000 feet
(-) - 980 feet

THEN:

+ 35,000 feet
+ 980 feet
+ 35,980 feet

2-7. Multiplication:

a. Multiplication is nothing more than a shortcut for addition. It is the process of adding one number as many times as there are units in the other number.

Multiplying 2 X 4 is the same as adding 2, 4 times (2 + 2 + 2 + 2 = 8).

b. Terms used in multiplication are:

(1) The sign "X" (read "multiplied by") shows multiplication.

(2) The number multiplied is the "multiplicand."

(3) The number you "multiplied by" is the "multiplier."

(4) The result of the multiplication is the "product."

c. Normally, the larger of the two numbers used in multiplication is the multiplicand and the smaller the multiplier. This simplifies calculations.

d. When numbers in a multiplication problem accompany some unit of measurement such as miles, pounds, inches, etc. the units of measurement must be in the product of the problem. For example, if the problem was 6 pounds X 4 pounds, then "pounds" must appear in the product (24 pounds).

e. If the unit of measurement associated with the multiplicand and the multiplier are different terms. Both measurements should appear with the product separated by a "/" mark. Normally, the measurement or term related to the multiplicand would appear first.

EXAMPLE: 6 inches X 4 pounds = ?

```
OR:      6  inches (multiplicand)
       x 4  pounds (multiplier)
        24  inches/pounds (product)
```

f. To check multiplication, use the multiplier as the multiplicand and the multiplicand as the multiplier. In other words, swap the number's position in the problem. The products should be the same; if not, there is an error. For example, 6 X 4 = 24. Swapping the numbers; 4 X 6 = 24. Both products agree so 24 is the correct answer.

EXAMPLE: An aircraft maintaining a speed of 435 nautical miles per hour, how far will it travel in 12 hours? (435 X 12 = ?)

```
OR:     435  nautical miles per hour
       x 12  hours
        870
       435
      5,220  nautical miles
```

NOTE: Like terms appearing in both numbers of a problem are "understood" in the product, and the unlike term is set down with the answer. Thus, "hours" in the above problem need not appear, while "nautical miles" appears in the final answer.

g. The multiplication process is simplified if one of the factors is in even tens, hundreds, etc. Use the factor containing the zeros as the multiplier, placing the zeros below and to the right of the units place of the multiplicand. For example, 100 X 12; use 100 as the multiplier and 12 as the multiplicand, as shown here.

EXAMPLE 1: (100 X 12 = ?)

```
OR:      12  (multiplicand)
      x 100  (multiplier)
       1200  (product)
```

NOTE: The zeros were brought straight down into the product, then proceeded by the product of 12 X 1 or 12.

EXAMPLE 2: If each engine of a four engine aircraft is using 2,000 pounds of fuel per hour, how many pounds of fuel per hour are all engines using? (2,000 X 4 = ?)

```
OR:          4  number of engines
       x 2,000  pounds of fuel for each engine
         8,000  pounds of fuel for all engines
```

2-8. Division:

a. Division is the process of finding how many times one number contains another, the reverse of multiplication. If 7 X 8 = 56, then 56 divided by 8 = 7 or 56 divided by 7 = 8.

b. Terms used in division are as follows:

(1) A line between numbers shows division. (6 / 2)

(2) The number you divide is the "dividend."

(3) The number you "divide by" is the "divisor."

(4) The result or answer is the "quotient."

(5) The part left over when the quotient is not exact is the "remainder."

c. The two methods of division, short and long division, are not being discussed at great length here since most of us use calculators. Following is one example of short division for study.

EXAMPLE: Five crewmembers' baggage weigh a total of 721 pounds. If each individual's baggage weighs the same, how many pounds does each have? (721 / 5 = ?)

```
OR:               144  r1/5 (quotient)
   (divisor)  5 ) 721  (dividend)
                  5
                  22
                  20
                   21
                   20
                    1  is"r" (the remainder)
```

Each crew member had 144 and one-fifth pounds of baggage.

d. When the divisor and dividend contain zeros, a short cut is taken to solve the problem. Simply drop as many zero places in the dividend as we do in the divisor.

EXAMPLE 1:

80 divided by 10: 8 divided by 1 (zeros dropped) = 8
10,000 divided by 100: 100 divided by 1 = 100
30,000 divided by 1,000: 30 divided by 1 = 30

EXAMPLE 2:

An aircraft traveled 1,200 miles and used 1,000 pounds of fuel. How many miles were traveled for each pound of fuel?

(1,200 divided by 1,000) : (12 divided by 10)

```
OR:          1  r 2/10     OR: We could say the
         10 ) 12           correct answer is 1.2
              10
              --
               2  is the remainder
```

2-9. Fractions:

a. Earlier we mentioned whole numbers and how you read them. Now we will go a step beyond that and discuss "parts" of whole numbers. Numbers like 3, 5, 18, 25, etc. are whole numbers. If we talk about any amount less than a whole number then we are using "fractions."

b. In explaining the meaning of the words "parts or part" of a whole, the most clearly understood example is that of a whole, undivided apple. If you cut the apple into 4 equal pieces, it is no longer a whole apple and each of the pieces become a "part" of the whole apple. Think of this manual you are reading. The whole book contains around 150 pages and each page is a part of the whole. Each page would represent 1/150th of the book. The "parts" we have been thinking about are given names depending on the number of total parts.

c. To review, think of the apple we cut into 4 equal parts. Each of these 4 parts is one part of the apple. Each of the parts is one-fourth of the apple because there are 4 parts. Anything divided into a certain number of equal parts, we call each part "one/(total number of parts)." The word fraction itself means small or one of a whole number. The apple we have been discussing is a whole, just like 12 or 86 is a whole number.

d. When we divide the number 1 into any number of equal parts, we cannot see those parts as we could see the parts of the apple. When we think of the number 1 being divided into parts, we have to see these parts in our minds. In an effort to imprint this visual mental picture, let's go through a clear illustration of the division of the number 1. Figure 2-3 is a square we will let represent the whole number 1.

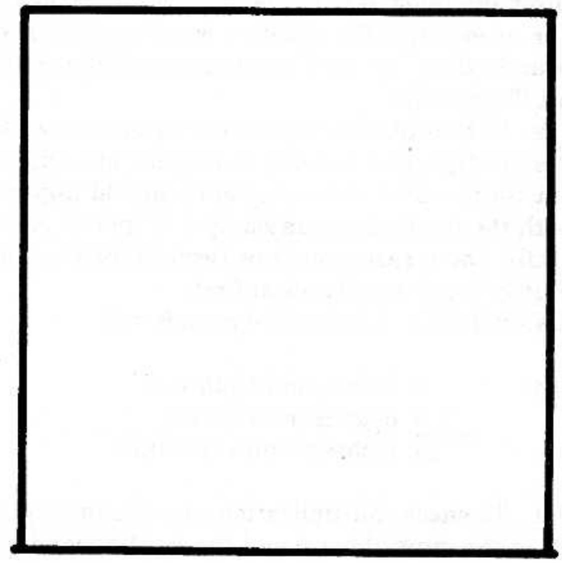


Figure 2-3. Fractions--Square Representing 1 as the Whole Number.

e. Now we divide the same square into two equal parts in figure 2-4 and each part is "half" of the square so each part is "one-half."

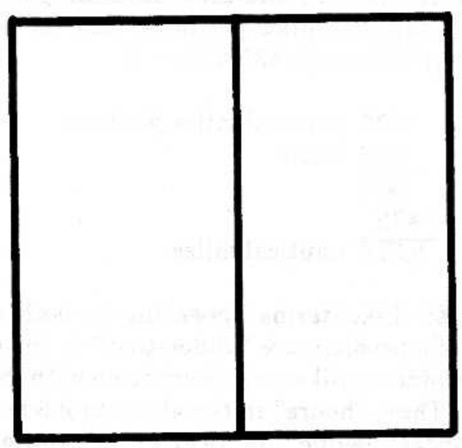


Figure 2-4. Fractions--Square Representing Two-Halfs.

f. Continuing with the same square, we divide even further into four equal parts in figure 2-5 and each part is "one-fourth."

g. We could go on dividing the square into more and more equal parts. This shows that the number 1 or any whole number can be divided into any number of equal parts. Each figure shows that each part is a fraction of the whole square, the square representing the number 1 or any whole number.

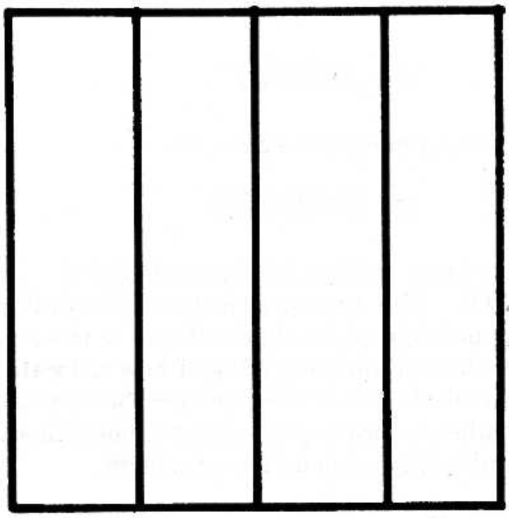


Figure 2-5. Fractions--Square Representing Four-Fourths.

h. A much shorter and simpler way to write these same fractions is to use only numbers. For example: write "one-half" as 1/2 and "one-fourth" as 1/4.

Each part of a fraction has a name. Study the following illustration and remember their names:

one-half is the same as:
(numerator) 1/2 (denominator)

Or as more commonly used:

$$\frac{\text{(numerator)}}{\text{(denominator)}}$$

i. The portion above the line is the numerator and represents the number of parts of the whole being considered. The portion below the line is the denominator and represents the total number of divisions of the whole.

j. The flight engineer does not deal with fractions a great deal, but understanding them clearly, lays the groundwork for solving more complex problems such as ratio and proportion.

2-10. Decimals:

a. The beginning of this chapter dealt with whole numbers and the meaning of a figure due to its location in the number. We saw that a figure in the tens place is just ten times the figure in the units place. The figure in the hundreds place is ten times the digit in the tens place, and so on. A digit moved to the left, place by place, increased its value ten times for each place moved.

b. A decimal point is placed or imagined to the right of the units place of any whole number. Any value to the right of the decimal place represents a fraction of the single unit or value of a whole number. If we move a digit to the right of the decimal point, place by place, we "decrease" its value ten times for each place moved! As an example, the number .6666 is the sum of the following numbers:

	.0006	six ten-thousandths
	.006	six thousandths
	.06	six hundredths
+	.6	six tenths
	.6666	six thousand six hundred sixty six ten-thousandths

c. A decimal, or decimal equivalent is a fraction having either 10, 100, 1000, or any other multiples of ten as a denominator. For example:

.5 means 5/10 which is read "five tenths"
.25 means 25/100 which is read "twenty-five hundredths"
.755 means 755/1000 read "seven hundred fifty-five thousandths"

d. When there is no whole number preceding the decimal, as in the examples above, the quantity is a "pure decimal." Where the decimal accompanies a whole number it is a "mixed decimal." A number like 3.75 reads "three point seven five" or "three and seventy-five hundredths."

e. Probably the best illustration of the use of decimals would be the US monetary system. The dollar is the basic whole unit of the system and divides into 100 divisions called cents. Each cent is one hundredth of the whole dollar or $.01. Twenty-five cents is the decimal $.25 and represents the fraction 25/100. If the fraction is reduced to its lowest term, it would be 1/4 (one quarter).

f. To convert any fraction to a decimal, one would simply divide the numerator by the denominator. For example, converting to a decimal is 1 divided by 4 = .25!

g. To add and subtract decimals, one would place the decimal points in a column, add or subtract as if it were whole numbers, place the decimal point directly below the decimal column in the answer.

EXAMPLE: An aircraft climbs for .3 hours, cruised for 6.7 hours and took .2 hours to descend to landing. How long did the aircraft fly? (.3 + 6.7 + .2 = ?)

OR:		
	6.7	hours
	.2	hours
	+ .3	hours
	7.2	hours total

EXAMPLE: The leading edge of an aircraft wing is 858.9 inches from the nose of the aircraft and the center of gravity is 928.43 inches from the aircraft nose. How far past the wing leading edge does the center of gravity extend? (928.43 - 858.9 = ?)

OR:		
	928.43	inches; center of gravity
	- 858.90	inches; leading edge
	69.53	inches past leading edge

h. Multiply decimals as you would whole numbers. To locate the decimal in the answer, begin at the right of the product and count off toward the left the same number of decimal places that are in the two numbers being multiplied.

EXAMPLE: An aircraft is covering a distance of .125 miles for each pound of fuel it burns. How far will it go on 484.8 pounds of fuel? (484.8 X .125 = ?)

OR:		
	484.8	(1 decimal place)
	x .125	(3 decimal places)
	24240	
	9696	
	4848	
	606000	(product) now mark off 4 decimal places and the answer is 60.6000 (60.6) miles!

i. In division, we treat decimals as we do whole numbers. To locate the decimal point in the answer (quotient), move the decimal place in the divisor (the number we are dividing by) all the way to the right, making it a whole number. Next, move the decimal place in the dividend (the number being divided) the same number of places to the right as moved in the divisor. The decimal in the answer is located directly above the moved decimal place in the dividend.

EXAMPLE: An aircraft is covering a distance of .136 miles for each pound of fuel burned. How much fuel do we need to cover a distance of 3,673.5 miles? (3,673.5 / .136 = ?)

OR:

$$.136\ \overline{)\,3673.500}$$

THEN: by moving the decimal,

$$136\ \overline{)\,3673500.00}$$

The answer is 27,011.029 pounds of fuel.

NOTE: The extended, drawn out solution to this problem is not depicted due to the simple fact that an understanding of how to locate the decimal place was the objective. Most of us use calculators locating the decimal point in either a multiplication or division problem.

2–11. Percentage:

a. Percentage is the name given to a group of rules and methods used when computing in fractional parts called "hundredths." The expression "percent" refers to the number of hundredths. For example, if we think of 50 cents we would say this represents 50% of the whole dollar. Fifty parts of the whole 100 are being considered. The percentage symbol is " %. "

b. Equivalents are those values, a fraction, decimal, etc. which represent equal amounts. The process of converting numbers to percentages is nothing more than depicting a value in an equivalent "percentage" form. Review the examples below, which represent the relationship of equivalents.

1/2 = (1 divided by 2) = .50 = 50% = 50/100, etc.
1/4 = (1 divided by 4) = .25 = 25% = 25/100, etc.

c. To convert a decimal to a percent, one simply moves the decimal point two (2) places to the right. For example, .25 with the decimal moved two places to the right would be 25. and represents 25% (.25 X 100) or 25/100.

d. To convert a percent to a decimal, one moves the decimal point two (2) places to the left. For example, 50% is understood to be 50.%, so moving the decimal place two places to the left we have .50 % and once the decimal is moved the percent sign is dropped giving us .50!

e. Many times the flight engineer deals with percentages which are larger or smaller than 100. Values like 4%, 10%, 85%, etc., are less than the whole, which in percentages is of course 100%. As decimal equivalents they would be .04, .10, .85, etc. being less than the whole 100. Values above 100% represent more than 1 whole unit. Thus 104%, 110%, 150%, etc., mean 1 whole amount plus the shown amount of another whole. Take the 104% for example, it means 100% plus 4% more or 100/100 + 4/100. Here we have 1 whole unit and a fractional part of another. In writing 104% as a decimal, we move the decimal place as mentioned earlier giving us 1.04 (104 divided by 100).

f. To find the percent of any quantity, convert the percent to a decimal and multiply the two factors. Place the decimal in the product as described in the discussion on multiplying decimals.

EXAMPLE 1: A turbine engine is turning at 6,826.2 revolutions per minute (RPM) at 100%. How many RPM will it be turning at 85%? (6,826.2 X .85 = ?)

```
OR:  6,826.2  RPM (100%)
        x .85  (85%)
      341310
     546096
     5,802.2-  RPM (85%)
          70
```

EXAMPLE 2: An aircraft's total range is 5,782 miles. A higher altitude would increase our range by 4%. What would be the range at the higher altitude? (5,782 X 1.04 = ?)

```
OR:     5,782  Miles
       x 1.04  (4% increase)
        23128
        0000
       5782
     6,013.28  Miles/4% increase
```

2–12. Rounding Off. Ironically "rounding off" is a much misunderstood process and, hopefully, this section will clear up the confusion. To round off a number:

a. Select the digit to be retained (nearest tenth, whole unit, hundredth, etc.) and if the number to its right is 5 or more, increase the value of the digit to be kept by 1, then drop all remaining numbers to the right. If the number to the right of the digit to be kept is 4 or less, leave the digit "as is" and drop all the numbers to the right.

EXAMPLE 1:
0.1414 rounded to the nearest thousandth is 0.141
475 rounded to the nearest hundred is 500
3.147 rounded to the nearest tenth is 3.1

b. Do not treat the rounding off process as a "chain reaction!" Many people are under the false conception that numbers are rounded by starting at the right and rounding each number off toward the left until the selected number is reached. This is incorrect! For example, if this incorrect method is used on the number 3.147, shown in the example above, the result will be 3.2 not the correct value of 3.1.

EXAMPLE 2: Round off 5.547986 hours to the nearest hundredth of an hour. The "7" occupies the position immediately to the right of the hundredth digit. Since it is more than 5, we increase the value of the hundredth digit (4) by 1 and it becomes "5," then drop all numbers to the right. The correct answer would be 5.55 hours.

2–13. Ratio:

a. We are continually making comparisons between things in our everyday life. Many of these comparisons are in numerical terms, comparing one number to another. Some typical examples may be comparisons made between automobile prices, time, ages, sizes, units of measure, etc.

b. In order to make the principle of "ratio" clear, suppose we are comparing the prices of two different secondhand automobiles. One priced at $2400 and the other at $800. There are a couple of ways in which we could make the comparison; we may say:

(1) One auto is $1600 higher than the other, or

(2) One auto is three times as high as the other. The first comparison is made by subtraction ($2400 minus $800 is $1600) and the second by division ($2400 divided by $800 is 3). When comparing two values by division, use the "ratio" comparison method.

c. Ratio is the relationship between two quantities or numbers by division. The quantities or numbers found in a ratio are "terms" and in all ratios must be of the same kind. Find the ratio by dividing the "first term" by the "second term" revealing a numerical relationship of how much larger or smaller one term is to the other. Once again, any two terms being compared must be of the same kind. We cannot compare pounds to minutes or inches to miles.

d. The two terms given in a ratio are "ratio sets." Earlier we had two terms mentioned in the secondhand auto example; $2400 and $800. Since $2400 is first, it became the "first term" and $800 became the "second term" of the "ratio set." Let's "ratio" (compare) the numbers 2 and 8. The "first term" is 2 and the "second term" is 8. The "ratio set" is "2 to 8" or 2/8 (2 divided by 8) which would equal .25 or 1/4 or any equivalent amount.

e. The colon (:) is the symbol traditionally used to replace "to" in the statement of a ratio set. Instead of writing the ratio "15 to 5," we place the symbol between the two terms for brevity: 15:5. Normally, the flight engineer writes a ratio set in the form of a fraction.

EXAMPLE:

Ratio set 15 : 5 can be written 15/5 or (15 divided by 5) = 3 or 1/3

Any of the methods shown above mean exactly the same thing.

2–14. Proportion:

a. A proportion is an expression of equality between two different ratio sets. To illustrate this, think of the two different ratio sets: 8/4 and 12/6. Both sets contain different numbers, but both their ratios are 2 (8 divided by 4 equals 2, and 12 divided by 6 equals 2). Since the ratio of both ratio sets is the number 2, the ratio sets are equal. To show that one ratio set equals another, place the equal sign (=) between two ratio sets. For example:

8/4 = 12/6 reads: "8 is to 4 as 12 is to 6."

Notice that since every proportion contains two equivalent ratio sets there must be four terms in any complete proportion.

b. As mentioned earlier, the numbers in ratio sets were called first and second terms, but once these sets are placed in a proportion the names of these terms change. Let's review these new names and become familiar with them before we begin to "solve" proportion problems. Reviewing the preceding proportion, the new terminology becomes:

First Ratio Set		Second Ratio Set
(first term) 8 now EXTREME	=	(first term) 12 now MEAN
(second term) 4 now MEAN		(second term) 6 now EXTREME

The above diagram illustrates how the new names "mean" and "extreme" apply to the ratio set terms in a proportion. The first term of the first ratio set and the second term of the second ratio set are "extremes" in a proportion. The second term of the first ratio set and the first term of the second ratio set are "means" in a proportion.

c. If we know the value of three of the four terms in a proportion, the unknown or missing fourth term is found by following three basic rules.

RULE 1. The product of the "means" is equal to the product of the "extremes."

d. In the proportion depicted above the product of the "means" is 4 X 12 = 48, and the product of the "extremes," is 8 X 6 = 48. Since 48 = 48, rule 1 applies to our proportion.

RULE 2. The product of the known extreme divided by the known mean gives the value of the unknown mean.

e. Once again let's take our sample proportion (8/4 = 12/6) and imagine that the mean 12 is unknown or missing. It would be set down as follows:

8/4 = ?/6

f. Using rule 2, we find the product of the two known extremes: 8 X 6 = 48. Then we divide the product of the two extremes by the known mean: 48/4 = 12. In our proportion the missing mean would be the number 12. This can be double-checked by using rule 1: 8 X 6 = 48 then 4 X 12 = 48. Since 48 = 48, the solution must be correct!

RULE 3. The product of the known means, divided by the known extreme gives the value of the unknown extreme.

g. Again, using our sample proportion (8/4 = 12/6) imagine the 6 as missing or unknown. Our proportion would now appear as follows:

8/4 = 12/?

h. In using rule 3 to solve for the unknown extreme, we find the product of the two known means: 4 X 12 = 48. Divide this product by the known extreme, 48/8 = 6. Six is the unknown extreme. Proof: 4 X 12 = 48, and 8 X 6 = 48, 48 = 48. Thus, the number 6 found by using rule 3, satisfies the requirements of rule 1. Memorize and fully understand these rules before solving proportion problems.

EXAMPLE: An aircraft is flying at a speed of 435 miles per hour. How far will it go in 24 minutes?

SOLUTION: A sound method of forming "word problems" into a proportion format is to place the two related known quantities in the first ratio set of the proportion. In this situation the phrase "miles per hour" provides us with two known quantities: "miles traveled" and a unit of time "1 hour." Another known quantity found in the word problem is a unit of time stated "24 minutes." Now our three known quantities are (1) 435 miles, (2) 1 hour, and (3) 24 minutes. The fourth unknown value will be miles (covered in 24 minutes). We will set up our first ratio set as a time comparison since we have two known related values. Before doing this, remember, terms in a ratio set must be like units! We must convert the terms used in our time comparison to either minutes or hours. Twenty-four minutes is one known and 1 hour contains 60 minutes, so "60 minutes" now becomes our new time comparison known.

$$\frac{24 \text{ minutes}}{60 \text{ minutes}} = \frac{\quad}{\quad}$$

Notice: 60 represents the "whole" number of units, while 24 is the "part" of the whole being considered. Refer to the discussion on fractions.

To construct the second ratio set, we begin by asking ourselves a question. "The third known quantity relates to which term in the first ratio set?" Since 435 miles relates to the time of 60 minutes (distance covered in 1 hour), we place it directly across from the 60 minutes found in the first ratio set:

$$\frac{24 \text{ minutes}}{60 \text{ minutes}} = \frac{?}{435 \text{ miles}}$$

To solve for the unknown mean, we apply rule 2. Flight engineers over the years have started to call the use of rules 1, 2, and 3 "cross multiply and divide." Now we have 24 X 435 = 10,440 (cross multiplication of two knowns), then 10,440/60 = 174 (dividing the product by the other known). One hundred seventy-four miles is the unknown mean and shows the number of miles flown in 24 minutes. For review:

$$\frac{24 \text{ minutes}}{60 \text{ minutes}} = \frac{174 \text{ miles}}{435 \text{ miles}}$$

Our proportion reads, "24 is to 60 as 174 is to 435" and the aircraft will travel 174 miles in 24 minutes at a speed of 435 miles per hour!

EXAMPLE:- A procedure states, "Take fuel flow readings at 2/3 of the climb." If we are climbing a distance of 37,500 feet, at what height in the climb will we take the fuel flow readings?

Set up proportion: $$\frac{2}{3} = \frac{? \text{ feet}}{37{,}500 \text{ feet}}$$

Cross Multiply: 2 X 37,500 = 75,000

Divide: 75,000/3 = 25,000

Take a reading 25,000 feet into the climb.

2-15. Denominate Numbers:

a. Numbers such as 2, 3, 4, 5, etc., combined with a unit of measure are "denominate numbers"; values like 50 feet, 20 miles, 5 hours, etc. Values containing more than one unit of measure are "compound" denominate numbers. Numbers like 6 feet 8 inches, 2 hours and 40 minutes, etc. are examples of compound denominate numbers.

b. Time is the most common compound denominate number used by flight engineers and is the one this manual will discuss in detail. Although "time" is divided into many separate units of measure, engineers use these units:

60 Seconds = 1 Minute
60 Minutes = 1 Hour
24 Hours = 1 Day

c. One should use either of two methods for adding and subtracting compound denominate numbers (time):

METHOD 1. Reduce the numbers to their lowest denomination, perform the required operation, then convert the answer back to the various denominations.

EXAMPLE: Subtract 2 hours and 40 minutes from 3 hours and 50 minutes.

3 hours 50 minutes = 230 minutes
(3 X 60 + 50 = 230)
- 2 hours 40 minutes = 160 minutes
(2 X 60 + 40 = 160)
70 minutes

Answer: 70 minutes converted back is 1 hour and 10 minutes.

(70 / 60 = 1 with 10 minutes left over)

METHOD 2. The method most often used by flight engineers is to perform the operation on the numbers given, changing the denominations as required.

EXAMPLE: Subtract 5 hours and 55 minutes from 7 hours and 30 minutes.

7 hours 30 minutes
- 5 hours 55 minutes

Always work from the right to the left in time problems. Looking at the minutes column at the right, we know we cannot subtract a larger number from a smaller number, so we borrow an hour "unit" from the hour column, convert it to minutes then add the 60 minutes to the top figure in the minutes column giving us:

6 hours 90 minutes
- 5 hours 55 minutes
Answer: 1 hour 35 minutes

d. If you work and study the following example you will have a good grasp of working with denominate numbers.

EXAMPLE: An aircraft had a takeoff time of 1847 hours on the 16th and landed at its destination at 0123 on the 17th.
What was the elapsed time for the flight?

SOLUTION: Avoid errors in time computations by following one very important point: always subtract the takeoff (beginning) time from the landing (ending) time, disregarding which value is the larger. Our problem should be set down like this:

01	23	Landing time (1hour + 23 minutes)
-18	47	Takeoff time (18 hours + 47 minutes)

To avoid confusion, make the distinction between the units of time (hours and minutes) by drawing a line between the two columns, showing that separate operations are to be performed. Once again we begin by working from right to left. We can see that the upper number is smaller than the lower one. Borrow an hour (60 minutes) from the hour column to the left and added to the upper number in the minutes column. Now we complete the subtraction operation for the minutes column:

00	83	(60 + 23 = 83 and 01 - 1 = 00)
-18	47	
	36	

Now that the "minutes" column of the problem is solved, we move to the left and subtract the hours column. Again, since the lower number is larger than the upper one, we have to borrow. To do this we will take "24 hours" (1 day) from the day column imagined to the left of the hour column. This is available since we flew into the next day. Expanded for clarification, the problem now looks like this:

days	hrs	min
01	00	83
	18	47
		36

then borrowing...

days	hrs	min
00	24	83
-	18	47
	6	36

Write the answer as "6:36" or "6 + 36" normally preceded by the abbreviation "ET" which means "Elapsed Time". (ET 6:36 or ET 6 + 36.)

e. In adding denominate numbers, the flight engineer primarily uses the second method. The following addition problem provides review of the above method of dealing with denominate numbers.

EXAMPLE:- An aircraft will takeoff at 2248 CUT (Coordinated Universal Time) and is going to fly for 8 hours and 25 minutes. What time (CUT) will it land at its destination?

SOLUTION: In time prediction problems, remember to add the elapsed time to takeoff time. This will help keep "carrying" clear. We set the problem down as follows:

hrs	min
22	48
+ 8	25

Working from the right to the left, we add up the columns as independent addition problems.

hrs	min
22	48
+ 8	25
	73

We cannot show more than 24 hours in 1 day or 60 minutes in 1 hour. We need to convert our answer into minutes less than 60 and hours less than 24. Working from right to left, we convert the minutes by dividing by 60 and carrying the number of whole units to the left, added to the upper hours figure.

1

hrs	min	
22	48	Takeoff time
+ 8	25	Elapsed time
	13 (73/60 = 1 with 13 left over, the 1 is "carried" to hrs. column.)	

Now, moving to the left, we add the hours column including the "carried" amount.

1

hrs	min	
22	48	Takeoff time
+ 8	25	Elapsed time
31	13	

Following our conversion method for hours, we divide the answer in the hours column by 24 (hours in a day), carry the whole number to the left and retain the remainder in the hours column.

1

day	hrs	min	
	22	48	Takeoff time
+	8	25	Elapsed time
1	7	13	(31/24 = 1 with 7 left over, carry the 1 to the days column.)

The answer is 1:07:13 and reads "Arrival will be at 0713 on the NEXT day."

2-16. Equations and Formulas:

a. An equation is a means of showing that two numbers, or two "groups" of numbers are equal to the same amount or a statement of equality between two quantities. When using the sign of equality (=), the quantities on one side of the sign balance (equals) the quantities on the other side of the sign.

b. If you recall, in paragraph 2-13, a ratio set on one side of the equality sign was equal to the ratio set on the other side. For instance, in the proportion 3/6 = 4/8, the ratio set "3 to 6" has the same value as the ratio set "4 to 8." The reduction of both would make 1/2 and 1/2 = 1/2 in a statement of equality.

c. To be sure of a visual understanding of equality, we will review a very simple analogy. Figure 2-6 is a rough drawing of a scale used to weigh groceries.

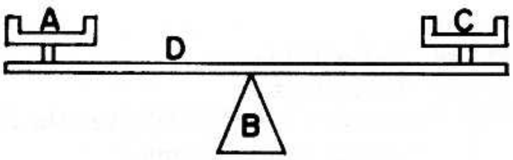


Figure 2-6. Equations and Formulas.

d. In figure 2-6, A and C represent the weighing pans, the balance arm at D, and the balance point at B. In order for the arm D to be perfectly horizontal, the weights in both pans (A and C) must be equal. You may use this simple balance principle to illustrate equations.

e. If we place the ratio set "3/6" in plan A, and "4/8" in pan C, we can visualize the system being balanced. Remember: ALL EQUATIONS MUST BALANCE. Multiplication tables illustrate simple equations, combinations such as 8 X 7 = 56, 2 X 2 = 4, etc. Other forms of simple equation might be; 6 + 5 = 11, 12 - 5 = 7, etc., even though numbers on either side of the equation are joined by signs, such as +, -, X, /, root, powers, etc. they are equations.

f. In flight engineering we know that in applications of speed, time, and distance, the distance traveled by an aircraft equals the speed it is traveling multiplied times the time flown. This statement is actually a "rule" or "principle" since it always holds true. We can write this rule in equation form as follows:

D = S X T
D = Distance
S = Speed
T = Time

This is an equation because it balances.

g. The primary difference between an equation and a formula is that in an equation the numbers haven't any particular meaning. By inserting letters that represent something, such as the D, S, and T above, it becomes a "formula." A "formula" is a RULE! The formula D = S X T is a rule for finding distance when we already know the speed and time; 7 + 2 = 4 + 5 is an equation because it balances and the numbers have no particular meaning. Yet, D = S X T is a formula since the letters mean definite things and it is a rule for finding distance. Equations and formulas are the same when concerning methods of working and balance.

h. The distance an aircraft travels is equal to the speed traveled times the length of time it maintains that speed. This would be a long and time-taking rule to write each time we wanted to show it, so in flight engineering we have given such names as Distance, Speed, and Time letter symbols which we can substitute for their terms in formulas. This allows us to write rules as short and easily expressed formats called formulas.

i. Express appropriate units of measure in practical problems for D, S, and T. The measure for D is nautical miles. The measure for S is nautical miles per hour. The measure for T is hours.

j. When we have formulas written in a simple form, we can substitute actual numerical values for the symbols, and if one value is unknown, "solve" the formula. In the formula D = S X T, let's demonstrate "substitution" of actual values to illustrate the importance of balance in a formula. Suppose we know that D = 2,175 nautical miles, S = 435 nautical miles per hour, and T = 5 hours. The formula D = S X T becomes: 2,175 nautical miles = 435 nautical miles per hour X 5 hours after the "substitution" process. Study figure 2-7.

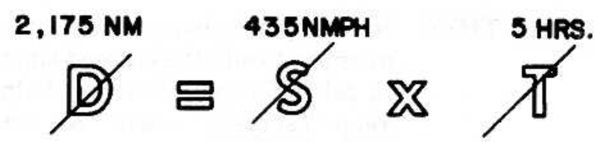


Figure 2-7. Distance, Speed, and Time.

k. Here we first wrote down the formula using symbols to state the rule and then crossed out the D and replaced it with its value of 2,175 nautical miles. Continuing, 435 nautical miles per hour replaces S and 5 hours replaces T. We can quickly see that the formula balances mathematically because:

2,175 nmi = 435 nmi/h X 5 hr and 2,175 nmi = 2,175 nmi

Notice:nmi is the abbreviation for nautical miles , h stands for hours and nmi/hr means nautical miles per(/) hour.

l. Now we come to the point where we can explain the real use of formulas. In actual practice, there are only two known values and the value we need is unknown. We must find the value of the unknown symbol by calculation. For example, we may know that the speed is 435 nmi/h. and 5 hrs. have elapsed, but we do not know what distance we have flown. Selecting the rule or principle that applies, we set down our formula:

D = S X T

Then we substitute the known values:

D = 435 nmi/h. X 5 hrs.

Now, the multiplication to the right of the = sign is calculated:

D = 2,175 nmi

m. Flight engineers use, to a great extent, formulas. Let's study a simplified method of using and rearranging formulas to make them easier to solve.

n. Working with equations or formulas requires an in depth knowledge of over 13 "theorems" and "postulates" of algebra, an exceptional understanding of all the "rules" in formula, and equation solution arrangement. However, it is not within the scope of this section to provide you with the studies required to become a mathematician. Instead, we will show you a method of rearranging formulas, developed over the years by flight engineers, which satisfies all the algebraic "rules" of the mathematicians and is very easy to use!

o. A key problem when working with formulas is "isolating" the unknown value being sought. In other words, rearranging the formula so the unknown is on one side of the equal sign and the substitutions are on the other side. Looking back at our example of the D = S X T formula, as long as we were looking for D (with S and T's values known), we were in pretty good shape. This formula can be arranged as it needs to be. Let's look at a situation that is more common for the flight engineer:

Find S if D = 2,175 nmi and T = 5 hrs.

After making the substitutions, writing the formula would look like this:

2,175 nmi = ? X 5 hrs.

To make this problem easier to work it is better to have the unknown value (S) by itself or "isolated" in some fashion. Let's study an easy way to do this!

p. In any "base" formula (no division indicated on either side of the equal sign i.e., D = S X T), simply draw a line above the symbols to the right of the equals sign, then place the symbol to the left of the equals sign above the line and drop the equals sign. Study the process below:

EXAMPLE: Arrange D = S x T isolating all the symbols.

q. In this more visual form of the formula, the value of the symbols above the line are equal to the value of the symbols below the line. Notice how the line and the "X" (times sign) form sort of a "T" shape when the symbols are missing. Study the "T" shape of the formula and see if you can see that it now represents all three formulas listed below:

1. D = S x T
2. S = D/T
3. T = D/S

EXAMPLE: Solve for S, if D = 2,175 nmi and T = 5 hrs.

Convert our formula toD/SXT

Substitute known values2175 nmi/Sx5

r. Since the line we drew also shows "division," after substitution, the formula is telling us that S is equal to 2,175 nmi divided by 5 hrs. which is 435 knots (nmi/h).

s. Remember: the value of the symbol remaining after substitution will be equal to the computation shown by the numbers substituted.

t. Let's work a couple of examples all the way through for a thorough understanding.

EXAMPLE: How long will it take an aircraft traveling at a speed of 435 knots to cover 2,175 nmi?

List known values with symbols

S = 435 knots,
D = 2,175 nmi
T = ?

Convert D = S x T to our "T" form D/S X T

Substitute known values in "T" form 435 knots

Symbol (T) equals computation, 2,175 divided by 435 or 5; 5 hrs

Proof: The value of symbols above the line equal 2,175 and the value of the symbols below the line (435 X 5) equal 2,175, so the formula is "balanced" and correct.

u. The discussion up to this point has concentrated on the reformatting of formulas in their "base" form, meaning no division indicated on either side of the equals sign. Many times the engineer has to use a formula with division indicated. Don't panic! Dealing with these formulas are as easy as the first demonstrations. You may see any formula in one of its many forms and our goal is to be able to convert any formula into a more visual format.

v. A formula used by the engineer, not usually in it's base form, is the weight and balance formula:

A = M/W Where: A = Arm
M = Moment
W = Weight

Right now we are not concerned with exactly what the symbols mean, but arranging the formula into our "T" form which will make it much easier to work with! The key point now is to arrange any formula in any form it may appear into our "T" format, even if we have no idea what the symbols stand for.

w. Here is what we need to do in a formula where division is shown. Place the symbol standing alone to the left of the equals sign into the lower part of the division shown to the equal signs right, followed by the "X" (times) sign, then simply drop the equals sign. Study the following example to ensure you know how this is done:

EXAMPLE: Convert the formula, A = M/W, to the "T" format.

Step 1. = M/AW Move symbol
Step 2 = M/AxW Add "x" sign
Step 3. M/AxW Drop "=" sign.

x. Study the "T" form in step 3 and see if you can readily see the three formulas it represents. The remaining symbols and their position in the format show the calculation required to find the symbol. W e should see:

1.M = AW
2.A = M/W
3.W = M/A

y. To reinforce what we have learned to this point, let's review a basic problem step by step:

EXAMPLE: Use the formula M = A X W, solving for A if M = 30 and W = 5.

Convert to our "T" form M/A x W

Substitute known values30/A x 5

Calculate A's value... A is equal to 30 divided by 5.

The value of A is 6!

z. On occasion, an engineer will have to deal with a modified formula. This ensures the answer will appear in the exact form required. In place of the symbols found in a base formula, the procedure or calculation required to find the symbols' value is shown. We must keep a couple of things in mind while reformatting. We will work one through step by step mentioning the things to keep in mind as we go.

EXAMPLE: Formula: (AA - LEMAC) X 100 = C.G.%MAC X MAC

Knowns: AA = 915
LEMAC = 850
MAC = 260
C.G.%MAC = ? (must find)

This might appear frightening at first, but don't panic. The only difference between this formula and the one we just discussed is that instead of the symbols (A, M, and W) appearing in the formula, we enter the procedure or calculation to find their values. The value obtained by subtracting LEMAC from AA multiplied times 100 will be equal to the value obtained by multiplying C.G.%MAC times MAC!

Step 1. *Before we arrange this into our "T" form, we should place a "bracket" around each group of functions to be sure we do not get confused during our procedure. Like this...*

[(AA - LEMAC) x 100] = [C.G.%MAC] X [MAC]

Now we deal with the bracketed groups as we would symbols in a base formula. Using the procedure we learned we now convert this to our "T" form.

[(AA - LEMAC) X 100]
―――――――――――――
[C.G.%MAC] X [MAC]

Step 2. Now that the formula is in our "T" format, we can drop the brackets and substitute the knowns we have for their letters.

$$\frac{(915 - 850) \text{ X } 100}{\text{C.G.\% MAC X } 260}$$

Before solving for C.G.%MAC in the formula we need to simplify the process appearing above the line. This brings us to an important rule: Always perform the operation within parenthesis first! So...

$$\frac{65 \text{ X } 100}{\text{C.G.\% MAC X } 260}$$

Continuing our simplification of the process above the line, we complete the multiplication.

$$\frac{6500}{\text{C.G.\%MAC X } 260}$$

*Step 3. Now that we have single value substitutions placed in the formula, we can solve for the unknown value; C.G.% MAC. The indicated operation in our format is: the division of 6500 by 260 will give us the value of C.G.% MAC... 6500 divided by 260 is 25, so...*The value of C.G.% MAC is 25 or C.G.% MAC = 25.

aa. Another common situation encountered by the flight engineer is solving a formula in which there are two unknowns. Since we cannot do this we must solve one formula to find the needed value to plug into the original formula we wanted to solve. Explaining this process is best accomplished by simply working through an example of this situation step by step:

EXAMPLE:- After level off, the pilot asks, "Engineer, we have been asked if we can make an alternate destination 1,950 miles from here. Can we make it on the fuel we have?" First, we jot down the information available to us from where we sit and the formulas we will use. Our notes may look something like this...

Fuel onboard = 24,000 lbs (pounds)

4 Engine Fuel Flow = 4,800 lbs/hr. (pounds per hour)

True Airspeed (TASK) = 435 KNOTS

Formulas:

1. Fuel/Pd (fuel for the period) = FF (fuel flow) X Time.
2. Distance = TASK X Time

Since the pilot asked if we can make a given distance, we select the second formula for distance to find how far we can go. After selecting the formula we suspect will provide the ultimate answer, we want to put it into our "T" shape, essentially isolating the symbols:

$$\frac{\text{Distance}}{\text{TASK X Time}}$$

Now, values are substituted in the formula:

$$\frac{\text{Distance}}{435 \text{ X Time}}$$

Notice that we can't solve for "Distance" because we have no value to substitute for "Time"! We must now look to the first formula to find a value for "Time" we can plug into the initial formula. Once again, we configure it into our "T" format...

$$\frac{\text{Fuel/Pd}}{\text{FF X Time}}$$

Substituting our numbers in this formula...

$$\frac{24{,}000 \text{ lbs}}{4{,}800 \text{ lbs/h X Time}}$$

Time is equal to the computation; 24,000 divided by 4,800 is 5 or 5 hrs. Now, we have a value to substitute in the original formula for "Time." So, returning to that formula with this value...

$$\frac{\text{Distance}}{435 \text{ X } 5}$$

Distance is equal to the computation; 435 times 5 is 2,175 or 2,175 nmi. We found through the solution of two different formulas that we are capable of flying 2,175 nmi. Comparing this to the 1,950 nmi stated by the pilot, we see that making the new destination should represent no problem.

ab. The flight engineer needs to be able to work with many formulas quickly and accurately in order to obtain the information needed by the pilots. Review this section and become as proficient as you can in formula procedures. In the next section we will discuss even faster and easier ways to find the answers to extremely complex formulas, and without using mathematics.

2–17. Charts and Graphs:

a. Aircraft performance charts are "graphed" representations of aircraft performance formulas. Charts aid the flight engineer a great deal in finding answers to aircraft performance problems. Their biggest advantages are:

(1) A lot of information can quickly be taken from a chart.

(2) Charts prevent the flight engineer from solving complicated and lengthy performance formulas.

(3) They replace reams of tabulated data. One minor disadvantage of charts is the slight inaccuracy that occurs during their construction. This falls well within the tolerances necessary for finding significant performance answers.

b. In the following text we will talk about chart basics and go through the steps of constructing a simple chart because understanding chart construction is best accomplished by actually building one!

c. Before we begin, let's review some basic mathematical facts that relate to charts. A pair of numbers can determine a position on a surface; one number as a horizontal distance and the other a distance measured vertically. Anyone who has used graph paper, read a street map, or studied latitude and longitude lines on an atlas should be familiar with this idea. The concept of "graphing numbers" is simply the crossing of lines at a specific point. This "point" is an actual pictorial representation of a "pair of numbers."

d. Since formulas contain numbers, these numbers represent a series of plotted points. When connected they appear as straight or curved lines. This system of plotting these points by the crossing of two straight lines is the "Cartesian Coordinates System." The vertical (up and down) number line is the "Y" axis. The horizontal (across) number line is the "X" axis. Where the number lines cross is the numbered pair Y = 0, X = 0. This is the "zero" point for both axes. Study figure 2-8.

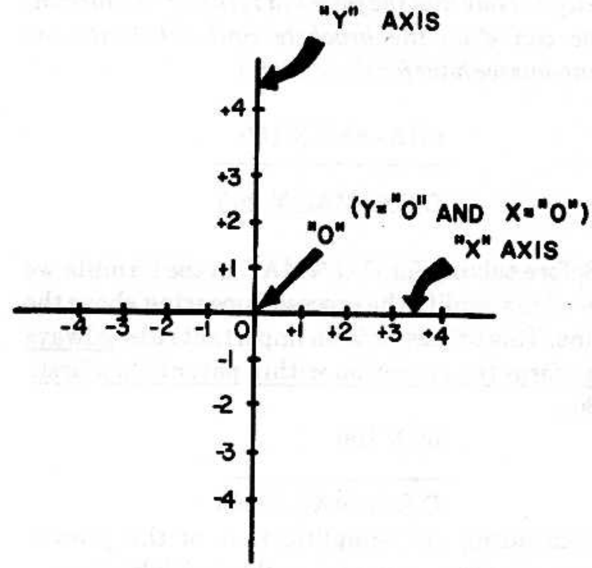


Figure 2-8. Charts and Graphs.

e. We can find any positive or negative number on the "X" or "Y" axis and a point representing a combination of the two numbers. Studying figure 2-9, let's plot a "pair of numbers." We will plot the pair of numbers (point) representing "X" = +2, and "Y" = +3. We find +2 on the "X" number line and draw a line straight up. Then find +3 on the "Y" number line and draw a line straight across. Where the two drawn lines cross is the point: "X" = +2, "Y" = +3.

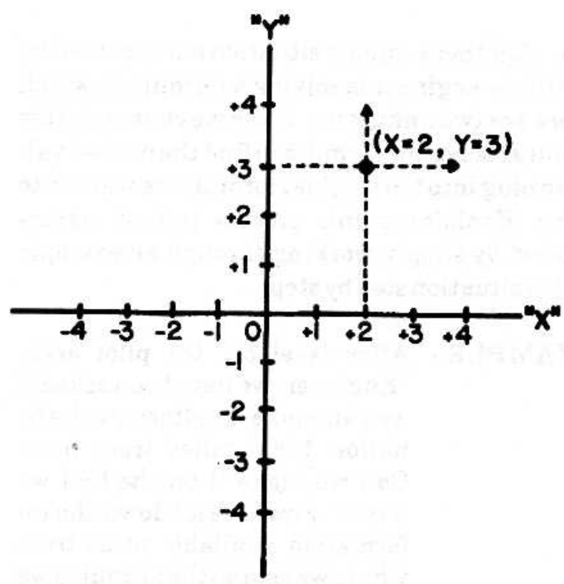


Figure 2-9. Plotting a Point.

f. Graph paper is nothing more than a blank sheet of paper with an entire network of vertical and horizontal reference lines. We are going to add the numbers and axes during the construction of our chart. Most graph paper has every fifth line, darker than the other lines to aid in chart construction and reading. The heavy lines are "major lines" and the lighter lines, "minor lines."

g. Let's start building our chart. We take a blank piece of graph paper and draw a very heavy line in the center of the paper all the way across the sheet from left to right. This divides the sheet in half vertically. We now do the same thing to the sheet horizontally, drawing a line in the center of the sheet from top to bottom. These lines become our "X" and "Y" axis respectively. Now the line running across the sheet is "X Axis". The line we drew up and down is "Y Axis". Both of our axis lines cross in the exact center of the graph paper. This represents "zero" for either axis or the plot; X = 0, Y = 0. Study figure 2-10.

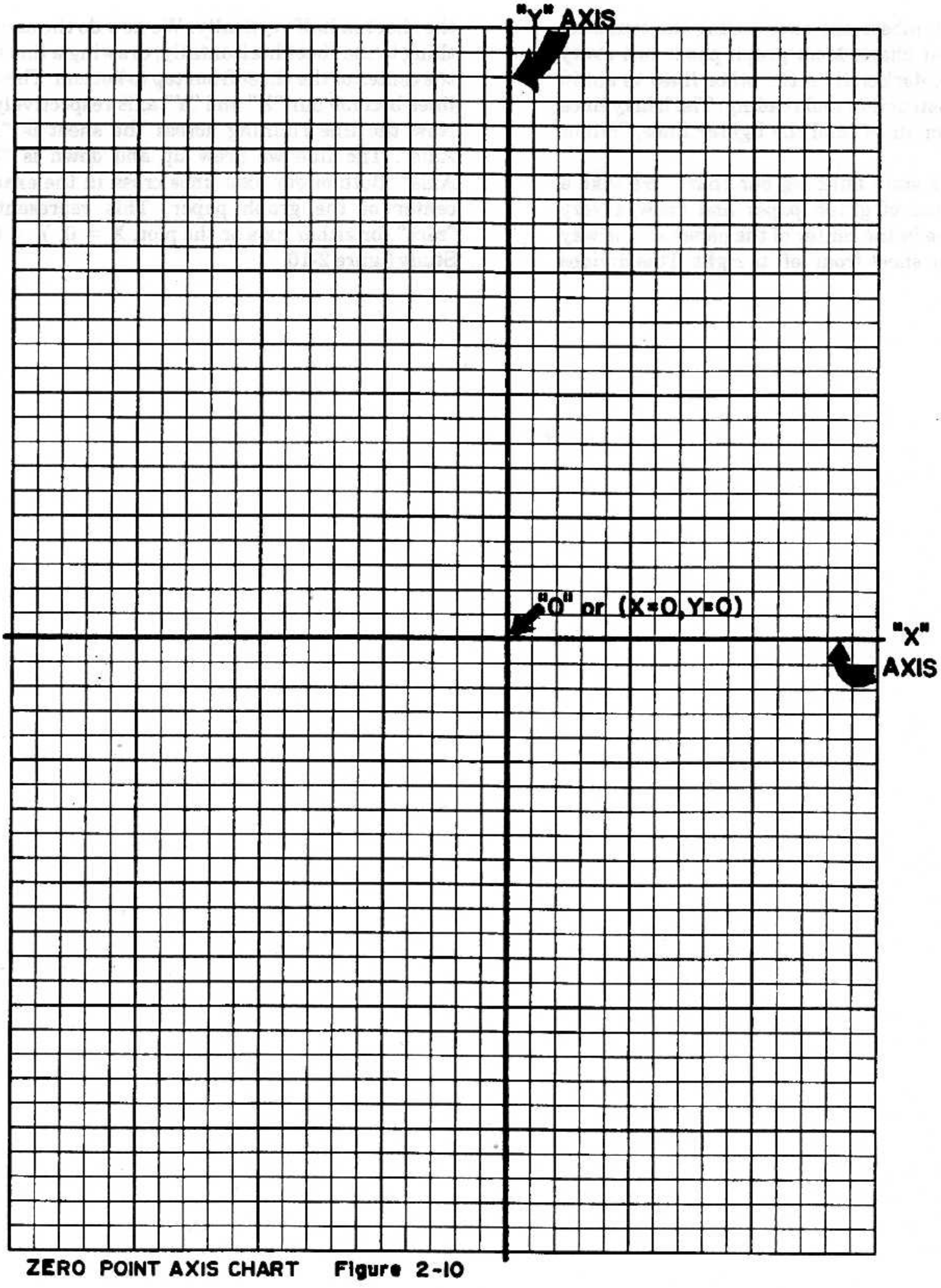


Figure 2-10. Zero Point Axis Chart.

h. We need to establish some values along each axis. To avoid cluttering of the chart, we label every other major line in increments of 20. The second major line to the right of the zero point along the "X" axis is "+20." The second major line to the left of zero along the "X" axis is "-20." Remember, numbers to the right of the zero point are positive numbers and those to the left of zero are negative. Complete this throughout the entire length of the "X" axis number line. We now complete the same process along the "Y" axis, labeling every other major line in increments of 20. The second major line above the zero point is "+20," the second major line below this point is "-20," etc. Once again, continue this throughout the entire length of the "Y" axis. Figure 2-11 illustrates the results of our work:

i. We are now ready to construct a chart. Let's build one from a table of facts with which we are familiar by converting Fahrenheit temperature to a Centigrade temperature. Our table of specific known facts could look something like this:

	Centigrade	Fahrenheit
Water freezes at	0	32
Both scales equal at	–40	–40

j. Let's call "degrees Centigrade" the "X" axis and "degrees Fahrenheit" the "Y" axis. This added labeling enables us to make two statements, each of which will provide us with a "pair of numbers:"

Statement 1. Water freezes at X = 0, Y = 32 (first X, Y pair)
Statement 2. Both scales equal at X = -40, Y = -40 (second X, Y pair)

k. With some values to work with, let's plot a point representing our first pair of numbers: X = 0, Y = 32 (refer to figure 2-12). The point X = 0 is right where the two axis cross. You may find Y = 32 by moving straight up from the X value of 0, along the Y axis to a value of 32. Since the value of each block is 2 (found by dividing the difference between two known values by the number of blocks between them). We move up a total of 16 blocks. Make a mark that indicates the numbered pair: X = 0, Y = 32. Finding the next pair of numbers, X = -40, Y = -40, is an identical procedure. Starting at the zero point, we move left along the X axis to a value of -40 (20 blocks). This is the X = -40 point. From this point we move straight down to a value of -40 (20 blocks). Remember, downward and parallel with the Y axis gives us negative Y values! We mark the plot which is the numbered pair, X = -40, Y = -40.

l. Now that the two plots are made, we are ready to add the most important part of our chart, the "answer" line. Using a straight edge, draw a line the entire distance that intercepts the center of the two plots. Study figure 2-12.

m. In order to make our chart easy to use, a couple of formating alterations are needed. Since all the numbers on the axes of the chart make it difficult to read, we move the "Y" axis and all its values to the left border of the graph sheet. Move the "X" axis and all its values to the bottom border of the graph. This in no way alters the mathematical relationships of the axes, nor the positive and negative values depicted. It simply clears the way for bionic chart readers to find what they need! Study figure 2-13, which illustrates our completed chart.

n. An actual chart of this type would need larger parameters. It is possible that values of up to 120 degrees fahrenheit (120°F) may be needed in the operational environment while temperatures below -50 degrees fahrenheit (-50°F are unlikely. The chart is expanded upward and reduced horizontally to meet these requirements shown in the final form of the chart in figure 2-14.

o. Let's see if we can find the Centigrade temperature if our Fahrenheit temperature is 50 degrees. Entering the chart on the left border (Y axis; Fahrenheit scale) at +50 we proceed horizontally to the center of the "answer" line. We then read downward to the values of degrees Centigrade (X axis). Ten degrees Centigrade is the number the exit point represents. We now have a chart that will give us any value of degrees Centigrade for any known value of degrees Fahrenheit or vice-versa.

p. Though we plotted our pairs of numbers as taken from a given table we actually made a chart that represents the formula:

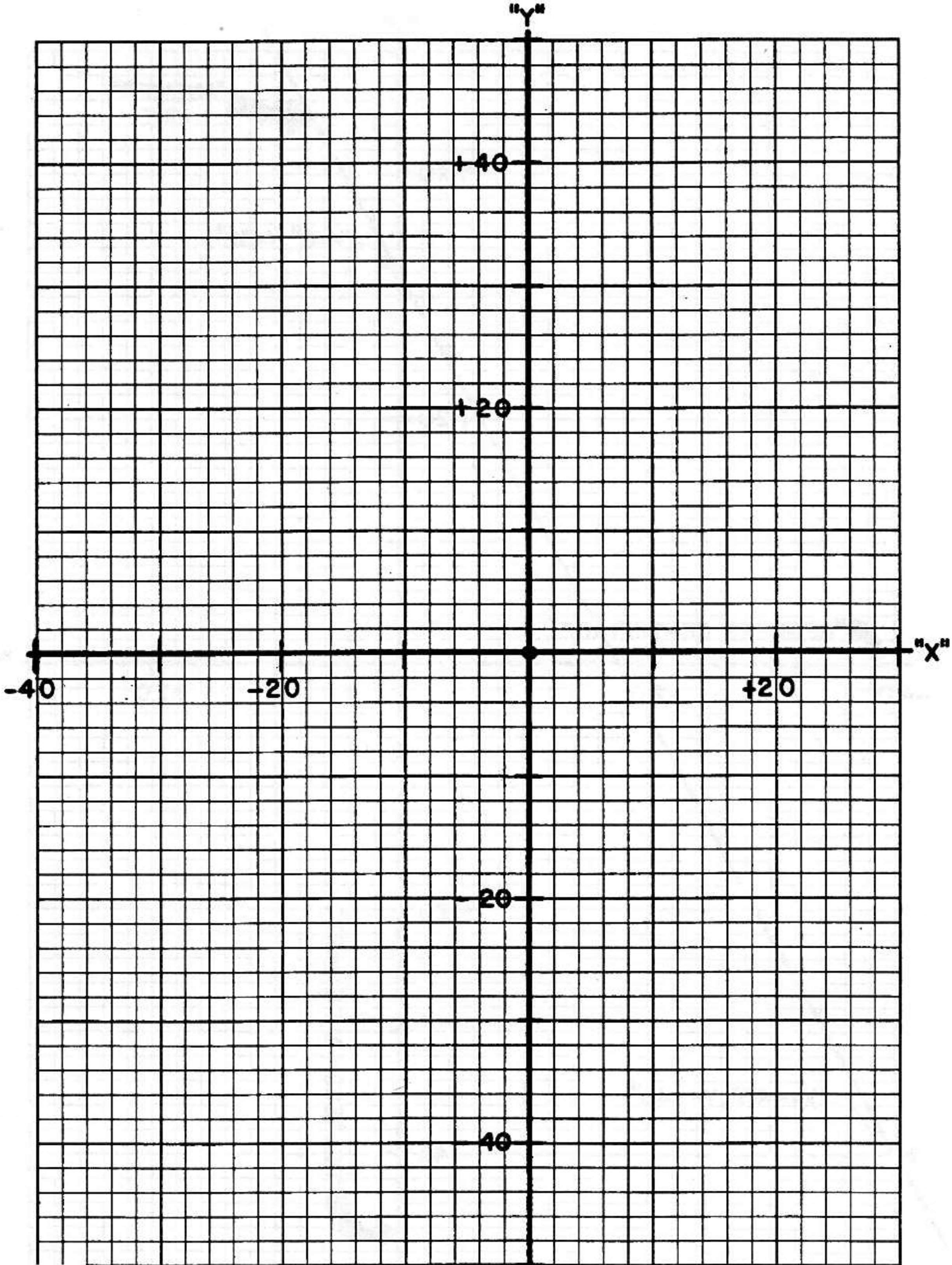
$$\text{Degrees C} = (\text{Degrees F} - 32)\ 5/9$$

NOTES:
1. For every 5-degree change in Centigrade, there is a 9-degree change in Fahrenheit.
2. To get degrees C and degrees F at the same starting point, subtract 32 from the degrees F

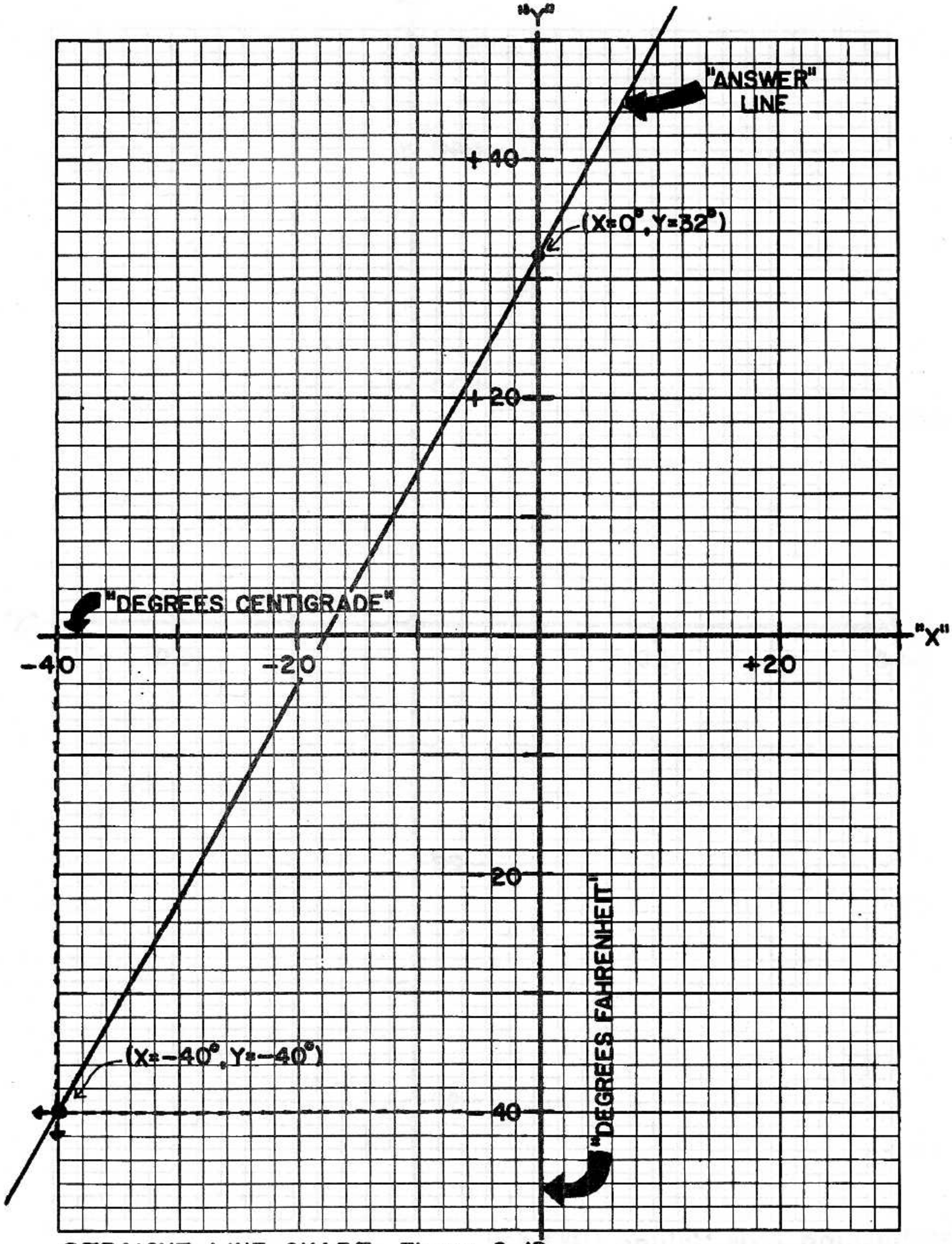
scale (Y axis - 32). Study figure 2-14 and see if the answer line we plotted agrees with the notes just mentioned about the temperature conversion formula.

q. The temperature conversion chart we constructed is typical. One minor difference is this particular chart is "straight line" while most are "curved line." The answer line is straight on our chart because there is a direct relationship between values of X and Y. Most aircraft performance formulas are not direct relationships. Most values do not change by fixed or set rates. The basic procedure for construction is the same for either a straight line or curved line chart.

r. Figure 2-15 is a good example of a curved line chart depicting many different formulas. The pairs of numbers were plotted then connected to form the various answer lines. This enables us to predict aircraft performance without lengthy computations. Onboard and hand-held performance computers are increasing in popularity and our dependency on them is increasing. When the batteries go dead, the power feed fails, and the lights go out we will need to read the "old" charts quickly and accurately to get where we are going.



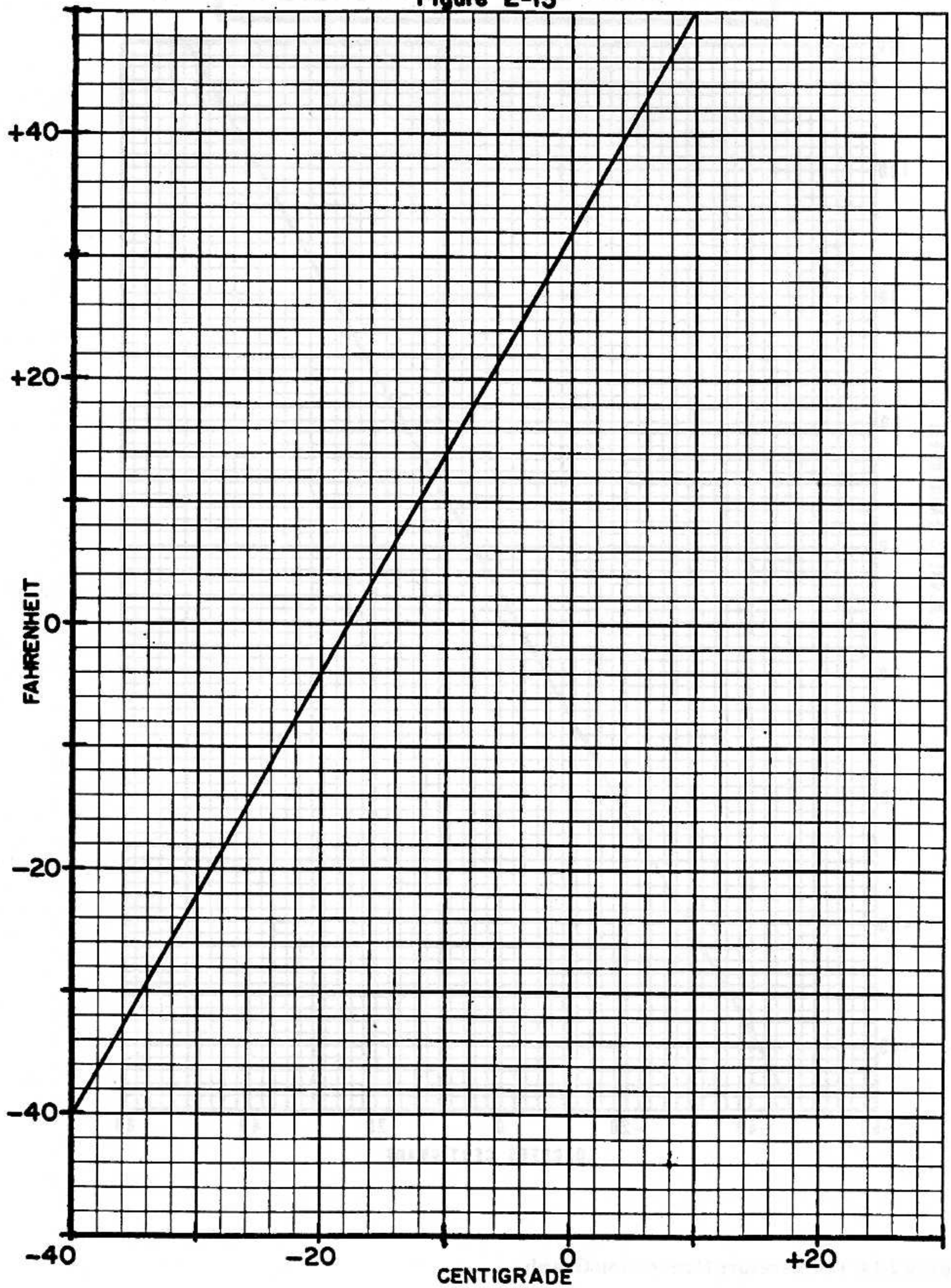
Establishing Axis Values Figure 2-11



STRAIGHT LINE CHART Figure 2-12

Completed Graph

Figure 2-13



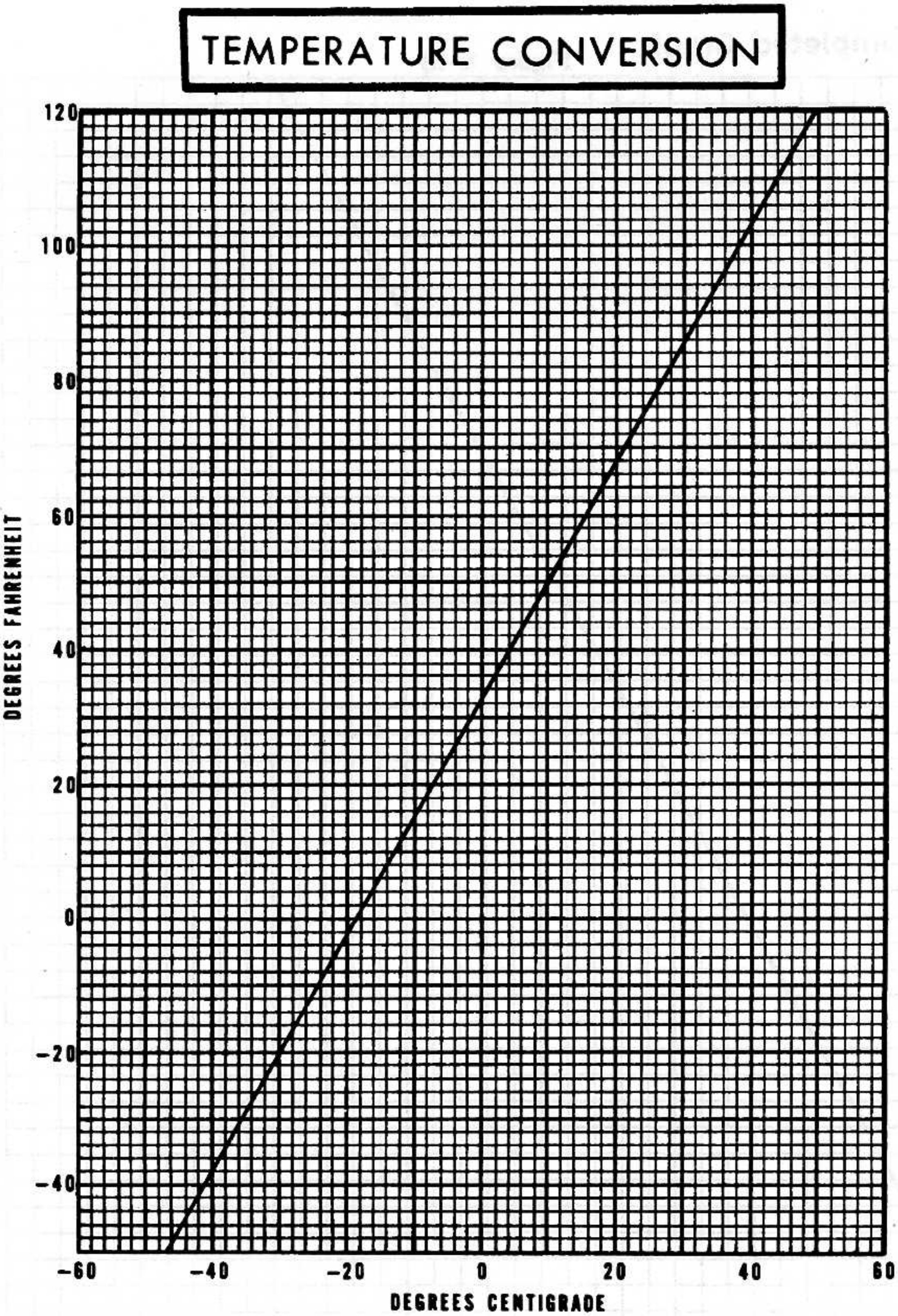


Figure 2-14. Temperature Conversion Graph.

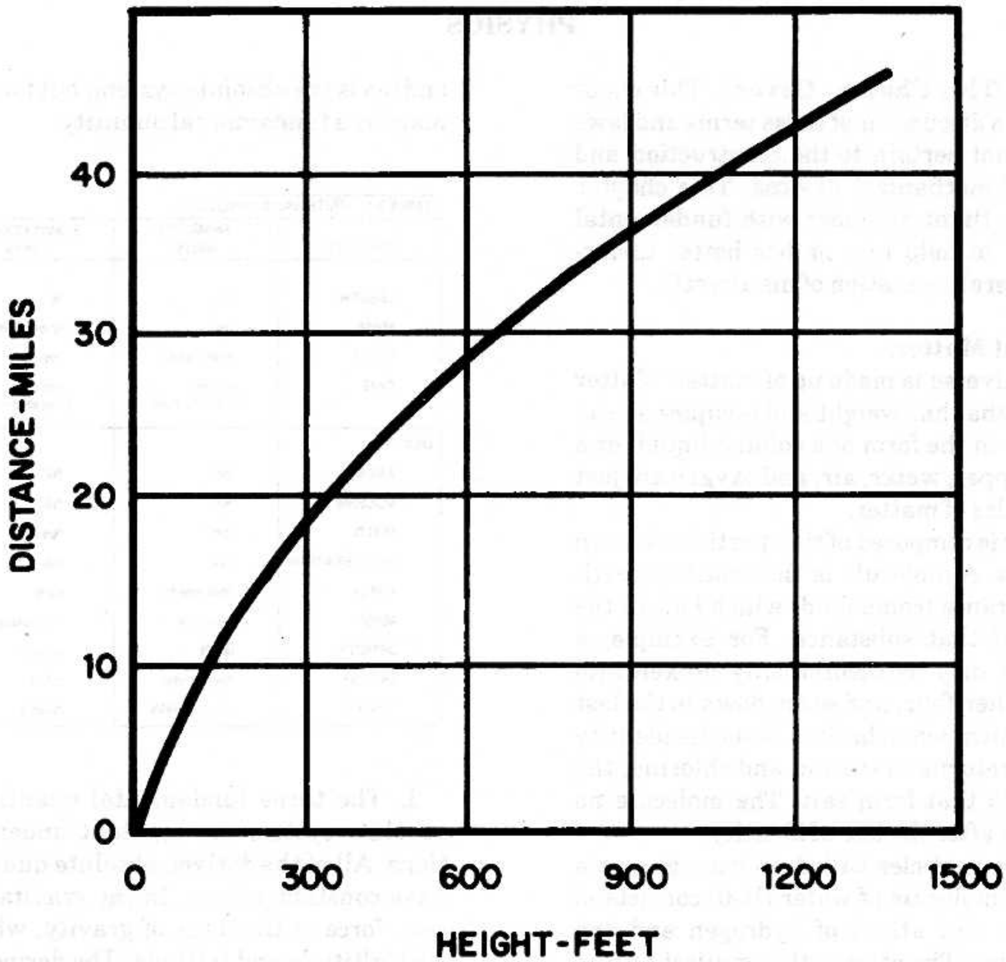


Figure 2-15. Curve Line Graph.

Chapter 3

PHYSICS

3–1. What This Chapter Covers. This chapter includes a discussion of those terms and laws of physics that pertain to the construction and operation of mechanical devices. This chapter provides the flight engineer with fundamental information to help him or her better understand the overall operation of his aircraft.

3–2. About Matter:

a. The universe is made up of matter. Matter is anything that has weight and occupies space. It may exist in the form of a solid, a liquid, or a gas. Iron, copper, water, air, and oxygen are just a few examples of matter.

b. Matter is composed of tiny particles known as molecules. A molecule is the smallest particle of a substance (compound) which has all the properties of that substance. For example, a grain of salt may be theoretically broken into two pieces, then four, and so on, down to the last molecule which, when broken, loses its identity as salt and returns to sodium and chlorine, the two elements that form salt. The molecule no longer exists after the loss of identity.

c. Smaller particles called atoms make up a molecule. A molecule of water (H_20) consists of three atoms, two atoms of hydrogen and one atom of oxygen. The atom is the smallest part of an element which retains the property of the element. Now, to review these relationships:

(1) The smallest unit of a compound is the molecule.

(2) The smallest unit of an element is the atom.

(3) All compounds are made up of one or more of the elements.

3–3. Units and Symbols:

a. One of the essentials to understanding the subject of physics is a knowledge of the units and symbols used to measure and represent quantities, such as mass, area, volume, speed, etc. There are two primary systems in use: the absolute and the gravitational. Table 3-1 shows these systems.

b. The absolute system is based on the foot as the unit of length, the pound as the unit of mass, and the second as the unit of time. We know this as the foot-pound-second (fps) system.

c. The gravitational system is based on the same fundamental units (foot, pound, and second) as is the absolute system, but force replaces mass as a fundamental quantity.

TABLE 3-1. UNITS AND SYMBOLS.

QUANTITY	ABSOLUTE UNITS	GRAVITATIONAL UNITS	SYMBOLS
LENGTH	ft.	ft.	1
MASS	lbs.	(not used)	
FORCE	(not used)	lbs.	F
TIME	sec or (s preferred)	sec or (s preferred)	t
DERIVED			
AREA	ft^2	ft^2	A
VOLUME	ft^3	ft^3	v
SPEED	ft/s	ft/s	V
ACCELERATION	ft/s	ft/s	a
FORCE	(not used)	slug	F
MASS	poundal	(not used)	m
DENSITY	lbs/ft	slug/ft	
ENERGY	ft-poundal	ft/lbs	E
POWER	ft-poundal/s	ft-lbs/s	P

d. The three fundamental quantities of the absolute system are constant under all conditions. All of the derived absolute quantities also have constant values. In the gravitational system, force is the force of gravity, which varies with altitude and latitude. The derived gravitational quantities that involve force are also variables. Since the force of gravity varies so slightly within the earth's atmosphere, we use the gravitational system in "everyday" calculations. When we require precise calculations, such as those related to space travel, we use the absolute system.

3–4. States of Energy. Energy is the ability to do work and is of two general states: potential and kinetic. These two states can be more specifically classified as types of energy, such as mechanical energy, electrical energy, heat energy, and chemical energy.

a. Potential Energy:

(1) Potential energy is defined as stored energy which can be released. A substance possesses potential energy because of its position, physical state, or chemical state. Water in an elevated reservoir and the lifted weight of a pile driver are examples of the first group. A stretched rubber band or a compressed spring is an example of the second group. The energy of

coal, food, and a storage battery is an example of the third group.

(2) The measure of potential energy of any lifted body is equal to the work done in lifting the body. Work done is the measure of energy and expressed in foot-pounds (ft X lbs).

b. Kinetic Energy. Kinetic energy is the energy that an object possesses because of its motion. The wind, flowing water, an aircraft in flight, and an automobile skimming over the highway all have kinetic energy, and the faster they go, the more energy they have.

3-5. Conservation of Energy:

a. One of the many laws of physics is the Law of Conservation of Energy, which states that *energy can be neither created nor destroyed, but its form may change.* For instance, energy given up by one body doing work is passed on to another body on impact or divided between them without loss. The amount of energy in the universe remains unchanged and is only transformed from one kind or another. When you ignite a mixture of gasoline and air inside the combustion chamber of an engine, the resulting combustion process generates heat energy. The remaining gases in the chamber (principally nitrogen) absorb the heat. As the temperature of the gases increases, their pressure also increases (Charles' Law). This increased pressure gives straight line motion in all directions to the gases. The straight line motion of the gases converts into rotary motion when directed through a turbine wheel. We have just converted heat energy into mechanical energy.

b. The mechanical energy of the rotation shaft is further transformed into other types. For example, the rotating shaft turns the pumps and generators. The generator transforms mechanical energy into electrical energy. The electrical energy is then used to operate motors that convert the electrical energy back into mechanical energy. This is used for the operation of such aircraft units as the retractable landing gear and wing flaps. The generator also supplies electrical energy for aircraft lighting systems, radio operation, and recharging the aircraft battery. When the battery is being charged, electrical energy is being transformed into chemical energy. When the battery is being discharged, chemical energy is being transformed back into electrical energy.

3-6. Heat Energy. Since the aircraft engine uses heat energy, a further discussion of heat energy is of importance. When compressing gas, the gas becomes hot. Conversely, when a gas under high pressure expands, the gas becomes cool. In the first case, we converted work into heat energy. In the second case, unexpanded heat energy. Experimentation shows that the work required to overcome and the amount of heat produced by friction are proportional. So heat is as a form of energy. According to this theory of heat as a form of energy, the molecules, atoms, and electrons in all bodies are in a continuous state of motion. In a hot body, these small particles possess relatively large amounts of kinetic energy, while in cooler bodies they have less. Because the small particles are given motion, and hence, kinetic energy, work must be done. Mechanical energy apparently is transformed and what we know as heat is really kinetic energy of the small molecular subdivisions of matter. Unfortunately, no engine is capable of transforming all of the available heat energy in the fuel it burns into mechanical energy. Heat losses and operational friction waste a large portion of this energy.

3-7. Gravitation. From his experiments, Sir Isaac Newton concluded that all bodies in the universe attract each other. For example, the earth attracts the moon and the moon attracts the earth. This mutual attraction is gravitation. More commonly, the term applies to the attraction between the earth and all things upon it. Because of the great mass of the earth, the attraction in this case is in one direction--toward its center. This force is gravity, which is the force that pulls an aircraft to earth when its engines fail, that makes a kite drop when the wind dies down, and that keeps us from hurtling off the face of this rapidly spinning sphere into space.

3-8. Weight and Mass:

a. The pull of gravity causes objects to have weight. Weight is defined as a measurement of the force of gravity acting on an object. Mass is defined as the amount of matter in any object. Since weight depends on gravity, the weight of an object decreases with altitude (distance from the center of the earth). The force of gravity decreases with altitude. An aircraft that weighs 100,000 pounds on the ground weighs a little less at 50,000 feet. The mass of the aircraft has not changed however, because mass, unlike weight, is not dependent on gravity. The mass of an object is the same throughout the universe, regardless of how far it is from a gravity source. Within the earth's atmosphere, the change in the force of gravity of an object does not produce any significant change in the weight of the object. As a result, in engineering calculations the numerical value for the mass of an object is, for all practical purposes, the same as the weight of the object. The terms mass and weight are commonly used interchangeably. One must keep in mind that technically the two are not the same. Since weight is a force, pulling a body toward the center of the earth, the units of measurement which apply to force also apply to weight. The gravitational system unit is the pound. The absolute system unit is the poundal.

b. The poundal is the basic unit of force in the absolute system. It is defined as the force that will give a mass of one pound an acceleration of 1 foot per second per second. At 0 degrees latitude (the equator) the force of gravity on a one pound-mass is 32.08 poundals, and at the poles it is 32.25 poundals. The average value is 32.16 poundals, figured at 45 degrees N latitude (45N.), the value commonly used in engineering calculations.

c. In the absolute system, pounds measures mass. In the gravitational system slugs measure mass. The slug is an engineering unit of mass and is defined as the mass that accelerates one foot per second when acted upon by a one-pound-mass force. Mathematically, one slug has the same value as the acceleration of gravity. The value commonly used is 32.16 pounds and used to calculate air density.

3-9. Density. The density of a substance is defined as the mass per unit volume. Mathematically, density is represented by the Greek letter rho (p) and is calculated by dividing mass volume, or:

$$\text{Rho} = \frac{\text{Mass}}{\text{Volume}} \quad P = \frac{M}{V} \quad \text{or} \quad \frac{M}{PV}$$

You may express the value of M in the formula in pounds or slugs. Express P in pounds or slugs per unit volume. When changing pounds per cubic foot to slugs per cubic foot, divide by 32.16. For example, the density of air at sea level and 15 degrees Centigrade, is .07651 pounds per cubic foot (lbs/ft3). Dividing .07651 by 32.16 gives 0.002379 slugs/ft3. Sometimes we use the term mass density for density to remind the reader that the mathematical value of M is in terms of mass and not weight.

3-10. Specific Gravity. The definition of specific gravity is the ratio of the density of a substance to the density of water. For example, aluminum has a specific gravity of 2.7. This means that a cubic foot of aluminum weighs 2.7 times as much as a cubic foot of water. The reason that lubricating oil floats on top of water is because it is less dense than water. Oil has a specific gravity of .90 to .93.

3-11. Force. Force is defined as a push or pull. Force is any action that produces, retards, modifies motion, or changes the shape of a body. In the gravitational system, one of the ways to measure force is in pounds. Since force is a vector quantity, you may represent it by a straight line.

a. A force has three characteristics: magnitude, direction, and point of application. When we consider a force acting on an object, we cannot know its complete effect unless we know these three things.

b. When several forces act upon a body, they produce the equivalent of a single force, termed the resultant force, equal to the individual forces. As far as the effect of the individual forces on the actual motion of the body, it is the same as though only the resultant force was acting on the object. To find the single force use the rules of vector calculation. The resultant force is the vector sum of all the acting forces. Use simpler methods if there are only two vectors or if they are at right angles. In figure 3-1, two forces of 100 pounds each are applied to an aircraft, one is lift and one is thrust. What is the resultant force on the aircraft?

First, we must solve the problem through graphics by using the parallelogram. According to the parallelogram law,*the resultant of two forces acting at a point is indicated by the diagonal of a parallelogram the two adjacent sides of which represent the two forces in both direction and magnitude.* In our example, the two force lines, A.T. and A.L., are each two miles long and represent 100 pounds. The resultant force is the diagonal, A.C., which measures 2.82 miles. Since the 2 mile scale represents 100 pounds, by the ratio and proportion method we can determine the resultant force:

$$\frac{2 \text{ miles}}{2.82 \text{ miles}} = \frac{100 \text{ lbs}}{?}$$

We could solve the same problem by using the Pythagorean theorem. This theorem states that *in a right-angle triangle, the square of the hypothenuse equals the sum of the squares of the other two sides.*

$R^2 = A^2 + B^2$
$R^2 = 10{,}000 + 10{,}000$
$R = 141$ pounds

(R = resultant force)

Use this theorem only when the forces are at right angles to each other.

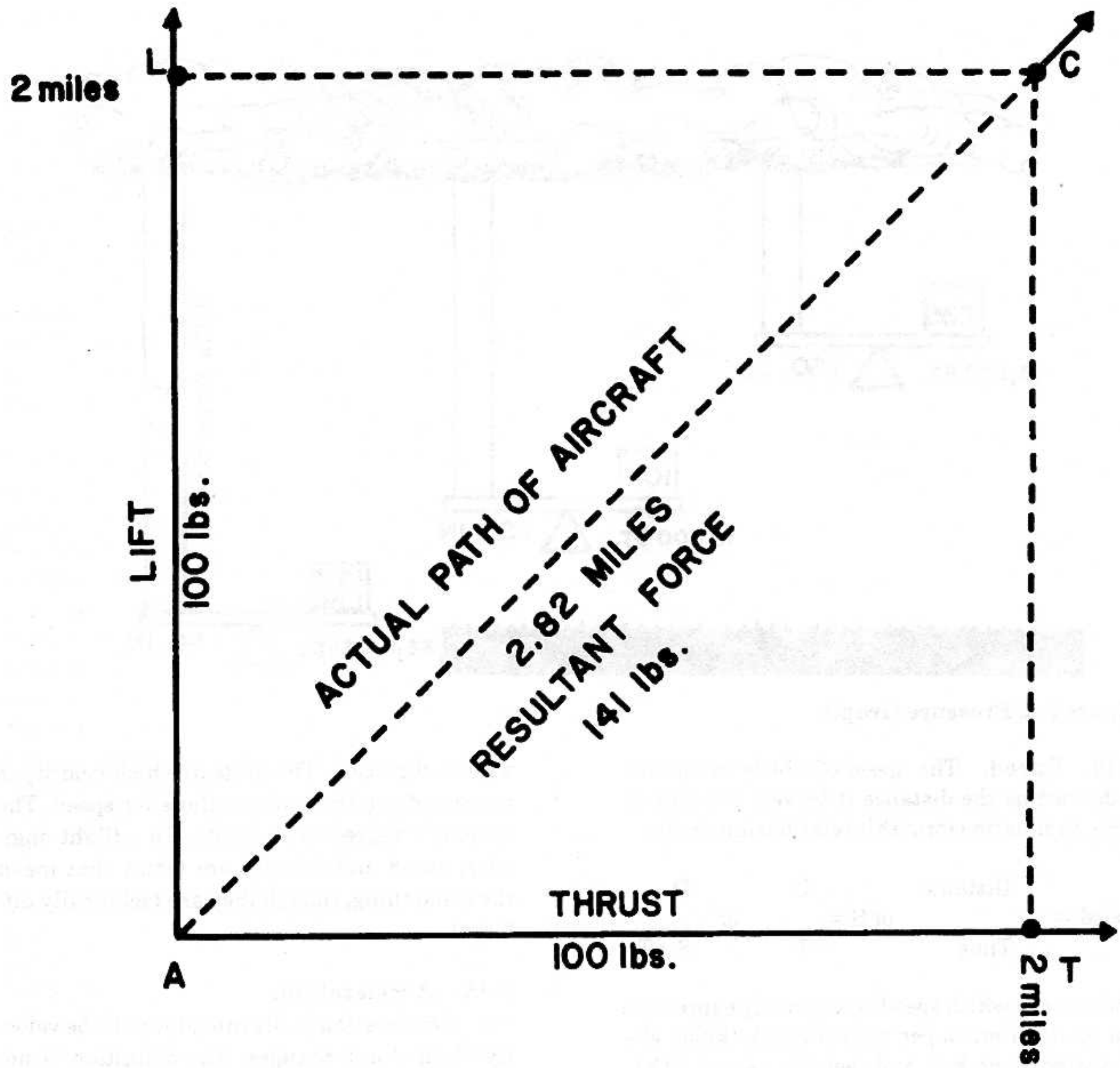


Figure 3-1. Force Graph.

c. If the vector sum of all the forces such as lift, thrust, gravity, and drag on a body is zero; the body is in equilibrium and there will be no acceleration in any direction. This condition of equilibrium is a balance between all forces so there is a cancellation by oppositely directed forces. Mathematically, the rule for equilibrium of several forces is that *the algebraic sums of their X and Y components must equal zero.* If any body remains at rest or moves at a constant speed, the forces acting on it must be in equilibrium.

3–12. Pressure. Pressure is the push or pull (forces) applied by its surface divided by its area. Pressure is usually expressed in pounds per square inch (lbs/in^2). In equation form the pressure relationship reads:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} = P = \frac{F}{A} \text{ or } \frac{F}{P \times A}$$

Figure 3-2 shows how the pressure of a column of air using the above formula could be calculated.

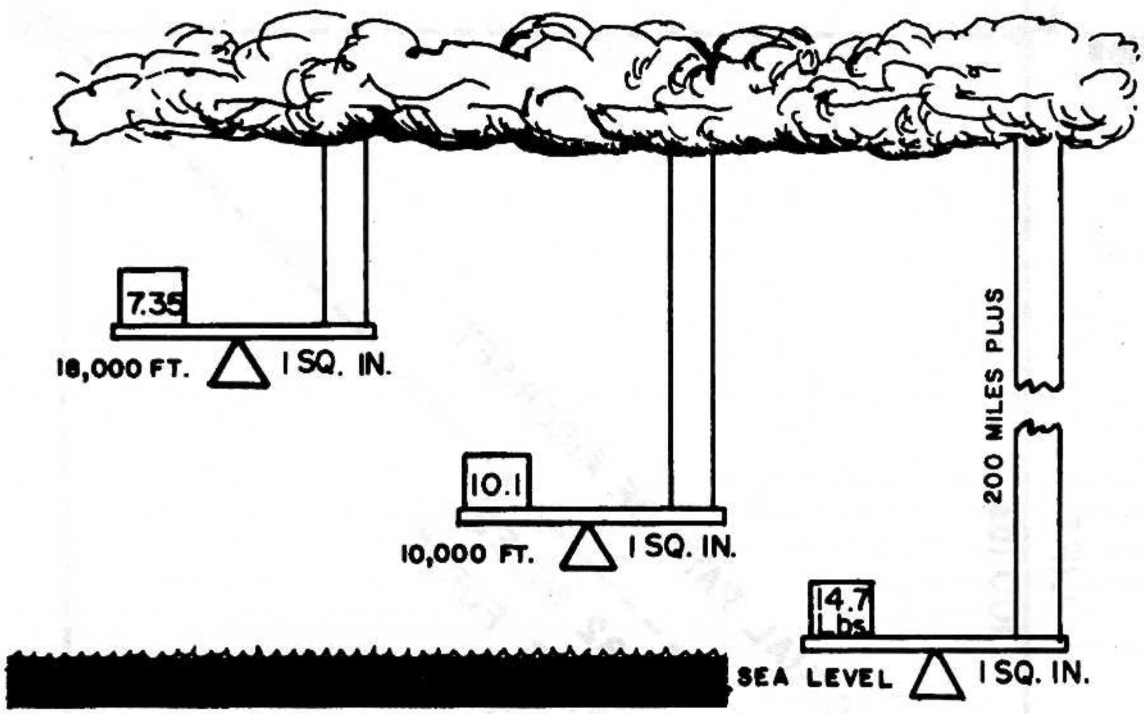


Figure 3-2. Pressure Graph.

3–13. Speed. The speed of a body in motion is defined as the distance it travels per unit of time. In equation form this relationship reads:

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}} \text{ or } S = \frac{D}{T} \text{ or } \frac{D}{S \times T}$$

The units in which speed is commonly expressed are nautical miles per hour (nmi/h), (knots abbreviated K or kn), and feet per second (ft/s). The symbol "nmi" is used in the term nautical miles per pound (nmi/lb).

3–14. Velocity. Speed makes no reference to the direction in which a body moves. Velocity includes the use of direction. Velocity is speed in a given direction. The units in which velocity is expressed are the same as those for speed. The symbol V represents velocity. To a flight engineer, speed and velocity are terms that mean the same thing, though they are technically different.

3–15. Acceleration:

a. Acceleration is the rate at which the velocity of an object changes. The definition is not based on the distance traveled, but on the loss or gain of velocity with time. The equation form is:

$$\text{Acceleration} = \frac{\text{change of motion}}{\text{unit of time}}$$

$$= \frac{\text{final velocity - original velocity}}{\text{Time}}$$

$$= \frac{V^f - V^o}{t}$$

Where V^o is the original velocity, V^f is the final velocity, V^f-V^o is the change of velocity, and t is the time interval during which this change occurs.

b. Figure 3-3, shows the relationship of time, acceleration, velocity, and distance.

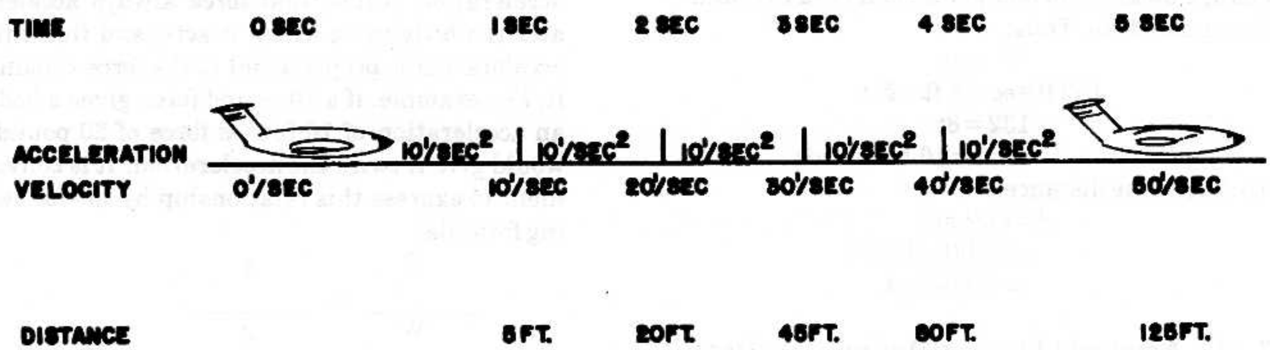


FIGURE 3-3. RELATIONSHIP OF ACCELERATION,TIME, DISTANCE, AND VELOCITY

c. If velocity is measured in foot per second (ft/s), then acceleration would be measured in foot per second squared (ft/s^2). The following example explains this measurement:

EXAMPLE: An aircraft moves from point A to point B. At point A, its velocity is 40 ft/s. At point B, its velocity is 70 ft/s. The aircraft requires ten seconds to travel from point A to point B. Calculate the average acceleration per second. Substituting in the formula above, we have:

$$a = \frac{70 - 40}{10}$$

$$= \frac{30}{10}$$

$$= 3 \text{ ft/s}^2$$

d. Acceleration is any change in velocity whether positive or negative. We use the term deceleration to mean a decrease of velocity. If a body starts from rest, V^o is zero and the equation can be written:

$$a = \frac{Vf}{t} \quad \text{or} \quad V^f = at$$

V = velocity in feet per second
a = acceleration in foot per second squared
t = time in seconds

e. Distance traveled is the product of the average speed and the time, where the average speed (in the case of a uniformly accelerated body) is one-half the sum of the initial speed and the final speed. Therefore, the average speed of a uniformly accelerated body, starting from rest, is equal to: one-half (1/2) V^f.

$$Vavg = 1/2 \text{ at}.$$

Since the distance is equal to the average velocity for a certain length of time, this relationship can be expressed by the equation, or:

$$d = 1/2 \text{ at} \times t, \quad \text{or } d = 1/2at^2$$

f. If one knows the acceleration and the time, he or she can calculate the distance a body traveled during that time. All over the surface of the earth acceleration of freely falling bodies is nearly the same. The symbol generally used for the acceleration cause by the earth's gravity is "g" and its numerical value is approximately 32.2 ft/s. Using g instead of "a" in the equation, we have the distance equation for freely falling bodies starting from rest. It is $d = 1/2gt^2$.

g. You can apply previous equations to examples of acceleration. Use equation V_f = at in problems of aircraft acceleration at takeoff or aircraft braking at landing.

h. An aircraft is decelerated at a rate of 8 ft/s. How much runway will it need for stopping if it comes in at a landing speed of 90 knots?

i. Using equation V^f = at, solve for the time in seconds needed to come to a stop. First, change 90 knots to feet per second (132 ft/s) and then substitute. Thus:

$$V^f = at$$
$$132 \text{ ft/sec} = 8 \text{ ft/s} \times t$$
$$132 = 8t$$
$$t = 16.5 \text{ seconds}$$

To determine distance:

$$d = (1/2\ at^2)$$
$$= (1/2)(8)(16.5^2)$$
$$= 1089 \text{ feet}$$

3–16. Newton's Laws of Motion. Sir Isaac Newton developed three basic laws which relate force to motion. These laws are: the law of inertia, the law of acceleration, and the law of reaction.

a. Newton's first law, the law of inertia, states, "A body at rest tends to remain at rest, and a body in motion tends to stay in motion with constant speed unless acted upon by an outside force." The force portion of this law is acceptable by a person's own experiences. For example, when a car starts suddenly, the occupants are thrown backward, and likewise, if the car stops suddenly, the occupants are thrown forward. It is harder to accept the part that states a body in motion tends to remain in motion. According to the law, if all friction could be removed from a bearing, a wheel could coast forever.

b. Newton's second law, the law of acceleration, states, "When force acts upon a body, it changes the acceleration of that body." This change of acceleration is proportional to the applied force and to the mass of the body giving the body momentum. Momentum of a body is defined as the product of its mass and its velocity. Thus:

Momentum = mass X velocity
F = force on object
W = weight of object
a = acceleration of object
g = acceleration of gravity

A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at low velocity is difficult to stop because of its large mass. Likewise, the mass of a bullet is small, but its penetrating power (momentum) is tremendous because of its high velocity. Since we cannot change the mass of a body, a force can affect the acceleration (momentum) of a body only by changing its velocity; that is, by accelerating it positively or negatively. The law of acceleration states, that force always accelerates the body upon which it acts, and that this acceleration is proportional to the force causing it. For example, if a 10-pound force gives a body an acceleration of 10 ft/s^2, a force of 20 pounds would give it twice the acceleration. It is convenient to express this relationship by the following formula:

$$\frac{F}{W} = \frac{a}{g}$$

The following examples demonstrate the use of the formula:

EXAMPLE 1: An aircraft weight 6,400 lbs. How much force is needed to give it an acceleration of 6 ft/s?

$$\frac{F}{W} = \frac{a}{g}$$

$$\frac{F}{6{,}400} = \frac{6}{32}$$

$$F = \frac{6{,}400 \times 6}{32} = 1{,}200$$

W = 6,400 lbs
a = 6 ft/s
g = 32 ft/s
F = ?

A force of 1,200 pounds is needed.

EXAMPLE 2: A body that weighs 40 pounds has a resultant force of 10 pounds acting on it. What is the acceleration?

$$\frac{F}{W} \quad \frac{a}{g}$$

$$\frac{10}{40} = \frac{a}{32}$$

$$a = \frac{10 \times 32}{40} = 8$$

The acceleration is 8 ft/s.
W = 40 lbs
F = 10 lbs
g = 32 ft/s
a = ?

c. The second law of motion also may be expressed by the following mathematical equation:

$$F = Ma$$

Where F is force, "a" is acceleration and M is mass. You may obtain this condensed formula by substituting mass (M) for weight (W) and gravity (g).

d. Using the values for W and g as given in example 1, we can find M as follows:

$$M = \frac{W}{g}$$

$$= \frac{6400}{32}$$

$$= 200$$

Then using the value 6 ft/s for "a" as given, we have:

$$F = MA \quad = 200 \times 6 \quad = 1200 \text{ lbs}$$

e. Newton's third law, the law of reaction, states, "For every action (force) there is an equal and opposite reaction (force)." This means that if we apply force to an object, the object provides an opposing force exactly equal to and in the opposite direction to the force applied. It is easy to see how this might apply to objects at rest. For example, when you stand on the floor, the floor exerts an upward force on your feet exactly equal to your weight. This law also applies when the force sets an object in motion. When a force applied to an object is more than enough to overcome friction, the excess force produces acceleration. The inertia of the object causes a resistive force such that the force opposing the motion equals the force producing the motion. Inertia is that property of matter which caused it either to remain at rest or to maintain uniform motion in a straight line unless acted upon by an exterior force. This resistance to change in velocity due to inertia is usually referred to as internal force. When several forces act upon an object to produce accelerated motion, the sums of the external forces are in a state of unbalance; however, the sums of the external and internal forces are always in a state of balance, whether motion is being either sustained or produced. Forces always occur in pairs. The term acting force means the force one body exerts on a second body. The reacting force means the force the second body exerts on the first. Two words sum up this law: action and reaction. We frequently demonstrate this law in everyday life.

(1) The recoil of a rifle demonstrates this law of action and reaction. The percussion cap ignites the gunpowder charge, combustion takes place, and the bullet accelerates rapidly from the rifle. As a result of this action, the rifle accelerates rearward against the shoulder of the rifleman. The recoil felt by the person firing the rifle is the reaction of the action which ejected the bullet.

(2) An aircraft propeller pushes a stream of air backward with a force of 500 pounds. The air pushes the blades forward with a force of 500 pounds. This forward force causes the aircraft to move forward. In like manner the tremendous rush of hot gases from the tailpipe of a jet aircraft is the action which causes the aircraft to move forward rapidly (reaction).

NOTE: The previously discussed, three laws of motion in many cases, may be operating on a body at the same time.

3-17. Centrifugal and Centripetal Force. The discussion so far has centered around straight-line motion and the forces involved. Now let us consider circular motion and the two forces involved: centrifugal and centripetal. When an object is moving in a circular path, centrifugal force is acting on the object to make it break away and move outward in a straight line. Opposing the centrifugal force is centripetal force, which acts inward to hold the object on its circular path. Both are equal and opposite. For example, when a weight attached to a cord is whirled, it is held in the circle by the tension of the cord (centripetal force); at the same time there is an outward pull by the weight against the cord (centrifugal force). If the cord should break, both forces would instantly disappear and the body would continue in a straight line because of inertia; in other words, the first law of motion would be in effect.

3-18. Moments and Torque. If you mount a body on a pivot or axis and apply force, there is a tendency for rotation to take place. The further the force is from the axis, the greater is the tendency to rotate the body about its axis. You normally place your hand at the end of a wrench when attempting to tighten or loosen a nut. This tendency to produce rotation is a moment of force, or torque. Torque is the product of a force and the distance of the force from the axis. Thus, we have the following equation:

Torque = force X distance (lever arm)

a. Do not confuse work with torque. Torque is a measure of load in pound-feet or pound-inches. For example, you must tighten a certain propeller nut to a torque of 720 pound-feet. This job requires a 180-pound force on a 4-foot bar or 120 pounds on a 6-foot bar.

b. When applying two forces in the same direction but at different points on a body, refer to the forces as parallel forces. For example, the forces shown in figure 3-4 exert parallel forces on the bar. The forces need not be equal to be parallel forces. If force A were greater than force B, the bar would turn about its pivot (fulcrum) in a counterclockwise direction. If force B were heavier than A, the bar would turn in a clockwise direction (see figure 3-4). If the two moments are equal, the bar is in balance, for under these conditions the clockwise moments equal the counterclockwise moments. Thus, using the numbers shown in the illustration, we get the following result:

$$5 \times 50 = 5 \times 50$$

c. There are many practical applications of the principle of moments. We use the principle to determine the balance of an aircraft in weight and balance calculations. We also see this principle in use in our everyday life. We employed this principle when we moved a wheelbarrow full of dirt or when we put the various weight blocks on the balance scales.

EXAMPLE: Lets go to the wheelbarrow full of dirt. How much force do you need to lift the load? Let us assume that the center of the load was two feet from the fulcrum (wheel) and that we apply the force six feet from it.

Clockwise moments = counterclockwise moments

$$6 \times F = 2 \times 300$$

$$6F = 600$$

$$F = 100 \text{ pounds}$$

The wheelbarrow handles require 100 pounds to balance (lift) the load of 300 pounds.

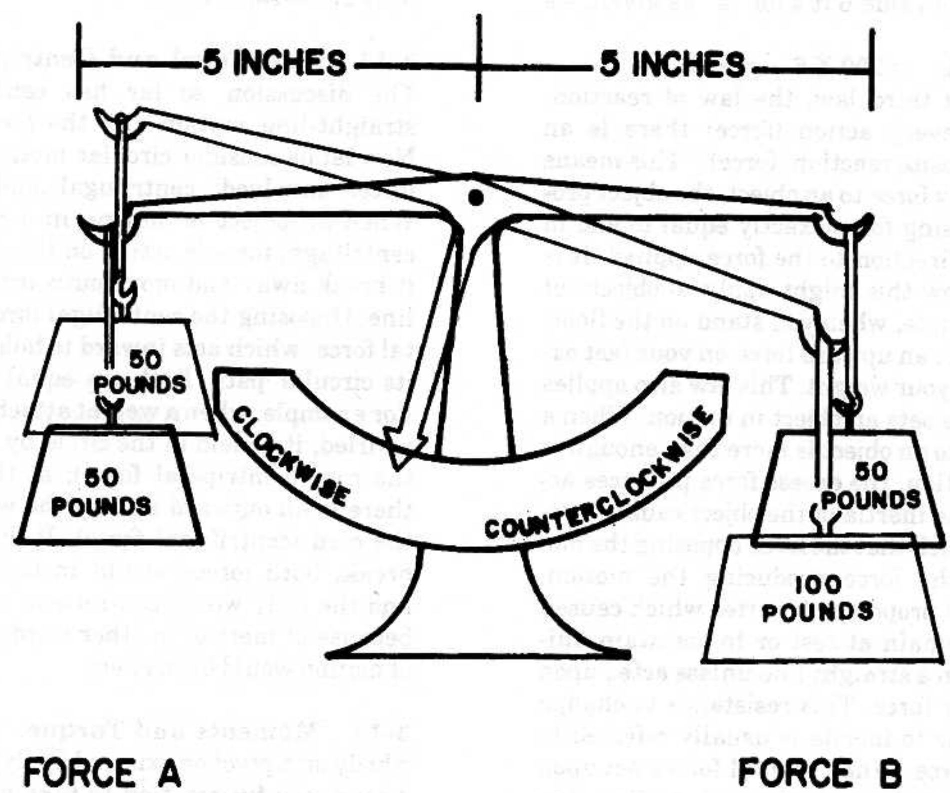


Figure 3-4. Parallel Forces.

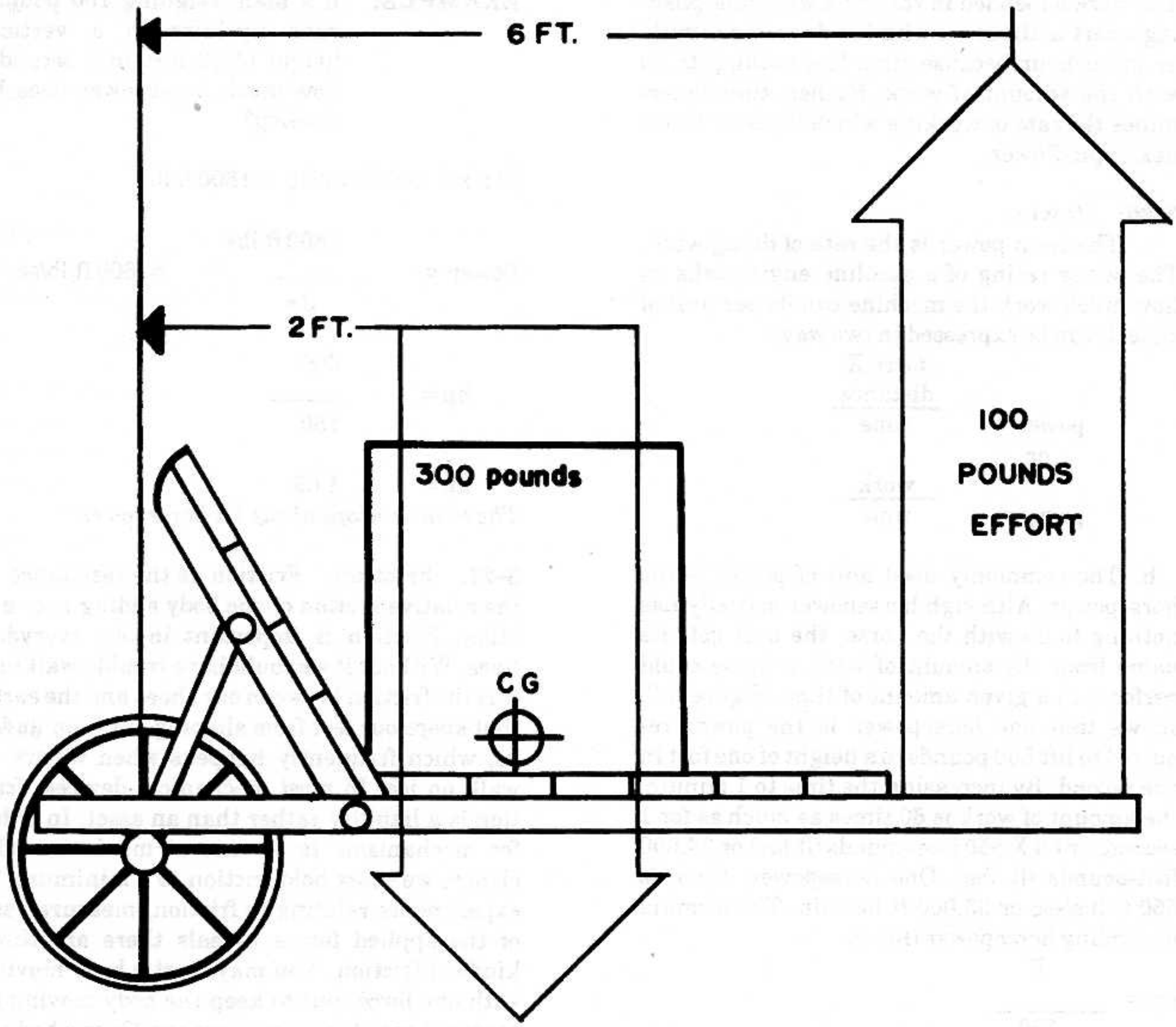


Figure 3-5. Wheelbarrow Problems.

3–19. Work. Earlier in this chapter we defined energy and force. Energy is the ability to do work, and force is a push or pull. We accomplish work when using energy to produce a force that moves an object. If there is no motion, there is no work. If your car gets stuck in the mud and you try to push it out, regardless of how hard you push, you do no work unless you move the car. It makes no difference how hard you push, how long you push, or how tired you get, you have done no work until the car moves. Mathematically,

Work = force X distance
W = fd

If you lift a 20-pound stone to a height of 3 feet, how much work have you done? The amount of work you did is the product of the force and the distance.

Work = force X distance
W = 20 lb X 3 ft
W = 60 ft lbs

In the previous section we explained that torque, like work, is force times distance. Torque is the result of force times distance in a rotary direction. Work is the result of force times distance in a straight line, as shown in figure 3-6. The unit of work, the foot-pound, is defined as the work necessary to move one pound a distance of one foot against the force of gravity.

The work expended in raising a weight or pushing a cart is the same whether done in a minute or in an hour because time has nothing to do with the amount of work. Rather, time determines the rate of working which leads us to our next topic-Power.

3-20. Power:

a. The term power is the rate of doing work. The power rating of a gasoline engine tells us how much work the machine can do per unit of time. It can be expressed in two ways:

$$\text{power} = \frac{\text{force X distance}}{\text{time}}$$

or

$$\text{power} = \frac{\text{work}}{\text{time}}$$

b. The commonly used unit of power is the horsepower. Although horsepower actually has nothing to do with the horse, the unit gets its name from the amount of work a horse could perform in a given amount of time. Figure 3-7, shows that one horsepower is the power required to lift 550 pounds to a height of one foot in one second. By increasing the time to 1 minute, the amount of work is 60 times as much as for 1 second, or 60 X 550 foot-pounds (ft lbs) or 33,000 foot-pounds (ft lbs). One horsepower, then, is 550 ft lbs/sec or 33,000 ft lbs/min. The formula for finding horsepower (hp) is:

$$hp = \frac{P}{550}$$

where P = power in foot-pounds per second.

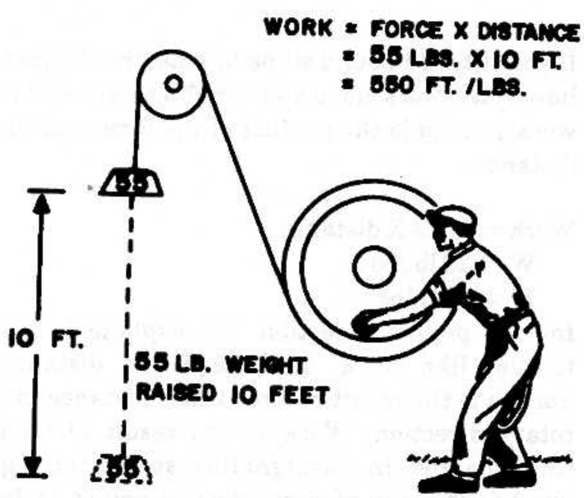


Figure 3-6. Work Equals Force X Distance.

EXAMPLE: If a man weighing 150 pounds runs upstairs to a vertical height of 12 feet in 3 seconds, how much horsepower does he develop?

Work = 12 ft X 150 lb = 1800 ft lb

$$\text{Power} = \frac{1800 \text{ ft lbs}}{3 \text{ s}} = 600 \text{ ft lb/sec}$$

$$hp = \frac{600}{550}$$

$$hp = 1.09$$

The man develops about 1.1 horsepower.

3-21. Friction. Friction is the resistance to the relative motion of one body sliding over another. Friction is important in our everyday lives. Without it we could have trouble walking. It is the friction between our shoes and the earth that keeps our feet from slipping out from under us, which frequently happens when we try to walk on ice. In most mechanical devices, friction is a liability rather than an asset. In order for mechanisms to operate at maximum efficiency, we must hold friction to a minimum. In experiments relating to friction, measurement of the applied forces reveals there are three kinds of friction. You may start a body moving with one force, but to keep the body moving at constant speed requires another. Once a body is in motion, it requires a definitely larger force to keep it sliding than to keep it rolling. The three kinds of friction are starting (static) friction, sliding friction, and rolling friction.

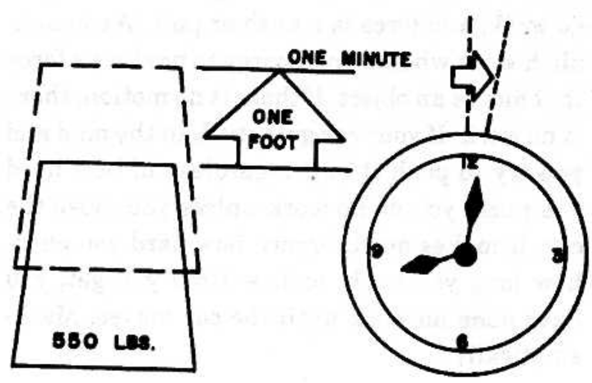


Figure 3-7. Power.

a. Static Friction. You must break an object loose before attempting to slide it along a surface. Once in motion, it slides more easily. The breaking-loose force is proportional to the weight of the body. Let us consider "F" as the force necessary to start the body moving slowly and "f" as normal force pressing the body against the surface. We must consider the nature of the surface rubbing against each other. The letter "k" is the measure of starting friction. This measure is established for various materials. When the load (weight of the object) is known, starting friction can be calculated by the use of the equation:

$$F = kf$$

For example, if the measure of sliding friction of a smooth iron block on a smooth, horizontal surface is 0.3, the force required to start a 10-pound block would be 3 pounds; a 40-pound block, 12 pounds. Starting friction for objects equipped with wheels and roller bearings is much less than that for sliding objects. A locomotive would have difficulty getting a long train of cars in motion all at one time. There are a few inches of play between the couplers on the cars. This is intentional. When the engineer is about to start the train, he pushes all the cars together by backing the engine. Then, the engineer sets the first car in motion with a quick start forward. The engineer employs this technique to overcome the static friction of each wheel (as well as the inertia of each car). It would be impossible for the engine to start all of the cars at the same instant. The resistance to being set in motion would be greater than the force exerted by the engine. You greatly reduce static friction by putting the cars in motion. To keep the train in motion requires a smaller force than was necessary to start it.

b. Sliding Friction. Sliding friction is the resistance to motion offered by an object sliding over a surface after the object is in motion. It is always less than starting friction. The amount of sliding resistance is dependent on the nature of the surface of the object, the surface over which it slides, and the normal force between the object and the surface. This resistive force may be computed by the formula:

$$F = \mu N.$$

"F" is the resistive force due to friction expressed in pounds; "N" is the force exerted on or by the object perpendicular (normal) to the surface over which it slides. The μ (mu) is the measure or coefficient of sliding friction. On a horizontal surface, "N" is equal to the weight of the object in pounds. The area of the sliding object exposed to the sliding surface has no effect on the results. A block of wood will not slide any easier on one of the broad sides than it will on a narrow side (assuming all sides have the same smoothness). Area does not enter into the equation above.

c. Rolling Friction. Mounting an object on wheels or rollers reduces its resistance to motion. The force of friction for objects mounted on wheels or rollers is rolling friction. You may compute this force by the same equation used in computing sliding friction. The values of μ will be much smaller. For example, μ for the rubber tires on concrete or metal is about .02. The value of μ for roller bearings is very small, usually ranging from .001 to .003 and is often disregarded.

EXAMPLE: Towing an aircraft with a gross weight of 318,000 lbs over a concrete ramp, what force must the towing vehicle exert to keep the aircraft rolling after it is in motion?

$$F = \mu N$$
$$= .02 \times 318{,}000$$
$$= 6{,}360 \text{ lbs}$$

Chapter 4

THE ATMOSPHERE

4–1. The Importance of the Atmosphere. We, as humans, continue to think of ourselves as self-sufficient beings, ruling the face of the earth in spite of the accumulated knowledge of the world. We never look upon ourselves as creatures, dwelling like fish in this sea of air, doomed and helpless without this life supporting environment in which we exist. Our existence in this "sea of air" is much like the life of creatures from our ocean floors. When these animals are lifted from their natural environment, the pressures acting on their bodies, inner and outer, produce such changes as to cause unconsciousness or death. The effects on our bodies would produce the same results if we were raised to the surface of our ocean of air. All around earth, like a protecting blanket, lies the earth's atmosphere. Men and women have been at work since the beginning of time trying to find out more about it. Now, in the age of air travel and atomic explosions, they must know what air is made of, how it moves, and the forces within it at work. Air is so important to our existence that, without it, we would have no plant or animal life. Earth would be a dead planet. There would be no trees, flowers, fruits, or vegetables. No birds or other animals could live and the human race would not exist. An atmosphere supports such things as wind, rain, snow, clouds, fire, and the transmission of sounds.

4–2. Composition. Our atmosphere, described as an ocean of air, is much more vast than any ocean of water men know about. Because it is so large, knowledge of it is important. Discoveries about the atmosphere, have increased the scope of air travel and made radio and television possible. Some meteorologists think the atmosphere is about 600 miles thick. They know it has four properties that keep people alive:

a. The power to protect the earth from dangerous extremes of heat and cold.

b. The necessary gas for life--oxygen.

c. The ability to screen out the deadly portions of the sun's rays.

d. The ability to store and carry moisture. After just saying how vast this ocean of air is, it is relatively small compared to the size of the earth. Let's take a look at the big picture. If the earth was a baseball, the outer skin of that baseball would be its atmosphere. The atmosphere is separate from the earth and rotates in relation to the earth. This movement of the atmosphere is circulation. The large difference between tropical and polar temperatures primarily creates circulation. If the air stopped moving, no wind would blow life-giving warm air into the frigid regions, or bring life-saving cool air to the unbearably hot tropical regions. There would be no medium to carry moisture from the sea to the thirsty land. The sun is the source of **energy** that causes winds. Radiant energy from the sun falls upon the earth. Some of the energy, while passing through the air, turns into heat energy, but most of it passes through the air to the earth. The clouds and the earth reflect a small amount of radiant energy which is lost in space. Unequal heating of the earth and water causes the air to move in the form of wind from place to place. The rotation of the earth influences the wind's direction. Land heats more rapidly than water, and the air over land becomes warmer than the air over water. The cooler air is more dense and exerts greater pressure than the warmer expanded air. The cooler air flows toward the regions of warm air and forces the warm air upward. This upward movement of air is convection. Violent convection currents of air, with downdrafts of cooler air cause thunderstorms. The atmosphere consists of a mixture of various gases. The composition of pure, dry air is about 78 percent nitrogen, 21 percent oxygen, and 1 percent of other gases, mostly argon (figure 4-1). Suspended in the air is water vapor, which varies in amounts from 0 to 5 percent by volume. The maximum amount of water vapor the air can hold depends primarily on the temperature of the air. The higher the temperature, the more vapor it can hold. The water vapor will remain suspended in air until, through condensation, it grows to sufficient droplet or ice crystal size to fall to the earth as precipitation. The depth of the atmosphere is as much as 300,000 feet at points. Roughly half of it, by weight, lies below 18,000 feet because of the gravitational pull of the earth. This creates a blanket of dense air at the earth's surface upon which other forces act.

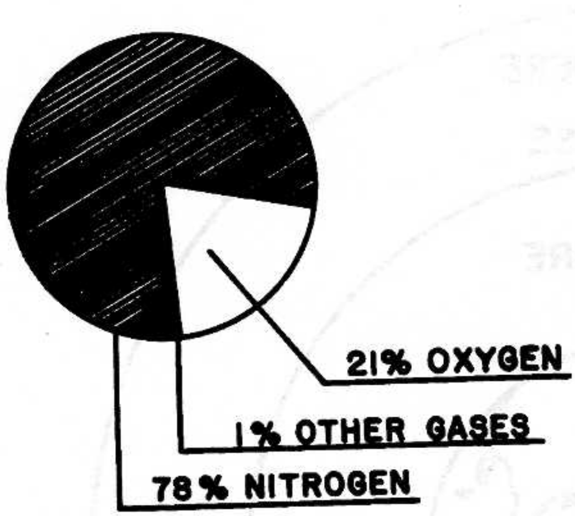


Figure 4-1. Gasses in Our Atmosphere.

4–3. Layers. The atmosphere is divided into layers, or spheres, each having certain properties and characteristics. Since most weather occurs in the troposphere and since most flying is in the troposphere and stratosphere, we will spend most of our time learning about these two layers (figure 4-2).

a. Troposphere. The troposphere is the layer adjacent to the earth. It varies in depth from an average of 55,000 feet over the equator to 28,000 feet over the poles, with greater depth in summer than in winter. It is characterized by a decrease in temperature with height (figure 4-3). The top of the troposphere is the tropopause which serves as the boundary between the troposphere and the stratosphere. The location of the tropopause is usually characterized by a pronounced rate of temperature change with altitude. The tropopause acts like a "lid" in that it resists the exchange of air between the troposphere and the atmosphere above. This explains why almost all water vapor is in the troposphere. Above the tropopause are the stratosphere, the mesosphere, and the thermosphere (figure 4-4).

b. Stratosphere. The atmospheric layer just above the tropopause is the stratosphere. The average altitude of the top of this layer is 22 miles. Characteristics of this layer are a slight increase in temperature with weight (as opposed to the decrease encountered in the troposphere) and the near absence of water vapor and clouds. Occasionally, a strong thunderstorm will break through into the tropopause. Except for a substantial increase in the amount of ozone, the composition of the stratosphere is the same as that of the troposphere. Ozone is important because it absorbs most of the deadly ultraviolet rays from the sun. Ozone also has a corrosive effect on certain metals and has become increasingly important as supersonic aircraft operate in the regions of higher ozone concentration.

4–4. Aircrew Environment. Because the atmosphere contains 21 percent oxygen, the pressure oxygen exerts is about one-fifth of the total air pressure at any one given level. This is important to aircrews because the rate at which the lungs absorb oxygen depends upon the oxygen pressure. The average person is accustomed to absorbing oxygen at a pressure of about 3 pounds per square inch (3 lbs/in^2). Since air pressure decreases with increasing altitude, oxygen pressure also decreases. Prolonged high altitude flight without supplemental oxygen will usually produce a feeling of exhaustion, then an impairment of vision, and finally unconsciousness--symptoms of hypoxia. Use auxiliary oxygen during flights above 10,000 feet.

4–5. Fronts. Meteorologists recognize four kinds of fronts--cold, warm, occluded, and stationary. Fronts are especially important to the aircrew. Specific weather conditions precede and follow a front as it moves through an area. Weather associated with one section of a front is frequently different from the weather in other sections of the same front. Frontal weather varies according to the type of front formed. Most important, many weather hazards to aviation may accompany a frontal system.

a. Cold Front. The leading edge of an advancing cold air mass is a cold front. That is, the cold air is overtaking and replacing warmer air. Some of the hazards that may accompany a cold front include turbulence (which may be extreme), wind shear, thunderstorms, lightning, heavy rain showers, hail, icing, and possibly tornadoes. Another hazard is the strong, variable, gusty low-level winds (wind shear) at the surface and around and under the thunderstorms.

b. Warm Front. The edge of an advancing warm air mass is a warm front. That is, warmer air is overtaking and replacing colder air. Some of the hazards accompanying a warm front include low ceilings and poor visibility; freezing rain, ice, or both. Low level wind shear can be a very significant problem and can last for hours at a location prior to warm frontal passage.

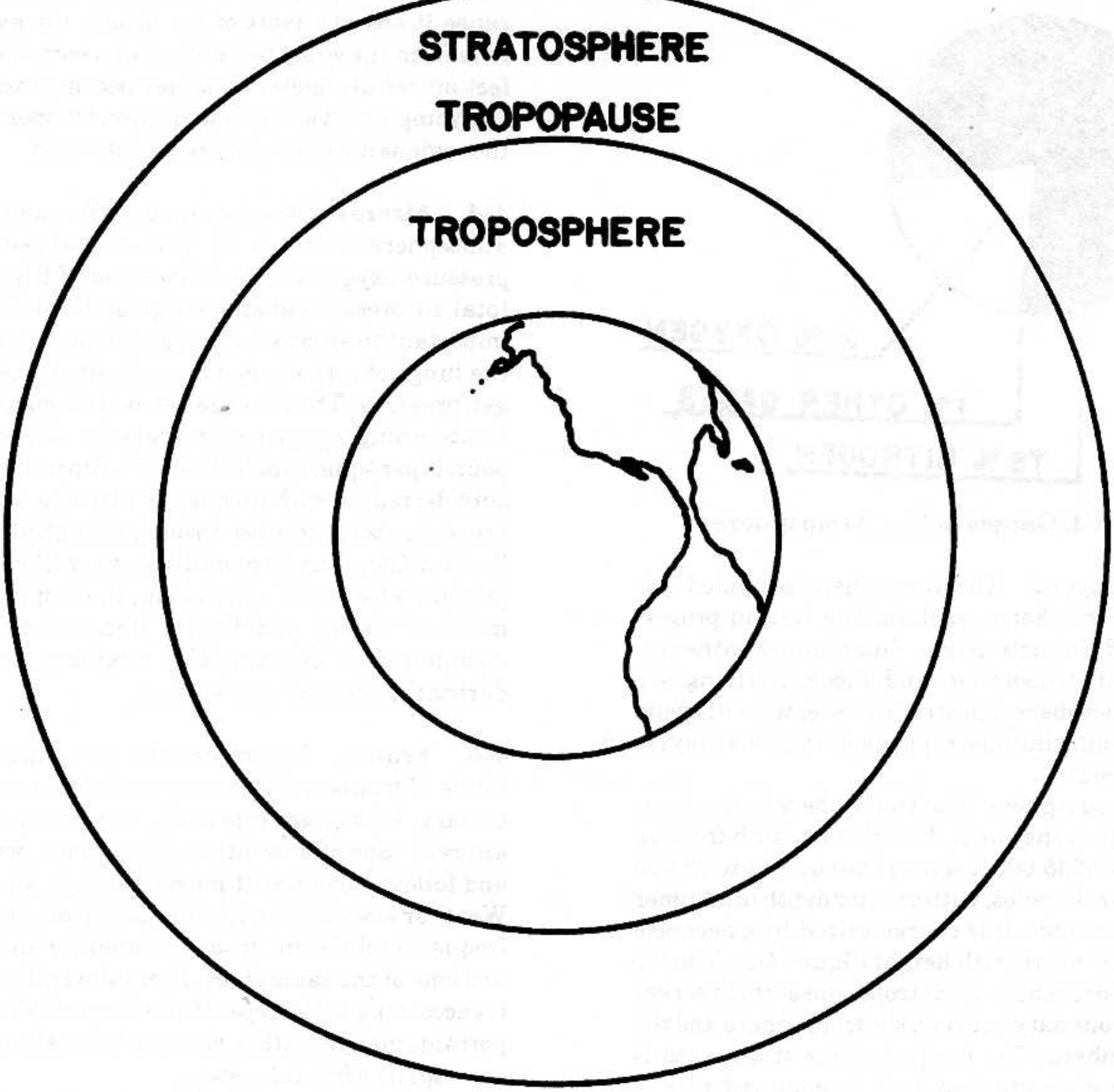


Figure 4-2. Layers of Atmosphere.

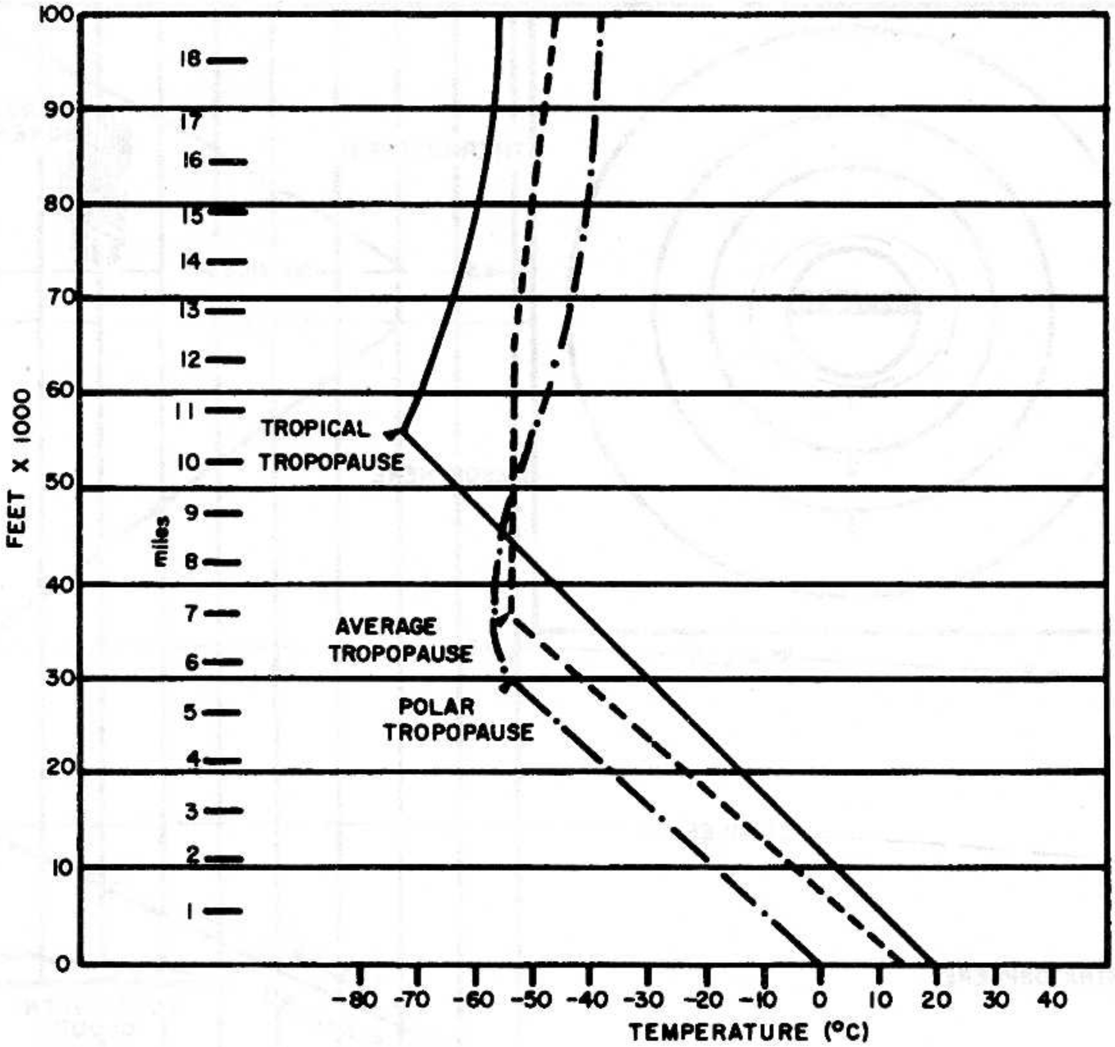


Figure 4-3. Temperature vs. Height.

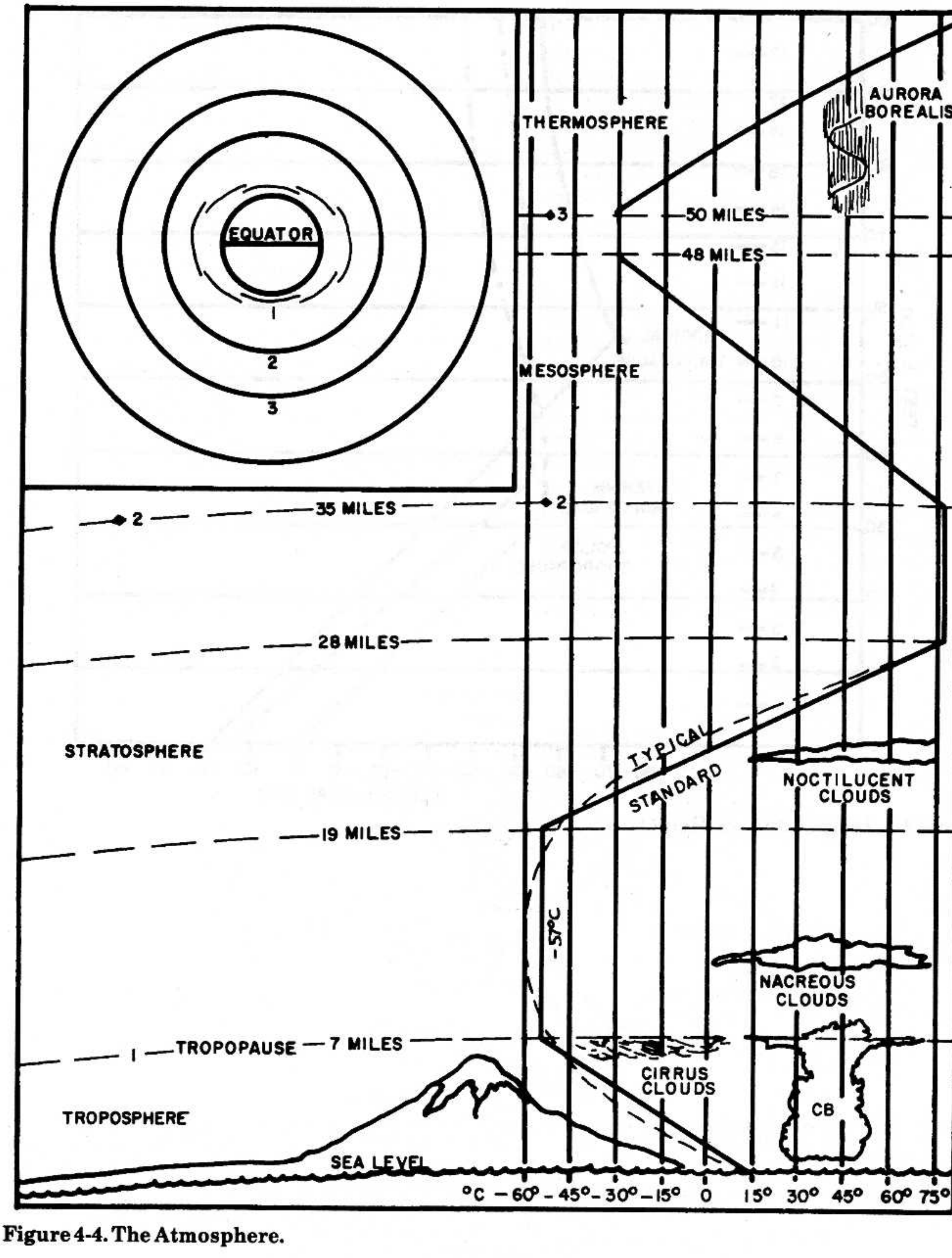


Figure 4-4. The Atmosphere.

c. Occluded Front. When a cold front overtakes a warm front and lifts it completely from the ground so the line of contact is aloft, an occluded front develops. This occurrence displays characteristics of both warm and cold fronts.

d. Stationary Front. Sometimes a warm front or cold front just does not move. When this happens. we call that a stationary front. Weather on either side of this type front remains the same until conditions change and the front moves on.

4-6. Winds:

a. The most noticeable property of air is its mobility. This mobility of the atmosphere manifests itself both in flow of local winds and in a vast, orderly system of air movements that appear to govern weather conditions around the globe. We know the greater winds of the earth are impelled by two great forces, the heat of the sun and the rotation of the earth on its axis. In this process, the sun is the real source that drives the winds. The earth's rotation is the steering mechanism. If the sun alone worked on the atmosphere and the earth did not rotate, all large scale winds would blow to a point directly under the sun and move radially in all directions at some higher level. The earth's rotation directs air flow (see figure 4-5). Warm air from the tropics continually mixes with the cool air from the polar regions. This moderates the climate and adjusts temperature extremes around most of the world. In each hemisphere, warm and cool air masses form a large, shifting, and unstable boundary which is both mobile and irregular. Aloft, this area has deep folds which alternately advance and retreat to the north and south. They swirl in huge orbits around the poles from the west to the east. This hurls great waves of cold air toward the equator and draws warm air back toward the poles. At the same time, huge cells of high and low pressure areas develop which relates to the wind systems at sea level. In addition to these large pools of air, minor ones are caused by the effects of local earth formation, such as oceans, continents, mountain ranges, lakes, deserts, valleys, and even large tracts of forest land. These local disturbances create updrafts, downdrafts, cold fronts, and warm fronts. This creates or destroys cloud patterns which, when carefully analyzed by pilots and flight engineers, may help them arrive at decisions relating to their missions.

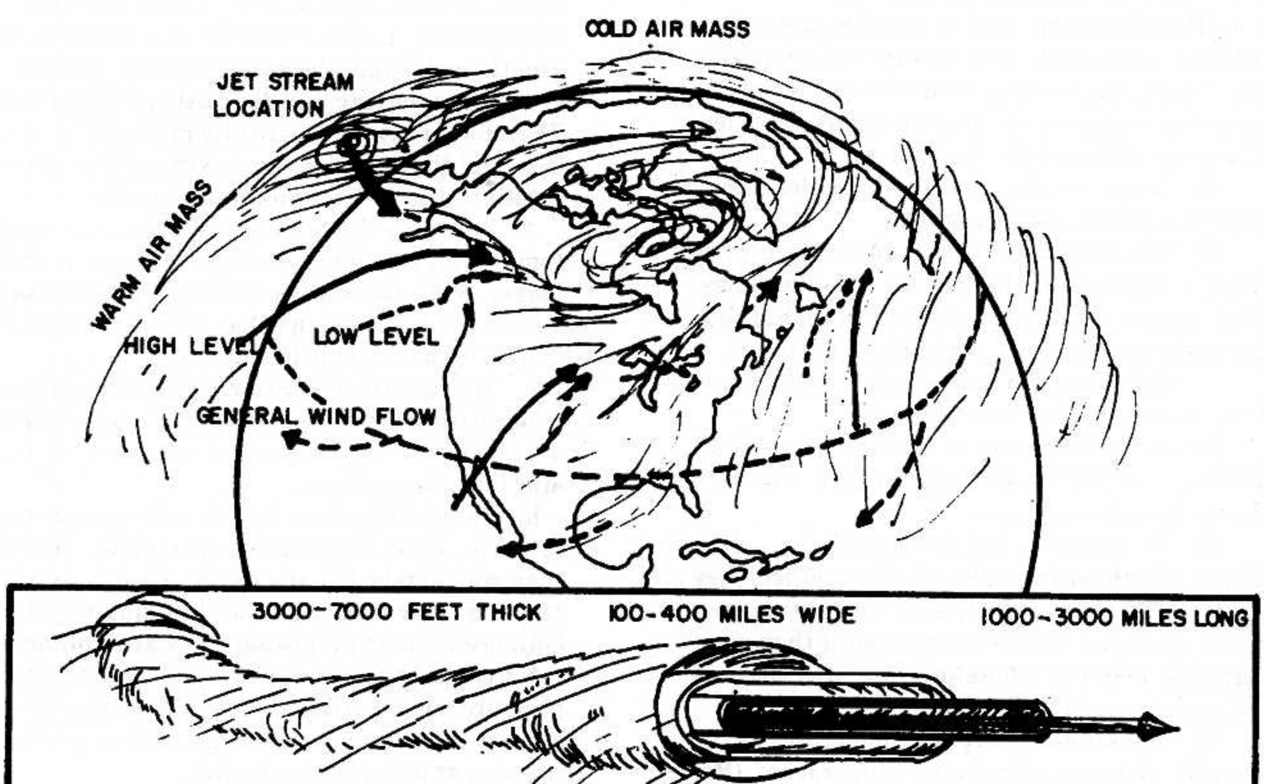


Figure 4-5. The Jet Stream.

b. A jet stream, as illustrated in figure 4-5, is a narrow, shallow band of strong westerly winds of 50 knots or more which meanders vertically and horizontally around the hemisphere in wave-like patterns. Jet streams are characteristic of both the Northern and Southern Hemispheres. We will limit this discussion to the northern hemisphere. Wind speeds in the jet stream sometimes may reach 300 knots but generally are between 100 and 150 knots. Since the jet stream is stronger at some places than at others, it rarely encircles the entire hemisphere as a continuous river of wind. More frequently it is in segments from 1,000 to 3,000 miles in length, 100 to 400 miles in width, and 3,000 to 7,000 feet in depth. The strength of the jet stream is greater in winter than in summer. The mean position of the polar jet stream shifts south in winter and north in summer with the seasonal migration of the polar front. As the jet stream moves southward, its core rises to a higher altitude and, on the average, its speed increases. The core of strongest winds is generally between 25,000 feet and 40,000 feet, depending on latitude and season.

4–7. Kinetic-Molecular Theory:

a. Here is a term that is new for most of us. Although different, this theory will give us a foundation for dealing with the gas laws. We base this theory on the motion of gas particles. The assumptions of the theory are:

(1) Gases consist of tiny molecules. They must be little; we can't see them.

(2) The distance between the molecules is large compared to the size of the molecules. Each gas molecule is of a different size, but they do not change in size as variables affect them.

(3) Molecules do not attract each other. They are free to float on their own.

(4) Molecules move in straight lines in all directions colliding with each other and with the walls of the container.

(5) No energy is lost in the collisions. It is almost like throwing rubber balls together, they spring away from each other at almost the same speed. (It would be the same speed if they were perfectly elastic). Therefore, we will assume molecules are perfectly elastic.

(6) The kinetic energy for molecules is the same for all gases at the same temperature. (Remember, kinetic energy is the energy matter possesses due to its motion). For example, when releasing water from behind a dam its potential energy changes to kinetic energy.

b. Let's take a look at how this applies to the Gas Laws and the aircraft. We will put our imagination to work and put a balloon over a glass flask. Is the flask filled with gas? Yes, and we can prove it. First we will warm the gas. As the gas warms up, the molecules move faster and that increases their kinetic energy. What happens is the balloon inflates with the increase in temperature.

c. Now let's take the balloon and squeeze it. The gas that was in the balloon rushed back into the glass jar. What happened? We increased the pressure of the gas and the volume of gas decreased. How do we know? Release the balloon and it will fill with air (gas) again, the pressure decreased and the volume increased.

d. Let's look at another example using an aircraft portable oxygen bottle. If we look at the pressure gauge, it reads 300 lbs/in^2 at the top of the bottle. What does it read on the side and bottom of the bottle? It also reads 300 lbs/in^2 because a gas exerts equal amounts of pressure in all directions.

e. And one last one, imagine being in a room where someone has just opened a bottle of ammonia. It seems that as soon as they take the cap off you smell it. The reason for this is that as the kinetic molecular theory states that molecules are always moving and don't attract each other. Therefore, they automatically mix with the oxygen, and they are always moving so the odor of the ammonia reaches your nose quickly.

f. You may be wondering why you smell some things quickly and others take a little longer. Well the kinetic molecular theory says all molecules move and that it is the size of the molecule that establishes its speed.

g. The kinetic molecular theory does give us a foundation for the gas laws. Now would probably be a good time to look at other factors that affect the atmosphere.

h. Gases differ from liquids in two important respects. First, they are compressible. Second, they completely fill any closed vessel. In most respects, however, gases act like liquids. Since both are capable of flowing, they are commonly referred to as fluids. Gases, like liquids, exert pressure upon surfaces with which they are in contact. Heat affects gases, expanding and contracting as do liquids and solids.

i. In any temperature scale, it is necessary to define at least two fixed points on the scale, then divide the space between the fixed points into equal increments. The two fixed points commonly used are the temperature at which pure ice melts, and the temperature at which pure water boils under standard barometric pressure (14.7 lbs/in^2). On the two common thermometers used today, the Fahrenheit and the Celsius, these fixed points are 32 degrees and 212 degrees Fahrenheit, and 0 degrees and 100 degrees Celsius, respectively. On the two absolute scales, the Rankine and the Kelvin, the scales differ from the regular Fahrenheit and Celsius scales only in position of the zero point, the divisions being the same as on each respective scale.

j. The zero point on the Rankine and Kelvin scales is equal to -459.4 degrees on the Fahrenheit and -273 degrees on the Celsius scale. To change Fahrenheit to Rankine temperature, add 459.4 degrees to the Fahrenheit reading. To change Celsius to Kelvin, add 273 degrees to the Celsius reading. To convert from Celsius to Fahrenheit, or vice versa, use the following equations:

$$F = 1.8C + 32, \text{ or } F = 9/5C + 32$$

$$C = \frac{F - 32}{1.8} \text{ or } C = 5/9\,(F - 32)$$

Now that we have refreshed our memories on the temperature scales, we can look at the gas laws.

4–8. Gas Laws. If you had air or any other gas enclosed in a chamber equipped with a movable piston, you could study the behavior of the gas under varying conditions. You could heat the gas and let it expand and move the piston, thus keeping the pressure constant. You could increase the pressure and keep the temperature constant to see how it affects the density. You could vary the temperature and the density simultaneously to see how it affects the pressure. The laws of Boyle, Charles, and the General Gas Law show the relationship of density, pressure, and temperature.

4–9. Boyle's Law. Boyle's Law states that if the temperature remains constant, the density of any gas is directly proportional to the pressure. This relationship may be expressed mathematically as follows:

$$\frac{D1}{D2} = \frac{P1}{P2}$$

Where D1 and P1 represent one condition of density and pressure. D2 and P2 represent another condition of density and pressure of the same sample of gas. In other words, if you double the pressure you double the density.

EXAMPLE: The density of air is .00238 slugs/ft when the pressure is 14.69 lb/in^2 and the temperature is 15°C. If the temperature remains constant, find the density if the pressure drops to 14.27 lb/in^2.

Substituting in the equation, you obtain

$$\frac{.00238}{D2} = \frac{14.69}{14.27}$$

Therefore:

$$D2 = \frac{.00238 \times 14.27}{14.69}$$

$$D2 = \frac{.0339626}{14.69}$$

$$D2 = .002312 \text{ slugs/ft}$$

Notice that as the pressure dropped from 14.69 lb/in^2 to 14.27 lb/in^2, the density decreased from .002378 slugs/ft to .002312 slugs/ft while the temperature remained constant at 15°C. This example illustrates that the density and pressure of any gas are directly proportional when the temperature remains constant.

4–10. Charles' Law. Charles' law states that if the pressure remains constant, the density of a gas is inversely proportional to the absolute temperature. This relationship is expressed by the mathematical proportion:

$$\frac{D1}{D2} = \frac{T2}{T1}$$

EXAMPLE: The density of the air is .001756 slugs/ft when the pressure is 9.90 lb/in^2 and the temperature is -5°C. If the pressure remains constant, find the density if the temperature drops to -20 °C. First convert the temperature to Kelvin:

T1 = -5c, or T1 = -5c + 273
= 268°K
T2 = -20c, or T2 = -20c + 273
= 253°K

Substituting in the equation, we obtain

$$\frac{.001756}{D2} = \frac{253}{268}$$

Therefore,

$$D2 = \frac{.001756 \times 268}{253}$$

$$D2 = \frac{.470608}{253}$$

$$D2 = .001860 \text{ slugs/ft}$$

This example shows that the density of a gas is inversely proportional to the absolute temperature when the pressure remains constant.

4–11. General Gas Laws. You may combine Charles's and Boyle's Laws into a single relationship which considers the variation of both the temperature and the pressure. This combination is the General Gas Law. You may also express it mathematically, but there is no need to do so since it is no more than a combination of the other two laws.

4–12. Moisture:

a. More than two-thirds of the earth's surface is water. Water from this extensive source is continually evaporating into the atmosphere, cooling by various processes, condensing, and then falling to the earth again as precipitation. This never ending process is the hydrologic cycle. This cycle keeps the atmosphere supplied with moisture and aids in producing temperature and pressure changes.

b. Water in the atmosphere is in three states: vapor, liquid, and solid. Water vapor is water in the gaseous state and is not visible. As a liquid, it is rain, drizzle, and the small water droplets forming clouds and fog. As a solid, it takes the form of snow, hail, ice pellets, ice crystal clouds, and ice crystal fog. Water vapor is the most important single element in the production of clouds and other visible weather phenomena. However, it can create problems or hazards for the flyer when it changes into the liquid or solid state.

c. Most of the atmosphere's moisture is in the lower troposphere, and only rarely found in significant amounts above the tropopause.

d. There is a limit to the amount of water vapor that air, at a given temperature, can hold. When reaching this limit, the air is saturated. The warmer the air temperature, the more water vapor the air can hold before reaching saturation and condensation occurs. For approximately every 11°C increase in temperature, we double the capacity of a volume of air to hold water vapor. Unsaturated air containing a given amount of water vapor will become saturated if its temperature decreases sufficiently. Further cooling forces some of the water vapor to condense as fog, cloud, or precipitation.

e. Absolute humidity is the density of the water vapor in the air. The amount of water vapor that can be present in the air is almost entirely dependent upon the temperature. The higher the temperature, the more water vapor the air is capable of holding. When the air has all the water vapor it can hold, it is saturated.

f. Relative humidity is the ratio of the amount of water vapor actually in the air to the maximum amount the air can hold at that temperature. When the air contains all of the water vapor possible for it to hold at its temperature, the relative humidity is 100 percent. A relative humidity of 50 percent indicates that the air contains half of the water vapor which it is capable of holding at its temperature.

g. The dew point is the temperature, at a given atmospheric pressure, to which air must be cooled to become saturated. When this temperature is below freezing, it is the frost point. The difference between the actual air temperature and the dew point temperature is an indication of how close the air is to saturation. This temperature difference is the spread. Relative humidity increases as the temperature spread decreases and is 100% when the spread is 0 degrees. Aviation weather reports include the dew point because it indicates the behavior of water in the atmosphere.

h. Aircrews should be alert for the possibility of fog or low cloud formation at any time when the surface air temperature is within 4 degrees F of the dew point. When the surface air temperature is higher than the dew point temperature the spread is increasing. Any existing fog and low clouds are likely to dissipate because the air is becoming capable of holding more water vapor. This is especially true in the morning hours while air temperature near the ground is increasing.

i. If we add moisture after saturation, condensation occurs. Condensation also occurs, if cooling of the air reduces the temperature to the saturation point. The most frequent cause of condensation is cooling of the air and often results when air:

(1) Moves over a colder surface,

(2) Is lifted (cooled by expansion), or

(3) Nears the ground cooling at night as a result of radiational cooling.

j. The most common forms of condensation and sublimation products are clouds and fog. Clouds and fog form by very small droplets of water collecting on water-absorbant particles of solid matter in the air. Condensation generally occurs as soon as the air becomes saturated.

k. Precipitation is liquid or solid moisture that falls from the atmosphere in the form of rain, drizzle, ice pellets, snow, or combinations of them. The form of precipitation is largely dependent upon temperature conditions and the degree of turbulence present. Although there can be no precipitation without clouds, most clouds do not precipitate.

l. During clear, still nights, aircraft surfaces often cool by radiation to a temperature equal to the dew point of the adjacent air. Moisture then collects on the surface just as it does on a pitcher of ice water in a warm room. The moisture comes from the air in direct contact with the cool surface. Often heavy dew forms on grass or plants when there is none on the pavements or on large, solid objects. Since large objects absorb so much heat during the day, their temperature falls slowly. Their temperature may not cool below the dew point of the surrounding air during the night.

4–13. Standard Atmosphere Chart. We have defined for purposes of all computations which include meteorological parameters, a standard atmosphere. We make three basic assumptions based on observed data. They are a sea level pressure (29.92" Hg), sea level temperature (15 c), and a temperature decrease with altitude of 6.5 c per kilometer up to the tropopause. From these assumptions we mathematically define the pressure and temperature at each height. The general gas law allows us to calculate the density at each height. The Standard Atmosphere Chart shows the conditions for each height. The chart (figure 4-6) is also the Standard Day Chart and lists average values for temperature, pressure, and density of the air at various altitudes up to 50,000 feet. The purpose of the chart is to provide constant values for computation purposes. It is the basis for aircraft performance charts and data. Above the tropopause, approximately 36,000 feet, the temperature remains constant.

PRESSURE ALTITUDE -FEET	DENSITY RATIO - $\rho/\rho_0 = \sigma$	$\frac{1}{\sqrt{\sigma}}$	TEMPERATURE		SPEED OF SOUND - KNOTS	MILLI-BARS	PRESSURE	
			DEG C	DEG F			IN. Hg	RATIO - $P/P_0 = \delta$
0	1.0000	1.0000	15.000	59.0	661.7	1013.2	29.92	1.0000
1,000	.9711	1.0148	13.019	55.4	659.5	977.3	28.86	.9644
2,000	.9428	1.0299	11.037	51.9	657.2	942.1	27.82	.9298
3,000	.9151	1.0454	9.056	48.3	654.9	908.2	26.82	.8962
4,000	.8881	1.0611	7.075	44.7	652.6	875.0	25.84	.8637
5,000	.8617	1.0773	5.094	41.2	650.3	843.2	24.90	.8320
6,000	.8359	1.0937	3.113	37.6	647.9	812.1	23.98	.8014
7,000	.8106	1.1107	1.132	34.0	645.6	781.9	23.09	.7716
8,000	.7860	1.1279	-.850	30.5	643.3	752.5	22.22	.7428
9,000	.7620	1.1456	-2.831	26.9	640.9	724.3	21.39	.7148
10,000	.7385	1.1637	-4.812	23.3	638.6	696.9	20.58	.6877
11,000	.7156	1.1822	-6.794	19.8	636.2	670.2	19.79	.6614
12,000	.6932	1.2011	-8.775	16.2	633.9	644.4	19.03	.6360
13,000	.6713	1.2204	-10.756	12.6	631.5	619.4	18.29	.6113
14,000	.6500	1.2404	-12.737	9.1	629.1	595.3	17.58	.5874
15,000	.6292	1.2607	-14.718	5.5	626.7	572.0	16.89	.5643
16,000	.6090	1.2814	-16.700	1.9	624.3	549.3	16.22	.5420
17,000	.5892	1.3028	-18.681	-1.6	621.9	527.3	15.57	.5203
18,000	.5699	1.3247	-20.662	-5.2	619.4	505.9	14.94	.4994
19,000	.5511	1.3470	-22.643	-8.8	617.0	485.6	14.34	.4791
20,000	.5328	1.3701	-24.624	-12.3	614.6	465.6	13.75	.4595
21,000	.5150	1.3935	-26.605	-15.9	612.1	446.3	13.18	.4406
22,000	.4976	1.4176	-28.587	-19.5	609.6	428.0	12.64	.4223
23,000	.4806	1.4424	-30.568	-23.0	607.2	410.1	12.11	.4046
24,000	.4642	1.4678	-32.549	-26.6	604.7	392.8	11.60	.3876
25,000	.4481	1.4939	-34.530	-30.2	602.2	375.9	11.10	.3711
26,000	.4325	1.5207	-36.511	-33.7	599.7	360.0	10.63	.3552
27,000	.4173	1.5480	-38.492	-37.3	597.2	344.4	10.17	.3398
28,000	.4025	1.5763	-40.473	-40.9	594.7	329.2	9.72	.3250
29,000	.3881	1.6051	-42.455	-44.4	592.1	314.9	9.30	.3107
30,000	.3741	1.6348	-44.436	-48.0	589.5	301.1	8.89	.2970
31,000	.3605	1.6656	-46.417	-51.6	587.0	287.5	8.49	.2837
32,000	.3473	1.6969	-48.398	-55.1	584.4	274.6	8.11	.2709
33,000	.3345	1.7292	-50.380	-58.7	581.8	262.1	7.74	.2586
34,000	.3220	1.7624	-52.361	-62.2	579.2	249.9	7.38	.2467
35,000	.3099	1.7963	-54.342	-65.8	576.7	238.4	7.04	.2353
36,000	.2981	1.8315	-56.324	-69.4	574.0	227.2	6.71	.2243
37,000	.2844	1.8753	-56.500	-69.7	573.8	216.7	6.40	.2138
38,000	.2710	1.9210	-56.500	-69.7	573.8	206.6	6.10	.2038
39,000	.2583	1.9677	-56.500	-69.7	573.8	196.7	5.81	.1942
40,000	.2462	2.0155	-56.500	-69.7	573.8	187.6	5.54	.1851
41,000	.2346	2.0646	-56.500	-69.7	573.8	178.8	5.28	.1764
42,000	.2236	2.1148	-56.500	-69.7	573.8	170.3	5.03	.1681
43,000	.2131	2.1662	-56.500	-69.7	573.8	162.2	4.79	.1602
44,000	.2031	2.2189	-56.500	-69.7	573.8	150.8	4.57	.1527
45,000	.1936	2.2729	-56.500	-69.7	573.8	147.3	4.35	.1455
46,000	.1845	2.3282	-56.500	-69.7	573.8	140.5	4.15	.1387
47,000	.1758	2.3848	-56.500	-69.7	573.8	134.1	3.96	.1322
48,000	.1676	2.4428	-56.500	-69.7	573.8	127.7	3.77	.1260
49,000	.1597	2.5022	-56.500	-69.7	573.8	121.6	3.59	.1201
50,000	.1522	2.5631	-56.500	-69.7	573.8	115.8	3.42	.1144

Standard Sea Level Air: T = 15°C (59°F)

P_o = 14.70 lb/sq in. = 29.921 in. of Hg; w = 0.07651 lb/cu ft

1 in. Hg = 70.727 lb/sq ft = 0.49116 lb/sq in.; ρ_o = 0.002378 slugs/cu ft

Figure 4-6. ICAO Standard Atmosphere.

4-14. Measuring Atmospheric Conditions. Previously, we discussed the structure and behavior of the atmosphere. Now it becomes necessary, as a requirement for precision flight engineering, to measure the atmosphere when the aircraft is in flight. This measurement involves temperature, altitude, and airspeed. We will first describe the instruments used to make these measurements--the temperature gauge, the altimeter, and the airspeed indicator.

a. There are several types of temperature gauges in use in the Air Force. One of these, the bimetallic thermometer, is a unit consisting of a stainless steel stem which projects into the airstream and a head which contains the pointer and scale. The bimetallic element consists of two dissimilar metals fused together. Variations in heat cause the metals to expand and contract, but the dissimilar metals expand and contract at different rates and this difference causes the element to actuate the pointer. The scale is in degrees (C) (Celsius) and reads from approximately -60°C to +50°C in increments of 2 degrees.

b. Like other instruments, temperature gauges are subject to error. One error, known as scale error, is caused by slight errors in calibration. Another error is heat of compression error. The element being immediately outside the fuselage in the airstream is rushing through the air at the speed of the aircraft. This rapid movement of air around the sensitive element produces compression and friction, this causes the thermometer to indicate a temperature higher than the actual temperature of the air. The heat compression error depends on the true airspeed of the aircraft. As airspeed increases, the error increases.

NOTE: Extract from charts in the flight performance section of the TO pertaining to your aircraft the corrections for errors at different airspeeds.

4-15. Altitude:

a. Altitude is the vertical distance above a point or plane used as a reference. There may be as many kinds of altitudes as there are reference planes from which to measure. These are true altitude, absolute altitude, pressure altitude, and density altitude.

b. True altitude is the height measured from the terrain directly below the aircraft, and pressure altitude is the height in a standard atmosphere where the actual existing outside air pressure should occur. Pressure altitude, as the name implies, is altitude measured by determining existing air pressure. The altitude-measuring instrument is the altimeter, the internal mechanism of which is an aneroid barometer that responds to changes in air pressure. There are two types of barometers used to measure air pressure, the mercury and aneroid.

c. Figure 4-7 shows the principle of the Mercury Barometer. Under standard conditions at sea level, the pressure of the air column raises the column of mercury 29.92 inches. The pressure at the bottom of an air column one-inch square extending to the top of the atmosphere is the same as that at the bottom of a column of mercury one-inch square and 29.92 inches high. Since one cubic inch of mercury weighs 0.491 pounds, 29.92 cubic inches weighs 14.69 pounds. Under standard conditions, at 40 degrees latitude at sea level with perfectly dry air, the atmosphere has a pressure of 14.69 pounds per square inch. This is a pressure of one atmosphere.

d. The all-mechanical aneroid barometer mechanism is more practical for use in aircraft than the mercury type. The aneroid barometer, is a sealed corrugated-metal unit with some of the air pumped out. Atmospheric air enters the case through the pressure entrance and surrounds the aneroid. As the altitude increases (lower air pressure), the aneroid expands, moving the pointer to a higher reading. As the altitude decreases (higher air pressure), the aneroid contracts moving the pointer to a lower reading.

e. The two most common units of measurement are inches of mercury (Hg) and millibars. The Kollsman window of pressure altimeters in US aircraft is in inches of mercury. The US Military and civil weather agencies express altimeter settings in inches of mercury.

f. Inches of mercury do not directly express pressure in terms of force-per-unit-area. A common unit of pressure that does is the millibar (mb), a unit of measurement equal to a force of 1,000 dynes per square centimeter. Many foreign nations use the millibar for altimeter settings. Crewmembers flying in these countries can consult your TO or the appropriate En Route Supplement, or the Flight Information Publication (FLIP) for a conversion table of millibars to inches of mercury. The standard atmospheric pressure at sea level in millibars is 1013.2 which corresponds to 29.92 inches of mercury.

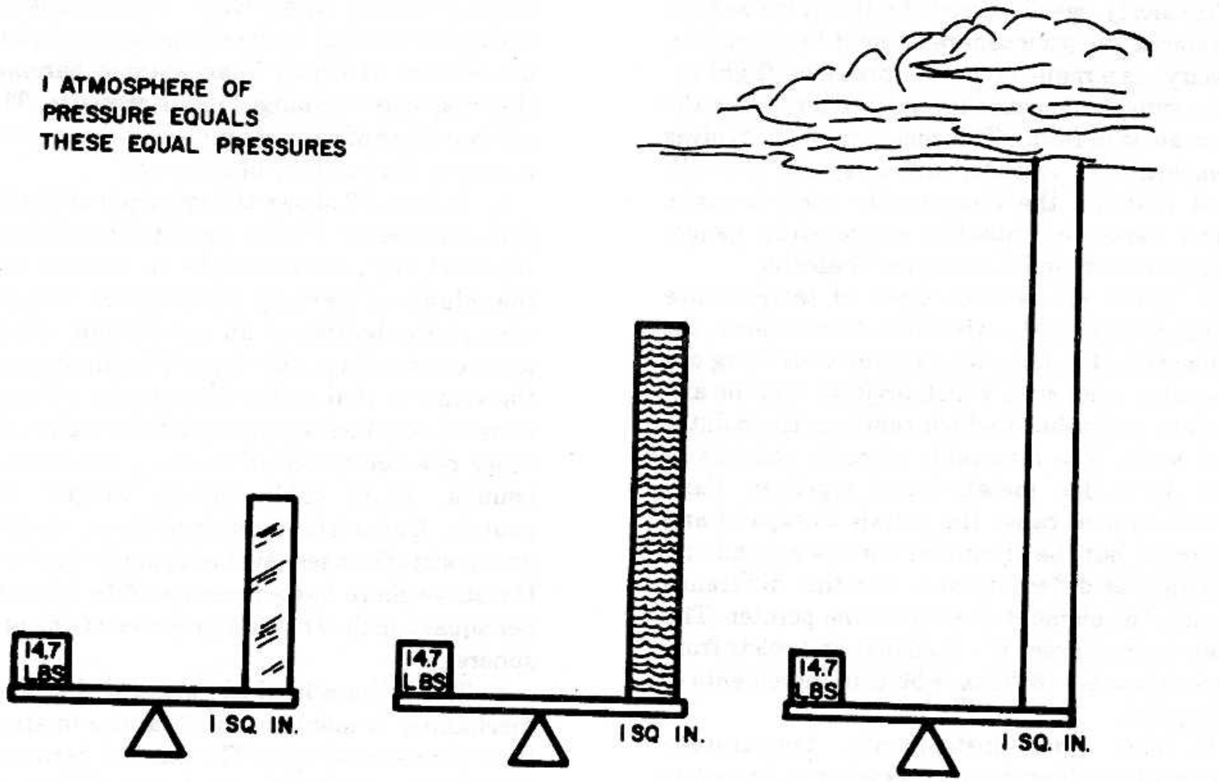


Figure 4-7. Atmospheric Pressure.

g. Pressure variations are continually occurring at any given location with occasional abrupt changes due to thunderstorms and fronts. Pressure varies most with altitude and temperature of the air.

h. The biggest change in barometric pressure comes with height in the lower few thousand feet of the troposphere. Most of the atmosphere concentrates, because of gravity in the lower few thousand feet of the troposphere. The change amounts roughly to 1 inch of mercury for each 1,000 feet of altitude. An observer at a station located 5,000 feet above sea level would get a reading of approximately 24.90 inches (figure 4-6).

i. Air expands as it becomes warmer and contracts as it cools. Pressure is equal at the bottom of each column and at the top of each column. Vertical expansion of the warm column makes it higher than the cold column at standard temperature. Contraction of the cold column makes it shorter. Since pressure decrease is the same in each column, the rate of decrease of pressure with weight in warm air is less than standard. The rate of decrease of pressure with weight in cold air is greater than standard.

j. At and above the transition altitude (18,000 feet MSL in the United States), you must set aircraft altimeters to 29.92 inches Hg. The pilot flying above the transition level must adjust the altimeter to the current setting when descending through the transition level. This will provide proper air traffic and terrain separation. When flying below the transition altitude adjust the altimeter to the surface pressure setting of the nearest ground reporting station.

k. Even when sea level pressure does not change along a route of flight, incorrect altitude indications may result from temperature changes. If the air is colder than standard atmosphere, the aircraft will be lower than the altimeter indicates; if the air is warmer, the aircraft will be higher than the altimeter indicates. It is important that crewmembers understand these errors so that when flying in cold weather and operating in mountainous regions at minimum en route altitudes, they do not have difficulty maintaining terrain clearance.

l. Density altitude is defined as the altitude at which a given density is found in the standard atmosphere. Since we rarely encounter standard atmospheric conditions, the density altitude for an airfield may vary several thousand feet from the actual MSL elevation of the field.

m. The varying densities of the atmosphere affect the efficiency of aircraft performance. Low density altitude increases aircraft performance. High density altitude decreases aircraft performance. The density of the air through which it moves affects the lift of the wing or blade. Takeoff and landing rolls are lengthened, and rates of climb and service ceiling are reduced.

4–16. Airspeeds. Speed is the rate of motion or, in other words, distance traveled per unit of time. You measure airspeeds in nautical miles per hour, or knots. Modern aircraft use the pitot-static system to measure airspeed. It combines sensing holes for static pressure and a pitot tube to sense ram pressure. These are the two pressures used for airspeed indications. Now let's take a look at the airspeeds we will be dealing with.

a. Indicated Airspeed in Knots (IASK). You read it directly from the airspeed indicator.

b. Calibrated Airspeed in Knots (CASK). The pitot-static probe systems used to sense airspeed are so accurate that only a small error occurs in the static reading for changes in pitch and yaw. After this static position error is corrected, we get calibrated airspeed. Aircraft with central air data computers (CADC) fly calibrated airspeed. The computer automatically adjusts IASK to CASK before displaying. Some aircraft use a chart to find the calibrated airspeed from indicated airspeed.

c. Equivalent Airspeed in Knots (EASK). Only one error remains. Ram compression heats the pitot-static probe hanging in the airstream. Correcting CASK for this Ram compression results in EASK. The lift of an airfoil depends upon the kinetic energy of the airstream flowing over it. When more molecules of air are moving faster, the result is more energy for producing lift. EASK represents the actual kinetic energy of the airstream, in knots. Or EASK is the equivalent speed at sea level, which would produce the same amount of airflow over the wings so that the lift would be equal.

d. True Airspeed in Knots (TASK). EASK corrected for variations in air density. Groundspeed is speed in relation to the ground. Wind is the link between TASK and groundspeed. By subtracting headwinds from TASK and adding tailwinds to TASK, one can find groundspeed. Flight at high altitudes requires knowledge of one other speed indication. Mach number is the ratio of the aircraft's speed to the speed of sound for existing conditions. A decimal number expresses Mach number and is another calculated value.

NOTE: We did not design this chapter to make us experts on the atmosphere, just to give us a better understanding of what aircrafts fly through. There are many excellent books available about the atmosphere, and if this chapter really stirred your interest, visit your local library.

Chapter 5

PRINCIPLES OF DYNAMICS, AERODYNAMICS, AND THEIR APPLICATIONS

5-1. Aerodynamics and Dynamics:

a. Fuel economy in engine operation is one of the principal aims of flight engineering. By proper choice of power settings, low specific fuel consumption is attained. This is not entirely the job of the pilot. It is up to you, the flight engineer, to establish the power which will enable the pilot to fly the aircraft most efficiently under the prevailing conditions. You must understand the relationship of the engine operation and the relationship of aircraft aerodynamics to efficient flying. This chapter introduces certain principles of dynamics, aerodynamics, and their applications.

b. Dynamics is the branch of physics which deals with motion caused by forces and with forces resulting from motion. Aerodynamics is the special application of the branch of physics to the medium air. Therefore, aerodynamics is the special study of objects in motion through the air.

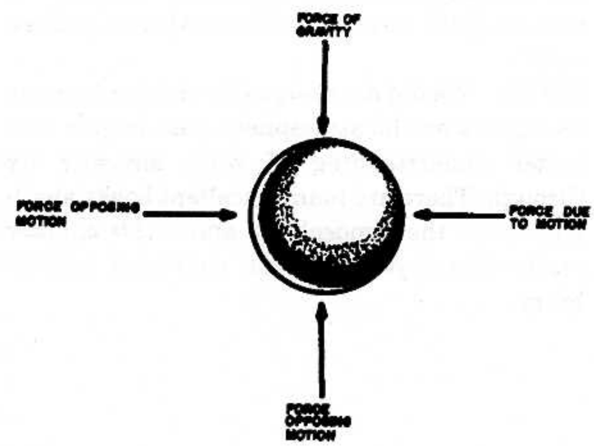


Figure 5-1. Equal Forces Acting on an Object.

5-2. Airflow:

a. An earlier chapter defined the term force as any action which tends to produce, retard, or modify motion. The "sea of air" through which aircraft fly has mass and inertia and is capable of exerting forces on any object moving through it. There are numerous forces acting on all parts of an aircraft. Consider an object moving through the air at a certain speed. There are four general forces present as shown in figure 5-1. One is the force the object exerts on the air when moving forward (thrust). In opposition to this is the force the air exerts on the object (drag). Another force is the force of gravity pulling the object toward the earth (weight). This same object exerts a force in the opposite direction to keep itself aloft (lift).

(1) Figure 5-1 shows that an object will remain in the same condition (no acceleration) when all the opposing forces are equal. The object is in a state of equilibrium. When any of the opposing forces acting on the object are not equal acceleration results in the direction of the greater force. In figure 5-2 you see another representation of forces acting on an object. The lengths of the arrows represent the respective magnitudes of the forces. The arrowheads point in the direction of the forces. The illustration shows that force A is equal to and in the opposite direction to force B. Force C is equal to and opposite to force D. But force E is greater than its opposing force F, and as indicated, the object will move in the direction of force F.

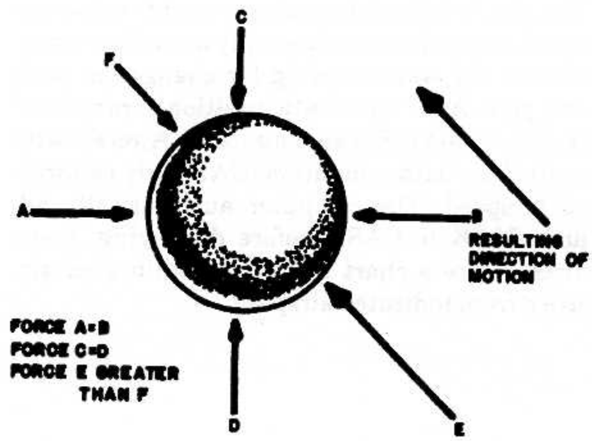


Figure 5-2. Unequal Forces Acting on an Object.

(2) The preceding discussion is an example of a vector representation of the forces acting on an object. We may show any number of forces by a vector representation. This chapter uses this type of force diagrams.

b. Since air possesses mass and inertia, a stream of air moving at a certain velocity will continue to move in the same direction at the same velocity until some outside element exerts force against it. If you hold a flat plate at a 90-degree angle against the airstream, the air that strikes the plate must change both its immediate direction and velocity to pass around the plate. The plate and the airstream exert the same force against each other. We use this principle to change the direction of an aircraft in flight. The control surfaces of the aircraft apply forces to the air mass, and the air mass, in turn, applies equal and opposite forces to the aircraft.

(1) When you hold a flat plate at an angle of 45 degrees to the airstream, as shown in figure 5-3, you turn the airstream downward. The position of the plate changes the direction of the airstream and reduces its velocity. Hence, the plate must apply a force on the air both downward and forward. The reaction to the air must be an equal pressure upward and backward as shown by vector AR. The vectors AL and AD are the vertical and horizontal components of the airstream pressure against the plate. To maintain a balance of forces between the airstream and the plate, there must be a downward force (AL2) equal to that of the upward force (AL1), and a forward force (AD2) equal to the backward force (AD1) (see figure 5-3)

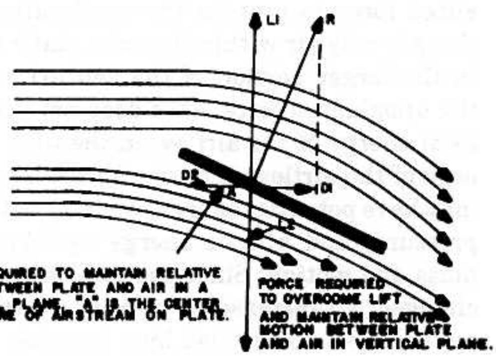


Figure 5-3. Airflow About an Inclined Flat Plate.

(2) When you hold a flat plate parallel to the airstream, as shown in figure 5-4, the airstream lines separate at the leading edge, flow smoothly over the upper and lower surfaces, and reunite just back of the trailing edge. The little resistance offered by the flat plate is largely skin friction caused by the air tending to cling to the surfaces. The small amount of drag that results from skin friction will vary with the smoothness of the surfaces. When surface irregularities such as rivet heads and lapped joints exist, the drag from skin friction is much greater, especially at high speed.

c. We show the airflow over a sphere in figure 5-5. As the speed of the air increases, its momentum causes greater application of pressure on the leading edge of the sphere. This increase in pressure distorts the lines of air so that they are unable to push together promptly at the rear of the sphere, creating a low pressure area there. This low pressure area causes burbling airflow and increased resistance of the sphere to the flow of air.

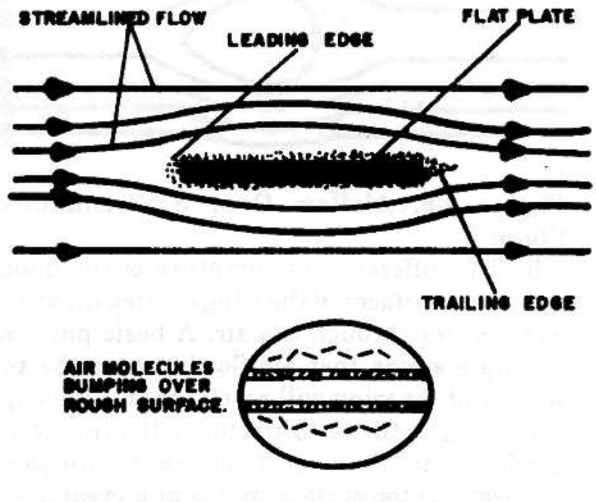


Figure 5-4. Airflow About a Thin Plate Held Parallel to the Airstream.

(1) Figure 5-6 shows that the resistance is reduced by filling in the burble space at the rear of the sphere. As a result, the air flows smoothly over this additional surface.

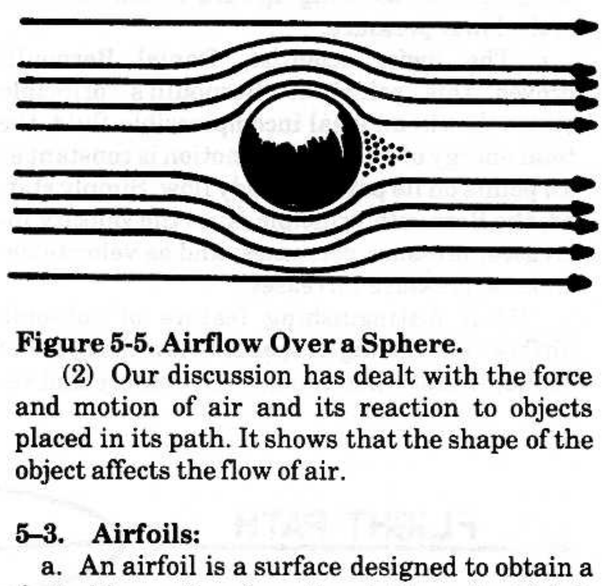


Figure 5-5. Airflow Over a Sphere.

(2) Our discussion has dealt with the force and motion of air and its reaction to objects placed in its path. It shows that the shape of the object affects the flow of air.

5-3. Airfoils:

a. An airfoil is a surface designed to obtain a desirable reaction from the air through which it moves. Any part of the aircraft which converts air resistance into a force useful for flight is an airfoil. Propeller blades, wings, stationary and movable control surfaces, and even the fuselage are airfoils. The term airfoil is usually applied to the wings of an aircraft. The profile of a conventional wing, shown in figure 5-7, is an excellent example of an airfoil. Notice that the top surface of the wing has greater curvature than the lower surface.

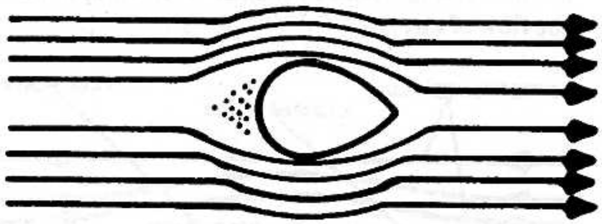


Figure 5-6. Airflow Over a Streamlined Shape.

b. The difference in curvature of the upper and lower surfaces of the wing creates lift as the wing moves through the air. A basic physical principle states that air flowing over the top surface of the wing will reach the trailing edge of the wing in the same amount of time as the air flowing under the wing. To do this, the air passing over the top surface moves at a greater velocity than the air passing below the wing because of the greater distance it must travel along the top surface. This increased velocity means a corresponding decrease in pressure on the surface. This creates a pressure differential between the upper and lower surfaces of the wing, forcing the wing upward in the direction of the lower pressure.

c. The Swiss scientist, Daniel Bernoulli proved this principle. Bernoulli's principle states that in an ideal incompressible fluid, the total energy of a particle in motion is constant at all points on its path in steady flow. Simply stated, the Bernoulli principle is: as the velocity increases, pressure decreases; and as velocity decreases, pressure increases.

(1) A distinguishing feature of subsonic airflow (air moving at speeds below the speed of sound) is that when changes in pressure and velocity occur, there are only small and negligible changes in density. We can simplify the study of subsonic airflow by assuming the flow to be incompressible. We must consider the flow as compressible when it approaches the speed of sound. At this point "compressibility effects" are taken in account. If the flow through the venturi remains below the speed of sound, the density of the air is essentially constant at all stations along the length of the tube.

(2) When the density of the airflow remains constant, static pressure and velocity are the variables. As the airflow approaches the throat of a venturi (station two, figure 5-8), the velocity must increase to maintain the same mass flow. As the velocity increases, the static pressure decreases. This decrease in static pressure can be verified in two ways:

(a) By Newton's second law of motion, which stated that an unbalanced force is required to produce an acceleration. If the airflow increases in velocity while approaching the throat of the venturi, there must be an unbalanced force to provide the acceleration. Since there is only air within the tube, static pressure in the larger portion of the venturi generates the unbalanced force. This does not change the total energy of the airflow in the tube. The energy of the airflow is in two forms. The airflow may have potential energy, relating to the static pressure, and kinetic energy by virtue of its mass and motion. Since the total energy is unchanged, an increase in velocity (kinetic energy) will be accompanied by a decrease in static pressure (potential energy). This situation is similar to that of a ball rolling down a hill in that the potential energy converts into the kinetic of motion. If friction is negligible, the change of potential energy would equal the change in kinetic energy. This is also true for the airflow within a venturi tube.

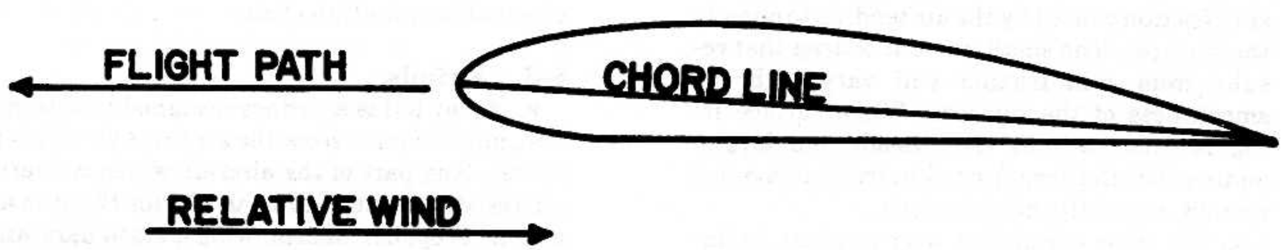


Figure. 5-7. Conventional Airfoil.

(b) The relationship of static pressure and velocity is maintained throughout the length of the tube. As the air moves beyond the throat and into the larger area of the exit (station 3, figure 5-8), the velocity decreases and the static pressure increases.

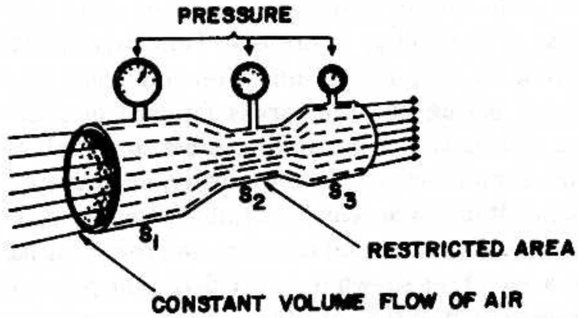


Figure 5-8. Airflow Through a Venturi.

d. We can test Bernoulli's principle by attaching manometers to a venturi tube, as shown in figure 5-9. From the difference in heights of the columns of mercury in the manometers, you can see that the pressure is less at the throat of the venturi than at the inlet.

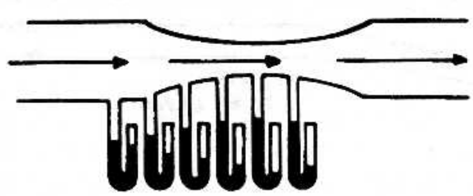


Figure 5-9. Pressure Differences Along a Venturi.

5-4. Airfoils and Bernoulli's Principle:

a. If air were forced through a venturi of a rectangular shape with a movable curved surface, the streamline patterns would appear as shown in figure 5-10. You will notice the particles of air are curved and crowded together in the narrow portion of the tube. The particles close to the curved surfaces are also curved and have speeded up. Thus far, Bernoulli's principle has been applied to the airflow in a venturi, but it is equally applicable to the airstream passing over an airfoil.

b. In figure 5-10 we have removed half of the venturi. Notice that the streamlines adjacent to the curved surface are still curved and crowded. They are traveling at a greater velocity than those farther away from the curved surface. There must be a region of lower pressure where the velocity of the particles of air is greatest because when the velocity is high, the pressure is low.

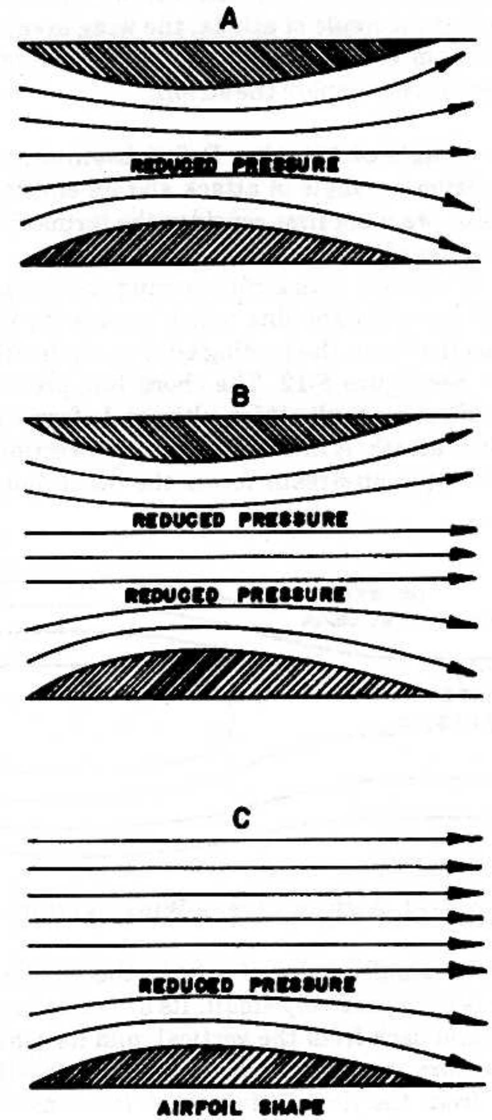


Figure 5-10. A Venturi Tube Developed into an Airfoil Section.

c. Figure 5-11 shows the airflow over an airfoil. We determined the theoretical amount of lift of the airfoil at the velocity of 100 knots by sampling the pressure above and below the airfoil. The pressure is 14.54 pounds per square inch above the airfoil. Subtracting this pressure from the pressure below the airfoil, 14.67, gives a difference in pressure of 0.13 pounds per square inch. Since there are 144 square inches in a square foot, multiply 0.13 by 144 and you will find that each square foot of this wing will lift 18.72 pounds. From this you can see that a small pressure differential across an airfoil section can produce a large lifting force. This lifting force is induced lift and subsequent illustrations shows a vector drawn perpendicular to the relative airstream. We can increase lift by increasing the angle of attack, the wing area, the air stream velocity, the density of the air, or by changing the shape of the airfoil.

5-5. Angle of Attack. Before beginning our discussion on angle of attack and its effects on airfoils, we must first consider the terms chord and center of pressure.

a. The chord of an airfoil or wing section is an imaginary straight line which passes through the section from the leading edge to the trailing edge. See figure 5-12. The chord line provides one side of an angle which ultimately forms the angle of attack. A line indicating the direction of the relative airstream forms the other side of the angle. The angle of attack is the angle between the chord line of the wing and the direction of the relative wind. Do not confuse this with the angle of incidence which is the angle between the chord line of the wing and the longitudinal axis of the aircraft. From our previous discussion of airfoils, you should conclude that on each minute part of an airfoil or wing surface, a small force is present. This force is different in magnitude and direction from any forces acting on other areas forward or rearward from this point. It is possible to add all of these small forces mathematically, and the sum is resultant force. This resultant force has magnitude, direction, and location, and represented as a vector, as shown in figure 5-12. The point of intersection of the resultant force line with the chord line of the airfoil is the center of pressure.

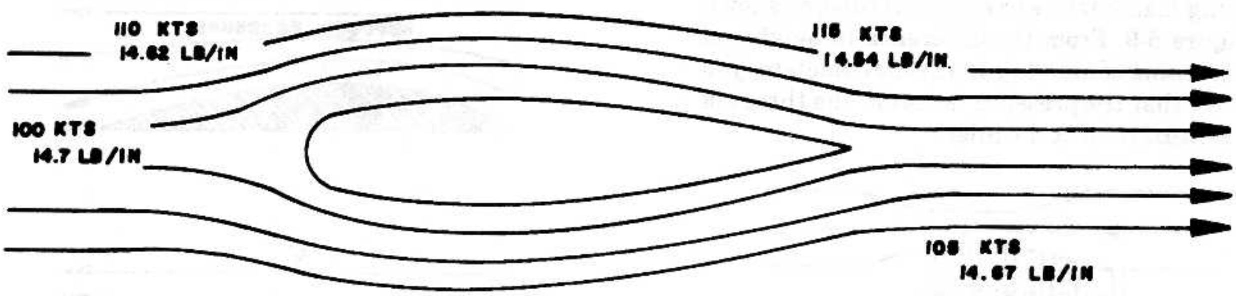


Figure 5-11. Airflow Over a Wing Section.

b. For small angles of attack, the resultant force is comparatively small. Its direction is upward and back from the vertical, and its center of pressure is well back from the leading edge. Note from the illustrations that the center of pressure changes with the angle of attack and the resultant force line has an upward and backward direction. At positive angles of attack of three or four degrees, the resultant force attains its most nearly vertical direction. Either increasing or decreasing the angle causes the direction of the resultant force to be farther from the vertical.

c. Although the following discussion deals primarily with positive angles of attack, it begins with the airfoil position called angle of zero lift (angle of attack with zero lift). This angle is normally a negative angle of attack. It is one which places the chord line of the airfoil below the line which represents the direction of the relative wind. See figures 5-13 and 5-14. The airfoil obtains an angle of zero lift when the resultant force line is exactly parallel to the relative wind line. At this angle, the force acting on the airfoil is entirely drag. We could show this in a wind tunnel test by holding a wing section at the angle of zero lift and suddenly releasing it. Upon release of the wing section, it would neither lift nor fall, but would move straight rearward in the direction of the relative wind. By gradually increasing the angle of attack, the lift component increases rapidly up to a certain point and suddenly begins to drop off. See figure 5-14. During this action, the drag component increases slowly at first and then rapidly as lift begins to drop off. When the angle of attack increases to approximately 18 to 20 degrees (on most airfoils), the air can no longer flow smoothly over the top of the wing surface. This is because of the excessive change of direction required. See figure 5-14. This is the stalling angle of attack, sometimes called the burble point. At this point, turbulent airflow, which appears in small amounts near the trailing edge of the wing at lower angles of attack, suddenly spreads forward over the entire upper wing surface. The result is a sudden increase in pressure above the wing accompanied by a sharp loss of lift and a sudden increase in resistance or drag. These events show that Bernoulli's principle is true only in streamline or smooth airflow and not in turbulent airflow. The center of pressure at the point of stall is at its maximum forward position, and as the wing stalls, the resultant force tilts sharply backward.

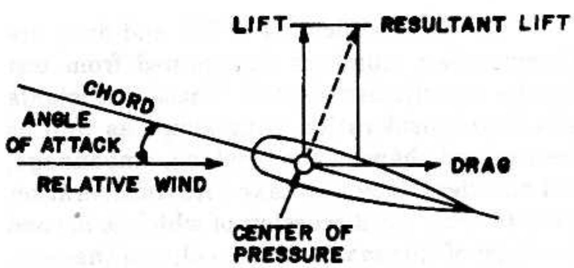


Figure 5-12. Positive Angle of Attack.

5-6. Wing Area. We measure wing area in square feet and includes the part blanked out by the fuselage. Wing area is the shadow cast by the wing at high noon. Tests show that lift and drag forces acting on a wing are roughly proportional to the wing area. This means if we double the wing area, the lift and drag created by the wing doubles.

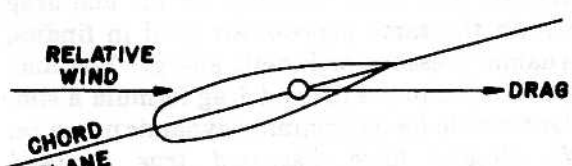


Figure 5-13. Negative Angle of Attack.

5-7. Shape of the Airfoil:

a. The shape of the airfoil determines the amount of turbulence or skin friction that it will produce. The shape of a wing consequently affects the efficiency of the wing.

b. The fineness ratio controls turbulence and skin friction. This is the ratio of the chord of the airfoil to its maximum thickness. If the wing has a high fineness ratio, it is a very thin wing. A thick wing has a low fineness ratio. A wing with a high fineness ratio produces a large amount of skin friction. A wing with a low fineness ratio produces a large amount of turbulence. The best wing is a compromise between these two extremes to hold both turbulence and skin friction to a minimum.

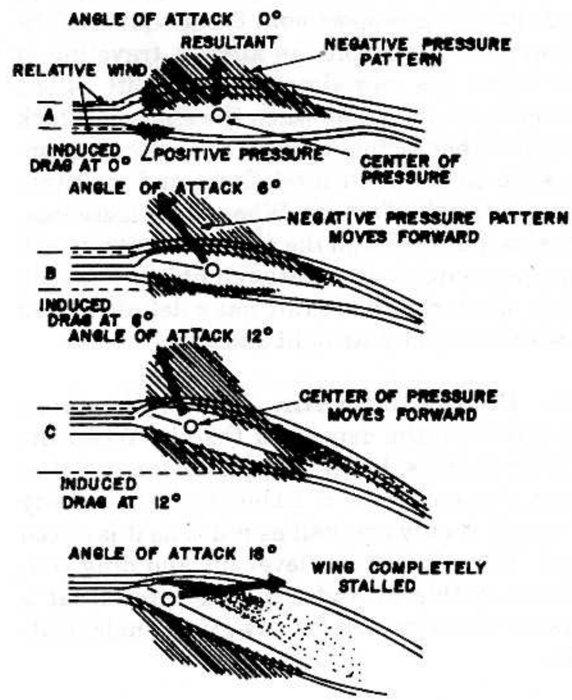


Figure 5-14. Effect of Increasing Angle of Attack.

c. The lift over drag (L/D) ratio measures the efficiency of a wing. This ratio varies with the angle of attack but reaches a definite maximum efficiency. The shape of the airfoil is the factor which determines the angle of attack at which the wing is most efficient. It determines the degree of efficiency. Research has shown that the most efficient airfoils for general use have the maximum thickness occurring about one-third of the way back from the leading edge of the wing.

d. The amount of lift produced by an airfoil will increase with an increase in wing camber. Camber refers to the curvature of an airfoil above and below the chord line surface. Upper camber refers to the upper surface, lower camber to the lower surface, and mean camber to the average of the section. Camber is positive when curvature from the chord line is outward, and negative when it is inward. Thus, high lift wings have a large positive camber on the upper surface and a slight negative camber on the lower surface. Wing flaps and slats cause an ordinary wing to approximate this condition by increasing the upper camber and by creating a negative lower camber.

5–8. Velocity and Angle of Attack. The shape of the airfoil or wing cannot be effective unless it is continually attacking new air. When computing the lift and drag of an aircraft, you find that lift is proportional to the square of the velocity. For example, an aircraft traveling at 200 knots has four times as much lift as one traveling at 100 knots when the angle of attack and the other factors remain the same. It is impossible to travel in level flight and maintain the same angle of attack. When speed increases, lift also increases and the aircraft climbs or will carry a greater load without climbing. For each angle of attack, an aircraft has a definite speed at which it will fly straight and level.

5–9. Density of the Air. Lift and drag vary directly with the density of the air. When the density doubles, lift and drag doubles, and vice versa. At an altitude of 18,000 feet, the density of the air is only one-half as much as it is at sea level. To maintain sea level lift and drag conditions at this altitude, fly the aircraft at a greater true airspeed for any given angle of attack.

5–10. Lift and Drag Computations:

a. Devising a Formula for Computing Lift and Drag Forces. To devise a formula for computing lift and drag forces on an entire aircraft, it is necessary to consider all of the following factors that affect lift and drag. That:

(1) Lift and drag are directly proportional to the density of the air.

(2) Lift is directly proportional to the area of wing.

(3) Drag depends both upon wing area and the size and shape of the fuselage, nacelles, and empennage.

(4) Lift and drag are proportional to the square of velocity of the air.

(5) Lift and drag build with increases in the angle of attack. (Lift increases only up to the stalling angle of attack.)

(6) Lift and drag are dependent upon the shape of the airfoil.

With these relationships, the equations for computing lift and drag are:

$$\text{LIFT} \quad L = C_L \frac{Rho}{2} V^2 S$$

$$\text{DRAG} \quad D = C_D \frac{Rho}{2} V^2 S$$

where

L = is lift in pounds
D = is drag in pounds
C_L = is the coefficient of lift
C_D = is the coefficient of drag
R_ho = is density of the air in slugs per cubic foot
V = is velocity (TAS) in feet per second
S = is wing area in square feet

(a) The coefficients of lift and drag are dimensionless numbers determined from test data for a particular aircraft. These coefficients take into consideration wing shape as well as the size and shape of the fuselage, empennage, and nacelles. They also take into consideration other factors, the discussion of which is beyond the scope of this manual. The value of these coefficients varies with the angle of attack.

(b) By the use of models in a wind tunnel, it is possible to determine values for CL and CD. They plot these values against an angle of attack on a graph. The results of such data, for a representative aircraft, show on the lift and drag characteristic curve (figure 5-15). The main use of the characteristic curve is to find either the coefficient of lift or the coefficient of drag for a particular angle of attack.

b. Computing Lift and Drag (Simplified Method). The basic formulas for lift and drag contain the same expressions used in finding dynamic pressure or kinetic energy. You may substitute into the lift and drag formula a simpler formula for determining dynamic pressure. We already have discussed true airspeed (TASK), density altitude (Hd), SMOE value and equivalent airspeed (EASK). Using EASK rather than TASK, the density factor and SMOE are eliminated, since EASK is itself dependent upon the density of the air (Rho). The simplified formulas are:

$$\text{Lift} = \frac{C_L \times S \times EASK^2}{295} \quad \text{Drag} = \frac{C_D \times S \times EASK^2}{295}$$

The constant 295 used in the formula is derived by substituting EASK for TASK. By doing this we are able to use $EASK^2/295$ in place of V (TAS in feet per seconds).

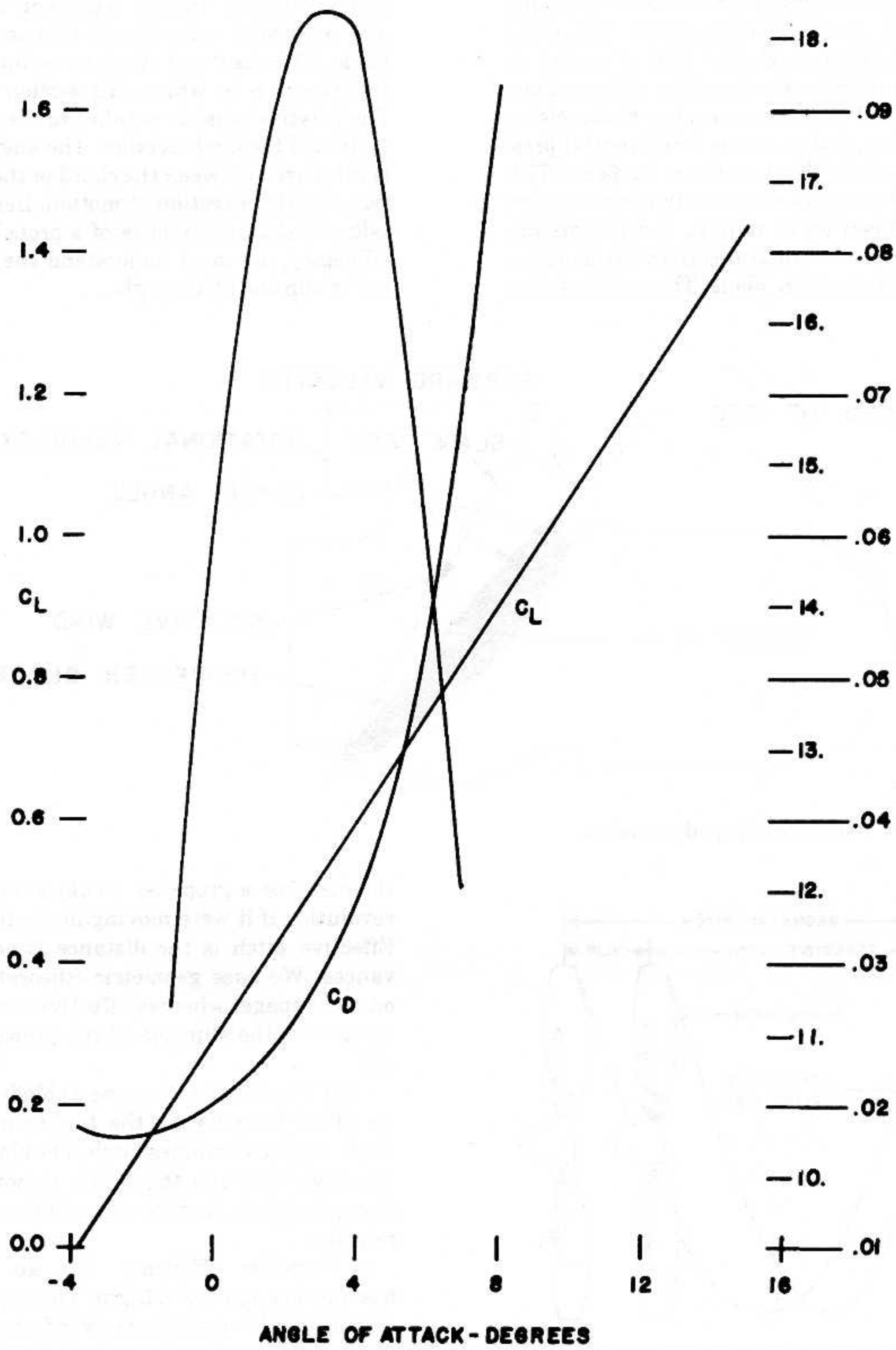


Figure 5-15. Characteristic Curve.

5-11. Propeller aerodynamics:

a. A propeller consists of two or more blades, each having an airfoil cross section. The action of these blades is much like that of a wing although the motion of a propeller blade is more complex. Air flows over a propeller blade, just as it does a wing, and produces a differential pressure between the front and rear surfaces. This differential pressure causes a dynamic reaction in such a direction as to push the aircraft forward. Figure 5-16 illustrates the path of motion or action of a propeller blade. The airfoil section shown is at some particular station along the blade. The two vectors represent the forward and rotational velocities of this section of the blade. The resultant of these vectors indicates the direction in which this section is moving. The relative wind is parallel to the path of the motion of the blade section. The angle of attack is measured between the chord of the blade section and the direction of motion. Before we can talk about aerodynamics of a propeller and its efficiency, we must understand the terms propeller slip and blade angle.

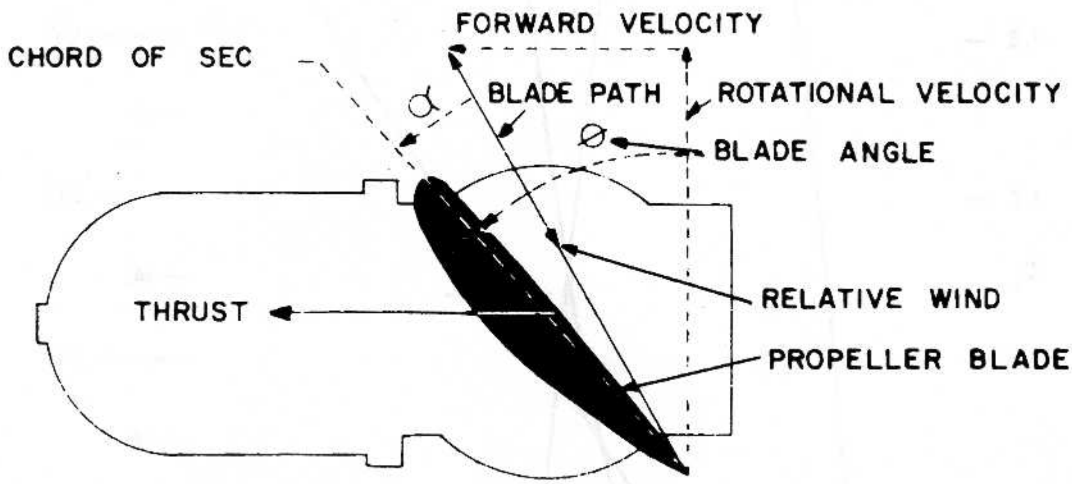


Figure 5-16. Propeller Aerodynamics.

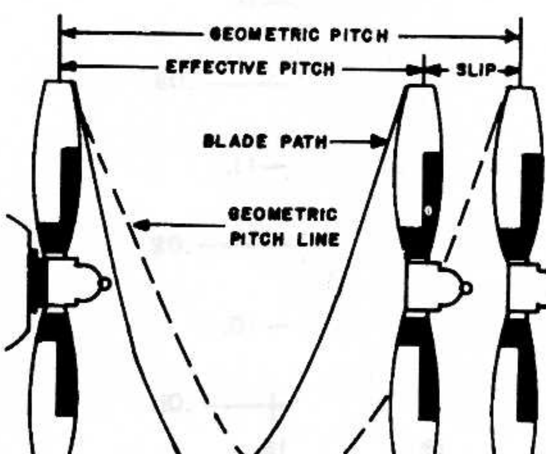


Figure 5-17. Propeller Pitch and Slip.

(1) Propeller slip is the difference between the geometric pitch of the propeller and its effective pitch. See figure 5-17. Geometric pitch is the distance a propeller would advance in one revolution if it were moving in a solid medium. Effective pitch is the distance it actually advances. We base geometric (theoretical) pitch on no slippage, whereas effective (actual) pitch recognizes the slippage of the propeller in the air.

(2) Pitch is not the same as blade angle, but we often interchange the two terms because blade angle determines pitch. The blade angle is the angle between the chord, at some station along the blade, and the plane of the propeller's rotation.

b. Propeller efficiency has an important bearing on economy in flight. The propellers are responsible for absorbing power from the engine and converting this energy into aircraft forward motion. For any airfoil there is one angle of attack at which it is more efficient than any other. This is also true for a propeller blade which is an airfoil. We must maintain this angle of attack down the entire length of the blades. To accomplish this we twist the blades in the manner shown in figure 5-18. Near the hub, the rotational velocity is small compared with forward velocity. Consequently, the relative wind approaches from almost directly in front of the blade. Near the blade tips, the rotational velocity is high compared with forward velocity. The relative wind approaches from a direction near the plane of the propeller's rotation. You should see that twist is essential in order to obtain efficient propeller operation. Constant speed mechanisms are also an aid in obtaining high propeller efficiency. In order for a propeller to be efficient over a wide range of speeds, altitudes, and gross weights, it must be capable of changing its blade angle to adapt itself to varying flight conditions.

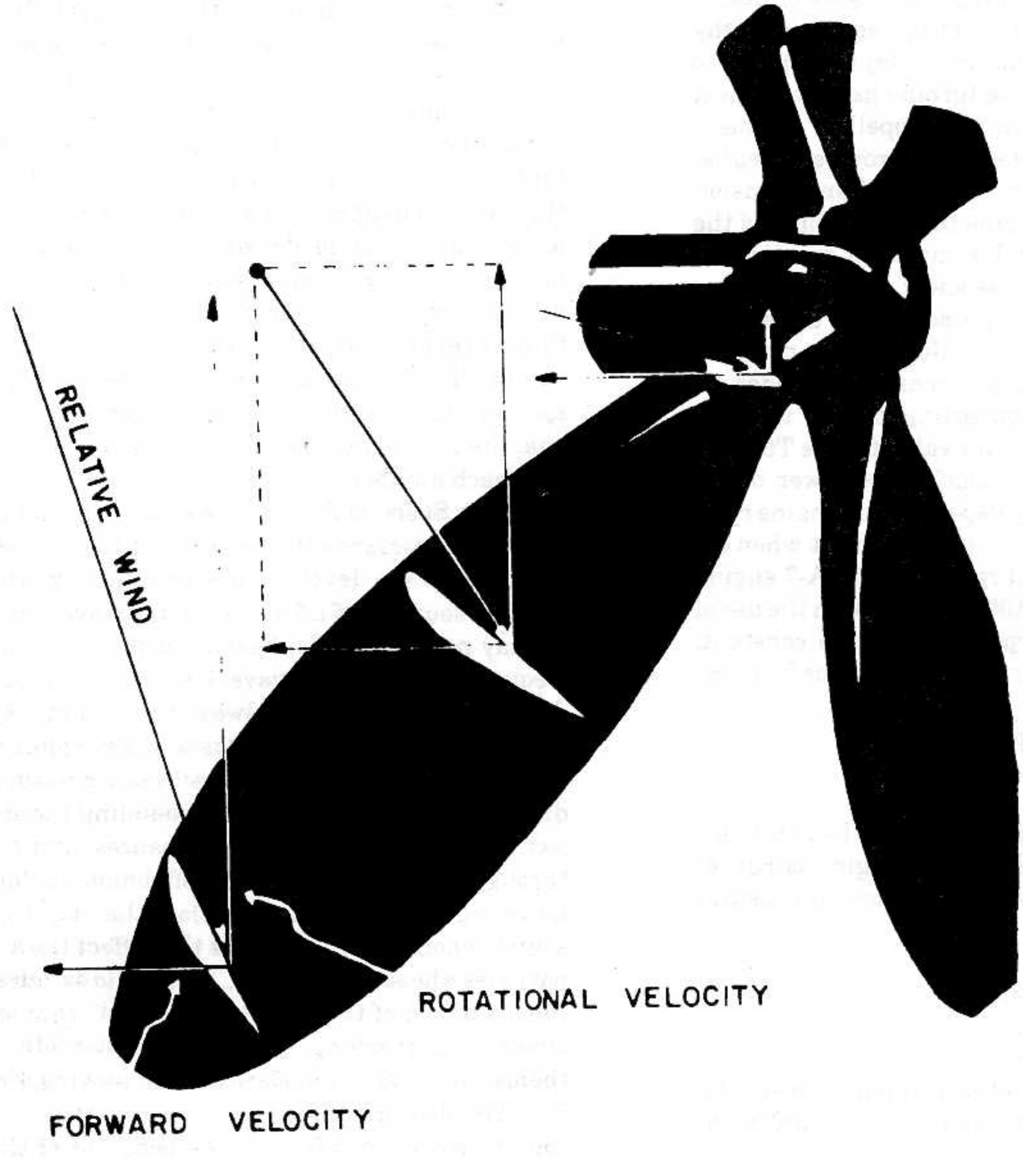


Figure 5-18. Propeller Efficiency.

c. Aerodynamically, thrust is the result of the shape and angle of the propeller blade. Another way to consider thrust is in terms of the mass of air handled. In these terms, thrust is equal to the mass of air handled, times the slipstream velocity, minus the velocity of the aircraft. The power expended in producing thrust depends on the mass of air moved per second. On the average, thrust constitutes approximately 80 percent of the torque (total horsepower absorbed by the propeller). We lose the other 20 percent in friction and slippage. For any speed of rotation, the horsepower absorbed by the propeller balances the horsepower delivered by the engine. For any single revolution of the propeller, the amount of air handled depends on the blade angle (which determines how big a "bite" of air the propeller takes). Adjusting blade angle is a means of adjusting the load on the propeller in order to control engine torque.

d. We rate the turboprop engine by the amount of shaft horsepower (shp) it applies to the propeller. Since the turbine harnesses most of the energy, to turn the propeller, the measurement of shaft horsepower provides a realistic horsepower rating. The use of an extension shaft between the engine power section and the reduction gear assembly makes it practical to measure the shaft horsepower with the torquemeter system. The manufacturer of the engine computed a constant (K) value, used to compute engine power. The engine constant includes all of the factors for converting torque to shaft horsepower. The constant value for the T56-A-7 engine is 63,025. The shaft horsepower on an engine is also directly dependent on engine rpm. The turboprop engine is most efficient when operating at 100 percent rpm. The T56-A-7 engine turns 13,820 rpm at 100 percent. With the use of torque (T), engine rpm, and engine constant, use the following formula to find shaft horsepower:

$$\text{shp} = \frac{T \times \text{rpm}}{K}$$

We can compute shaft horsepower by substituting known values. When the engine is run at 100 percent rpm, the rpm becomes a constant 13,820.

$$\text{shp} = \frac{T \times 13{,}820}{63{,}025}$$

Using this formula, let us compute the shp developed by an engine indicating 15,500 inch-pounds of torque.

$$\text{shp} = \frac{15{,}500 \times 13{,}820}{63{,}025}$$

$$\text{shp} = 3{,}398.8$$

5-12. High Speed Aerodynamics. In the discussion of aerodynamics, you have been studying the behavior of air at velocities less than the speed of sound. When the movement of an object, or of the air relative to the object, is below the speed of sound, it is subsonic. We will discuss how air behaves as the relative velocity nears or goes beyond the speed of sound; that is, when it becomes transonic or supersonic. The primary difference between subsonic, transonic, and supersonic air flow is one of compressibility (density changes). At subsonic velocities, the density changes that take place are so slight that they can generally be disregarded. We can compare airflow at these low velocities to the flow of liquids, "incompressible flow." At high velocities, large pressure changes produce significant changes in air density. We can no longer ignore these density changes and we must account for--"compressible flow." We cannot use Bernoulli's principle for incompressible fluids to explain lift at transonic and supersonic speeds. To understand the principles of high speed flight, we must consider three phenomena: the speed of sound, shock wave formation, and mach number.

a. The Speed of Sound. The speed of sound is of great importance in the study of high speed airflow. At sea level on a standard day, the speed of sound is 661.5 knots. Sound waves may or may not be audible, hearing depends on the frequency of the sound wave. Under normal conditions, the velocity will always be the same. As an object moves through a mass of air, velocity and pressure changes occur that create pressure disturbances in the airflow surrounding the object. These pressure disturbances travel through the air at the speed of sound. Airfoil traveling through the air below the speed of sound generates sound waves that affect the air particles ahead of the airfoil. You could say that the air ahead of the airfoil is "warned" that an object is approaching. The air molecules adjust themselves to accommodate the fast moving airfoil. The distance ahead of an airfoil at which sound waves can influence the behavior of the airflow constantly decreases as flight speeds increase. When reaching sonic speed, the influence of the sound wave has decreased to the point where the air particles actually remain undisturbed until violently pushed aside by the oncoming airfoil.

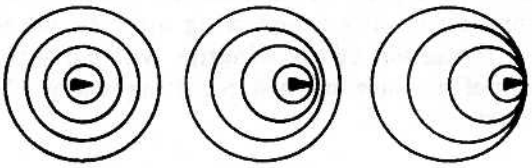


Figure 5-19. Shock Wave Formation.

b. Shock Wave Formation. The formation of shock waves relates to the speed of sound. We show the influence of sound waves on the behavior of the air around a moving object by the use of a single point in space sending out sound waves. See figure 5-19. The stationary point of disturbance radiates pressure waves at the speed of sound in all directions. The point moving at half the speed of sound disturbs the air around it so the center of each wave is further along than the center of the preceding wave. The point traveling at the speed of sound prevents the pressure waves from moving ahead of it because the velocity of the point and the velocity of sound are the same. The waves now superimpose themselves one upon another in a narrow band that is about one ten-thousandths of an inch thick. This narrow band of pressure is a shock wave.

c. Mach Number. A mach number is the ratio of speed of flight to speed of sound. This is named in honor of the Austrian scientist, Ernst Mach. If an aircraft is flying at twice the speed of sound, it is flying at Mach 2. If it is flying at half the speed of sound, then its mach number is 0.5. As the flight engineer of a high speed aircraft, you must know the ratio of your flight speed to the speed of sound, because as an aircraft approaches the speed of sound, it may become uncontrollable or even disintegrate as a result of the stress imposed on it. We describe high speed flight in terms of two speed ranges: transonic and supersonic.

(1) We know that any airfoil must have an aerodynamic shape, and the velocity of the air passing over an airfoil will always be higher than the actual speed of flight. When the speed of flight is less than the speed of sound but of high enough velocity to induce supersonic airflow over some part of the aircraft structure, the aircraft is in the transonic speed range.

(2) As flight speed increases further, we reach a point where the airflow over all parts of the aircraft is supersonic, or above the speed of sound. When this happens, the aircraft is in the supersonic speed range. The following, in terms of their mach number, are the speed ranges which were referred to earlier:

(a) Subsonic - Mach numbers below 0.75.

(b) Transonic - Mach numbers from 0.75 to 1.2.

(c) Supersonic - Mach numbers from 1.2 to 5.0.

5–13. Transonic Aerodynamics:

a. The beginning of the transonic speed of range for a particular aircraft is the flight speed at which the airflow over a part of the wing becomes supersonic. As the airflow becomes supersonic, a normal shock wave always forms on top of the wing as shown in figure 5-20. A "normal" shock wave is one that forms at 90 degrees to the airflow and mixes the airflow--part of it moving at subsonic speeds, part of it moving at supersonic speeds. Supersonic airflow will always decrease to subsonic speed after passing through a normal shock wave. Both the shock wave and the mixed airflow present serious aerodynamic problems. The flight speed at which this occurs is the critical mach number. We reach this mach number when 1.0 occurs somewhere on the wing. Figure 5-21 shows the airflow moving over an airfoil as speed increases from the subsonic through the transonic ranges. The representative aircraft reaches the critical mach number of 0.72. Since no shock wave forms, there are no adverse aerodynamic forces. As we exceed the critical mach number, Mach 0.77, a shock wave develops on top of the wing. The velocity ahead of the shock wave becomes supersonic, but slows down to subsonic velocity as the air particles pass through the shock wave. Energy is dissipated in the form of heat, and static pressure and density increase behind the shock wave. There may also be some separation of the boundary layer. Note that at Mach 0.82 there is a strong shock wave on top of the wing which moves further to the rear. There is also the beginning of a shock wave on the bottom of the wing. In this case, separation takes place because the boundary layer does not have enough kinetic energy to withstand the large adverse pressure gradient. Since the area of the supersonic flow is greater, the shock waves are nearer the trailing edge of the wing at Mach 0.95. The boundary layer may remain separated, or it may attach itself again to the airfoil, depending on the airfoil shape and the angle of attack. At a flight speed of Mach 1.05, the air ahead of the leading edge has no warning of the approach of the airfoil. The airfoil suddenly pushes the air out of the way. The shock wave formed at the leading edge is a bow wave. Increasing the flight speed to a still higher mach number, the bow wave will move closer to the leading edge, and the oblique angle it forms with the line of flight will incline more.

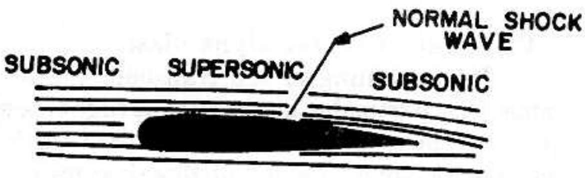


Figure 5-20. Formation of a Normal Shock Wave.

b. A shock wave loses energy in the form of heat. This loss of energy results in a sudden increase in total drag called wave drag. At transonic speeds, wave drag accounts for a large percentage of total drag. We can illustrate this by plotting the drag coefficient against mach number for a constant coefficient of lift. At approximately five to ten percent above the critical mach number, a sharp rise in drag will be noted. There will also be a loss of lift due to the shock wave because the pressure and density of the air behind the shock wave will increase greatly. If the loss of lift is severe enough, the aircraft will stall. Separated, turbulent airflow behind the shock wave affects the control surfaces in two ways. First, because of separation and turbulence, the air loses its kinetic energy and becomes aerodynamically dead. Deflection of the control surfaces will have no effect, and the pilot will have no means of controlling the attitude of the aircraft. Second, conventional control surfaces, subjected to high frequency buffeting due to turbulent airflow, may flutter. If buffeting is severe and prolonged, structural damage may result.

c. The loss of lift due to shock wave formation can have a serious effect on stability. If the shock wave does not occur on both wings at the same place and at the same time, the lift of the two wings will not be equal and the aircraft will roll or suffer "wing drop." On the other hand, if shock wave induced separation occurs symmetrically near the wing roots, a decrease in downwash on the horizontal stabilizer will create a diving moment and the aircraft will drop its nose at its critical mach number. If these conditions occur on a swept wing aircraft, shock wave formation at the wingtips will move the center of pressure forward, resulting in a "pitch-up" attitude.

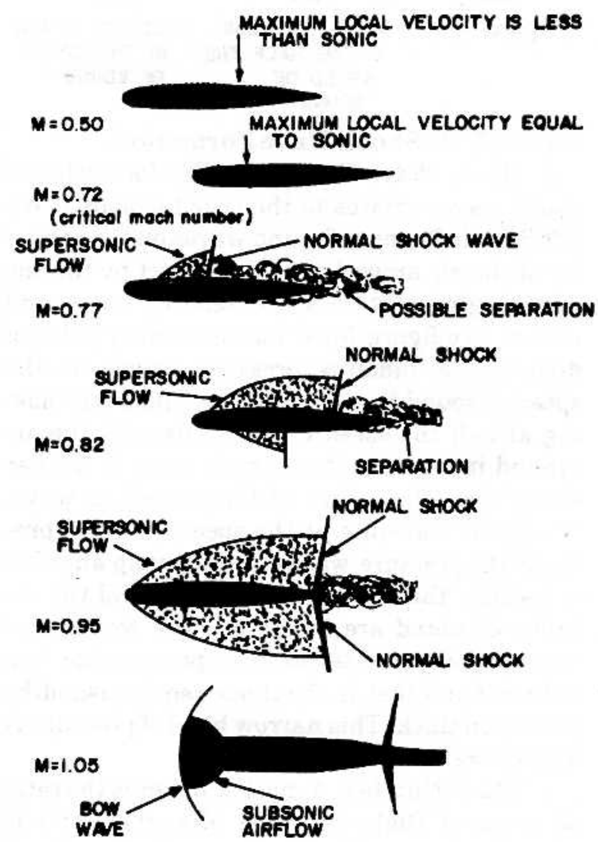


Figure 5-21. Behavior of Airflow as Speed Increases.

d. Regardless of the amount of thrust available, the critical mach number limits the maximum speed of today's transport aircraft. For example, if an aircraft has a critical mach number of 0.70, its top speed at sea level would be approximately 530 mph. If certain design changes were made, then we would raise the critical mach number to Mach 0.85. This permits a top speed of approximately 650 mph--a gain of 120 mph. See figure 5-22.

e. A high speed airfoil differs in shape from a low speed, high lift airfoil. The shape of a low speed airfoil must provide sufficient thickness to generate lift at relatively low speeds. The difference in the profiles of high speed and low speed airfoils is in figure 5-22.

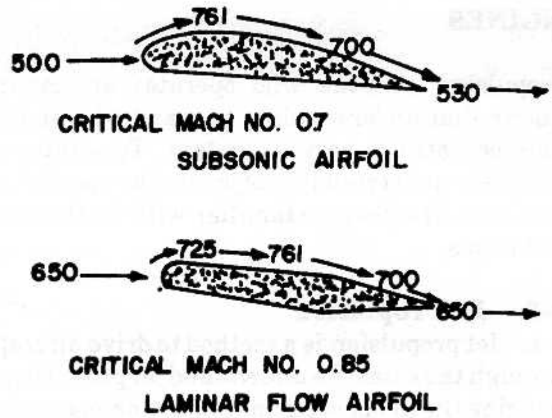


Figure 5-22. High vs Low Speed Airfoils.

(1) An ideal wing for high speed aircraft is one which the airflow will remain subsonic until we reach Mach 1.0. In other words, an ideal wing eliminates the transonic speed range entirely. However, such an airfoil would not have enough strength to support a load, and takeoff and landing speeds would be impossibly high.

(2) The airfoils (wings) used on our transport aircraft are of sufficient thickness for structural purposes and allow for the provision of high lift devices (flaps and slats) that are necessary for reasonable takeoff and landing speeds.

Chapter 6

JET AIRCRAFT ENGINES

6–1. Powerplant History:

a. The steady progress of powered flight has closely followed the development of suitable aircraft power plants. The first airplanes were powered by piston engines that turned a propeller. This was the only means known at the time which could propel a heavier-than-air machine in continuous flight. From Kittyhawk until the latter part of World War II, aircraft and reciprocating engines where continually refined and improved. Larger and more efficient engines led to larger, faster, and higher flying aircraft. Aerodynamically clean monoplanes replaced the biplane with all its struts and wires. Yet, the basic means of propulsion remained the reciprocating engine which was limiting aeronautical progress because of its increasing weight and size.

b. The development that dramatically advanced the progress of aeronautical science was the successful evolution of the jet engine. With this lightweight yet tremendously powerful engine, we could now deliver thrust that eliminates past problems and limits. The possibility of going faster than the speed of sound becomes a reality.

6–2. Jet Engine Development:

a. Serious development of jet engines began in the early 1930s when two individuals, working along similar lines, each developed a reaction engine that could produce thrust by compressing air, burning fuel with air, and expelling the hot gases at a high velocity. One of the engines employed a centrifugal compressor while the other engine used a more efficient axial flow compressor. Both the engines were used to power aircraft by the end of World War II. During the post war years, jet powered aircraft proved to be vastly superior to conventional aircraft in speed, power, and simplicity of design. Their ability to fly higher, faster, and further on almost any type of fuel basically led to the end of the reciprocating engine. In the United States military goals directed most of the development of jet propulsion. Fighter aircraft led the way, then strategic aircraft, and, finally, cargo aircraft until almost all military aircraft were powered by some type of jet engine.

b. The development of the jet engine also created a relatively new and strange field of aircraft propulsion. Anyone who operates an engine knows that understanding how and why an engine operates is very important. To attain an adequate understanding of jet engine operation, one must first become familiar with its theories and terms.

6–3. Jet Propulsion:

a. Jet propulsion is a method to drive aircraft through the skies. To understand jet propulsion, imagine the firing of a gun. The action may refer to the motion of the bullet, the reaction being the motion of the gun itself. You feel the reaction of the gun as a "kick" against the shoulder. A jet engine drives forward by using a similar reaction. The engine takes the place of the gun. The jet exhaust takes the place of the bullet. When the jet exhaust shoots into space, the reaction to it drives the engine forward. For this reason, jet engines are reaction-type engines. Turbojet, turbofan, and turboprop jets are all members of the reaction family.

b. Many persons believe that jet propulsion is caused by the exhaust gases "pushing" against the outside air. This is not so. In fact, jet propulsion will work just as well in a vacuum as long as we provide oxygen to burn the engine's fuel. The scientist, Sir Isaac Newton, stated the principles used by jet propulsion engines in his laws of motion (chapter 3). One of the easiest ways to understand these laws to develop thrust is to observe the effects on a toy balloon.

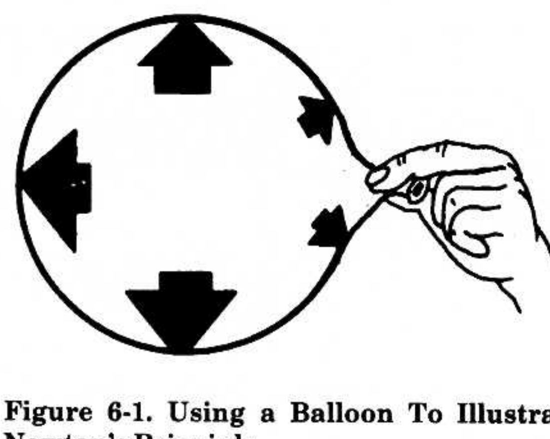


Figure 6-1. Using a Balloon To Illustrate Newton's Principle.

(1) First, blow up the balloon and pinch the stem so the air cannot escape (Figure 6-1). The air pressure in the balloon is equal in all directions. There are no unbalanced forces in it that

can propel the balloon. This is a sample of Newton's first law that states a body at rest will remain at rest unless it is acted upon by an outside force.

(2) Now, let go of the stem and the balloon will zip away (figure 6-2). Escaping air, like a jet exhaust, releases the pressure near the stem. The unbalanced pressure on the opposite side pushes the balloon forward. This is a simplified view of Newton's second law that states force is proportional to the product of mass and velocity. The faster the air escapes, the greater the force produced. Therefore, this action not only develops a force, it also determines the amount of force developed.

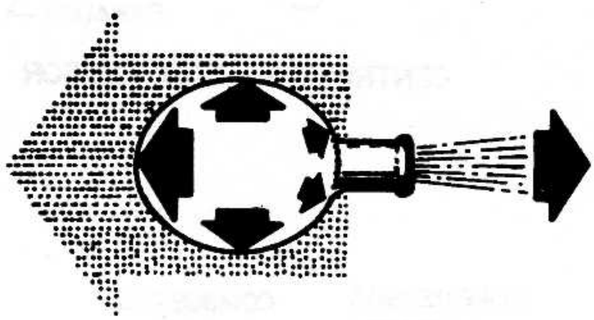


Figure 6-2. Reaction = Action.

c. Newton's third law states that for every action there is always an equal and opposite reaction. After a jet engine builds up inside pressure, it expels burned gases from the tailpipe in a stream called the jet exhaust. The reaction inside the engine to this jet exhaust drives the engine forward. This is jet propulsion and is basically how reaction engines develop thrust. The ACTION and REACTION forces described by Sir Isaac Newton occur inside the engine in the same manner as they did inside the balloon. A great force is exerted to accelerate the burned gases through the engine's nozzle. It is the reaction to this force that thrusts the aircraft forward.

6-4. Basic Operation. Most of the large subsonic aircraft in the Air Force inventory are now powered by turbojet, turboprop, or turbofan engines. Although their looks vary greatly, a gas turbine engine generates their thrust. By definition, a gas turbine engine is a machine that produces high velocity air at the jet nozzle. This happens by compressing the air, adding fuel, then burning the fuel-air mixture as it passes through the engine. It is the most versatile of the reaction engine family; however, it is also the most complex. It is fairly easy to understand how and why a gas turbine engine develops thrust. It would be difficult to understand the many principles of aerodynamics, thermodynamics, pneumatics, and gas law physics, which we must consider to learn exactly what occurs at each point within the engine. Fortunately, those who deal with jet aircraft need to understand only the basic principles of the engine's operation. Most of these become apparent when we examine the basic operation of the gas turbine.

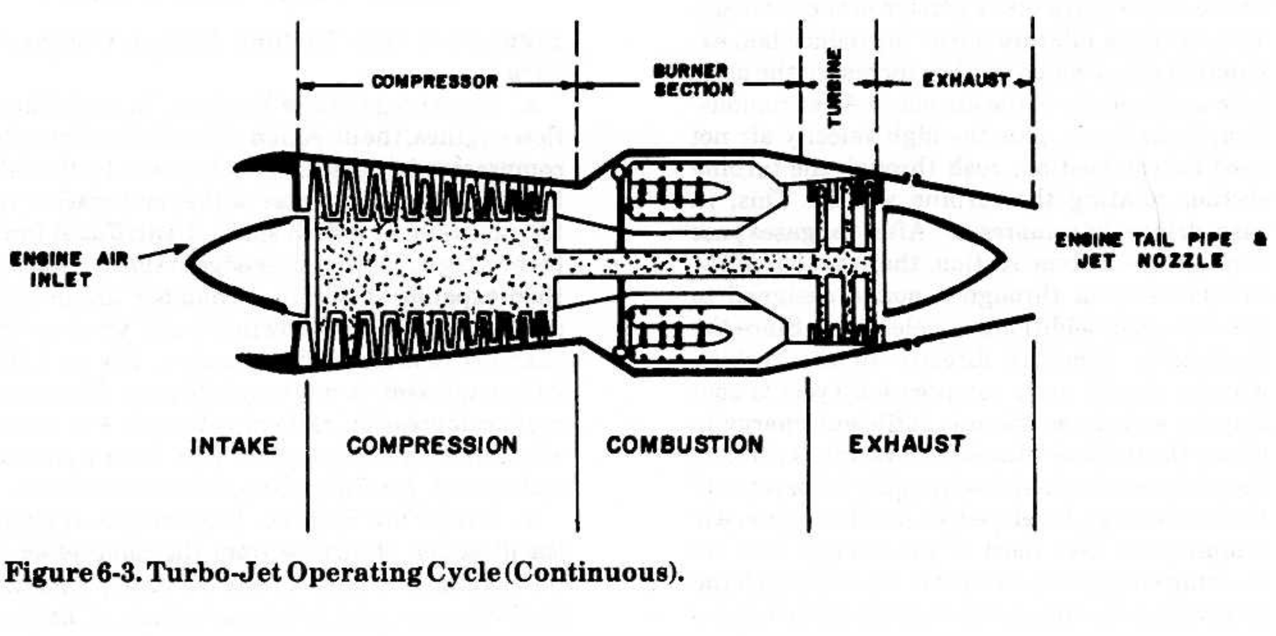


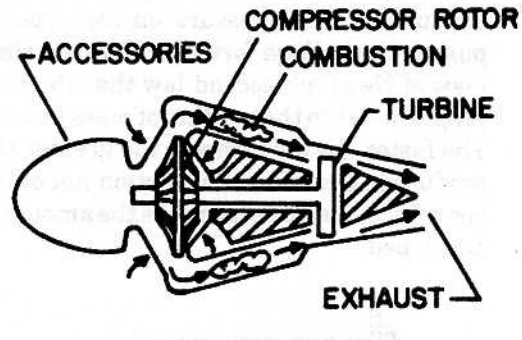
Figure 6-3. Turbo-Jet Operating Cycle (Continuous).

a. The gas turbine engine develops thrust by burning a combustible fuel-air mixture and changing the energy of the expanding gases into a propulsive force. Though they differ quite a bit from the reciprocating engine, gas turbine engines use the same basic continuous four cycle process of intake, compression, combustion, and exhaust. This is done by the taking in of an air mass, compressing it, adding fuel and burning the mixture, and expelling the air/gas mass through a nozzle. When the engine is operating on its own, this process is continuous as long as fuel is available for combustion.

b. The simplest gas turbine engine for aircraft is the basic turbojet engine. A tubelike container open at both ends makes up the engines case. Figure 6-3 illustrates the four normally distinguishable sections contained within the tube (engine) and their relationship to each of the turbojet's four continuously operating cycles. Normally, the engine air inlet duct (intake) is part of the airframe and not a section of the engine. The front section contains a rotating compressor (compression). The burner section (combustion) follows. Then comes a set of driving turbines. We mount the turbines and the compressor on one shaft and operate as a single unit. The aft section is the engine tailpipe or exhaust cone (exhaust). The opening at the rear of the engine is the nozzle.

c. When the turbojet is operating, a continuous amount of air passes through it. When this air enters the compressor section, it is compressed and accelerated by the rotating compressor and then forced into the burner section. There, fuel sprays into a portion of the air mass. The resulting mixture burns to produce hot, expanding gases which further increases the pressure and velocity of the air mass. After combustion, these gases, plus the high velocity air not used for combustion, rush through the turbine section rotating the turbine wheels. This, in turn, drives the compressor. After the gases pass through the turbine section, they exit out of the exhaust section through a nozzle designed to give the gases additional acceleration. Since the compressor connects directly to the turbine wheels, the air mass compression cycle is continuous as long as there is sufficient energy to rotate the turbine wheels. The turbines turning the compressor consumes roughly 70 percent of the total energy developed within the engine. Air compression uses most of the energy. The remaining energy expels the air mass through the jet nozzle. According to Newton's third law of motion, the reaction (thrust) to this force is what drives the engine (and aircraft) forward.

6–5. Gas Turbine Components. The types of compressors used determine the two basic types of gas turbine engines. See figure 6-4.



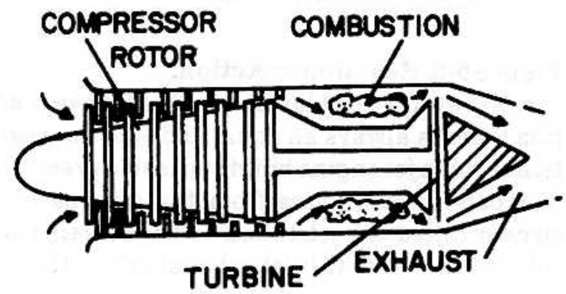


Figure 6-4. Gas Turbine Engine Compressors.

a. Centrigugal Flow Engines. In centrifugal flow engines, the direction of the airflow from the compressor is vertical. This happens by the taking in of air at the center of the compression rotor, spinning at a high speed. Centrifugal force throws the air to the outer edge of the impeller. It then expands slowly in a chamber around the compressor while throwing more air into the chamber to increase compression. The centrifugal compressor is not very efficient. The maximum compression ratio may be only 4 or 5 to 1, whereas axial compressors may have a ratio of up to 20 to 1. For this reason, it is more efficient.

b. Axial Flow Engines. In axial flow engines, the direction of airflow from the compressor is horizontal. The term axial flow comes from the air flowing parallel to the shaft of axis of the compressor. The axial flow compressor with the same size intake as the centrifugal compressor can also produce more thrust. Manufacturers build engines with several sections. These consist of an air inlet section, a compressor section, a combustion section.

(1) Inlet Section. The air inlet duct is normally an airframe part but is so important to engine performance, we take it into consideration in any discussion of a complete engine. The air inlet duct serves to furnish the required air to the front of the compressor. A uniform and steady airflow is necessary to avoid compressors stalls which initiate heat buildup at the turbine. The inlet has two functions. First, it recovers as much total pressure as possible and delivers it to the front of the engine. Second, it delivers air to the compressor inlet with a minimum of turbulence and pressure variation. The duct usually has a diffusion area which changes ram air velocity into a higher static pressure at the face of the engine. This is called ram recovery and is possible because of the shape of the inlet duct. There are basically two types of inlet ducts, the single and divided entrance. The single entrance duct is the most common and most effective since its location is directly in front of the engine so it scoops undisturbed air from in front of the aircraft. Also, it is short which minimizes pressure loss. The configuration of the duct depends on its location on the aircraft and the airspeed, altitude, and the design of the aircraft. It also avoids inlet air distortion when the aircraft is flying at low airspeeds and steep climb angles. For these reasons, the single entrance duct is standard for all subsonic multiengine aircraft. Inlet ducts for turboprop engines require a different configuration. The relatively large reduction gear section limits the quantity of air to the engine and distorts the airflow. We minimize these problems by offsetting the nose section from the main axis of the engine and using an underscoop type of inlet duct. Around the perimeter of the single entrance inlet duct is a series of ports that deliver more air to the face of the engine during high thrust, low speed operations, which normally occur during takeoff. The ports are covered with hinged, spring-loaded doors which open automatically to permit more air to enter the duct. As the airspeed increases, ram pressure will close the doors to their normal flight configuration. The air inlet section consists of a welded steel ring with a number of struts positioned within the ring-like spokes on a wheel. The struts are inlet guide vanes and have an airfoil cross section. They serve to direct the air from the inlet duct to the face of the compressor. On larger engines, the inlet guide vanes are hollow through which engine bleed air circulates to prevent ice build up on the surface of the vanes. Several of the vanes will accommodate oil lines for lubrication of the engines' front main bearings.

(2) The Compressor Section. The axial flow compressor compresses the air and forces it through a series of rotating rotor blades and stationary stator blades which are in line with the axis of rotation. Manufacturers mount the rotor blades on a rotating compressor drum. The blades pick up the air and force it rearward, with a slight deflection in direction, to a set of stator blades. Stators are also airfoil shaped and serve to straighten and direct the air into another set of rotor blades. The pressure of the air increases each time it passes through a set of rotors and stators (one stage of compression). As the pressure builds up by successive sets of rotors and stators, the volume is gradually decreases and the air is increasingly compressed. A single axial flow compressor could consist of as many stages as necessary to produce a required compression ratio. However, high compression ratios are possible only at one specific compressor speed. At any other speed, the rearmost stages of compression would be inefficient and the front stages would be overloaded. Such a condition produces compressor stall. To compensate for these conditions and still obtain high compression ratios, the compressors on most gas turbine engines are split into two mechanically independent rotor systems. Each turbine section drives its compressor section at its best speed. See figure 6-5. With both compressors working together instead of against one another, compression ratios increase without decreasing efficiency. In addition, dual compressor engines are able to maintain high compression ratios at high altitudes where the ram air is less dense. Since thinner air offers less resistance, the free turning, low pressure compressor rotates at a higher rpm, permitting it to deliver air to the high pressure compressor at a nearly constant pressure.

(a) Compressor Stalls. It is a common characteristic of all gas turbine compressors to stall under certain operating conditions. The stall characteristic is most noticeable in high compression ratio, axial flow compressors. They occur in varied forms and under many different conditions. Compressor stall is neither easy to describe nor understandable since no two engine designs will have the same stall characteristics.

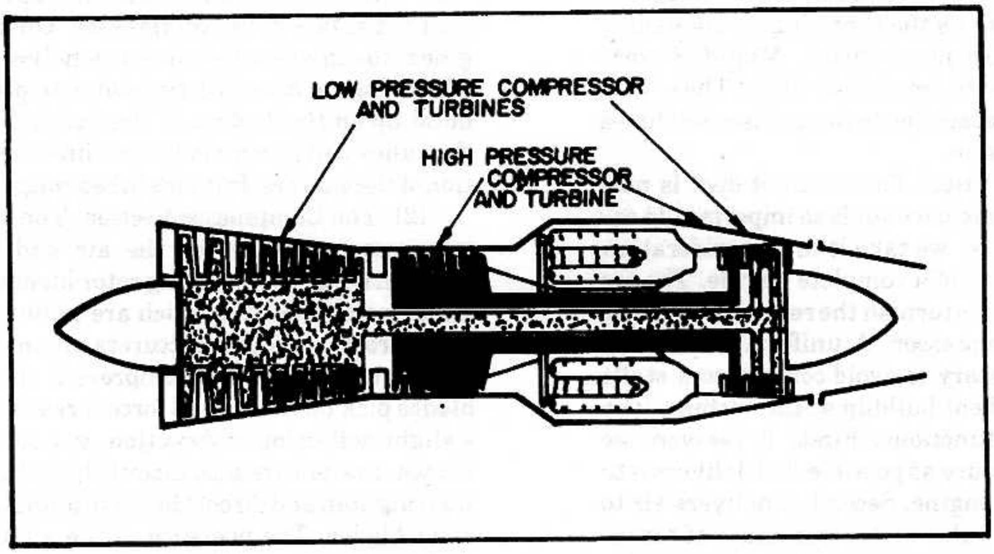


Figure 6-5. Dual Axial Flow Gas Turbine Engine.

Stalls result from an unstable air condition within the compressor which is usually caused by air piling up in the rear stages of compression. In its milder form, compressor stall makes a "choo-choo" sound, we occasionally encounter this during low thrust operation. Severe compressor stalls resulting from quick throttle movements when flying in turbulent air or when anything upsets the air flow at the engine inlet, may cause loud bangs and engine vibration. In most cases, compressor stall is of short duration. It is corrected by bringing the throttle back to idle and advancing it again, slowly. One way to reduce compressor stalls is to "unload" the compressor during certain operating conditions.

(b) Values. By fitting compressors with automatic dump valve ports which open during a specific range of engine rpm we unload the compressor. The rpm at which the air bleed valves open or close is a function of compressor inlet temperature, pressure, or pressure ratio. When open, the air bleed valves remove excess airflow through the low pressure compressor, thus removing the prime cause of stall. The air bleed valves automatically close during high thrust operations. Many large, high compression ratio engines use several stages of variable angle stator blades as a method to avoid compressor stalls. The angle of attack of these stator vanes (called variable vanes) changes automatically to prevent choking of the downstream compressor stages as engine operation conditions vary. Actuators installed in the first stages of the low speed compressor position automatically the variable stators. They provide sufficient stall margins within the compressor during engine starting, acceleration, and partial thrust operation.

(3) Combustion Section. The air leaving the compressor passes through a diffuser section which has an expanding internal diameter and serves to decrease the velocity and increase the pressure of the air. This prepares the air for entry into the combustion chamber at a low velocity which permits proper mixing with fuel. Manufacturers build ports into the diffuser case which bleeds air from the engine for aircraft environmental service functions. This high pressure hot air is available any time the engine is operating. The penalty for taking air from the engine, before it goes to the burners, is a loss of thrust and an increase in fuel consumption. The compressor forces air into the combustion section where it mixes with fuel and then burns. This combustion must add enough heat energy to the air to accelerate its mass enough to produce the desired thrust output and power to turn the compressors. The design of the combustion chamber is important because the flame is centered so it never comes in contact with the chamber's metal walls. Combustion must be complete so the flame will not leave the chamber and come in contact with the turbine wheel. Combustion uses less than a third of the air entering the chamber. The rest of the air shapes the flame pattern, cools the burner

surfaces, and mixes with the burned gases before they enter the turbine section.

(4) The Turbine Section. Swirl nozzles eject fuel into the airstream at the front of the burner cans. The nozzles employ a pressure atomizing principle to ensure the uniform distribution of fuel mist throughout the range of fuel flows encountered during engine operation. During engine start, igniter plugs ignite the fuel-air mixture. The flame quickly spreads to each of the other burner cans by crossover tubes. The igniter plugs are deenergized once the engine is running because the burning process within the combustion chamber then becomes continuous. The energy of combustion takes the form of hot, high velocity gases directed to the turbine section. The turbines of all gas turbine engines are of axial flow design. They consist of one or more stages located immediately to the rear of the burner section. The turbines extract energy from the expanding gases and convert it into shaft horsepower to drive the compressors and engine accessories. Turbines may be either single stage or multistage. When the turbine has more than one stage, a set of stationary vanes called turbine nozzle vanes are installed between each turbine wheel to direct the gases onto the blades of the turbine rotors. On engines equipped with dual compressors, the turbines are also dual or split. In the arrangement, the forward turbine, which drives the high pressure compressor, can be single stage since it receives gases of higher energy than the turbines of the low pressure compressor. To maintain the energy balance, a multistage turbine drives the low pressure compressor. Turbines incur high speeds, high temperatures, and high centrifugal forces. To obtain efficiency, turbines operate very close to limiting temperatures which, if exceeded, distorts the turbine blades and shortens the engine's useful life. When subjected to extremely high temperatures at high speeds, a condition known as creep tends to stretch or elongate the blades of the turbine wheel. Since the rate of creep is cumulative and reduces the engine's life expectancy, aircrews should respect all temperature limitations when operating the engine.

(5) Exhaust Section. Air leaving the turbine section flows through the exhaust duct and ejects through the jet nozzle. The term exhaust duct applies to the engine exhaust pipe or tailpipe which connects the turbine outlet to the jet nozzle. The exhaust duct collects and straightens the gas flow from the turbine and, through convergence, increases the velocity of the gases before discharging through the nozzle at the rear of the duct. The exhaust duct contains an engine tail cone and exhaust struts which serve to strengthen the duct and to direct and smooth the gas flow. The exhaust section is instrumented for exhaust gas, turbine inlet, or tailpipe temperatures. We may sense turbine discharge pressures as a means of determining the thrust output. The rear opening of the exhaust duct is the jet nozzle. The nozzle acts as an orifice, which determines the density and velocity of the gases exiting the engine.

(6) Bypass Ratio. On turbofan engines, the fan section lies to the rear of the air inlet section. The fan section and fan are part of the compressor section because the fan is the outer part of the front stage of the low pressure compressors. The fan permits use of a conventional air inlet duct, resulting in low inlet duct loss, and reduces engine damage from ingested debris by throwing debris outward. This debris usually passes through the fan instead of the main part of the engine. The fan consists of one or more stages of rotating blades and stationary vanes that are somewhat larger than the forward stages of the compressor. The air passing through the fan exhausts to the outside air through ducts just aft of the fan. However, some turbofan engines have a cylindrical-shaped duct around the case of the basic engine. The duct carries the fan discharge air all the way to the rear of the engine where it may or may not mix with the gases coming from the basic engine. The air which passes through the basic engine is the primary air stream, and the air which bypasses the basic engine and passes only through the fan is the secondary airstream. The ratio of secondary air to primary air, by weight, is the engine bypass ratio. Bypass ratio for most turbofan engines range from 1:1 and up. Several of the more modern engines have a bypass ratio of 10:1.

6-6. Thrust Generation Factors:

a. Changes in pressure, temperature, and velocity take place as the air mass moves through the engine. Of these factors, the velocity directly produces thrust. Temperature and pressure changes generate the velocity. Figure 6-6 illustrates the changes that take place when a stationary engine is operating at full throttle.

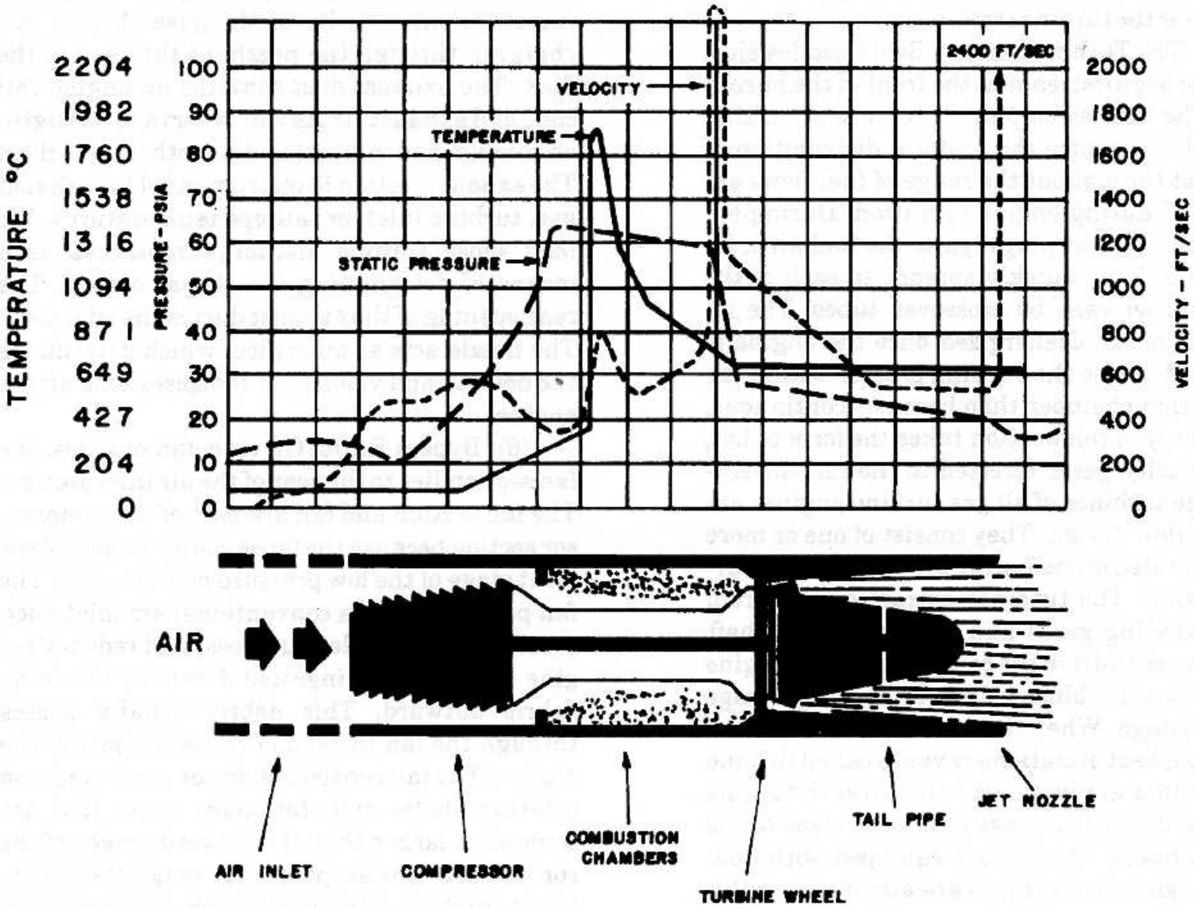


Figure 6-6. Velocity, Temperature and Pressure Relationships.

b. As the air enters the engine, there is a slight drop in pressure due to inlet turbulence. Pressure rises rapidly as the air mass passes through the compressor. The pressure gradually drops in the combustion chamber when the rapidly expanding burned gases increase in velocity. A rapid pressure drop occurs as the air mass passes through the turbine wheels. Then another gradual drop takes place as the mass passes through the tailpipe. The pressure of the air mass leaving the jet nozzle is roughly twice that of the inlet air.

c. The temperature of the air mass increases as it passes through the compressor section. A sharp rise in temperature occurs in the combustion chamber as the fuel-air mixture burns. Temperature drops rapidly as the burned gases mix with the cooling air. The temperature of the air mass drops considerably as it passes through the jet nozzle.

d. The velocity of the air mass increases in proportion to the temperature and pressure changes of the air mass until it enters the turbine section. Here, the velocity drops gradually as it expends energy to rotate the turbine wheels. The air then leaves the nozzle at a high velocity due to the tailpipe's construction.

e. The air mass was accelerated as it passed through the engine. This acceleration is produced entirely within the engine. According to Newton's second law of motion, this produces a force equal to the weight of the air mass times its rate of acceleration.

f. If gas turbine engines were always operated under standard conditions, the thrust would always be the same. When installed on an aircraft, these engines operate under varying atmospheric conditions, airspeeds, and altitudes. These conditions affect the pressure and temperature of the air entering the engine. This, in turn, affects the amount of air flowing through the engine and the velocity at the jet nozzle. Because these things change the amount of the airflow through the engine, we use different values to compute the actual thrust produced. The engine's fuel control compensates for some of the changes. Variable factors such as temperature, pressure, altitude, and airspeed affect the engine's thrust output directly. Together they determine the density (weight) of the air mass entering the engine. The movement of an aircraft through the air plays a part in engine acceleration. When the velocity of the air between the inlet and exhaust section decreases, the engine thrust decreases. At full throttle, the engine sucks in a tremendous amount of air to produce its flat-rated thrust. As the aircraft begins to move, the velocity of the air at the inlet increases. At a certain speed, the engine is no longer required to suck air. From this point, the increasing speed of the aircraft forces enough air into the inlet duct, which proportionately increases the pressure of the air in the inlet duct area. Increasing the pressure will increase the density of the airflow to the engine which, increases the thrust output. The increase in air pressure caused by motion is ram effect. What actually occurs is shown in figure 6-7. The A curve represents the thrust lost due to the forward speed of the aircraft. Remember, until you reach the predetermined speed (differs with each aircraft), the engine sucks air resulting in the loss of thrust. The B curve represents the thrust generated by the ram effect. As speed increases, the density of the inlet air increases; consequently, thrust increases. The result of these two curves is in curve C. Note the loss of thrust from forward speed is overcome by the increase in thrust from ram effect at point X. This point is called the thrust recovery point. When the airspeed becomes high enough, the ram effect produces a significant increase in thrust. Ram effect compensates for some of the thrust lost due to the low density of high altitudes. This is most noticeable in jet powered aircraft during cruise conditions.

6–7. Types of Jet Engines. We have just looked at the basic gas turbine engine. Now let's apply it to the engines we use: the turbojet, turboprop, and turbofan engines. Although their basic power generation is the same, each different engine develops its power in a different manner. Each engine also has its own limits, advantages, and disadvantages, which relegates the aircraft to specific mission operations.

a. Turbojet Engine. A turbojet engine is a straight gas turbine engine that gets its thrust by accelerating a mass of air through the engine. To maintain high speed air at the exhaust nozzle, the turbine takes only enough energy to drive the compressor and accessories. All thrust produced by a turbojet occurs within the engine. Large, high performance turbojets require single or dual axial flow compressors to obtain the greater efficiency of high compression ratios. An engine with a dual compressor is a dual spool engine. Compared with turboprop or turbofan, their fuel consumption is high, although it decreases with altitude and airspeed. To be at their best, turbojets need the ram air pressure at their inlet that comes with high forward speeds. They cannot produce exceptionally high thrust at low altitudes and airspeeds. They need long runways for takeoff and their climbout capabilities are poor.

b. Turboprop Engine. Turboprop propulsion combines the thrust developed by the propeller and the thrust produced by the exhaust gases at the exhaust nozzle. The turboprop turbines take the maximum possible gas energy from the gas stream. The power produced converts to shaft horsepower driving the propeller reduction gears and accessories. The remaining energy, approximately 10 percent, produces jet thrust as the gases exit out of the exhaust nozzle. The turboprop engine unites the gas turbine engine with the efficient low speed characteristics of a propeller. Turboprops develop high thrust at low altitudes. Because of the propeller's ability to accelerate a large mass of air while the aircraft is at relatively low ground and flight speeds. This makes turboprops ideal for lifting heavy loads off short or medium length runways. Propeller efficiency drops off as airspeed and altitudes increase. Despite their low fuel consumption, spectacular takeoff, and climbout performance turboprops are best suited for airspeeds under 400 knots and altitudes below 31,000 feet. The engine consists of an axial flow gas turbine unit and a reduction gear which join together by a extension assembly. We use the reduction gear assembly to reduce the high rotation speed of the turbines to a suitable propeller shaft speed. Changes in power of the turboprop engine do not relate to engine speed. Power relates to turbine inlet temperature. The propeller maintains a constant engine speed known as the 100 percent rated speed of the engine. The design speed obtains the most power and best overall efficiency. Since the rpm remains constant, an increase in fuel flow causes an increase in energy available at the turbines. The turbines absorb this energy and transmit it to the propeller in the form of

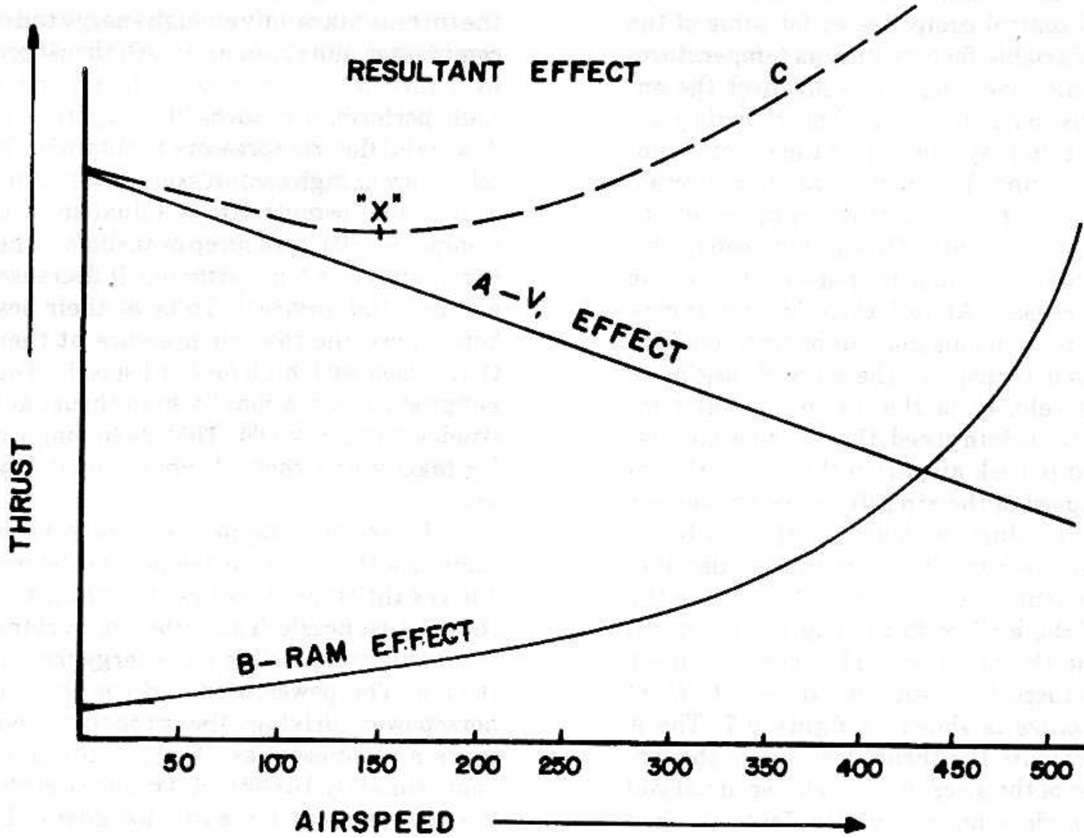


Figure 6-7. Acceleration Effect on Thrust.

torque. The propeller then, in order to absorb the increased torque, increases the propeller blade angle, thus maintaining constant engine rpm.

c. Turbofan Engine. The turbofan engine is similar to the turboprop except that an enclosed axial flow fan replaces the geared propeller. The fan consists of one or more stages of extra rotor blades which are considerably larger than the rotors of an axial flow compressor. The fan makes a substantial contribution to the total thrust by accelerating the air passing through it in a manner similar to that of the propeller on a turboprop engine. The fans produce between 30 and 85 percent of the total thrust, the actual amount depending upon the ratio of secondary airflow to the primary airflow through the basic engine. The fan air exhausts into the outside air through a fan discharge nozzle or an annular fan discharge duct. The turbofan combines the good operating efficiency and high thrust capability of the turboprop with the high speed, high altitude capability of the turbojet. The turbofan engine eliminates the weight of propeller reduction gearing and the intricate propeller governing system. The airflow through the fan is controlled by the design of the air inlet duct so that the velocity of the air through the fan blades is not greatly affected by aircraft speed. This means the loss of propulsive efficiency with speed is not a significant problem for the turbofan engine. When compared to a turbojet of equal thrust, the turbofan has the advantage of higher and more efficient cruise thrust and lower fuel consumption. Compared to the turboprop, it has other desirable features such as less weight, increased ground clearance, and higher and more economical flight speeds. The turbofan has the advantage of making less noise at high thrust settings. The turbofan engine is the most nearly ideal powerplant for all large conventional military aircraft.

6-8. Engine Ratings. Engine ratings represent the thrust that an engine develops during various operating conditions such as takeoff, climb, cruise, or for continuous operation under certain circumstances. An understanding of these ratings is necessary if one is to use the engine performance charts in the aircraft performance manual. The manufacturer of the engine establishes these ratings in terms of pounds of thrust, adding a time limit for the specific rating.

a. Most turbojet and turbofan engines are flat-rated according to their designed thrust output. The term flat-rated refers to the ability of the engine to produce a constant maximum thrust over a wide temperature range. The thrust, in pounds, which the engine develops for takeoff is the engine's flat-rated thrust. We interpret this rating in terms of engine pressure ratio, fan speed, torque, or turbine inlet temperature. We must use curves or charts to determine the value which will represent the desired engine rating for the current temperature and barometric conditions. Almost all the propulsive force from a turboprop engine comes from the propeller. The engine performs most of its work driving a shaft which turns a propeller. We measure the power supplied as shaft horsepower (SHP). We rate turboprop engines in terms of equivalent shaft horsepower (ESHP). Inch-pounds of torque represent this engine rating. Torque meters mounted on the extension shaft measure this torque. The torque meter senses the small amount of twisting on the torque shaft that occurs between the engine and reduction gear. We use performance charts and curves to determine torque and turbine inlet temperature.

b. On all flat-rated engines, takeoff power will normally be attained at a throttle position below its full forward position. Its position represents instrumented flat-rated parameters of engine rpm, temperatures, fuel flows, and pressures which vary somewhat by ambient temperatures and barometric pressures. We base engine ratings below takeoff-rated power on allowable, but not instrumented, turbine inlet temperatures for either a specific time period or continuous operation, as the case may be. These ratings and their time limits are expansively defined by your own Dash-1 and 1-1.

c. We obtain all engine ratings by adjusting the throttle to the position at which the fuel control will produce the desired EPR, torque, fan speed, or limiting turbine inlet temperature. Once we set the throttle for a given level of thrust, the engine fuel control meters fuel to the engine with automatic compensation for compressor rpm, compressor inlet temperature and/or inlet pressure, and internal burner pressure.

d. In the interest of conserving the useful life of the engine the manufacturer establishes the length of time we may operate an engine at each of the various engine ratings. By not following these standards, the engine could literally wear out in a very few hours of flying. Continued abuse of the specified time limits can lead only to early engine difficulties.

e. There is no operational technique which can reverse the effect of working an engine too hard for too long. The real purpose of limiting the engine operating time at high thrust ratings is to provide a suitable lag in the deterioration rate of the engine's internal parts throughout its normal life. There is no hard and fast rule for reducing the throttle setting for any specific length of time before using the higher thrust rating again. It is a very good practice to operate an engine at a reduced thrust for the same amount of time the engine was operated at a high thrust setting.

f. The more conservative the engine operation, the longer the turbine blades will last, the longer the engine's useful life. There are just so many operating hours at high thrust settings in every engine. Whether we use the operating hours up quickly or spread them evenly throughout a normal, calculated period of time, in large measure, depends upon how well we observe the time limits.

6–9. Jet Engine Operation. Aircraft engines have some operational characteristics and features peculiar only to themselves. Those who operate jet engines need to know these characteristics if they are to obtain the most from their engines, and if they are to understand why their particular engine behaves as it does. After looking at how and why jet engines were designed, we briefly looked at how Sir Isaac Newton's laws fit into the big picture. We looked at the basic operation of the gas turbine engine, its components, and how they work. Granted, we could not cover all of the aspects of jet engines in this chapter, but the intent was to cover the basic principles that affect each and every one of us that fly.

Chapter 7
WEIGHT AND BALANCE

7-1. What This Chapter Covers. This chapter discusses the basic principles of weight and balance.

a. There are many factors which are essential to the safe and efficient operation of an aircraft. One of these is the balance of the aircraft. The balance of an aircraft refers to a condition of stability that exists when all weights and forces are acting in a way as to prevent rotation on any axis. Accordingly, aircrew personnel must distribute the weight of the aircraft so the center of gravity falls within specified limits. Maintaining the balance of a small aircraft, such as fighter, is comparatively simple because most of the weight is fixed. With transport aircraft, the payload, fuel location, number of crewmembers, and weight of equipment vary greatly. Maintaining the balance of the aircraft involves precise mathematical calculations and careful attention to detail.

b. An unbalanced aircraft produces several unsafe conditions. These are:

(1) Longitudinal instability, in the form of light or reversed control column forces.

(2) Lateral instability, one wing appears heavier than the other.

(3) Increased takeoff distance.

(4) Increased stalling speeds.

(5) Decreased rates of climb.

(6) Decreased range.

(7) Decreased structural safety factors.

c. Weight and balance is not new. Commercial airlines have been exercising strict weight and balance control ever since the beginning of international operations to increase the efficiency and safety of the aircraft. The standardized weight and balance control system used by the Air Force makes it possible for the pilot or flight engineer to check the balance of the aircraft before takeoff and to determine proper load distribution. By making a few simple calculations, flight engineers determine the following essential information:

(1) Takeoff center of gravity.

(2) Zero fuel weight center of gravity.

(3) Probable landing weight.

(4) Center of gravity limitations for takeoff and landing.

(5) Center of gravity position prior to disposition of the load (fuel, bombs, cargo, etc.).

(6) Allowable cabin load.

(7) Center of gravity position after disposition of the load.

7-2. Weight and Balance Terms. As with other technical subjects, weight and balance has a definite language all its own. We use the terms defined here in the practical applications of weight and balance control.

a. Center of Gravity. The center of gravity (CG) is the point about which an aircraft would balance if suspended free in the air.

b. Reference Datum Line (RDL). The reference datum line is an imaginary vertical plane which is the beginning point for all horizontal weight and balance measurements made. It is perpendicular to the longitudinal aircraft axis and appears as a line when the aircraft is viewed from the side. For each aircraft type and model, all locations of stations (station numbers) are listed as being so many inches from the RDL. In most cases the reference datum line is located at a point some distance forward of the nose. However, it is possible that modification of an aircraft could cause the RDL to be at or behind the nose.

c. Arm. An arm is the horizontal distance, in inches, from the reference datum line to the center of gravity (CG) of a mass.

d. Torque. Torque is the physics term for the twisting effect when a force causes motion about a point. It is the result of a force acting at the end of an arm.

e. Moment. The moment (MOM) is the weight of an item in pounds, multiplied by the arm in inches. It is the torque the aircraft weight would produce relative to the RDL. The unit of measure is the inch-pound. The moment divided by a constant is used to simplify balance calculations by reducing the number of digits. The simplified moment is obtained by dividing the true moment by 1,000, 10,000, or 100,000 and rounding off the result to the nearest whole number.

f. Balance Arm (commonly called the Average Arm). This is the average length of all arms as measured from the RDL to each object in a group. It can be obtained by adding the weights of several objects, adding up the moments of the objects, and dividing the total moments by the total weight.

g. Mean Aerodynamic Chord. The mean aerodynamic chord (MAC) is the average chord (width) of the wing.

h. Center of Lift. The center of lift is the theoretical point at which the total lift of the airfoil is concentrated. It is usually equal to one-third of the mean aerodynamic chord and is located aft of the leading edge of the mean aerodynamic chord. The relationship between the center of the lift and the CG determines the balance of the aircraft.

i. Centroid. A centroid is the average arm or CG of a compartment, fuel tank, piece of equipment, cargo, etc.

j. CG Limits. CG limits specify the range of movement of the CG without making the aircraft unsafe to fly. The CG of the loaded aircraft must be within these limits. Takeoff and landing limits are also specified.

k. Basic Weight. The basic weight of an aircraft is its weight as it is equipped to fly before adding crew, fuel, and other items of variable load. The basic weight may vary from time to time due to equipment and structural changes. The basic weight is recorded on the Chart C (DD Form 365-3, Chart C - Basic Weight and Balance Record).

l. Basic Moment. The basic moment is the sum of the moments of all items making up the basic weight of the aircraft is recorded on the Chart C (DD Form 365-3).

m. Operating Weight. Operating weight is a term used for cargo aircraft which includes basic weight, crew, crew baggage, mission required and emergency equipment. This is the weight required to operate the aircraft before fuel and payload are added.

n. Zero Fuel Weight. The weight of a fully loaded aircraft without its fuel load. It includes cargo, passengers, and crew. All other weight must be usable fuel.

o. Allowable Gross Weight. Allowable gross weight is the maximum gross weight with which the aircraft may takeoff under any given set of runway and atmospheric conditions. This weight must never exceed the published maximum allowable gross weight except in an extreme emergency. It can be less than the published maximum allowable gross weight for takeoff because of runway length, performance of engines, field elevation, climatic conditions, and fuel load.

p. Takeoff Gross Weight. Takeoff gross weight is the gross weight at which the aircraft lifts off the runway. It is based on the fact that this is the point at which an aircraft actually begins to fly and inflight CG limits apply.

q. Takeoff Fuel Weight. Takeoff fuel weight is the weight of fuel aboard at takeoff. This does not include the fuel used during taxi.

r. Total Aircraft and Fuel Weight. Total aircraft and fuel weight is the operating weight plus takeoff fuel load.

s. Estimated Landing Gross Weight. The estimated landing gross weight is the weight of the aircraft minus the fuel to be used and other expendable weights.

t. Floor Load. Floor load is the weight of a load in pounds divided by the area of the floor upon which it is placed. Technical data usually specifies the floor loading limits and the limits for various compartment loadings.

u. Overloading. If the aircraft gross weight exceeds the limit determined by cargo, fuel, performance or basic structure, it is overloaded. It is important to determine which factor usually sets the normal weight limit. Note that most aircraft have emergency war planning (EWP) weight limits that allow the aircraft to be loaded above the normal maximums when authorized.

7-3. Principles of Weight and Balance. Aircraft balance deals with the longitudinal and lateral axes of the aircraft. Because vertical imbalance inside the fuselage has only a small effect on performance, they are often neglected.

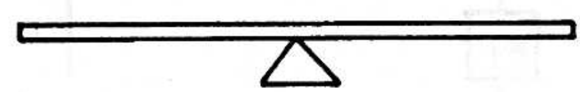


Figure 7-1. Balance Beam.

a. The pilot uses aileron trim to correct small amounts of lateral imbalance during flight. Pilots use elevator or horizontal stabilizer trim to raise or lower the tail section. This forces the aircraft to fly at the proper attitude even though its weight is not perfectly balanced. Trim cannot compensate for loads that are out of balance to any large extent, only small imbalances. Even then, the use of trim adds drag to the aircraft, increases fuel consumption, and decreases overall performance. One cannot depend on trim to compensate for an improperly balanced aircraft. Instead, one must apply the principles of balance to the loading of aircraft using basic laws of physics and the law of the lever.

To illustrate this law, let's place a beam on a fulcrum or pivot point (as shown in figure 7-1). If we place equal weights an equal distance on either side of the fulcrum, the beam will still balance (as shown in figure 7-2).

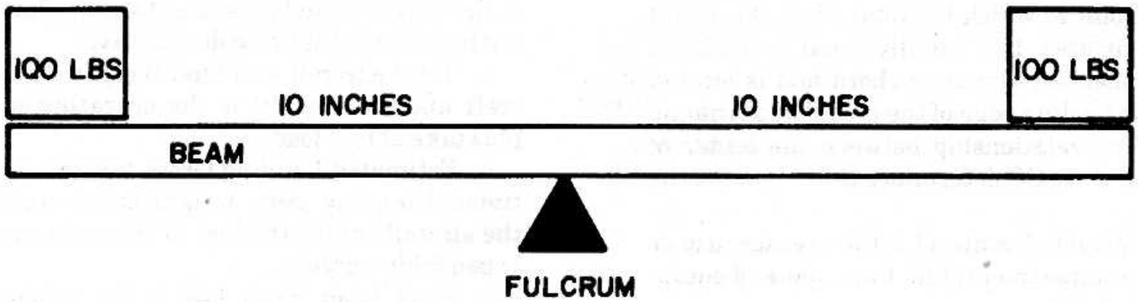


Figure 7-2. Balance Beam With Weight.

b. In order to compute the balance for all conditions, we must know the distance of the weights from the fulcrum. The lever law says the product of one weight (W1) multiplied by its distance (D1) from the fulcrum is equal to the product of the other weight (W2) multiplied by its distance (D2) from the fulcrum (figure 7-3). Each side of the beam acts as a lever, producing torque about the fulcrum equal to the other. Since both torques are equal, the beam balances and does not move. This holds true even when using different weights. For example, to balance the beam (shown in figure 7-4), a 6-pound weight has been placed 5 inches from the fulcrum, and a 3-pound weight, 10 inches from the fulcrum. Now, if the law of the lever is applied, we have:

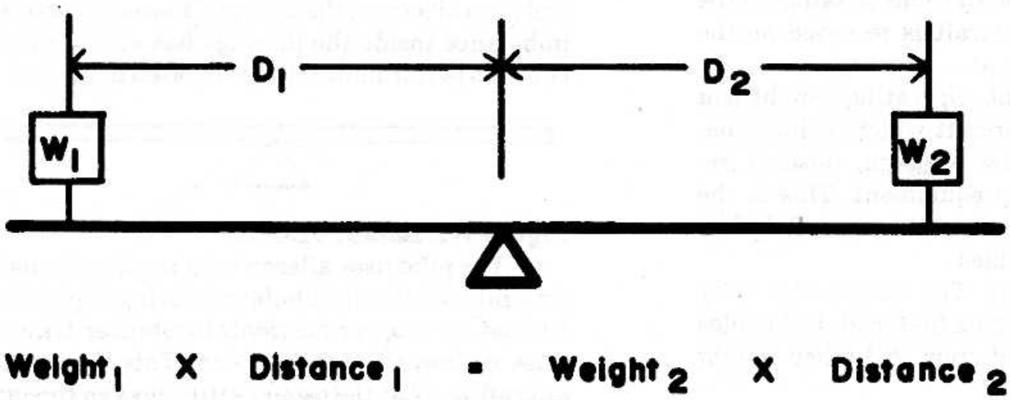


Figure 7-3. Lever Law.

$W_1 D_1 = W_2 D_2$

6 lb x 5 in = 3 lb x 10 in

30 in/lb = 30 in/lb

Since the same torque--30 inch pounds--applies to each side of the beam, the beam balances.

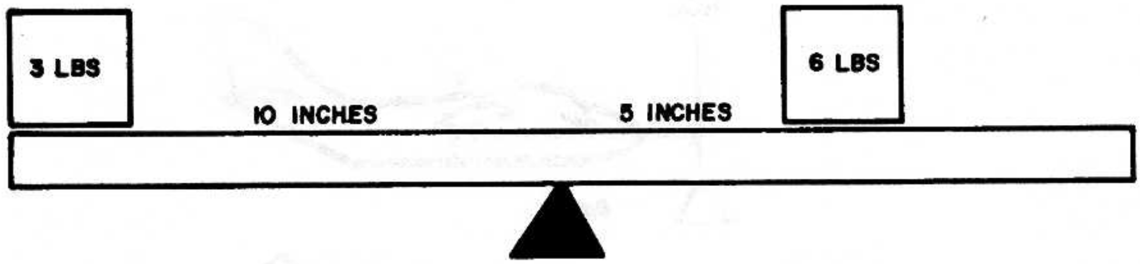


Figure 7-4. Balance Beam with Varied Weights.

c. Let's use the law of the lever to solve the problem shown below. If we place an 8-pound weight 3 inches from the fulcrum, how far from the fulcrum must you place a 6-pound weight to balance the beam? Here's how the problem is solved:

$$W_2 D_2 = W_1 D_1$$
$$8 \text{ lb X } 3 \text{ in} = 6 \text{ lb X } D_2$$
$$24 \text{ in/lb} = 6 \text{ lb X } D_2$$
$$\frac{24 \text{ in/lb}}{6 \text{ lb}} = D_2$$
$$D_2 = 4 \text{ in}$$

Thus,the 6-pound weight placed 4 inches from the fulcrum balances an 8-pound weight placed 3 inches from the fulcrum.

d. From the examples above, we can see that any system of weights has a balance point which we can calculate. This balance point is very important because it is the location of the apparent center of all the weights. The center of weights in a balance situation is the center of gravity (CG). We can describe it several ways, but aircraft use inches from the reference datum line (RDL).

e. We can calculate the center of gravity with relative ease. We can picture an aircraft in flight as an airframe suspended by a steel cable attached at the center of lift. It is easy to see that the CG must be fairly close to the center of lift, [illegible] gravity, and lift combine to twist the aircraft [illegible] down. *Since the center of lift* is fixed, aircraft balance work consists of moving the CG about to keep it near the center of lift.

f. We can calculate weight and balance calculations using moment, weight, and arm. From chapter two, the reader should recognize the remaining two forms of the moment equation:

$$\text{Weight x arm} = \text{moment}$$
$$\frac{\text{Moment}}{\text{weight}} = \text{arm}$$
$$\frac{\text{Moment}}{\text{arm}} = \text{weight}$$

The triangle form (figure 7-5) represents all three formulas in a simplified form. The horizontal line represents division and the vertical line represents multiplication. To use the triangle one needs only to cover the unknown quantity and multiply or divide as indicated. Using an aircraft as an example (figure 7-6), we can use the triangle to find the arm:

Moment 980,000
Weight 10,000

By covering "arm" we find that we must divide moment by weight which yields an answer of 98 inches.

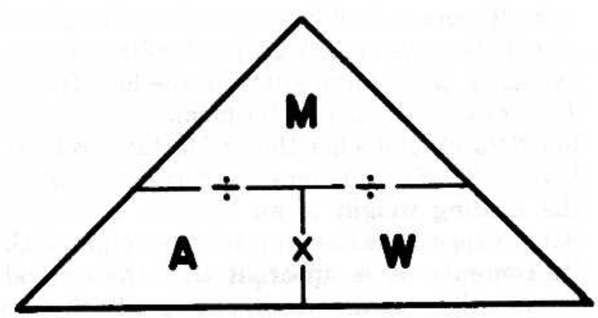


Figure 7-5. Balance Triangle.

7-4. Load Factor:

a. A load factor is the ratio of the force imposed on a particular object to the weight of that object. We express load factor in terms of *g's*, *1.0g* being one time the weight of the object. The letter *g* stands for gravity, the accelerating pull the earth exerts on all objects. Since gravity is an acceleration, it is easy to understand that other types of acceleration also can produce load factors such as turns, pull ups, and touchdowns.

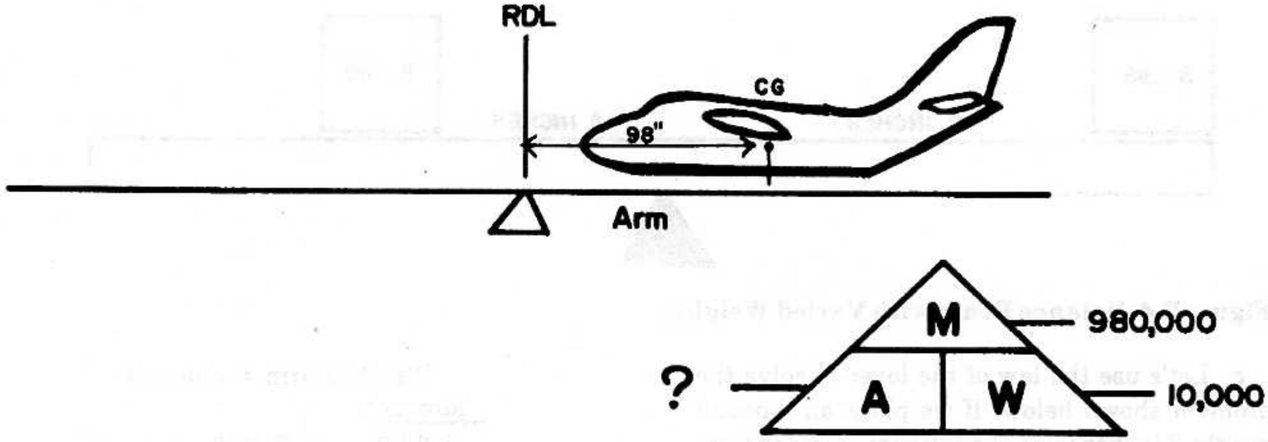


Figure 7-6. Aircraft Balance.

Because the aircraft structure (particularly the wings) can only withstand certain maximum forces, we must limit the number of *g's* (the load factor).

b. A load factor in excess of these safety limits may result in structural damage to the aircraft. The aircraft manufacturer specifies the maximum load that we can exert on a particular type of aircraft. The limitations section of your aircraft's -1 TO specifies the load factor for your aircraft.

c. An aircraft flying straight and level in still air has a load factor of 1.0. If it were to fly into an updraft, its mass would experience stress increased in proportion to the violence of the updraft. If its stress at the time of entry into the updraft were to double, its load factor might be zero (0.0) or even negative. The landing maneuver has a pronounced effect on the load factor. This is especially true at the moment the wheels touch the ground, when the load factor may be as high as 3.0. For this reason, there is a limit on the landing weight of an aircraft. Since the wings support the fuselage and the weight of all its contents, it is apparent that the critical strain will be on the wings, and specifically, on the wing roots. An empty aircraft will naturally have less strain on the wings during flight and will be able to withstand a load factor in excess of that specified. An overloaded aircraft, however, may have such a strain on the wing roots that the maximum load factor would damage the wing structure.

d. Any fuel contained within the fuselage contributes to the strain on the wings. We distribute fuel to tanks located throughout the wings for this reason. We can see this condition clearly in the illustration which shows the aircraft supported from two points representing center of lift of each wing. Supported in this manner, the aircraft has a vertical stress on the wings identical to the stress encountered in straight and level flight in still air. Weights near the tips represent the fuel load. This placement of fuel does not strengthen the wing structure, but it reduces the strain at the wing roots and spreads the stress throughout the length of the wings (figure 7-7).

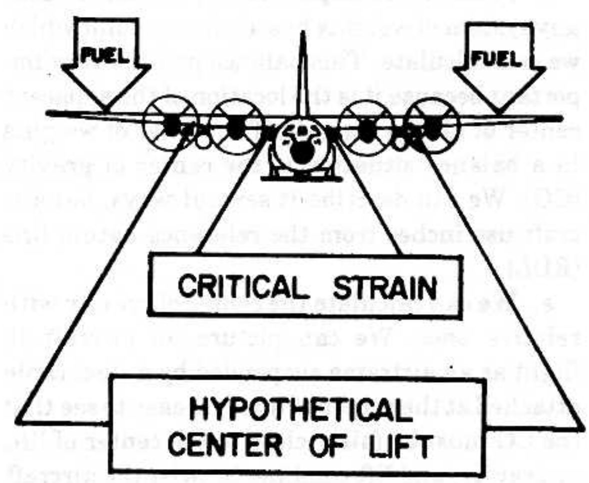


Figure 7-7. Center of Lift.

7-5. Weight Conversions. When computing weight and balance, it is often necessary to convert measurements of capacity to measurements of weight. Following are some of the conversions most often made:

JP-4 Fuel: 6.5 lb per gallon (the weight of fuel will vary with the temperature but is usually 6.5 lb per gallon).
Oil: 7.5 lb per gallon.
Water: 8.3 lb per gallon.

Your particular aircraft -5 TO has the volume to weight conversion tables.

7-6. Center of Gravity Calculations:

a. The basic CG represents the point of weight concentration of the basic aircraft before loading variables such as fuel, crew, equipment, and cargo. As we load these variables and later remove them from the aircraft, the CG will move. Uncontrolled, this movement could cause severe imbalances. Consequently, we establish fore and aft center of gravity limits. CG calculations thus form a definite part of the flight planning for cargo aircraft. These calculations ensure that the loading of aircraft is correctly accomplished to maintain proper balance during takeoff, flight and landing. We need to recalculate the center of gravity when the balance of an aircraft changes by the addition, removal, or shifting of weight. Normally, variable loads cause such calculations. Occasionally, however, the basic CG must be recomputed, which involves weighing the aircraft.

b. There are several methods of calculating the CG position: longhand, CG graph with fuel overlay, Chart E (TO 1X-XXX-5), and the load adjuster. The longhand method takes additional time, but is more accurate. It is actually the basis for the other methods. We use the following formulas in making longhand weight and balance calculations:

EXAMPLE 1: The basic formula:

Weight (lb) x arm (in) = moment (in lb)

We find moments by multiplying the weight of the object by its arm (distance from the RD).

EXAMPLE 2: The formula that computes the balance arm is:

$$\frac{\text{Total moment}}{\text{Total weight}} = \text{balance arm} = \text{distance from RD to CG}$$

In this formula, the total moment is the sum of the aircraft basic moment and the moments of items loaded in the aircraft. The total weight is the sum of the aircraft basic weight and the total weight of the loaded items. When dividing total moments by the total weight, the result is the distance in inches of the CG from the RD, it is also the length of the balance arm (figure 7-8).

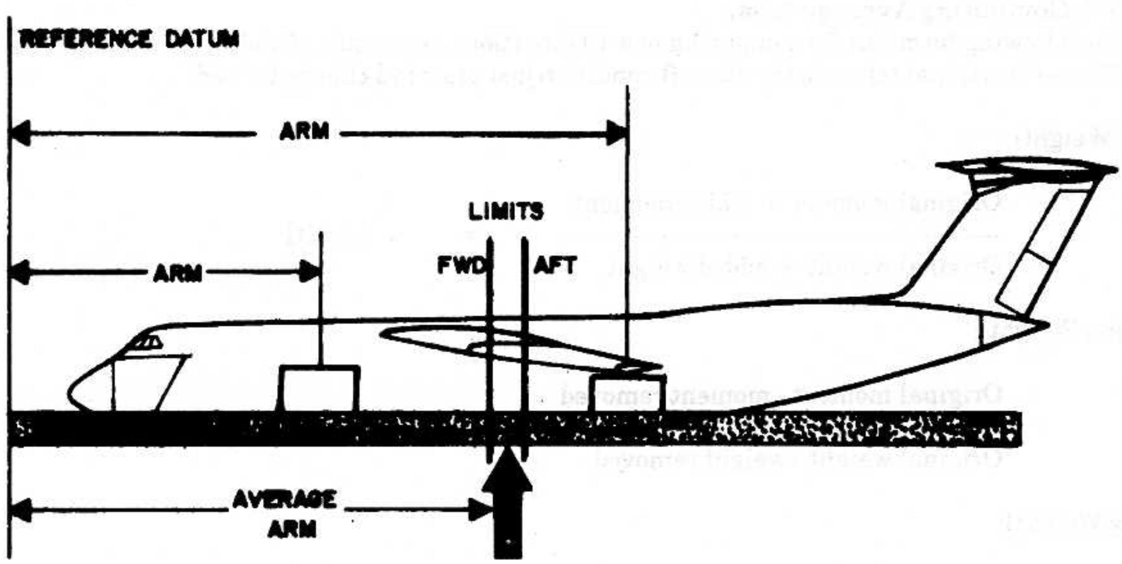


Figure 7-8. Weight and Balance.

c. The center of gravity on an operational aircraft is not a fixed point. The points shift when adding such items as fuel, passengers, crew, and cargo. The main shift in CG is along the longitudinal axis, but excessive lateral CG shift can occur with improper fuel usage. Such a CG shift leaves one wing heavy. Since CG location varies, we use a method for computing the location of CG (balance arm).

d. Figure 7-9 shows how to locate the balance arm, or CG. Since the moments are in inch-pounds and the weight in pounds, the balance arm is in inches from the RD.

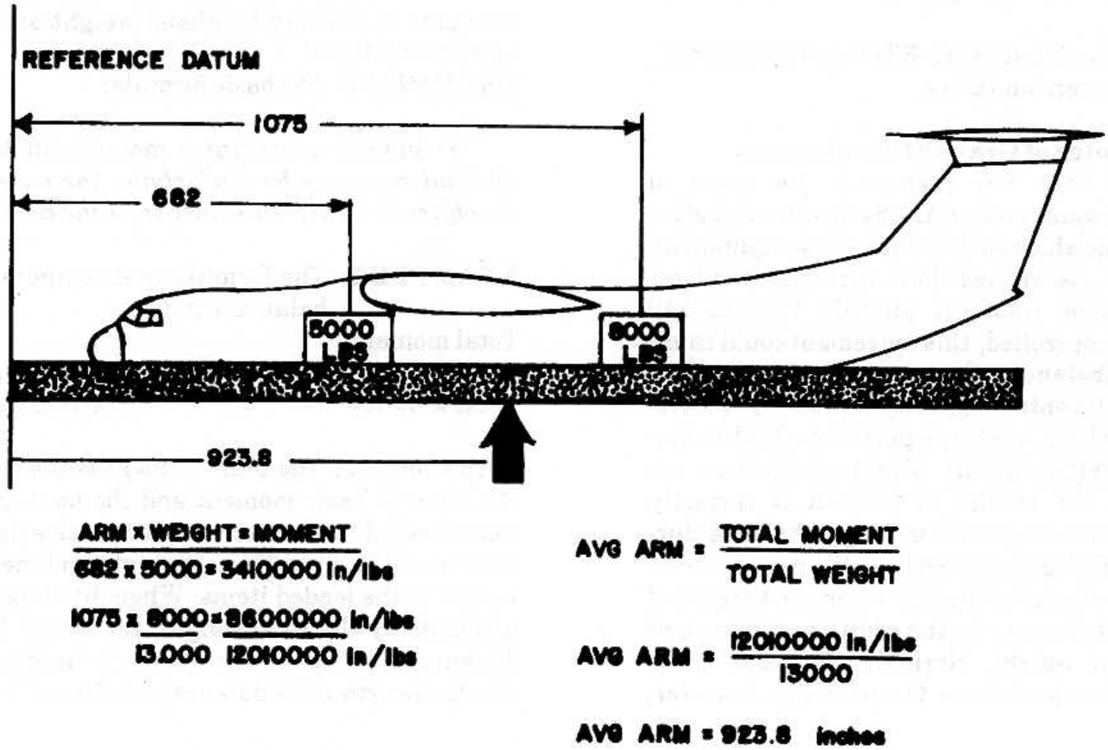


Figure 7-9. Computing Average Arm.

We use the following formulas for computing new CG locations as a result of adding, removing, or shifting weight. The term original refers to the aircraft condition just prior to a change in load:

(Adding Weight):

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

(Removing Weight):

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

(Shifting Weight):

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

We compute moment change by multiplying a weight by the distance it is moved. If the weight moves forward, we subtract the moment change from the original moment to determine the new CG. If the weight moves aft, we add the moment change to the original moment to find the new CG. We use this formula to obtain the amount of CG change which must be added to or subtracted from the old CG:

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

e. After the cargo has been loaded and determined to be within limits for the mission using the Chart E and math, the zero-fuel gross weight and zero-fuel CG are plotted on a graph representing the entire gross weight range and limitations of the aircraft. Transparent plastic overlays representing each fuel tank are then applied to the graph. These overlays have vectors which represent the weight and moments of the fuel in that tank. When all wing and body tank fuel vectors are in place, the flight engineer has an accurate "visual" picture of CG situation. He or she then can divert his or her full attention to the onloading, offloading, and transferring of fuel to meet mission requirements without exceeding limitations or lengthy calculations.

f. Simplified moments are the basis for most Chart E's found in the -5 TO for each aircraft. The Chart E is a list of weights, arms, and moments by compartment and/or station number. We use it to compute the CG of your aircraft. The load balance computer or load adjuster, like the Chart E, is another method used to save time when making weight and balance computations. The load adjuster is similar in appearance to a mathematical slide rule. We use the load adjuster to add and subtract moments, which we record as indexes on DD Form 365-4, Weight and Balance Clearance Form F - Transport/Tactical. The index number is a value expressing the combined effect of weight and moment.

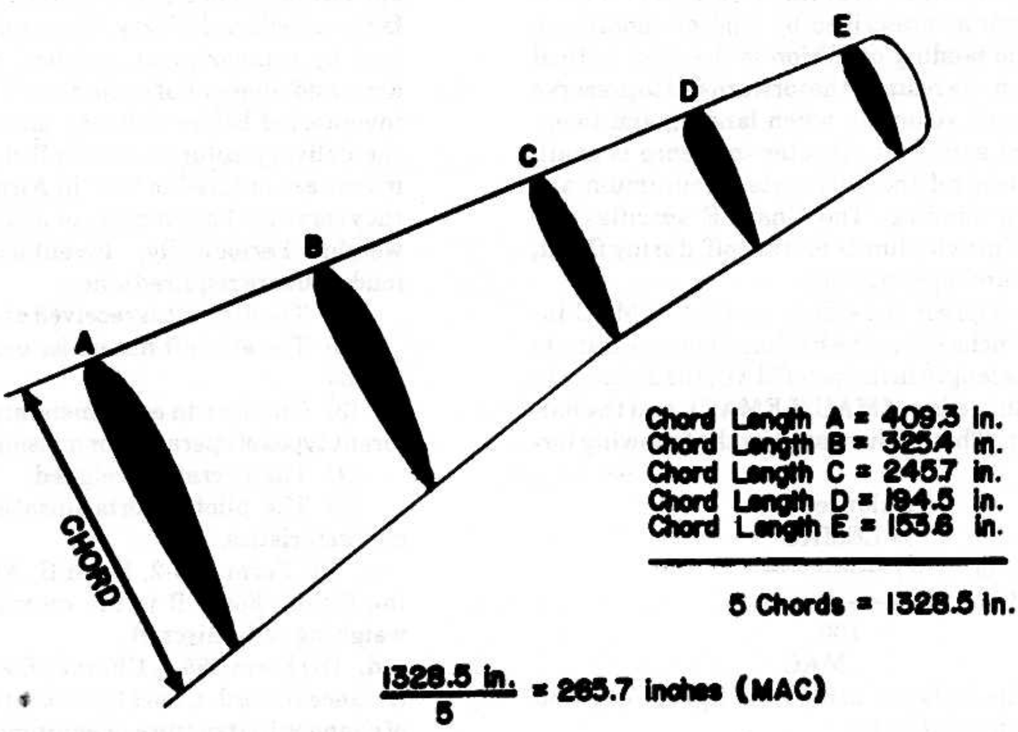


Figure 7-10. Mean Aerodynamic Chord.

g. We achieve balance in flight in most aircraft with the CG forward of the center of lift because of the combination of the forces of lift, weight, thrust, and drag action on the aircraft in flight. We express CG in terms of Mean Aerodynamic Chord (MAC). A chord is an imaginary straight line parallel to the axis of the airfoil through the leading and trailing edges of the wing section as shown in Figure 7-10.

h. Figure 7-10 presents an understandable method of computing the MAC. We measure a specific number of chord lengths. To find the average length, total the chord lengths and divide this number by the number of chords measured. The result is the MAC. We usually place the aircraft CG at a specified percent of MAC to obtain the desired stability. Because of the relationship between the CG location and the moments produced by aerodynamic forces, the greatest of which is lift, we express the CG location with respect to the wing.

i. An aircraft in flight has certain limits between which it is permissible to locate the CG or balance point. We should always load an aircraft so that any shift of crew members or use of fuel will result in a CG within these limits. Exceeding these limits will seriously degrade the safety margins normally maintained. The forward CG limit may vary with the gross weight of the aircraft and is often further restricted so as to control certain landing conditions. In such cases, it may be possible for the aircraft to maintain stable and safe flight with the CG ahead of the forward limit as prescribed by landing conditions. Since the landing condition is the most critical operation, we restrict the forward CG to preserve the aircraft structure when landing and to ensure that sufficient elevator influence is available to control the pitch axis at minimum airspeed for landing. The Chart E specifies the center of gravity limits for takeoff, during flight, and the landing condition.

j. To express the CG in percent of MAC instead of inches from the RD line, it is necessary to know the length in inches of MAC, the distance to the leading edge of MAC (LEMAC), and the balance arm. This is illustrated by the following formulas:

$$\text{CG (\% of MAC)} = \frac{\text{Balance Arm} - \text{LEMAC}}{\text{MAC}} \times 100$$

Using the balance arm from figure 7-9, and LEMAC from a C-141:

$$\text{CG (\% of MAC)} = \frac{923.8 - 858.9}{265.7} \times 100$$

$$\frac{64.9}{265.7} \times 100 = 24.4\%$$

k. We can find the percent of MAC by using a conversion table found in the aircraft Chart E as shown in figure 7-11. The conversion chart indicates the CG in percent of MAC when we know the average arm.

7-7. Handbook of Weight and Balance. There are two parts to the weight and balance problem. First, one must have correct information as to the weight and balance moment. Second, the gross weight and balance must fall within weight and CG limits. Charts A and C control the first part. DD Form 365-4 controls the second part. The Weight and Balance Data (TO 1-1B-40, 50) lists and explains these forms and charts:

a. DD Form 365, Record of Weight and Balance Personnel. Each aircraft must have a perpetual weight and balance record.

b. DD Form 365-1, Chart A, Basic Weight Checklist Record. Chart A is a list of fixed and operating equipment that is or may be installed in the aircraft or for which provisions for stowage have been made. It is initiated by the manufacturer before delivery. The equipment is itemized by compartment number, name, weight, arm, and moment of each item. These items are inventoried before delivery and checked off in the delivery column if installed. When checkmarks are entered in the "In Airplane" column, they serve as the inventory or equipment in basic weight. Periodically, Inventories should be made, but are required when:

(1) The aircraft is received at a new base.

(2) The aircraft has major overhaul or is repaired.

(3) Changes in equipment are made for different types of operation or mission.

(4) The aircraft is weighed.

(5) The pilot reports unsatisfactory flight characteristics.

c. DD Form 365-2, Form B, Aircraft Weighing Chart. Form B is the record of the actual weighing of the aircraft.

d. DD Form 365-3, Chart C, Basic Weight and Balance Record. Chart C is a continuous history of changes in structure or equipment changes affecting weight and balance. The main purpose of the basic aircraft bookkeeping system is to keep this historical information up to date. When weight changes occur, they are immediately recorded on the Chart C and the original basic weight and moment corrected to include the change. The latest basic weight and moment are used for loading calculations.

e. (TO 1X-XXX-5), Chart E, Loading Data Charts and Graphs. Chart E, consisting of several graphs, tables, or both, is intended to provide the information necessary to work a loading problem for the aircraft. Most of the Chart E data for cargo aircraft are provided in tabular form. Chart E consists of:

(1) Airplane Diagram.
(2) Wing Diagram.
(3) Center of Gravity Limits Diagram.
(4) Center of Gravity Tables.
(5) Fuel Moment Tables.
(6) Fuel Arm Table.
(7) Oil Table.
(8) Crew Moment Table.
(9) Troop Movement Table.
(10) Troop Configuration.
(11) Paratroop Configuration.
(12) Passenger Configuration.
(13) Litter Configuration.
(14) Fuel Pallet Configuration and Restraint Rail Lock Locations.
(15) Pallet and Platform Capacities.
(16) Compartment Moment Table.
(17) Station Moment Table.
(18) Compartment Capacity Table.
(19) Cargo Tiedown Data.
(20) Zero Fuel Envelope.

f. DD Form 365-4, Weight and Balance Clearance Form F - Transport/Tactical. Form F is a summary of the actual weight and disposition of the load in the aircraft. It is used to record the balance status of the aircraft step by step. It serves as a worksheet on which the responsible individual records the data, calculations, and any corrections made to ensure that the aircraft is within weight and CG limits before takeoff. A Form F must be completed before flight when an aircraft has been loaded in a manner for which no previous, valid Form F is available. We must complete the Form F according to TO 1-1B-40. The Air Force provides two versions of the form, one for transport and the other for tactical missions. Although the forms differ somewhat in detail, their general use and the end result are the same. Figure 7-12 shows the transport form. The Form F comes in expendable pads or as separate sheets. Normally, the loadmaster , but sometimes the engineer, prepare these forms in the original and a carbon copy for each loading. We use the original, which has a signature of responsibility, to serve as a certificate of proper weight and balance. The duplicate remains with the aircraft for the duration of the mission.

FUSELAGE STATION	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	PERCENT M.A.C.									
903	16.6	[illegible]	[illegible]	16.7	16.7	16.8	16.8	16.9	[illegible]	[illegible]
904	[illegible]	22.3		17.1	17.1	17.2	17.2	[illegible]		22.6
[illegible]	[illegible]	22.7	[illegible]	[illegible]	17.5	17.5	17.6		22.9	23.0
	23.0	23.0	23.1	[illegible]	17.9	17.9	[illegible]	[illegible]	23.3	23.3
921	23.4	23.4	23.4	23.5	[illegible]	[illegible]	[illegible]	23.6	23.7	23.7
922	23.7	23.8	23.8	23.9	[illegible]	[illegible]	24.0	24.0	24.0	24.1
923	24.1	24.2	24.2	24.2	24.3	24.3	24.4	24.4	24.4	24.5
924	24.5	24.5	24.6	24.6	24.7	24.7	24.7	24.8	24.8	24.8
925	24.9	24.9	25.0	25.0	25.0	25.1	25.1	25.1	25.2	25.2
926	25.3	25.3	25.3	25.4	25.4	25.4	25.5	25.5	25.6	25.6
927	25.6	25.7	25.7	25.7	25.8	25.8	25.9	25.9	25.9	26.0
928	26.0	26.0	26.1	26.1	26.2	26.2	26.2	26.3	26.3	26.3
929	26.4	26.4	26.5	26.5	26.5	26.6	26.6	26.6	26.7	26.7
930	26.8	26.8	26.8	26.9	26.9	26.9	27.0	27.0	27.1	27.1

Figure 7-11. CG Conversion Table.

WEIGHT AND BALANCE CLEARANCE FORM F - TRANSPORT
(Use reverse for tactical missions)

FOR USE WITH T.O. 1-1B-40, NAVAIR 01-1B-40, AND TM-55-1500-342-23 | Form Approved OMB No. 0704-0188

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DATE (YYMMDD) 900131	AIRCRAFT TYPE C-5A	FROM ALTUS AFB	HOME STATION ALTUS AFB
MISSION ACN 256	SERIAL NO. 68-213	TO RAMSTEIN AB	PILOT CAPT DAVIS

REMARKS

REF	ITEM	WEIGHT	INDEX OR MOMENT
1	BASIC AIRCRAFT (From Chart C)	341665	4777
2			
3	CREW (No.)	2800	21
4	CREW'S BAGGAGE	700	4
5	STEWARD'S EQUIPMENT	584	9
6	EMERGENCY EQUIPMENT CP-3	532	8
7	EXTRA EQUIPMENT	470	2
8	LN-2	1125	16
9	OPERATING WEIGHT	347876	4837
10	TAKEOFF FUEL (Gal.)	222200	3152
11	WATER Gal.		
12	TOTAL AIRCRAFT WEIGHT	570076	7989

LOAD ADJUSTER NUMBER

CORRECTION / MOST FWD / MOST AFT

13 DISTRIBUTION OF ALLOWABLE LOAD (PAYLOAD)

14 ZERO FUEL WT 451566
ZERO FUEL WT INDEX OR MOM 6219
ZERO FUEL % M.A.C. 33.2%

COMPT OR ARM	ITEM	CHANGES (+ or -) WEIGHT	CHANGES (+ or -) INDEX OR MOM	PASSENGERS NO.	PASSENGERS WEIGHT	COMPT OR ARM	CARGO LEFT	CARGO RIGHT	COMPT OR ARM	WEIGHT	INDEX OR MOMENT
						487	2400-24	00-2400		7200	35
						785	13000	13000		26000	204
				27	4320					4320	80
						1380	27	820		27820	364
						1691		9000		9000	152
						29	8700			8700	151
						32		6700		6700	122
						33	4500	4500	34	9000	172
						35	2400	2550	36	4950	102
TOTAL WEIGHT REMOVED											
TOTAL WEIGHT ADDED											
NET DIFFERENCE				27	4320		99	370		103690	1382

LIMITATIONS

CONDITION	TAKEOFF	LANDING	[1]FUEL
ALLOWABLE GROSS WEIGHT	712500	635850	498000
TOTAL AIRCRAFT WT. (Ref. 12)	570076		
(Ref. 9) + (Ref. 23)		407876	
OPERATING WT. (Ref. 9)			347876
ALLOWABLE LOAD (Ref. 13) (use smallest figure)	142424	227974	150124

[1]Zero Fuel or Limiting Wing Fuel.

	FORWARD	AFT
PERMISSIBLE C.G. TAKEOFF	22%	41%
PERMISSIBLE C.G. LANDING	19%	41%
PERMISSIBLE C.G. ZERO FUEL WT.	19%	41%

COMPUTED BY SIGNATURE: SIGNATURE

WEIGHT AND BALANCE AUTHORITY SIGNATURE:

PILOT SIGNATURE: SIGNATURE

REF	ITEM	WEIGHT	INDEX OR MOMENT
15			
16	TAKEOFF CONDITION (Uncorrected)	673766	9371
17	TAKEOFF C.G. IN % M.A.C. OR IN	37%	
18	CORRECTIONS (if required)		
19	TAKEOFF CONDITION (Corrected)		
20	TAKEOFF C.G. IN % M.A.C. OR IN		
21	ZERO FUEL WT (Ref. 14)	451566	6219
22	LESS AIR DROP LOAD		
23	ESTIMATED LANDING FUEL	60000	899
24	ESTIMATED LANDING CONDITION	511566	7118
25	ESTIMATED LANDING C.G. IN % M.A.C. OR IN	37%	

DD Form 365-4, APR 89 *Previous editions are obsolete.* [illegible]

Figure 7-12. Weight and Balance Clearance Form F-Transport.

Chapter 8

TAKEOFF PERFORMANCE

8-1. What This Chapter Covers. The preceding chapters presented background information concerning the factors governing aircraft and engine performance. In this and the remaining chapters, we will discuss the application of these factors and how they relate to aircraft performance. Takeoff performance data is critical because the aircraft is transitioning between the ground, and the atmosphere. Performance computations include every known factor that affects aircraft performance.

8-2. Variable Factors Affecting Takeoff. Each aircraft may have different procedures for takeoff, but there are common factors or conditions that affect all aircraft.

a. Friction. The effectiveness of nose wheel steering during takeoff or landing is dependent on friction. Friction plays a part in determining maximum crosswind values for takeoff or landing. When the aircraft accelerates for takeoff, rolling friction is overcome by thrust. Rolling friction determines the effectiveness of the wheel brakes used to decelerate the aircraft on landing roll. Its effect is a variable speed used in the construction of any performance chart which deals with acceleration or deceleration.

b. Aerodynamic Drag and Lift: Aerodynamic drag is the resistance created by a moving airfoil. This drag increases as airspeed increases. Its effect is also a variable used in the construction on any performance chart dealing with acceleration and deceleration. A moving airfoil develops aerodynamic lift. Like drag, lift also increases as airspeed increases. An increase in lift causes a decrease in rolling friction. This factor is another variable used in the construction of takeoff performance charts.

c. Thrust. Thrust is the force needed to overcome rolling friction and aerodynamic drag. An aircraft's rate of acceleration depends on how much the thrust force exceeds the two retarding forces. The forward velocity induced by thrust moves an aircraft through the air mass. Movement through the air mass allows the airfoil and dynamic pressure to create lift. We use these factors in the construction of any performance chart which deals with acceleration.

d. Wing Flaps and Slats. The primary purpose of wing flaps and wing slats is to allow the aircraft to takeoff and land at low airspeeds. At a given airspeed, extended flaps and slats increase both lift and drag. As speed rises, flaps and slats become more of a liability because drag increases faster than the amount of induced lift. In the takeoff and climb profile, flaps and slats are usually, but not always, retracted as soon as the aircraft accelerates to a safe retraction speed. Wing flap and settings are still another variable used in the construction of the appropriate takeoff and landing performance charts.

8-3. Environmental Factors Affecting Takeoff and Landing:

a. Higher temperatures decrease air density, reduce thrust, require higher airspeeds and longer takeoff and landing distances. So, make sure you obtain the predicted runway temperature for your scheduled takeoff or landing time from the base or airport weather forecaster.

b. Pressure altitude is the ICAO altitude equivalent to the pressure observed or forecast for the airfield at your scheduled takeoff or landing time. You may obtain pressure altitude from a base or airport weather forecaster. You may also obtain pressure altitude by reading an altimeter with a setting of 29.92 inches of mercury. Air density is inversely proportional to pressure altitude. Higher pressure altitudes reduce thrust, require higher takeoff speeds, and increase takeoff and landing distances. The primary function of pressure altitude and ambient temperature is to define the density altitude and its effect on takeoff performance.

c. Normally, the weather forecaster gives winds in terms of magnetic direction, steady velocity, and gust velocity. It is important to obtain wind information from the base or airfield weather forecaster, predicted for your scheduled takeoff or landing time. During takeoff and landing, the relationship of the wind to the runway is the basis for wind computation. The effect of a headwind on an aircraft during takeoff or landing is to shorten the takeoff ground run or landing ground roll. Conversely, a tailwind lengthens the takeoff ground run or landing ground roll. The possibility exists that wind direction and velocity may vary over several portions of the runway. Likewise, wind shear may result with heading changes during climbout or for landings. Within instrument limitations, winds are usually valid only at the point of measurement. Therefore, a conservative practice is to use 50 percent of a headwind component or 150 percent of a tailwind component as the effective wind in planning takeoff and landing performance. When computing ground run, maximum braking, tire limit, and acceleration check speeds, apply 100 percent of the headwind or tailwind component.

d. Performance charts provide grids to account for wind effects. We should accept headwind benefits as a safety margin and apply them only when mission requirements warrant their use. The erratic characteristics of gusts, as to magnitude and direction of the wind, may result in relative high airspeed instrument readings. This could result in a dangerous situation, if the wind should change direction or decay. During gusty conditions, increase the rotation, takeoff, approach, threshold, and touchdown speeds by the full gust increment not to exceed ten knots.

e. The effect of a crosswind on an aircraft is most important during takeoff ground run. The force of a crosswind has the effect of moving the aircraft toward the side of the runway. The wind condition of the runway drastically affects the pilot's ability to control the direction of the aircraft. On most aircraft, nose wheel steering controls the direction when the aircraft is below a speed where the rudder and ailerons are effective. Aircraft using a crosswind landing gear system can position the aircraft's fuselage into the wind reducing the effect of the crosswinds. We must consider the effect of a crosswind when computing minimum ground control speed.

8-4. Runway Conditions Affecting Takeoff:

a. Runway Condition Reading (RCR):

(1) We obtain RCR from base operations for takeoff and landing. RCR is a measurement of friction between the aircraft tires and the runway. This reading is an average of the total runway length within 20 feet of the runway centerline. RCR relates the average braking effectiveness of the runway surface to the braking capability of the aircraft. It becomes a factor in determining any performance that involves rolling friction and braking. For example: we correct for RCR values in critical field length, refusal speed, critical engine failure speed, ground minimum control speed, and landing distance.

(2) Grooved or porous runways improve braking coefficient and reduce hydroplaning speed by giving water a path through which it squeezes from under the tire. Some command operating procedures allow a more liberal use of RCR values on grooved runways.

b. Runway surface condition (RSC). We obtain RSC from base operations. It is the average depth and type of runway surface covering to the nearest one-tenth inch. The depth of this covering can cause a significant increase in takeoff distances and time. This is due to the retarding effect on the tires displacing the covering. The retarding effect increases with speed until hydroplaning occurs.

c. Slope. Slope is a percent of gradient to the nearest one-tenth of one percent. We obtain slope from base operations, approach plates, or departure plates. The slope is measured in percent, between two ends or points on a runway. Uphill slope degrades acceleration and improves deceleration. Downhill slope has the opposite effect. We correct for a negative effect and accept a positive effect as a margin of safety. Some foreign airfields predict slope in percentage of displacement. For example, for a reported 30 percent downhill slope runway displacement factor, you would increase your charted landing distance by 30 percent.

8-5. Maximum Takeoff Power:

a. Takeoff Rated Thrust (TRT). TRT is an extremely high thrust setting within the design limits of a turbofan or turbojet engine. It produces close to the maximum thrust of which an engine is capable, but compromises some amount of thrust in the interest of extending engine life. Turbine blade stretch is high at the resulting rpm and operating temperatures. The operating time allowed at this maximum power setting is limited. In the interest of extending engine life, we limit the operating time allowed at this maximum power setting. We express TRT in terms of engine pressure ratio (EPR) or fan speed (N1). The relationship between thrust developed and observed thrust developed is not constant. However a particular EPR or N1 value represents a predictable amount of thrust when we know pressure altitude, temperature, and airspeed (for ram effect). The engine does not use all of the potential thrust developed to propel the aircraft. We extract compressed air for pressurization, air conditioning, wing anti-ice, engine anti-ice, and engine cooling. Some of these systems are automatic and we cannot control them. We normally control large extractions and select as necessary. TRT with the unnecessary bleed systems turned off will provide the maximum thrust for takeoff. Takeoffs with bleed air off are either mandated under prescribed conditions or left to the discretion of the aircraft commander.

b. Torque and Turbine Inlet Temperature (TIT):

(1) Temperature and pressure altitude influence a turboprop engine as they would affect any jet engine and act on the propeller as they would any airfoil. Less mass produces less energy at the turbine. Ram effect is positive for an engine, but the propeller loses efficiency with acceleration. Additionally, as air becomes less dense, the propeller must take a larger bite to continue producing the same torque. Like any airfoil, the propeller has an optimum angle of attack for a given speed (rpm) and air density. Propeller efficiency decreases as air density decreases. TIT, torque, engine rpm, and blade angle all work together to produce optimum power for takeoff.

(2) Inch-pounds of torque is the primary indication of power available on turboprop engines. Torque is dependent on air density, TIT, and engine efficiency. Because the turbines of turboprop engines extract so much power we must account for the required efficiency ratings established by the major commands when computing aircraft performance. Bleed air extraction reduces torque. When takeoff performance is critical, all bleed air systems should be off and the takeoff should not be attempted at less than predicted torque.

8-6. Reduced Takeoff Power:

a. Traditionally, takeoffs were made using maximum thrust. This practice is no longer necessary. Under ideal conditions, particularly at low gross weights, today's aircraft do not need maximum thrust to make a safe takeoff. Reducing thrust saves wear and tear on engines and reduces some airframe stress caused by rapid acceleration. Most flight manuals either suggest or mandate reduced power takeoffs when performance is not critical. The procedures will vary slightly between aircraft types. We:

(1) Reduce the power setting from maximum takeoff power until some factors become limiting or until we reach a minimum EPR, torque, or maximum assumed temperature.

(2) Plan reduced thrust takeoffs, like maximum thrust takeoffs, to allow either a safe takeoff or abort with adequate stopping distance in case of engine failure. Some flight manuals allow an increase of inboard engine power after engine failure; others do not.

(3) Should not increase outboard engine thrust engine failure. Increased thrust will nullify computations based on differential thrust, such as air or ground minimum control speeds.

b. When making a reduced power takeoff, one must consider these factors:

(1) Reduced power for runway available. When runway available (length) exceeds critical field length (CFL), it is possible to extend CFL by reducing thrust until runway available and CFL are equal. This will establish a reduced takeoff power setting that will allow either a safe takeoff or abort with adequate stopping distance.

(2) Reduced power for climb gradient. An aircraft must be capable of maintaining a minimum climb gradient or rate of climb at liftoff. These limitations are not the same for all aircraft, and they are usually a limiting factor when using maximum power for takeoff. The reduced power computed for this limitation is the minimum thrust which will allow the aircraft to climb at a specified gradient or rate of climb.

(3) Reduced power for obstacle clearance. This is the minimum thrust which will allow an aircraft to clear with all engines operating, and/or one engine out depending on command criteria.

(4) Minimum reduced power. We do not base this thrust setting on any limiting consideration. It is either TRT reduced by a specific amount (turbofan engines), or it is maximum continuous TIT (turboprop engines) and its approximated climb power.

8-7. Performance Factors (Numbers). Performance factors are reference numbers used in performance charts to replace altitude and temperature grids. They account for variations in takeoff thrust due to changes in EPR, N1 or torque.

a. A thrust factor (TF) combines the EPR or N1, which will vary with temperature at a given altitude, with the actual altitude to produce a statement of thrust. A given thrust factor provides the same thrust output even though we may obtain it with various combinations of EPR or N1, altitude, and temperature.

b. Air performance number (APN) uses an EPR or N1 and pressure altitude to arrive at a reference number that is similar to a thrust factor. A given APN represents a specific amount of thrust we may obtain with various combinations of EPR or N1, temperature, and pressure altitude.

c. Takeoff factor (TOF) adds the effect of density altitude on the airframe to the thrust of the engines. This is true for both turbofan and turboprop aircraft.

d. Ground performance number (GPN) combines static EPR or N1, temperature, and pressure altitude to arrive at a reference number which also incorporates the effect of density altitude on the airframe. GPNs and their use are similar to takeoff factors.

e. Climbout factor (COF) combines the thrust developed by the engines with the aircraft gross weight to arrive at a reference number which expresses the aircraft weight to power ratio. This climbout factor is directly proportional to the climb capability of the aircraft.

8-8. Takeoff and Landing Speeds and Distances:

a. Air Minimum Control Speed. Air minimum control speed (VMCA) is the speed at which an aircraft can experience an outboard (or critical) engine failure and still maintain directional control using full rudder deflection and not more than five degrees of bank with the remaining engines at takeoff or go-around thrust. VMCA is critical during takeoff or landing. Safety oriented takeoffs require that VMCA be attained before rotation or liftoff assuring we maintain directional control with one or more engines out. We must maintain VMCA until the landing is assured.

b. Ground Minimum Control Speed. Ground minimum control speed (VMCG) is the minimum speed required to maintain directional control with an outboard (or critical) engine inoperative and the remaining engines at takeoff thrust, using full rudder deflection and nose wheel steering.

c. Critical Field Length. Critical field length(CFL) is the minimum length of runway required to accelerate on all engines to critical engine failure speed (VCEF), experience an engine failure at VCEF, and either continue the takeoff or abort the takeoff within the computed distance.

d. Critical Engine Failure Speed. Critical engine failure (VCEF) speed is the speed to which an aircraft can accelerate on all engines, experience an engine failure, and either (a) stop within the remaining CFL, or (b) continue the takeoff on the remaining engines, and liftoff at the end of CFL.

e. Refusal speed. Refusal speed (VR) is the maximum speed an aircraft can accelerate, using takeoff power (either maximum or reduced) and stop within the remaining runway available. Do not confuse VR with critical engine failure speed (VCEF). Refusal and critical engine failure speeds are only equal when CFL and runway available are equal. VR does not necessarily assure one engine out acceleration distance to liftoff. We base VR solely on acceleration and stopping distance. Refusal speed will assure one engine out acceleration distance only if runway available is equal to or greater than CFL. All safety oriented takeoff criteria require that runway available be equal to or greater than CFL.

f. Rotation and Takeoff Speeds (VROT and VTO). Rotation is the speed, reached during the takeoff run, at which the aircraft transitions from a three-point attitude to the takeoff attitude (nose gear leaves the ground). We reach this speed prior to takeoff speed. Takeoff speed is the speed the aircraft must accelerate before liftoff occurs (main gear leaves the ground). Rotation speed is always above stall speed and normally greater than air minimum control speed. Rotation speed must never exceed tire limit speed.

g. Tire Placard Speed (TPS) and Tire Limit Speed (TLS):

(1) Tire placard speed is the maximum ground speed that a tire can structurally withstand during takeoff or landing. This base speed varies among aircraft and the manufacturer designates. This numerical value has no practical application except as a base from which to compute tire limit speed. This is true because our transport aircraft do not use ground speed as a basis for takeoff and landing speeds. They all use calibrated airspeed in knots (KCAS) or indicated airspeed in knots (KIAS).

(2) Tire limit speed is tire placard speed corrected to either KCAS or KIAS using standard conversion factors: position correction, SMOE, and headwind or tailwind, as appropriate. Most aircraft flight manuals require an individual speed comparison between TLS and VROT or VTO; and between TLS and touchdown speed.

h. Maximum Braking Speed. Maximum braking speed (VBMAX or VB) is the highest speed the aircraft can stop without exceeding the maximum energy absorption capability of the brakes. Execution of an abort or landing (applying maximum braking) above this speed will cause brake failure.

i. Takeoff Ground Run. Takeoff ground run is the distance required to accelerate to takeoff speed. We base ground run on variables which affect acceleration: gross weight, thrust, density altitude, aircraft configuration, slope, wind, and RSC.

j. Acceleration Check Speed. Acceleration check speed allows for the comparison of aircraft takeoff acceleration versus time and/or distance using charted performance values. We use runway markers to check speed versus distance. Time versus speed checks compare acceleration against elapsed time. In either case, the aircraft can be aborted at a predetermined point if performance is substandard.

k. Minimum Climbout (VMCO) and Minimum Flap Retraction Speeds (VMFR). Wing flaps allow the aircraft to takeoff and land at slower speeds. However, they do not provide the best configuration. We base minimum climbout speed on a safe margin above stall speed for the takeoff or go-around at a specific flap setting. Normal takeoff procedures require that the aircraft accelerates from takeoff speed to minimum climbout speed and then climb at minimum climbout until a safe distance from the ground. If we must clear obstacles, we must maintain VMCO and takeoff power until we clear. The aircraft will stall at a higher speed when we retract the flaps. Therefore, we must accelerate to a VMFR before retracting the flaps.

l. Horizontal Stabilizer Trim Settings. Horizontal stabilizer trim settings for takeoff are designed for specific aircraft configurations during climbout. We determine the required stabilizer setting by the aircraft takeoff gross weight and center of gravity. This setting compensates for differences between the center of gravity and the center of lift.

m. Approach (VAPP), Reference (VREF), Threshold, and Touchdown Speeds. We fly segments of the approach to landing at approach and/or reference speed plus incremented airspeed increase (5, 10, 20 knots) depending on the type of aircraft, configuration, and position in the approach. Threshold speed is universally the airspeed at which we cross the runway threshold (normally at a height of 50 feet). Touchdown speed for most aircraft is 10 knots below threshold speed, however, other aircraft use a computed touchdown speed.

n. Landing Distance. Landing distance is normally based on the aircraft crossing the runway threshold at a height of 50 feet at threshold speed. It is further based on the normal approach angle, landing technique, and procedures for the specific aircraft concerned.

o. Landing Ground Roll. Landing Ground Roll is the distance required after touchdown to stop the aircraft. This distance will vary with specific aircraft configuration.

p. Hydroplaning Speed. Wet or slippery runways can lead to a situation called hydroplaning. In this situation, the aircraft rides on a film of water and the tires have little or no contact with the runway surface. The hydrodynamic lift force supports the aircraft much like a water skier supported on skis. There is a minimum speed at which hydroplaning will occur. Below this speed the aircraft tires will make contact with the runway. The velocity at which total hydroplaning occurs equals 9 times the square root of the tire inflation pressure (P). Partial hydroplaning may occur at even slower speeds. You as a flight engineer should be aware of this and carefully inspect the aircraft tires during preflight to ensure proper inflation. An under inflated tire can hydroplane at a slower speed.

8-9. Limiting Takeoff Performance Gross Weights:

a. Gross Weight Limits. In addition to the maximum ramp, maximum brake release, and maximum landing gross weights an aircraft has limiting performance gross weights, which have nothing to do with structural capacity limits of an aircraft. These are gross weight limited by critical field length, gross weight limited by engine out climb gradient or rate-of-climb, and gross weight limited by obstacle clearance. The major factors used in determining the gross weights are air density, the resulting thrust or power, the runway length, the flap setting, and the height and distance of the obstacle. For aircraft with fixed (or standard) flap settings, the limiting takeoff gross weight will be the lower of these three computations.

b. Effect of Variable or Multiple Flap Settings on Takeoff Performance. As discussed earlier, flaps increase the wing's ability to produce lift. The greater the flap setting, the lower the rotation speed will be, and therefore, the shorter the takeoff ground run. However, once airborne, this high flap setting becomes a liability rather than an advantage. We obtain greater climb gradients with lower flap settings and the associated higher climb speeds. An aircraft with the capability to vary this flap setting to match the runway and obstacle clearance requirements can use this to its advantage. Specific procedures will vary with each aircraft, but in general, we manipulate the flap position until we find the optimum balance between maximum gross weight limited by critical field length and maximum gross weight limited by engine-out climb gradient or obstacle clearance. This is the "optimum flap setting."

c. Gross Weight Limited by CFL. Gross weight limited by CFL is computed by first assuming that the entire runway length (runway available) is the critical field length and then working backwards through the CFL chart correction grids to compute a maximum gross weight. NOTE: If we know the takeoff gross weight and the computed CFL (based on the given weight) is less than runway length (available), it is not necessary to compute a gross weight limited by CFL.

d. Gross Weight Limited by Three-Engine Climb. Most flight manuals require a minimum rate-of-climb at liftoff on three engines. This allows the aircraft a reasonably safe climb capability. An established minimum rate-of-climb or climb gradient in conjunction with a predetermined airspeed also assures obstacle clearance for those not depicted on Standard Instrument Departure (SID) plates. We base climb gradient charts on temperature, pressure altitude, thrust, and gross weight. Minimum required gradients vary according to aircraft design. Some aircraft use rate-of-climb capability as opposed to gradient. Since gross weight is one of the determinants of either climb gradient or rate-of-climb, it is possible to reduce the aircraft gross weight to obtain the required gradient or rate-of-climb.

e. Gross Weight Limited by Obstacle Clearance:

(1) For safety of flight, the aircraft must never exceed a weight which will allow the aircraft to clear all obstructions in the climbout flight path. Though it is imperative that flight crews possess a thorough understanding of obstacle clearance procedures, the methods used to compute obstacle clearance data vary greatly between the types of aircraft concerned. For this reason, we will only discuss general obstacle clearance procedures that apply to most aircraft.

(2) The easiest and most popular method of determining if an obstacle exists in the climbout flight path is to consult the SID plate for your departure. We obtain SIDs from base operations for the airfield concerned. Normally, a SID does not depict all obstructions, only the controlling or most restrictive ones. SIDs depict both the obstacle height and distance. The SID shows the height in feet above mean sea level (MSL) and the distance in either feet or nautical miles (to the nearest tenth) as measured from the departure end of the runway.

(3) Regardless of the aircraft you fly, when determining obstacle clearance capability, you must consider the aircraft weight to power ratio (climb capability), the flight distance to the obstacle, and the effective height of the obstacle. In most cases, you will be computing obstacle clearance based on (1) an engine failure after go or decision speed, (2) continuing the takeoff regardless, and (3) lifting off or rotating at the critical field length point.

(4) The flight path charts used to compute obstacle clearance data are based on a dry, level runway. If you have other than a dry level runway, you must make adjustments to the obstacle distance. The three considerations for making these adjustments are runway slope, runway surface condition (RSC), and runway condition reading (RCR).

f. Downhill Slopes. A downhill slope aids in Acceleration. It shortens the takeoff ground run and the critical field length. Therefore, it effectively moves the obstacle farther from the liftoff point (CFL) and is not normally accounted for, but accepted as a safety margin when making obstacle distance corrections. An uphill slope increases the takeoff ground run and the critical field length distance. This effectively moves the obstacle closer to our latest possible liftoff point (CFL). To account for this, you must subtract the difference between the uncorrected CFL and CFL corrected for uphill slope from the obstacle distance.

g. Runway Surface Covering. Any runway surface covering such as snow, slush, or water will retard acceleration. This increases the takeoff ground run and critical field length, decreasing the flight distance to the obstacle. To account for this decreased flight distance, you must subtract the difference between uncorrected CFL and CFL corrected for RSC from the obstacle distance.

h. RCR Affects. RCR does not affect acceleration. It does not affect the takeoff ground run and we do not need to consider it in computing obstacle distance with all engines operating. However, when computing obstacle distance with an inoperative engine, we must consider the effect of RCR on critical field length. A RCR other than 23 (dry runway) affects stopping distance and increases critical field length. Therefore, when computing engine out obstacle clearance, reduce the distance to the obstacle by the difference between uncorrected critical field length and critical field length corrected for RCR.

NOTE: Not all aircraft flight manuals require RCR corrections.

i. The SID. The SID displays obstacle height in feet MSL. Field elevation is also given in feet MSL, and is the highest point on the airfield. To find out the height of the obstacle above field elevation, you subtract field elevation from the obstacle height. The result is the geographic obstacle height. After determining the geographic obstacle height, you must compute any corrections for runway slope or delayed gear retraction and add them to the geographic obstacle height.

j. Uphill Slope. Figure 8-1 shows an aircraft departing a runway with an uphill slope. As previously stated, the aircraft should always be airborne by the critical field length point. Field elevation, as shown, is the highest point on the airfield. By studying figure 8-1, you will notice that since the aircraft will liftoff at critical field length rather than at the departure end of the runway, it will have to climb some additional height to clear the obstacle. We use the following formula to find the additional height to climb:

(RA - CFL) x slope % = Height

subtracting numbers:

(12,000' - 7,000') x .6% = 30'

You would add 30 feet to the geographic obstacle height to obtain the effective obstacle height.

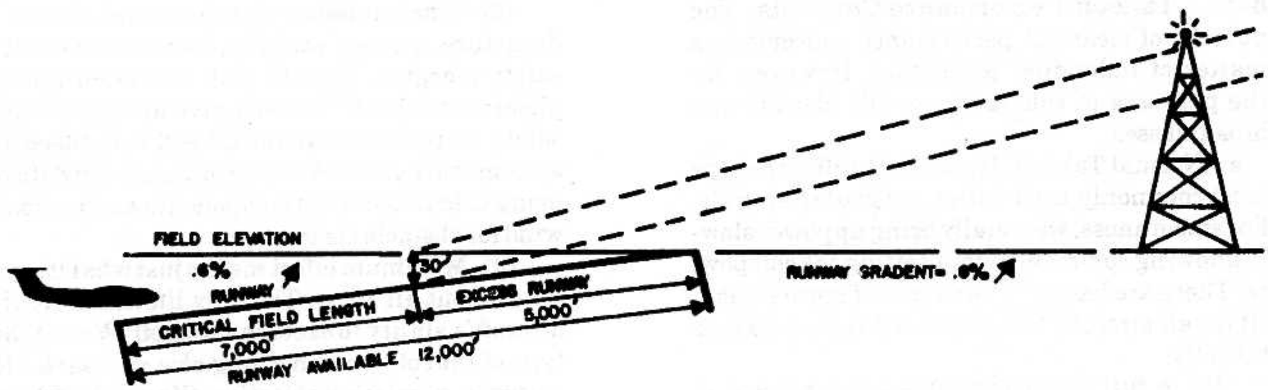

Figure 8-1. Uphill Slope.

k. Downhill Slope. Figure 8-2 shows an aircraft departing on a runway with downhill slope. Since field elevation is the highest point on the airfield (measured at the approach end in our illustration), we will liftoff below field elevation and have to climb some additional height to clear the obstacle. We use the following formula to find the additional height to climb:

CFL x slope % = Height

substituting numbers:

7,000' x .6% = 42'

You would add 42 feet to the geographic obstacle height to find the effective obstacle height.

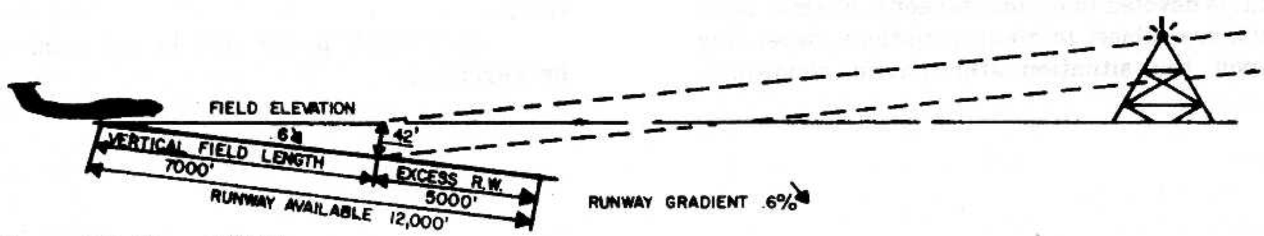

Figure 8-2. Downhill Slope.

l. Delayed Gear Retraction. Some aircraft have provisions for considering the effect of delayed gear retraction on the climbout flight path. The delayed gear retraction could result from mechanical problems, extreme cold weather, or takeoff from slush or water covered runway. Regardless of the reason for the delayed gear retraction, you must consider its effect on aircraft performance. Most aircraft flight manuals provide either correction grids or separate flight path charts which increase the effective obstacle height to account for this situation. Once we make all the corrections, we use the climbout factor and climbout flight path charts to determine if we can clear the obstacle.

8-10. Takeoff Performance Concepts. The number of clear-cut performance concepts is a matter of individual perception. However, for the purposes of this text, we will identify two broad classes:

a. Normal Takeoff. Normal takeoff is the type most commonly used with a particular aircraft. For smoothness, we usually bring up power slowly allowing some roll before setting takeoff power. There are basically two types of normal takeoff for all aircraft, full power and reduced power takeoffs.

(1) A full power takeoff is accomplished at maximum takeoff power with required bleed air systems turned on. Normally, it is used when a reduced power takeoff cannot be made. Full power allows takeoff distances to be shortened and takeoff time to be reduced while retaining all normal safety margins.

(2) A reduced power takeoff is accomplished at a reduced power setting with all normal safety margins retained. Since it minimizes stress on engines and airframe, it is the preferred type of takeoff. Most of an aircraft's performance manual is devoted to normal takeoffs. Normal takeoffs are subject to many variations, depending upon the situation--atmospheric conditions, type aircraft, and cargo. They involve the use of critical field length, refusal speed, and/or decision speed, plus several other speeds which depend on the type of airplane.

b. Abnormal takeoff is reserved for situations that require that one or more of the usual safety margins are disregarded

(1) Usually, some safety factor limits the gross weight or in some way restricts takeoff performance. Since aircraft manuals are pretty much patterned on civilian aviation procedures, they don't address abnormal procedures in much detail. Unfortunately, military aircrew members live with the small but real possibility of accomplishing a takeoff under hostile fire or to avoid a deadly storm.

(2) When mission requirements dictate a departure, we may sacrifice some of the normal safety margins. We will plan a mission accomplishment takeoff. We only give up only enough safety margin to make the takeoff with bleed air systems turned off. We determine takeoff data by using calculated wind components and no headwind for obstacle clearance.

(3) Maximum effort means just what it says, we pull out all stops. The only limitation is the aircraft's ability to execute a takeoff. We use this type of takeoff when nothing else will save life, property, or mission objective. We use the following guidelines for a maximum effort takeoff:

(a) All bleed air systems off unless required (i.e., anti-ice in winter).

(b) One hundred percent of reported wind component.

(c) An obstacle will be just cleared on all engines.

(d) GO or DECISION speed will be REFUSAL speed based on all-engine operating ground run.

(e) Critical field length will not be applicable.

(f) Takeoff power will be set prior to brake release.

Chapter 9

CLIMB PERFORMANCE

9–1. Climb Predications and Charts. After takeoff, the next condition of flight is the climb. As a flight engineer, you must compute climb performance. The climb prediction charts you will use vary from one aircraft to another, but some of the information you can determine are engine power, time, speed, distance, fuel used during a climb, and the altitude you can climb to based on the atmospheric conditions. Use your climb performance charts in both the mission planning phase and the actual flight phase to ensure optimum climb flight efficiency.

9–2. Basic Principles:

a. The forces of lift, thrust, weight, and drag are equal when the aircraft is flying in straight, level, unaccelerated flight. Airspeed is enough to maintain lift equal to weight and engine power is enough to maintain a thrust equal to drag condition. If we increase engine power and hold the angle of attack constant, the aircraft will begin to increase in speed because the power will be greater than the drag. The aircraft will start to climb due to the increase of air across the wings producing more lift. If we nose the aircraft up to increase our angle of attack, then our drag increases. It is possible to increase our power and angle of attack to climb without increasing airspeed. This is the principle we consider for computing climb performance.

b. The power output of the engines limits the power available for climb. Most aircraft use their maximum continuous power setting. Depending on the aircraft, this power setting is, Normal Power, Normal Rated Thrust, or even Max Continuous Power. Your performance manual will identify what you call your climb power. Once we identify how much power we will have, we need to find the speed that we climb out with. On some aircraft this is a charted speed based on the conditions for the day. Most of the larger transport type aircraft use a climb speed schedule.

c. Climb performance is dependent on the power output of the engines and the airspeed used in the climb. If we use a higher airspeed, then more of the power being produced would maintain that speed. Using a low airspeed requires less power to maintain the speed. This allows more power to overcome the increase of drag caused by a higher angle of attack, giving us more lift. It is desirable to use as low an airspeed as possible, yet high enough to maintain proper stability. As the climb progresses, the percentage of power required to maintain an airspeed increases as the altitude increases. Not only does the amount of power we have for the climb decrease, but our lift will decrease because the air is less dense at altitude. These two factors are the major reasons why, as our aircraft climbs, our rate-of-climb will decrease. Rate-of-climb is nothing more than vertical velocity measured in feet per minute. The aircraft will continue to climb, if allowed, until we use all the power being produced to maintain the airspeed.

(1) ABSOLUTE CEILING is the point all the forces, weight, lift, thrust, and drag will be equal. It is not a very good idea to fly at an altitude using all the power available just to maintain an airspeed. Why? Let's look at this for a minute. What will happen if we lose an engine? The power available will be reduced and we may not have enough power to maintain the airspeed. If we try to make a turn, then our drag will increase and we could find ourselves in a dangerous situation.

(2) PERFORMANCE CEILINGS are nothing more than limiting altitudes based on the day's conditions that keep some of our engine's power in reserve for emergency use. There are an unlimited number of performance ceilings, but we will limit our discussion to the ones that have a name for them. In c above, we stated that as the aircraft climbs in altitude, the rate-of-climb decreases. Well, this rate of climb is how we identify the performance ceiling.

(a) The first one is the SERVICE PERFORMANCE CEILING. At this ceiling, based on the day's condition, if we set our climb power and held our climb speed, then we will have a rate-of-climb of 100 feet per minute.

(b) The second performance ceiling is the CRUISE PERFORMANCE CEILING. At this ceiling if we try to climb, our rate-of-climb would be 300 feet per minute.

(c) The third performance ceiling is the PERFORMANCE PERFORMANCE CEILING. At this altitude we will be able to start our climb with a 400-foot per minute rate-of-climb.

(3) The fourth and last performance ceiling is the COMBAT PERFORMANCE CEILING. At this altitude we would be able to start our climb

with a 500-foot per minute rate-of-climb. Your performance manual will tell you which of these ceilings you will use.

These performance ceilings change continuously from day to day and throughout a flight. This is because weight of the aircraft has a direct effect on the altitude the aircraft is capable of climbing to. The heavier the aircraft, the lower the altitude. Weight is not the only factor that affects this altitude. Temperature plays an important part. Remember, the hotter the day, the less dense the air, lowering our power and lift being produced. This will also lower the altitude we can obtain.

d. There are many other factors associated with climb performance, but we cover them in detail in the next chapter. Following aircraft climb procedures is the single most important factor when predicting climb performance. Our predictions will be wrong if we do not keep the climb power set, or we do not climb at the proper speed. Crew effort ensures that our predictions are valid.

Chapter 10

CRUISE PERFORMANCE

10–1. The Cruise Phase. Once we accomplish takeoff and we complete our climb to cruise altitude, we can begin the process of computing cruise performance. Cruise is the most important phase of any mission in terms of time and fuel economy. If an emergency occurs and fuel becomes critical, you must be aware of profiles and procedures to conserve fuel. This awareness is also necessary during missions where time is the primary concern. To accomplish these missions, you must possess a knowledge of the factors involved with predicting cruise performance for various profiles and procedures and an ability to read and interpret performance charts with speed and accuracy. The cruise phase, like the climb phase of flight, is dependent on many factors which affect an aircraft's performance. Predicting cruise performance becomes an involved process. Although we chart some factors, they are constantly changing due to the relationships between atmospheric conditions, engine power, and the use of different profiles and procedures. The first thing a person needs to be able to do is identify the profile and procedure the aircraft is going to fly.

10–2. Basic Profiles. There are three basic profiles: Constant Altitude, Cruise Climb Cruise, and Optimum Step Climb. A profile is nothing more than how the aircraft flies through the air mass, a side view, if you will.

a. Constant Altitude. The first profile, Constant Altitude, means exactly what the name implies. It consists of an aircraft climbing to a cruise altitude and remaining there until we initiate descent as shown in figure 10-1. This profile is the simplest to fly and the easiest for Air Traffic Control (ATC). Of the three profiles, Constant Altitude is the worst for gas mileage, Air Nautical Miles per Pound (ANMPP). This is because as the aircraft gets lighter during the cruise we DO NOT take advantage of climbing to a higher more efficient altitude.

b. Cruise Climb Cruise. The second profile is a Cruise Climb Cruise. It consists of an aircraft climbing to its optimum altitude, starting a cruise and as the aircraft gets lighter from fuel burn off, we allow the aircraft to climb. Doing this, we allow the aircraft to stay at or near its optimum altitude for the entire flight as shown in figure 10-2.

(1) To understand this profile you must understand optimum altitude. Optimum altitude is the altitude, based on aircraft gross weight and temperature at altitude, that gives the greatest number of nautical miles per pound of fuel.

(2) Of the profiles, Cruise Climb Cruise obtains the best gas mileage (ANMPP), but it is the hardest to fly due to the constant increase in altitude. Air Traffic Control also limits its use for the same reason.

c. Optimum Step Climb. An Optimum Step Climb Profile is the compromise between the Constant Altitude and Cruise Climb Cruise Profiles. It consists of climbing to a performance ceiling, entering a level cruise, and staying at this altitude until the performance ceiling has increased either 2,000 or 4,000 feet, depending on the aircraft, certain conditions, or both. Your Performance Manual identifies the climb increment that your aircraft uses (see figure 10-3).

(1) Most aircraft use the 300 foot per minute Cruise Performance Ceiling when using the 4,000 foot increment step climb. Normally, the aircraft's Optimum Altitude is about 2,000 feet below its 300' Cruise Performance Ceiling (see figure 10-4).

(2) Notice how, by climbing to our performance ceiling, we start cruise #1 about 2,000 feet above our Optimum Altitude, and we end cruise #1 about 2,000 feet below our Optimum Altitude. We can now say we averaged our Optimum Altitude during cruise #1. Our performance during the cruise was roughly the same as if we did fly on our Optimum Altitude. This type of profile is better for ANMPP than Constant Altitude but not quite as good as the Cruise Climb Cruise Profile. The reason we don't get as good a performance as the Cruise Climb Cruise is because we set climb power to make our 4,000 foot climb. This profile also satisfies ATC's need for controlling the airways.

NOTE: Individual aircraft may modify a profile, but engineers will use one of the three profiles for time and range predictions.

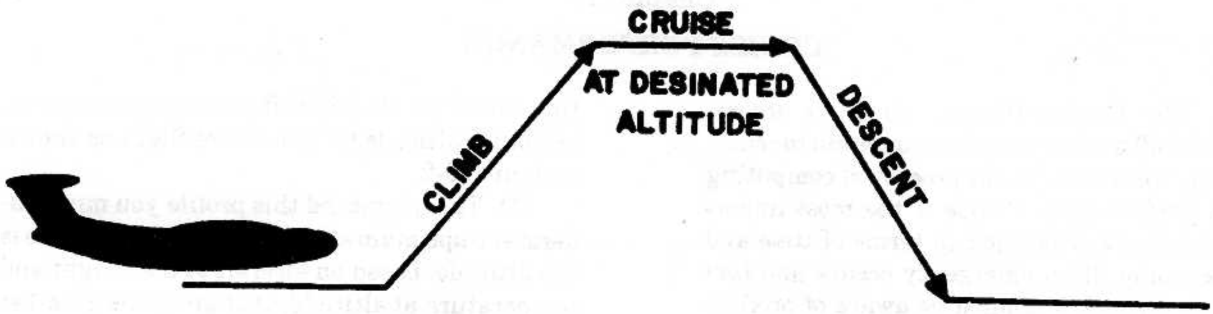

Figure 10-1. Constant Altitude Cruise.

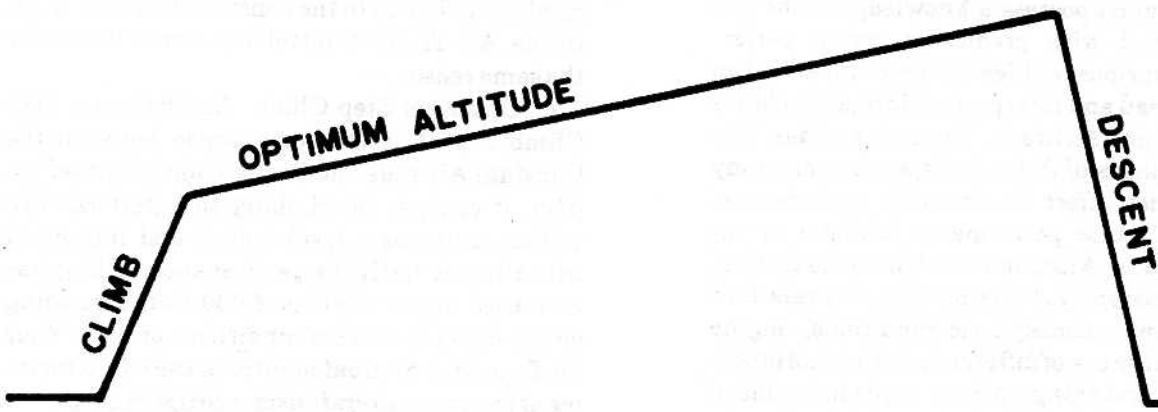

Figure 10-2. Cruise Climb Cruise Profile.

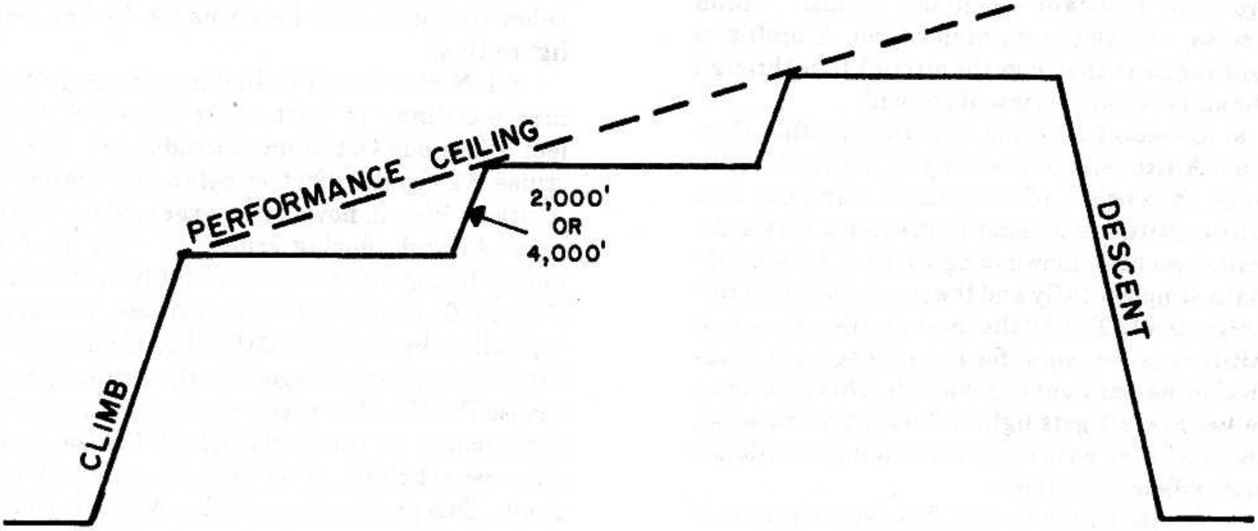

Figure 10-3. Optimum Step Climb Profile.

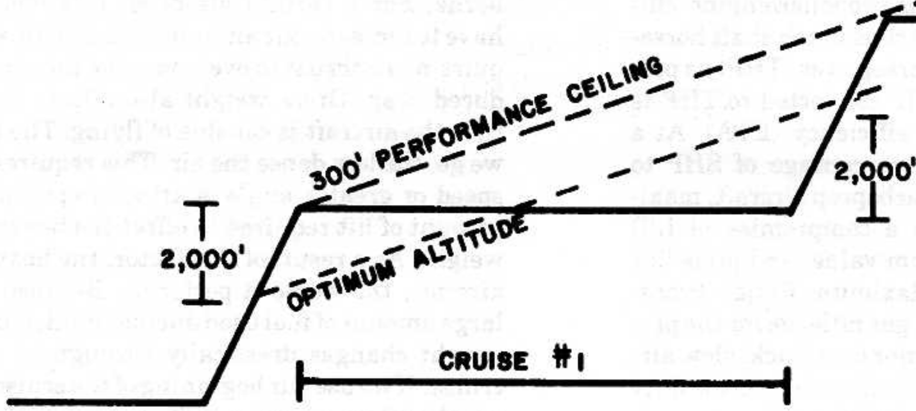

Figure 10-4. Cruise #1, Optimum Step Climb.

10–3. Basic Procedures. Now that we have identified the basic profiles, we must cover the basic procedures. Remember profiles are a side view of how our aircraft fly through the air; a procedure is how fast we go. There are five basic procedures: Constant Power, Constant Speed, Maximum Range, Long Range, and Endurance.

a. Constant Power. A Constant Power procedure is very seldom used on large aircraft. As the name implies, once we set our cruise power, we leave it alone. As the aircraft burns fuel and decreases its gross weight, we either increase our speed or altitude. Since this procedure is worst for gas mileage and structural limits normally stop us from constantly increasing our speed, we seldom use this type of procedure with large transport type aircraft.

b. Constant Speed. We use the second procedure, Constant Speed, quite often. Once we establish our cruise speed, the pilot will maintain it throughout the flight. The lighter the aircraft, the less power it takes to maintain the same airspeed. An engineer needs to understand why a lighter aircraft takes less power to fly a steady speed. Remember back to Aerodynamics we talked about the four general forces acting on the aircraft: thrust, drag, weight, and lift. As the aircraft gets lighter, the amount of lift needed decreases. We lower the lift by lowering our angle of attack. This will reduce the amount of induced drag. With less drag we need less power to maintain a constant speed. See how Aerodynamics ties in with cruise performance.

c. Maximum Range. The next procedure, Maximum Range, gives us the best gas mileage for the conditions of the day. This procedure is a little harder to fly than a Constant Speed since we have to keep slowing down as our aircraft gets lighter. To understand why we must slow down, we must understand what gives us our maximum range airspeed. Let's first talk about jet aircraft, for they have two basic considerations in finding the maximum range airspeed, Lift over Drag (L/D) and Specific Fuel Consumption (SFC).

(1) The aircraft's gross weight governs Lift over Drag (L/D). For any given gross weight, a specific angle of attack with a specific airspeed will produce the necessary lift with the least amount of induced drag. As the aircraft gets lighter, we attempt to keep the same angle of attack, so we have to lower our airspeed to reduce our lift in direct proportion to our decrease in weight. Our L/D maximum speed is the main reason why our maximum range airspeed decreases as our aircraft gets lighter. L/D speed is nothing more than the airspeed at which the AIRFRAME performs best.

(2) Now let's try our Specific Fuel Consumption (SFC). Simply stated, SFC is the amount of thrust (power) produced by the engine on one pound of fuel. A certain power setting, based on atmospheric conditions, gives us the most thrust for one pound of fuel. This power setting is the SFC minimum value. The SFC minimum value will achieve the airspeed at which the ENGINES perform best. To find a jet aircraft's maximum range airspeed, we have to consider both L/D maximum and SFC minimum value airspeed. Our maximum range airspeed will fall in between the two airspeeds, giving our AIRCRAFT the best airspeed combining power and angle of

attack. On turboprop aircraft there is one more factor to consider. This is propeller/engine efficiency. We want to convert as much shaft horsepower (SHP) to thrust horsepower (THP) as possible. The amount of SHP converted to THP is dependent on propeller efficiency (ETA). At a particular airspeed the percentage of SHP to THP is the highest. On turboprop aircraft, maximum range airspeed is a compromise of L/D maximum, SFC minimum value, and propeller efficiency. Using the Maximum Range Procedure will give us the best gas mileage for the procedures but it has one major drawback, slow airspeeds. Slow airspeeds result in long crew duty days and contribute to crew fatigue.

d. Long Range. The Long Range procedure is where we sacrifice a little range for an increase in airspeed. Flight test reveal, in most cases, that by sacrificing one percent of our range, we realized an increase of about five percent in airspeed. Since this procedure actually gets 99% of what Maximum Range Procedure attains, some aircraft call this 99% Max Range Procedure.

e. Endurance. Endurance is the last procedure we need to cover. Endurance is flying at the airspeed that will give us our lowest fuel flow Endurance is staying in the air for the longest amount of time with little concern for range. We use this procedure for search and rescue, holding, and orbit missions. Because we use this type of procedure on such special conditions, we have identified two basic types of endurance, Best Endurance and Maximum Endurance.

(1) Best Endurance. Best Endurance gives the greatest amount of time when flying a constant altitude. This is the type of endurance most of us are familiar with. We normally use it when holding or for search and rescue.

(2) Maximum Endurance. We obtain maximum endurance by flying our endurance airspeed while maintaining our optimum altitude. We may use this type of endurance on an orbit mission. Normally, ATC restricts its use due to controlling the traffic on the airways.

10–4. Factors Affecting Flight. Now let's go into factors that affect our cruise performance. The primary factors are gross weight, altitude, temperature, winds, bleed air extraction, and aircraft trim. Performance correction factors adjust for differences between actual and charted performance. We will discuss each one separately.

a. Gross Weight. An aircraft's gross weight has significant effect on cruise performance. Heavier aircraft require more lift to remain airborne. For a certain airspeed, this means we have to increase our angle of attack. This will require more thrust to overcome the increased induced drag. Gross weight also affects the altitude the aircraft is capable of flying. The higher we go, the less dense the air. This requires more speed or greater angle of attack to produce the amount of lift required to offset the heavy gross weight. As a result of this factor, the heavier an aircraft, the worse it performs. Because of the large amount of fuel used during flight, our gross weight changes drastically throughout a long cruise. If we use our beginning of the cruise gross weight to base our time and range prediction, our predictions will be wrong because our performance will improve as we use the fuel. To account for this steady performance improvement, we use an average gross weight for time and range predictions. We find this average gross weight by subtracting our fuel on board from what we weigh, giving us a Zero Fuel Weight. Now we add back 1/2 of the fuel to our Zero Fuel Weight, giving us an "average gross weight" for the cruise. See Example.

EXAMPLE:

BEGINNING OF THE CRUISE GROSS WEIGHT	280,000 lbs
FUEL ONBOARD	- 80,000 lbs
ZERO FUEL WEIGHT	200,000 lbs
1/2 FUEL ONBOARD	+40,000 lbs
AVERAGE GROSS WEIGHT	240,000 lbs

Remember, we base time and range predictions on using all the fuel in the tanks. By using our average gross weight in our charts, we find average performance numbers to base our time and range on.

b. Altitude. Altitude is another factor that has a direct bearing on our cruise performance. As discussed earlier, normally the higher we fly the better our cruise performance. Performance charts always consider these two factors, gross weight and altitude, for time and range predictions. Depending on the type of performance charts that were designed for your aircraft, the other factors may be part of the charts, or you may have to apply a math correction to account for them.

c. Temperature. Temperature at altitude has a direct effect on our cruise performance. Hotter than standard temperature will result in a decrease in air density. This decrease of air density would cause our engines to produce less thrust due to the compressor getting fewer air molecules to compress. However, the jet engine fuel control senses air density and automatically increases our fuel flow. This increase in RPM allows our compressor to gather enough air molecules to maintain our cruise. If we burn more fuel every hour, the amount of time we are capable of flying will decrease. If the density only affected our engine's performance, then our range would also decrease, but the density affects our aircraft's ability to fly through the air. With the less dense air, our true airspeed will increase because less drag is being created. When flying on speed and on altitude, hotter than standard temperatures will increase both fuel flow and true airspeed. Because of our fuel flow increases with an increase in true airspeed, our range remains relatively unchanged. This statement is only true if we remain on altitude. Let's go back to Chapter 9, Climb Performance for a minute. The Performance Ceiling section showed us how temperature affects the altitude our aircraft is capable of flying. Hotter than standard day actually lowered our Performance Ceiling. If we fly at a lower altitude because of a hotter temperature, then both our time and range will decrease. Colder than standard temperatures, work in just the opposite manner.

d. Winds. Winds at altitude is another atmospheric variable we must consider when computing performance. Our aircraft requires so much power to fly a set speed through an air mass. It does not require more or less thrust, depending on winds, because the speed is in relation to the surrounding air mass. Our endurance time we can remain in the air stays the same if we fly a set airspeed. Our range will change in direct proportion to the winds. If, for example, we are on an aircraft flying a true airspeed of 425 knots with a 50-knot headwind, in 1 hour's time we have had enough air pass us by to cover 425 nautical air miles. Now we need to change this air mileage into how many miles we covered across the ground. If we covered 425 nautical air miles in 1 hour, but 50 air nautical miles were due to the headwind, then we would have covered 375 nautical miles across the ground. Tailwinds work exactly opposite. If we had a 50-knot tailwind in the previous problem, then the ground distance traveled in 1 hour will be 475 ground nautical miles. If, for some reason, we have to be at a specific place at a certain time, then we must try to hold a set ground speed. Flying into a headwind, we will have to fly a faster airspeed. This will require a higher setting, increasing our fuel flow. Both our endurance time and range would decrease in this case. Once again, the exact opposite is true for tailwind. At a constant airspeed winds affect our range but not our endurance time, at a constant ground speed winds affect both our time and range.

e. Bleed Air Extraction. Bleed air extraction is another factor we need to consider. Bleed air extractions reduce engine efficiency by diverting air for other uses: i.e., air conditioning and pressurization. Most cruise performance charts take this extraction into consideration. Adjustments to cruise performance charts will be necessary when we use other systems requiring bleed air. Examples of these systems are engine anti-ice, pylon anti-ice, wing anti-ice, and rain removal. If any of these systems are operating, then we decrease both our time and range. We make corrections for these factors by either a standard correction factor or a separate correction chart. Your aircraft's Performance Manual will identify which method you will use.

f. Aircraft Trim. Now we can consider aircraft trim. Aircraft are designed to fly straight and level. If for any reason the aircraft is not flying straight and level then we have increased the amount of drag our airframe is producing. This extra drag is overcome by extra thrust, meaning fuel flow will increase, reducing our time and range. One of the factors that cargo aircraft have to keep in mind is the center of gravity. This will normally change with every mission due to the aircraft configuration and the cargo we carry. The center of gravity also changes during flight due to fuel usage. Most aircraft Performance Manuals have a center of gravity correction chart that gives you some form of correction factor to apply to time and range computations.

g. Performance Correction Factors. Performance correction factors are the last area we have to cover. We construct Cruise Performance charts using a standard external configuration as a basis. Any change in the external structure causes a change in total drag. This change in drag produces a change in aircraft performance. Often, an aircraft does not perform as predicted. In other words, the aircraft seems to "fly heavy." This could be the result of variables such as improper cargo weight, bent or warped cowlings or panels, or any other factors in which a drag or weight change occurs. We must take these changes in performance into account when predicting cruise performance. We use two basic procedures to correct for weight or drag increase or decrease, weight correction factor and drag index correction factor.

(1) Weight Correction Factor. A weight correction factor is the difference between actual weight of the aircraft and its performance weight. For example, if an aircraft weighs 450,000 pounds but it is performing as if it weighed 458,000 pounds, there will be a weight correction factor of 8,000 pounds. Weight correction factors are either a plus (+) or a minus (-) correction. In the example above, the performance weight is 8,000 pounds heavier than actual weight. In this case, the weight correction factor is a plus and we add it to the actual gross weight for making performance computations. When actual performance is better than predicted, the correction is a minus and we subtract it from the actual gross weight. One method we can use to find our performance weight is to take the true airspeed we are flying and divide it by our present fuel flow. This will give us our current air nautical miles per pound. We find this formula in attachment 1 under General Fuel Formulas.

$$ANMPP = \frac{TASK}{FF}$$

Now we can enter our performance charts with our current ANMPP and find the gross weight at which our aircraft is performing.

(2) Drag Index Correction Factor. Drag Index Correction Factor is the other method that the aircraft may use. The Performance Manual lists these factors and includes structural changes that affect the configuration of the aircraft. For example, if the aircraft is normally equipped with external fuel tanks and we remove them, the aircraft has less drag and performs better than the charts indicate. The drag index will correct for the improved performance. If we add equipment, the drag will increase and performance will be worse than charted.

h. Summary. We finally made it! We have the principles we need to make accurate time and range predictions from our Performance Manuals. They are profiles, procedures, aircraft gross weight, altitude, temperature, winds, bleed air extractions, aircraft trim, and performance correction factors. Even though we discussed each one as an individual element, they are all interrelated. A change in one may require us to change another such as, a change in temperature may force us to change our altitude. The ability to understand these relationships and use them in making our predictions is the heart and soul of why we have performance engineers on our aircraft.

10-5. Performance Analysis:

a. The many variables affecting aircraft and engine performance make it necessary for you to compare the actual performance of the aircraft to the charted performance of the aircraft. Analyzing the various conditions during flight enables you to determine how much, if at all, aircraft and engine performance varies from the charted values. When a variation exists, comparing and analyzing the results usually discloses the cause of the variation.

b. There are numerous methods used to analyze aircraft performance. The following paragraphs describe representative procedures that may or may not be applicable to your particular aircraft.

10-6. Analyzing Actual and Charted NMPP Values. A very effective method of evaluating aircraft performance is to compare actual air or ground nautical miles per pound of fuel (NMPP) values with the charted NMPP of fuel values.

a. Using the data recorded on your aircraft performance log, find the actual air NMPP by first computing an actual true air speed in knots (TASK) using the following formula:

$$TASK = Mach \times speed\ of\ sound$$

Then use the actual TASK and known recorded fuel to compute an actual NMPP using the following formula:

$$NMPP = \frac{TASK}{FF}$$

b. To find the charted NMPP, compute an average gross weight for the condition being considered (usually a cruise as recorded on a performance log). Do this by subtracting one-half of the total fuel burnoff of the cruise being analyzed from the beginning gross weight of that particular cruise. Once you find an average gross weight, compute the charted NMPP from the appropriate specific range performance chart using the known or recorded (on your performance log) true mach, or calibrated airspeed and the average gross weight for the condition.

c. Now, compare the actual and charted NMPP values. If the charted NMPP value is larger than the actual NMPP value, aircraft and engine performance is not as good as charted. On the other hand, if charted performance is lower than the actual value, aircraft and engine performance is better than charted.

10-7. Analyzing Actual and Charted NMPP Values (Turboprop). Let's us consider an analysis that applies principally to turbopropeller engine aircraft operation. The many variables affecting aircraft and engine performance make it necessary for you to compare the actual performance of the aircraft to the charted (standard) performance of the aircraft. A very effective method of evaluating turboprop aircraft performance is also to compare the known or logged air or ground nautical miles per pound of fuel with the charted nautical miles per pound of fuel. When we know the actual NMPP, TASK and fuel flow, engine and aircraft performance can by analyzed by comparing this performance with the charted NMPP. If the charted NMPP value exceeds the actual value, performance is not as good as charted. On the other hand, if charted performance is lower than the actual value, performance is better than charted.

a. To find charted NMPP, establish the charted TASK with the following formula:

$$\text{Charted TASK} = \frac{\text{logged TASK for cruise}}{\text{SMOE for cruise altitude}} \times \text{SMOE (from the closest 5000 ft specific range chart)}$$

NOTE: Since the manufacturer bases specific range charts on standard day conditions, density and pressure altitude are equal.

b. Establish the average gross weight for the condition analyzed by subtracting one-half of the total fuel burnoff for the condition from the beginning gross weight of the condition as follows:

c. Finally, enter the NMPP (specific range) chart, nearest your cruising pressure or density altitude, with the average gross weight and charted TASK. Where these two values intersect, you will find: (1) the charted NMPP value, and (2) the charted fuel flow. Compare the actual NMPP value and fuel flow with those known values, or those recorded for this condition, on your flight log. The difference, plus or minus, between the charted and actual computations is the amount of correction required for subsequent performance computations throughout the remainder of the flight.

10-8. Analyzing Air and Ground NMPP Values:

a. Air NMPP. Air nautical miles per pound of fuel represents the performance of the aircraft and engines compared to air miles covered. We normally compute air NMPP using the specific range charts in your performance manual. However, it can also be found by using the logged data and the following formula:

$$\text{Air NMPP} = \frac{\text{TASK}}{\text{FF}}$$

b. Ground NMPP. Ground nautical miles per pound of fuel represents the performance of the aircraft and engines, including the effects of winds, compared to ground miles covered. Ground NMPP can be computed using known or logged conditions and the following formula:

$$\text{Ground NMPP} = \frac{\text{TASK + wind}}{\text{FF}}$$

A comparison of the air NMPP with the ground NMPP indicates the loss or gain in NMPP caused by winds.

10-9. Computing Weight Correction Factors. Performance weights are one of the indications as to how the aircraft is flying. We use actual inflight data to find a performance weight. There are several methods and combinations of data that can compute this weight. The following paragraphs describe two methods used to compute a performance weight.

a. Using EPR and CASK or MACH. We will use two known or logged factors to obtain this performance weight: EPR and CASK or Mach. The first step is to compute and average EPR. We do this by adding the individual EPRs together and dividing by the number of engines operating. Next, using the known CASK or Mach and the average EPR, compute a gross weight using the specific range charts. This is the gross weight at which the aircraft is performing or its performance weight. If the performance weight is higher than the actual gross weight of the aircraft (at the time the EPRs and CASK or Mach were recorded), the aircraft is flying heavy or, in other words, the aircraft flies as if it weighs more than it actually does. If the performance weight is lower than the actual aircraft gross weight, the aircraft is performing better than normal (charted). The difference between the performance weight and the actual aircraft gross weight is the weight correction factor. When the aircraft is flying as if it weighs more than it actually does (flying heavy), then we use a plus (+) correction factor. The opposite is true when the aircraft is flying as if it weighs less than it actually does, then we use a minus (-) correction factor. To apply a weight correction factor, add a plus (+) correction or subtract a minus (-) correction from the actual average gross weight. We normally accept minus correction factors as an added safety margin.

b. Using CASK and Fuel Flow. Another method used (turboprop aircraft) to compute performance factors or weights, is to again use two known or logged factors, this time CASK and fuel flow, to obtain this correction factor or performance weight. To use the specific range chart, you must first convert the known or logged fuel to a charted fuel flow. This is accomplished by dividing the known or logged fuel flow by the SMOE for the altitude you are flying and then multiplying by the charted SMOE as follows:

$$\frac{\text{FF}}{\text{SMOE for cruise altitude}} \times \text{SMOE} \quad \text{(from the closest 5,000 ft specific range chart)}$$

We refer to this as taking it "to the chart." After making the conversion, interpolate an average performance gross weight (pounds) at the intersection of charted F/F and the CASK line on the appropriate specific range chart. The difference between the average performance weight and the average actual weight is the weight correction factor. In other words, the aircraft flies as if it weighs more than it actually does then we use a plus correction factor. If the aircraft flies less than it actually weighs then we use a minus correction factor. Remember a correction factor may change during flight because of such things as leaks, engine exhaust deposits on the aircraft, and changes in CG position. For these reasons, you should recompute correction factors frequently.

Chapter 11

DESCENT, LANDING AND GO-AROUND PERFORMANCE

11-1. Descent Defined. A descent is an integral part of a mission and we plan it accordingly. We make descents for a variety of reasons, such as, descending to a lower altitude to take advantage of reduced headwinds, descending for a rendezvous with a tanker, or just descending for an approach and landing. During descent, we must control the aircraft within the framework of mission and aircraft requirements. The type of descent selected will accomplish one of three objectives: maintain a particular (dictated) rate of descent, accomplish the altitude change in a given elapsed time, or cover a given distance during the altitude change.

11-2. Factors Affecting Descent Performance:

a. Power. Power required for descent is much less than that required for a cruise at the same gross weight and speed. An aircraft, because of its weight, possesses a certain amount of potential energy. In flight, if we reduce to where thrust develops less lift than the gross weight of the aircraft, the aircraft will descend. The potential energy the aircraft possessed in flight is now transformed into kinetic energy. The descent is now regulated by controlling the kinetic energy the aircraft is expending. We accomplish this by using engine power variations, adjusting airspeed, and using additional drag producing devices (wing flaps, landing gear, thrust reversers, and spoilers) to control the descent rate. When accomplishing descents at cruise airspeeds, the most efficient angle of attack and lift drag ratio obtains a high air NMPP value. Power required to maintain these airspeeds decreases with increases in descent rate. Because of this reduced power requirement, fuel flow is lower which results in additional range being available. The most economical descent is one we make at cruise airspeeds and at a rate of descent which is high enough to permit a minimum drag configuration. It is not so high as to require undesirable power settings. In general, there is no best technique to use for descent. Operational restrictions, the nature of the mission, the surface terrain, or the controlling agency dictate the technique and rate of decent.

b. Configuration. Like the cruise phase of flight, the external configuration of the aircraft directly affects the descent performance. The use of wing flaps, spoilers (speed brakes), thrust reversers, or an extended landing gear induces large amounts of drag that drastically alter the aircraft's performance characteristics. By extending the wing flaps and landing gear; and deploying the spoilers and thrust reversers we obtain the highest rate of decent.

NOTE: Different aircraft use various combinations.

We refer to these configurations as "dirty." In most cases, we reduce airspeed to the maximum placard speed for a specific external configuration of the aircraft concerned. The highest rate of descent allows a change of altitude in the shortest length of time. The aircraft obtains the longest horizontal distance with all of the external drag devices retracted or closed. We call this configuration "clean." In this case, we increased airspeed to the maximum placard speed for a clean configuration descent. For some aircraft, above standard temperatures increase the rate of descent and decrease descent time and fuel by as much as two percent for each ten degree increment above the standard. The opposite is true if the temperature is below standard. On these aircraft, temperature has little or no effect on range or distance during descent. For most aircraft, variations from standard day temperatures have little effect on descent performance because the time intervals involved are relatively short. For this reason temperature variations are generally not considered on most aircraft.

11-3. Types of Descents. There are several types of descent in use today. Descent types and descent procedures vary from one aircraft type to another because of mission requirements and individual aircraft characteristics. We will limit our discussion to three descent types which are common among the aircraft concerned. Keep in mind that the procedures used in accomplishing these descents may vary between aircraft.

a. Rapid Descents. Rapid descents obtain a very high rate of descent when air traffic control or mission requirements dictate. This high rate of descent is derived from the combination of gross weight versus power and the external configuration of the aircraft. There are variations of the amount of drag required and the maximum placard speed for the particular type of descent. We consider rapid descents as emergency type descents on some aircraft. A rapid descent is a constant speed variable rate type descent.

b. Penetration Descents. Penetration descents are made when the need for a faster than normal change in altitude exists. A penetration, like a rapid descent, is a constant speed variable rate type descent. We control it by bringing the engine power to idle, either extending the flaps or deploying the spoilers, and, on some aircraft, placing two engine thrust reversers in reverse idle.

c. En Route Descent. En Route descents are the most commonly used type. Fuel economy and passenger or crew comfort are the outstanding qualities which make this type of descent most practical. We initiate en route descents as much as one hundred miles from the destination. We accomplish this type of descent using a relatively small variable rate of descent at a constant cruising airspeed. As the descent progresses, we reduce the power requirements resulting in lower fuel flow and additional range. We accomplish aircraft pressurization changes at a comfortable rate. This reduces the chances of passengers or crewmembers experiencing ear blockage. Once the aircraft reaches the lower altitudes, we adjust the speeds easily to keep within the restrictions dictated by air traffic control agencies and still maintain the en route profile.

11-4. Computing Descent Data. There are several methods used to compute descent data. The computation method depends upon the aircraft concerned and the type of information desired. During a mission, it may become necessary to descend to a lower altitude and to be at a certain point when we reach this lower altitude. We can do this by controlling the rate of descent and speed. We control the speed (within the structural limits of the aircraft) so that we reach the lower altitude and the predetermined point at the same time. The time required to fly this distance can be computed by using the known distance and speed to be flown in the following formula:

$$\text{Time (min)} = \frac{\text{Distance x 60}}{\text{TASK}}$$

We use the elapsed time (computed above or a known time) and the amount of altitude change (beginning PA minus level-off PA) to establish the rate of descent. We must maintain this rate of decent in order to reach the predetermined point at the prescribed altitude.

$$\text{Rate of Descent (ft/min)} = \frac{\text{Altitude change}}{\text{Time (min)}}$$

If we use a desired or required constant rate of descent, then time is the unknown factor. We use the following formula:

$$\text{Time (min)} = \frac{\text{Altitude change}}{\text{Rate of descent (ft/min)}}$$

Most aircraft performance manuals provide descent charts to compute data for variable rate constant speed type descents. We find the speed schedule, rate of descent, elapsed time, distance covered, and fuel consumed by using these charts.

11-5. Energy Management During Landing. The energy management concept is a proven procedure for coping with wind shear during final approach. It resulted from an intense analysis of adverse weather airflows, motivated by the loss of several aircraft, and made possible by current weather technology. As you may know, an aircraft's ability to maintain lift is dependent on aerodynamic flow, airspeed, and movement within an air mass. Jet streams, independent air mass movement, and airflow in and around thunderstorms provide an environment where an aircraft can almost instantaneously transition from one air mass to another. This is wind shear. The effect of wind shear is similar to the effect of wind gusts, except it can be much more severe. It can increase or decrease airspeed until engine thrust has no opportunity to reestablish the proper airspeed within the new air mass. Further, it can increase or decrease airspeed by the difference in velocity between the two air masses. At high speeds, the aircraft could exceed its maximum design airspeed limit, or at low speeds it could stall.

a. Let's assume that an aircraft is on final approach at a safe margin above stall speed. Further assume that we have a 50-knot headwind on this approach and that the aircraft is flying within this air mass at 125 knots indicated airspeed. If this aircraft transits a wind shear into another air mass that suddenly gives up the 50-knot headwind, the indicated airspeed instantly would drop from 125 knots to 75 knots and the aircraft will stall. In preparation for transiting this wind shear, we increase approach speed by the amount of the predicted loss. After penetrating the shear, airspeed will immediately reduce to the approach speed. We predict this airspeed loss by making a comparison between the reference groundspeed and the actual approach groundspeed. We compute reference groundspeed by applying 100 percent of the reported runway winds to the approach true airspeed. We compute an approach groundspeed by applying 100 percent of the actual winds (at approach altitude) to the approach true airspeed. Any significant difference between these two groundspeeds is reason to expect a wind shear. For example: assume you have a 10-knot headwind on the runway and a 50-knot headwind at approach altitude. Obviously, the headwind must decrease by 40 knots by the time the aircraft reaches the runway. This can happen gradually or in a matter of seconds. If the pilot maintains approach speed plus the groundspeed difference (40 knots in this case), transiting the wind shear will reduce airspeed by 40 knots to the desired approach airspeed.

b. The conversion of approach indicated or calibrated airspeeds to true airspeed is standard as previously explained in this manual. We convert true airspeed to groundspeed by adding 100 percent of a tailwind or subtracting 100 percent of a headwind. The inertial navigation systems (INS) or other sophisticated navigation systems installed on most aircraft will provide the approach winds and approach groundspeeds. The flight engineer should compute and provide the other comparison factor and groundspeed, as discussed in the preceding paragraph.

11-6. Go-Around Performance:

a. Go-around in the event of a refused landing may be limited by performance, especially if one engine is inoperative. Generally, performance does not limit a go-around on normal engine power unless the aircraft is at a low speed and nearing touchdown. Before beginning an approach, give careful consideration to the situation and to the point where we will initiate a go-around. Speed, altitude, existence of obstacles, weather and atmospheric conditions, gross weight, and expected power available are factors you must consider when determining the point at which we initiate the go-around. The following are general procedures for a go-around:

(1) As soon as the go-around decision is made, apply the dictated power.

(2) Establish and maintain the minimum airspeed and altitude required for a successful go-around.

(3) As soon as practicable, retract wing flaps and landing gear and set controls for minimum drag.

(4) Considering terrain clearance, establish and maintain the dictated climb attitude and climb rate.

(5) Complete the appropriate checklist and "clean up" the aircraft before initiating another approach.

b. In computing go-around data, we use one engine out data to provide the necessary safety factors. Two computations are needed: the best speed for go-around and best rate of climb. This may require the use of go-around data charts or may be standard sets by your performance manual.

11-7. Transitional Flight Performance.

Transition flight is flying that allows our aircrew practice at different types of landings or landing at different airfields . We accomplish this by flying approaches and making a series of "touch and go" landings. This requires a special awareness because historically takeoffs and landings are the most critical phase of flying. Your performance manual identifies data required for this type of training.

CHAPTER 12

MISSION PLANNING

12–1. What This Chapter Covers. Mission planning involves many people in many jobs. However, in this chapter we limit the scope of discussion to those considerations of aircraft performance and associated planning procedures that are specific to most flight engineers.

12–2. Premission Planning:

a. Premission planning begins with the aircraft commander's briefing designed to provide the flight crew with all significant information applicable to the mission. After the briefing, premission planning proceeds in a logical sequence to specify all events and procedures accomplished by crewmembers for a safe flight.

b. The purpose of premission planning is to:

(1) Determine in advance the initial, intermediate, and the final airspeed.

(2) Establish altitudes, headings, elapsed time, distance for takeoff, climbs, cruises, descent, and landing.

(3) Determine the maximum payload that can be delivered to a given point and the maximum range of the aircraft.

(4) Determine the fuel necessary to safely accomplish a mission when cargo and distance are known.

(5) Fuel Reserve. Fuel Reserve is the amount of usable fuel that we must carry on each aircraft, beyond that required to complete the flight. MAJCOMs set these requirements for aircraft in their commands. If the command has not established reserves, we must carry enough usable fuel on each flight to increase the total planned flight time between refueling points by 10 percent or 20 minutes, whichever is greater.

(6) Weather Forecast and Fuel Requirements:

(a) Weather Forecast. Before your mission planning, you should get a weather forecast. This will help in your fuel planning, since a headwind will increase both fuel consumption and time airborne, and a tailwind will decrease your time and fuel consumption. From this you can see if you have a headwind and don't allow for the extra burnoff, you may not make your destination.

(b) Fuel Requirements. As a flight engineer, your primary concern will be the fuel required for your mission. The fuel requirements are found in the applicable aircraft, or MAJCOM-series regulations. You must have enough usable fuel aboard the aircraft before takeoff, or immediately after inflight refueling, to complete the flight to a final landing, either at the destination or alternate airdrome. The following table (figure 12-1) will give you an idea of what you can expect to find in applicable aircraft MACR 55-XXX series. It will give you expected fuel burnoff for different phases of flight and some definitions.

12–3. Mission Planning. Once briefed by the aircraft commander on mission requirements, we must figure out how much fuel is required to complete this mission. Normally, we can get our required fuel from the computer flight plan or use the fuel planning charts (55-XX series for specific aircraft). Sometimes these documents are not available to the flight engineer and he or she must use his or her aircraft 1-1. Aircraft 1-1's have a mission planning section in them and are quite accurate when used properly. One method of fuel planning with the 1-1 is to begin at the end of the mission with zero fuel and work toward the departure, building fuel with each segment of flight (figure 12-2). Starting on the runway at our alternate using aircraft zero fuel weight, we add the fuel it takes our aircraft to make an approach and landing. This fuel is a known value and is not found in a chart. We add this figure to our zero fuel weight. From here we must use the charts available in our aircraft 1-1's. The charts we will use are:

(1) Endurance.

(2) Short Distance Cruise.

(3) Constant Altitude Time or Range.

(4) Additional Fuel Required (Climb vs. Cruise).

a. Figuring Holding Fuel. Using our zero fuel weight plus our approach and landing fuel, we are ready to find holding fuel for our aircraft. To do this, we use the endurance chart. Normally, we use this chart with an average weight, but for mission planning purposes we will use zero fuel weight plus approach and landing fuel weight, entering on the maximum endurance line. This will give us fuel flow for 1 hour. By ratio and proportioning, we can find our fuel for 45 minutes holding.

<table>
<tr><td rowspan="8">REQUIRED RAMP FUEL LOAD</td><td colspan="3">START, TAXI, RUNUP, APU AND TAKEOFF (LBS)</td><td>1,900 LBS.</td></tr>
<tr><td rowspan="7">FLIGHT PLAN FUEL LOAD</td><td colspan="2">ENROUTE</td><td>Fuel for flight time from overhead to overhead destination at cruise altitude or initial penetration fix/altitude.</td></tr>
<tr><td colspan="2">ENROUTE RESERVE</td><td>10% of flight time fuel over a Category I route/route segment, not to exceed 1+00 fuel at normal cruise.</td></tr>
<tr><td rowspan="4">REQ FUEL OVHD</td><td>MISSED APPROACH (LBS)</td><td>4,000 LBS.</td></tr>
<tr><td>ALTERNATE</td><td>Fuel for flight time from overhead destination or initial pentration fix to alternate, or to the most distant alternate when two are required, at the speed and altitude for max fuel economy.</td></tr>
<tr><td>HOLDING</td><td>0+45 fuel computed from the endurance or holding charts. When an alternate is unavailable or is located in Alaska, Aleutian Islands, or at latitudes greater than 59° north/south, use 1+15. Determine G. W. by adding ZFW to approach and landing fuel, then(enter)the charts.</td></tr>
<tr><td>APPROACH AND LANDING (LBS)</td><td>2,500 LBS.</td></tr>
<tr><td colspan="2">IDENTIFIED EXTRA</td><td>Know holding delays
Performance fuel for fly heavy aircraft (10%)
Icing (LB/HR)1,100LBS.
Insufficient, unreliable navaids 2,500(LB/HR)
Off course maneuvering (LBS/Min) 300</td></tr>
</table>

Figure 12-1. Fuel Table.

Adding this weight to our accumulated aircraft weight, we are ready to find the fuel it will take to make a missed approach and fly to the alternate. We'll use the short distance cruise chart or alternate airport chart whichever is available. Read the notes on charts. Some charts include the missed approach, others have estimated fuel values for the missed approach. These charts include climb to optimum altitude and cruise at 99 percent max range to the alternate. To enter this chart, we must know the distance to the alternate, and we'll use our zero fuel weight plus accumulated fuel for diversion gross weight. Adding fuel to the alternate weight to our accumulated weight gives us a new aircraft weight and is the gross weight overhead destination (figure 12-3). Arriving overhead, our destination with this amount of fuel allows us to make a missed approach, climb to optimum altitude, cruise at 99 percent maximum range to the alternate, hold for 45 minutes, and make an approach and landing at the alternate airport.

b. Figuring En Route Fuel. Now we are ready to figure the en route fuel. To do this we need a time en route or a distance. We use the Constant Altitude Time or Range charts. Enter on the chart the gross weight over destination to cruise altitude, and apply the temperature deviation. This will give you a reference time. Now we will subtract time en route from this time. With the new reference time enter the chart backwards. This will give you a reference gross weight (if you are working range, apply it the same way except you will use the range charts). Subtract gross weight over destination from reference gross weight. The difference is en route fuel. To figure en route reserve fuel, check your appropriate command directives. (Normally, 10 percent of en route time or 20 minutes, whichever is greater.) Adding en route fuel and en route fuel reserve to our accumulated aircraft weight will give us our weight at the top of the climb. We know it takes more fuel to climb than it does to cruise, but we figured en route fuel from overhead departure to overhead destination so we cannot use our en route climb chart to find climb fuel. Instead, we use the mission planning chart, Climb Fuel vs. Cruise Fuel. Using our last known weight, we'll enter this chart. This will give us our gross weight at the start of the climb. At this time we can add in any identified extra fuel that may be needed for our mission. The next item we need to take into consideration is taxi, run-up, and takeoff fuel. This is from command directives. Adding all these weights together will give us required ramp gross weight. Subtract zero fuel weight from this and we have required fuel for the mission.

12–4. Air Refueling. Our air refueling mission will look similar to figure 12-4. We will begin planning fuel from the alternate, working back to the Air Refueling Exit Point. This portion of our fuel planning is the same as the previous mission planning example, except we won't need warm-up, taxi, and takeoff fuel. The fuel we have at the exit point is the fuel required to complete the mission after leaving the tanker. To find the amount of fuel we must receive from the tanker, we will start with takeoff gross weight and work forward. Takeoff gross weight will depend on payload and mission requirements. We will use the same charts and directives. Working forward with takeoff gross weight, we'll enter the additional fuel required (Climb vs. Cruise) chart and find the fuel used to altitude. Subtracting this fuel from takeoff weight will give us our gross weight at the top of the climb. To figure cruise or en route fuel, we'll use the Constant Altitude Time chart. Entering the chart with gross weight at the top of the climb, we will exit the chart with a reference time. Since we are working forward, we will add en route time to ARCP to our reference time and enter the chart backwards with this new time. This will give us an aircraft gross weight. The difference between gross weight at the top of the climb and the gross weight off the chart will be en route fuel. This new weight will also be the weight of our aircraft at the ARCP. While our aircraft is refueling, it is burning fuel. This is a set amount depending on the type of aircraft. Subtracting this from our weight at the ARCP will give us predicted gross weight at the exit point. Now we subtract our predicted gross weight at the exit point from required gross weight at the exit point and this will give us the amount of fuel needed from the tanker to complete the mission.

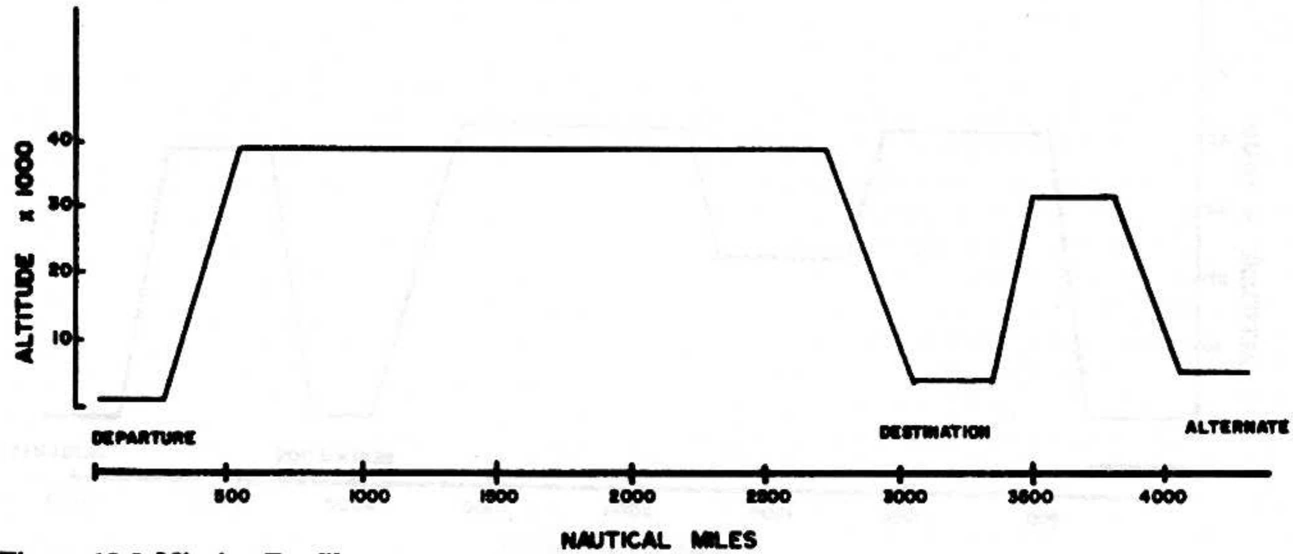

Figure 12-2. Mission Profile.

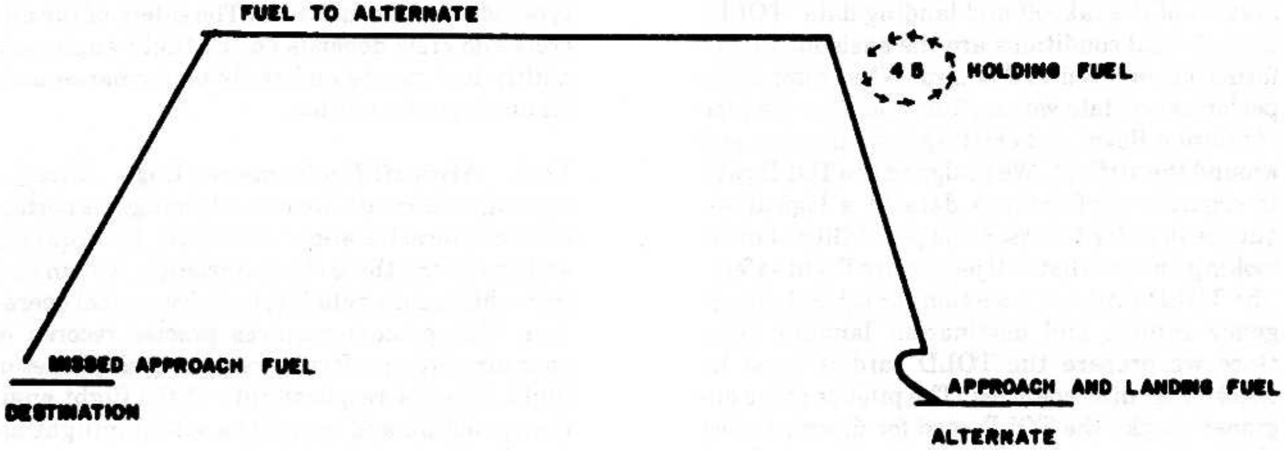

Figure 12-3. Gross Weight Overhead Destination.

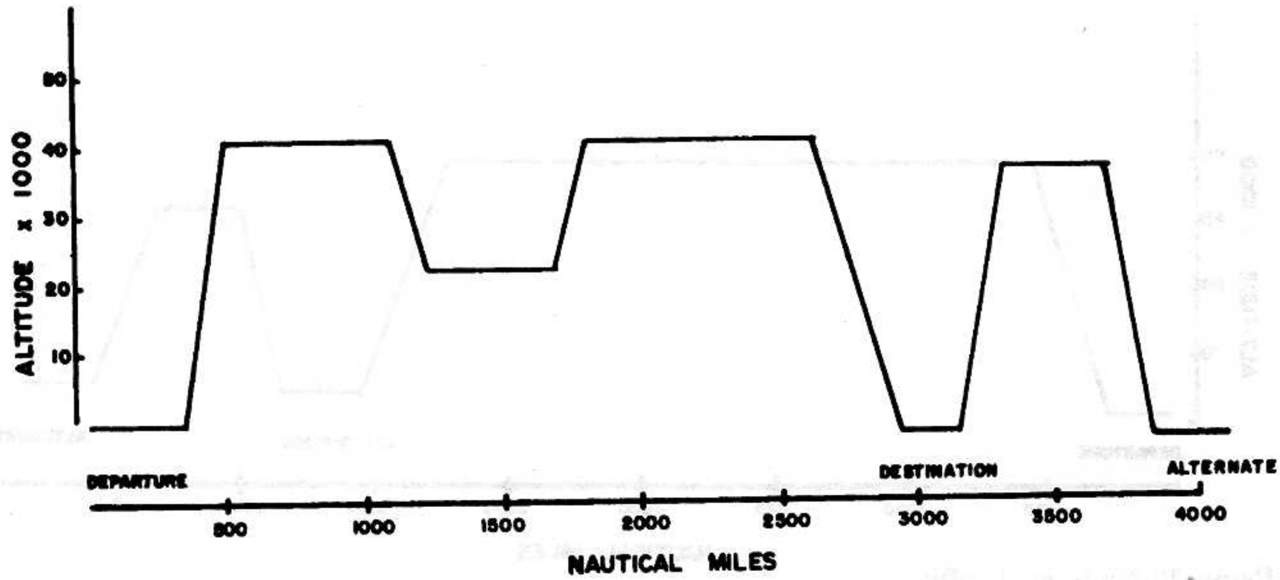

Figure 12-4. Air Refueling Mission Profile.

12–5. TOLD Card. The first action required after mission briefings and planning is the preparation of the takeoff and landing data (TOLD) card. Actual conditions are the basis for the information entered on this card. When computing performance data we carefully consider the type of mission flown and existing conditions on and around the airfield. We designed the TOLD card to organize performance data in a logical sequence in order to lesson the possibility of overlooking an area that will jeopardize flight safety. The TOLD card has a section for takeoff, emergency return, and destination landing data. Once we prepare the TOLD card it must be checked for discrepancies. The pilot or other engineer checks the TOLD card for discrepancies either by comparing the card with tabulated data, FSAS, electronic computer, or another TOLD card. This requirement exists in order to ensure that we have taken all precautions to prevent an unsafe takeoff. The flight manual applicable to your aircraft includes explanations of performance data requirements for different types of takeoff conditions. The safety of the aircraft and crew depends on the flight engineer's ability to compute and apply performance data for any type of condition.

12–6. Aircraft Performance Log. After designing an aircraft, we cannot change its performance characteristics. However, by studying and analyzing these characteristics, we can do a lot to obtain safe, reliable, and economical operation. This process requires precise records of your aircraft's performance during all phases of flight. It is the responsibility of the flight engineer to obtain and record the actual inflight atmospheric conditions, fuel consumption, gross weight, and engine performance data. From this data, the flight engineer can analyze the aircraft's performance and make decisions for successful completion of the mission.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

OFFICIAL

MICHAEL J. DUGAN General, USAF
Chief of Staff

EDWARD A. PARDINI, Colonel, USAF
Director of Information Management

SUMMARY OF CHANGES

This revision reorganizes the entire manual to effect required changes; provides guidance in solving mathematical problems (chap 2); separates physics for the flight engineer from aerodynamics (chap 3); deletes weather hazards (chap 4); adds transonic aerodynamics (chap 5); deletes reciprocating engine material (chap 6); adds load factor and center of gravity calculations (chap 7); expands factors effecting takeoff and adds reduced takeoff power (chap 8); discusses climb performance (chap 9); adds basic cruise profiles and procedures and factors effecting cruise (chap 10); adds energy management and transitional flight performance (chap 11); and adds air refueling and deletes preflight inspection.

ABBREVIATIONS AND FORMULAS

I. GREEK LETTER ABBREVIATIONS:

α (Alpha)	Angle of attack in degrees
β (Beta)	Blade angle of propeller in degrees
δ (Delta)	Increment of change in weight, drag, airspeed, etc.
η (Eta)	Propeller efficiency in percent
γ (Gamma)	Ratio of specific heats of gas at constant pressure and volume
μ (mu)	Coefficient of friction
π (Pi)	3.1416
ρ (Rho)	Air density at some specific altitude
σ (Sigma)	Air density ratio
θ (Theta)	Relatively absolute temperature

II. GENERAL ABBREVIATIONS:

A	Area or Arm
a	Acceleration
ACN	Aircraft classification number
Acft	Aircraft
AGL	Above ground level
ALT	Altitude
ANMPP	Air nautical miles per pound
APN	Air performance number
BASK	Basic airspeed in knots
BTU	British thermal unit
°C	Degrees Centigrade (Celsius)
CADC	Central air data computer
CALC	Calculated
CASK	Calibrated airspeed in knots

CBR	California bearing ratio
C_D	Coefficient of drag
CFL	Critical field length
CG	Center of gravity
C_L	Coefficient of lift
COF	Climbout factor
Cond	Condition
CUT	Coordinated universal time
D	Drag
d	Distance
Deg	Degrees
Dev	Deviation
EASK	Equivalent airspeed in knots
EDP	Equal/distance point
EGT	Exhaust gas temperature
Eng	Engine
EPR	Engine pressure ratio
ESHP	Equivalent shaft horsepower
ETP	Equal/time point
EWP	Emergency war planning
°F	Degrees Fahrenheit
F	Friction, force, or change in flat plate area
Fig	Figure
FF	Fuel flow
FL	Flight level
Flt	Flight
FPA	Field pressure altitude
F/Pd	Fuel for a given period or distance

Fpm	Feet per minute
Ft	Feet
fwd	Forward
g	Acceleration of gravity
Gal	Gallon
GNMPP	Ground nautical miles per pound
GPN	Ground performance number
GS	Ground speed
GW	Gross weight
H	Absolute altitude (tapeline)
h	Height
H_d	Density altitude
H_g	Inches of mercury
H_o	Optimum altitude
Hp or PA	Pressure altitude
hp	Horsepower
h	Hour
IAS	Indicated airspeed in miles per hour
ISA	International Standard Atmosphere
IASK	Indicated airspeed in knots
ICAO	International Civil Aviation Organization
IFF	Identification friend or foe
IOAT	Indicated outside air temperature
IM	Indicated mach
In	Inches
K	Constant
°K	Degrees Kelvin
k or kt	Knot

KCAS	Calibrated airspeed in knots
KIAS	Indicated airspeed in knots
KTAS	True airspeed in knots
KE	Kinetic energy
L	Lift
l	Length
lb	Pound
lb/gal	Pounds per gallon
lb/min	Pounds per minute
L/D	Lift-drag ratio
LEMAC	Leading edge mean aerodynamic chord
LSA	Load shift arm
LSW	Load shift weight
M	Mach number (also moment)
m	Mass
MAC	Mean aerodynamic chord
Max	Maximum
Mb	Milibars
Min	Minutes or minimum
mph	Miles per hour
MRT	Military rated thrust
MSL	Mean Sea Level
N_1	Low pressure compressor rpm
N_2	High pressure compressor rpm
No	Number
NM	Nautical mile
NMPP	Nautical miles per pound
NRT	Normal rated thrust

NTS	Negative torque system
OAT	Outside air temperature
oz	Ounce
P	Pressure or power
PA	Pressure altitude
Pax	Passengers
PCN	Pavement Classification Number
Pd	Period (unit of time)
PGW	Performance gross weight
psi	Pounds per square inch
psia	Absolute pressure, pounds per square inch
psig	Gauge pressure, pounds per square inch
pt	Pint
q	Dynamic pressure
QNH	Altimeter setting
qt	Quart
r	Radius or rate
R	Number of engines
R	Degrees Rankine
RA	Runway available
RCR	Runway condition reading
R/D	Rate of descent (feet per minute)
RD	Reference datum (line)
REF	Reference
RL	Runway length
rpm	Revolutions per minute
RSC	Runway surface covering
S_1	Area of wing in square feet

SAT	Static air temperature
Sec	Sections
SFC	Specific fuel consumption
shp	Shaft horsepower
SID	Standard instrument departure
SL	Sea Level
Slug	Unit of measurement of mass
SM	Statute mile
SMOE	Reciprocal of the square root of density ratio (sigma)
Spec H	Specific humidity
Std	Standard
S_1	Decision speed
T	Temperature or thrust
TACAN	Tactical air navigation
t	Time
TAS	True airspeed in miles per hour
TASK	True airspeed in knots
TAT	Total air temperature
Temp	Temperature
TF	Thrust factor
thp	Thrust horsepower
TIT	Turbine inlet temperature
TM	True mach
TMS	Type, model, series
TOF	Takeoff factor
TOLD	Takeoff and landing data
TOP	Torquemeter oil pressure
Tp	Torque pressure

TPSI	Torque pressure in pounds per square inch
TRT	Takeoff rated thrust
V	Velocity or volume
V_{app}	Approach speed
V_{ave}	Average speed
$V_{B(max)}$	Maximum braking speed
V_{cef}	Critical engine failure speed
VFR	Visual flight rules
V_f	Final velocity
$V_{G/A}$	Go around speed (KCAS)
V_{GO}	Go speed
VHF	Very high frequency
V_h	Structurally listed maximum speed
V_{MCA}	Air minimum control speed
V_{MCEF}	Max critical engine failure speed
V_{MCO}	Minimum climbout speed
V_{MCG}	Ground minimum control speed
V_{MFR}	Minimum flap retraction speed
V_{MS}	Minimum spoiler speed
V_{NEF}	Noncritical engine failure speed
V_O	Original velocity
VOR	nmi directional range
VORTAC	Combination of VOR and TACAN
V_R	Refusal speed
V_{REF}	Reference speed
V_{ROT}	Rotation speed
V_S	Stall speed
V_{SHO}	Shaker onset speed

V_{TL}	Tire limit speed
V_{TO}	Takeoff speed
V_{TP}	Tire placard speed
V_W	Wind velocity
V_1	Decision speed
V_2	Takeoff safety speed
W	Weight in pounds
w	Width
WR	Wind reserve
X-wind	Crosswind
yd	Yard

III. TIME, SPEED AND DISTANCE FORMULAS:

1. $$Distance = \frac{Speed \times Time\ (min)}{60}$$

2. $$Speed = \frac{Distance \times 60}{Time\ (min)}$$

3. *Time (min)* = $\frac{\textit{Distance} \times 60}{\textit{Speed}}$

   a. *Distance = status miles or nautical miles.*

   b. *Speed = miles per hour (mph), knots (TASK), or GS.*

   c. *Time = total minutes (divided by 60 = hours and tenths).*

4. *TAS = TASK* x 1.152

5. *TASK* = $\frac{\textit{TAS}}{1.152}$

6. *SM = NM* x 1.152

7. *NM* = $\frac{\textit{SM}}{1.152}$

8. *M* = $\frac{\textit{TASK}}{\textit{Speed of Sound}}$

9. *TASK = M x Speed of Sound*

10. *Speed of Sound* = $\frac{\textit{TASK}}{\textit{M}}$

11. *TASK = EASK x SMOE*

12. *EASK* = $\frac{\textit{TASK}}{\textit{SMOE}}$

IV. GENERAL FUEL FORMULAS:

1. *Pounds = Gallons x Fuel Density*

2. *Gallons* = $\frac{\textit{Pounds}}{\textit{Fuel Density}}$

3. *F/Pd* = $\frac{\textit{FF} \times \textit{Time (minutes)}}{60}$

4. *FF* = $\frac{\textit{F/Pd} \times 60}{\textit{Time (minutes)}}$

5. *Time (min)* = $\frac{\textit{F/Pd} \times 60}{\textit{FF}}$

6. *d = NMPP x F/Pd*

7. *NMPP* = $\frac{\textit{d}}{\textit{F/Pd}}$

8. *NM/1,000* = $\frac{\textit{d} \times 1{,}000}{\textit{F/Pd}}$

9. *F/Pd* = $\frac{\textit{d}}{\textit{NMPP}}$

10. $TASK = NMPP \times FF$

11. $FF = \frac{TASK}{NMPP}$

12. $F/Pd = \frac{FF \times Distance}{TASK}$

13. $ANMPP = \frac{TASK}{FF}$

14. $GMNPP = \frac{TASK + Wind}{FF}$

15. $Charted\ TASK = \frac{Logged\ TASK}{SMOE\ for\ cruise\ altitude}$ *x SMOE (from closest 5,000 ft specific range chart)*

16. $Charted\ FF = \frac{FF}{SMOE\ for\ cruise\ altitude}$ *x SMOE (from closest 5,000 ft specific range chart*

V. GENERAL PHYSICS FORMULAS:

1. $°F = 1.8°C + 32$ or $9/5°C + 32$

2. $°C = \frac{°F - 32}{1.8}$ or $5/9\,(°F - 32)$

3. $Work = Force \times Distance$

4. $Pressure = \frac{Force}{Area}$

5. $Speed = \frac{Distance}{Time}$

6. $Power = \frac{Work}{Time}$

7. $Torque = Force \times Distance$ (at right angles)

8. $Force = Mass \times Acceleration$

9. $Acceleration = \frac{Final\ Velocity - Initial\ Velocity}{Time}$

10. $Energy = Force \times Distance$

11. $Kinetic\ Energy = \frac{Mass \times Velocity^2}{2}$

12. $Momentum = Mass \times Velocity$

13. *Friction* = *μ x N. N is the force exerted on or by the object perpendicular (normal) to the surface over which it slides, and (μ) is the coefficient of sliding friction. (On a horizontal surface, N is equal to the weight of the object in pounds.)*

VI. GENERAL AERODYNAMIC FORMULAS:

1. $TASK = EASK \times SMOE$

2. $EASK = \frac{TASK}{SMOE}$

3. $g = \frac{Rho \times V^2}{2}$

4. $L = CL \times \frac{Rho}{2} \times v^2 \times S$ or $\frac{CL \times S \times EASK^2}{295}$

5. $D = CD \times \frac{Rho}{2} \times V^2 \times S$ or $\frac{CD \times S \times EASK^2}{295}$

6. $shp = \frac{T \times rpm}{K}$

VII. GENERAL WEIGHT AND BALANCE FORMULAS:

1. $Arm = \frac{Moments}{Weight}$

2. $Moments = Arm \times Weight$

3. $Weight = \frac{Moments}{Arm}$

4. $Average\ arm = \frac{Total\ Moment}{Total\ Weight}$

5. $CG\ (\%\ of\ MAC) = \frac{Av\ Arm - LEMAC}{MAC}$

6. $New\ CG\ (adding\ weight) = \frac{Original\ Moment + Added\ Moment}{Original\ Weight + Added\ Weight}$

7. *New CG (removing weight)* $= \frac{\text{Original Moment - Moment Removed}}{\text{Original Weight - Weight Removed}}$

8. *New CG (shifting weight)* $= \frac{\text{Original Moment} \pm \text{Moment Change}}{\text{Original Weight}}$

VIII. MISCELLANEOUS FORMULAS:

1. $V_{hydroplane} = 9\sqrt{9}$

2. $RD = \frac{\text{Altitude Change}}{\text{Time (min)}}$

3. $Time = \frac{\text{Altitude Change}}{RD}$

4. ***Uphill Slope Height Correction***

   Height = (RA - CFL) x Slope (%)

5. ***Downhill Slope Height Correction***

   Height = CFL x Slope (%)

SYSTEMS OF MEASUREMENT, WEIGHT CONVERSION, AND TABLE OF EQUIVALENTS

I. SYSTEMS OF MEASUREMENT

	Metric	English	Equivalent
Length:	Centimeter	Foot	
	1 centimeter = 10 millimeters	1 foot = 12 inches	1 in = 2.54 cm
	1 decimeter = 10 centimeters	1 yard = 3 feet	1 ft = 30.5 cm
	1 meter = 100 centimeters	1 mile = 5,280 feet	1 meter = 39.37 in
	1 kilometer = 1,000 meters		1 km = 0.62 miles
Weight:	Gram	Pound	
	1 gram = 1,000 milligrams	1 pound = 16 ounces	1 lb = 453.6 gr
	1 kilogram = 1,000 grams	1 ton = 2,000 pounds	1 kg = 2.2 lb

II. WEIGHT CONVERSIONS

Fuel: Gasoline = 6.0 lb per gallon
JP-4 = 6.5 lb per gallon

Oil: 7.5 lb per gallon

Water: 8.3 lb per gallon

Alcohol: 6.8 lb per gallon

1 NM = 1.152 statue mile OR 6,080 feet

1 mph = 1.467 ft/sec

1 Knot = 1.688 ft/sec

1 Atmosphere = 14.7 psi 29.92" Hg

1" Hg = 0.491 psi = 33.8 millibars

Standard sea level temperature = 15 C or 59 F

Standard sea level pressure = 14.7 psi = 29.92" Hg

Standard gravity (g) = 32.167 ft/sec^2

1 Horsepower = 33,000 ft·lb/min = 550 ft·lb/sec

Pressure lapse rate = 0.934" Hg/1,000 ft alt (approx)

III. TABLE OF EQUIVALENTS

1 SM = 5,280 Feet

Temperature lapse rate = 3.57 F (2 C)/1,000 ft alt (approx)

SUBJECT INDEX

A **PARAGRAPH**

N PARAGRAPH

P

R

S

T

U

V

W **PARAGRAPH**

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