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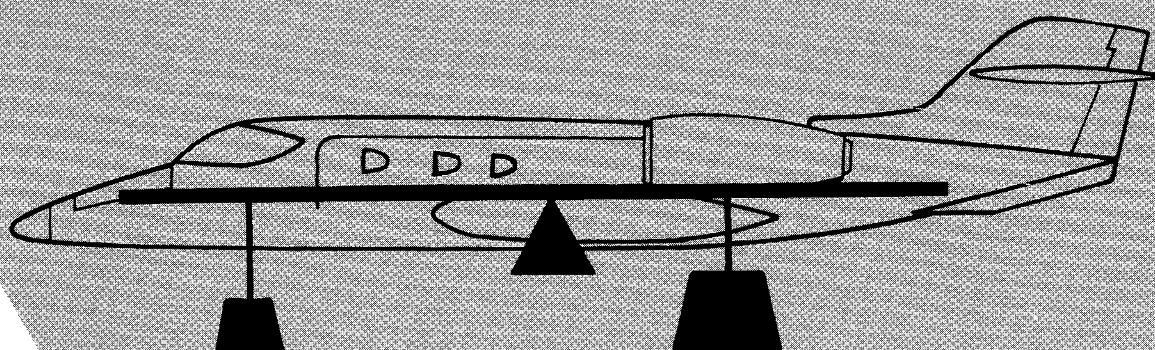
PILOT'S WEIGHT AND BALANCE HANDBOOK



U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

PILOT'S WEIGHT AND BALANCE HANDBOOK

Revised 1977

U.S. DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

Flight Standards Service

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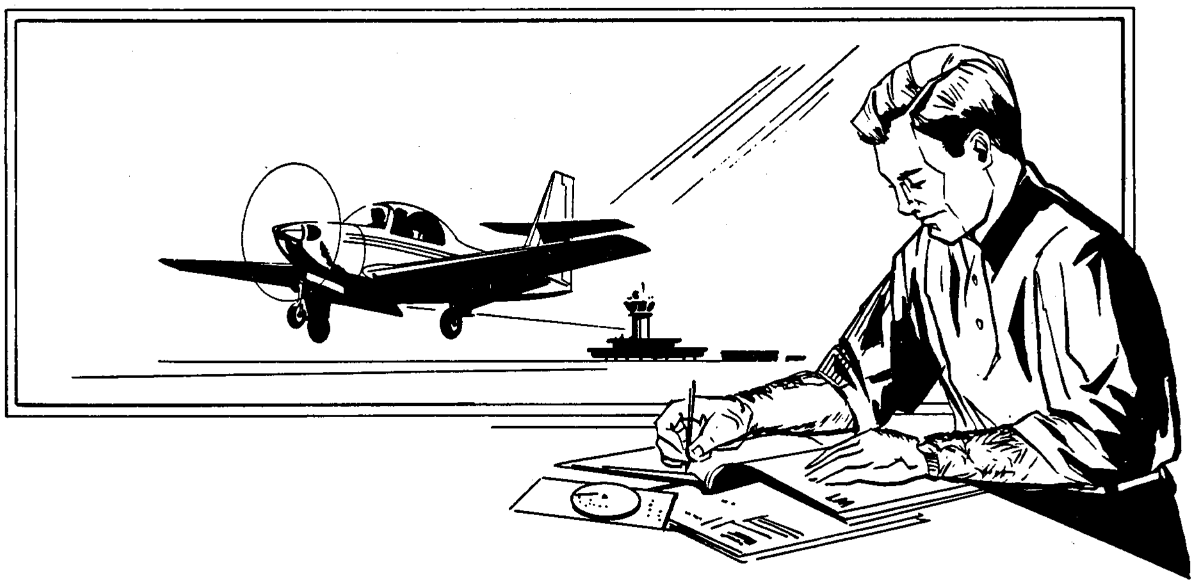
WEIGHT AND BALANCE CONTROL



Weight is a measure of the attractive force of the earth's gravity upon a material body. It is an indication of the mass or heaviness of the body. Weight is also one of the greatest enemies of the flyer. It is a factor which must be respected if flight is to be conducted safely.

The force of gravity acting on the mass of the aircraft continuously attempts to pull it down from flight. The force of lift which is generated by the airfoils of the aircraft is the only force available to counteract weight and keep the aircraft in flight. However, the airfoils can produce only a limited amount of lift for use in resisting gravity; therefore, any increase in aircraft weight is to be avoided if possible. The total lift of the aircraft depends on the design of the airfoils, the speed and angle of attack of the airfoils as they move through the air, and the density of the air through which the airfoils are moving. If the generated lift does not equal aircraft weight, level flight cannot be maintained and the aircraft must descend.

EFFECTS OF WEIGHT

Any object aboard the aircraft which increases the total weight significantly is an undesirable object as far as flight is concerned. However, aviators must accept a compromise and load some heavy objects in

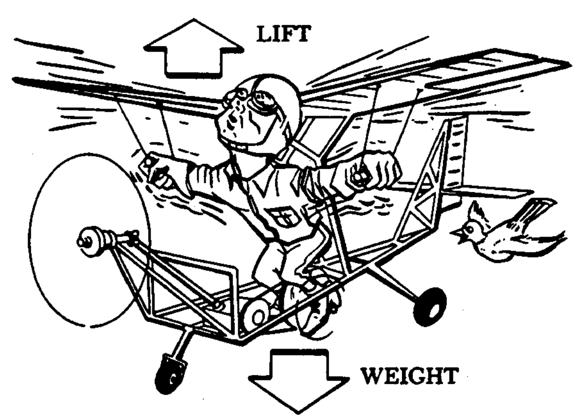


FIGURE 1. Lift and weight.

the fuselage or wings to make flight possible. Fuel is an example of a heavy but necessary item. It is always easier to fly when the aircraft is light and more difficult and dangerous when the aircraft is heavy. Therefore, it has always been a primary rule of flight to make the machine as light as possible without sacrificing strength or safety and to include only those loads essential for the particular flight.

The total weight of a vehicle changes as the contents (passengers, fuel, or cargo) are varied. If care is not taken, the vehicle can be weighted down with objects to a point where it can no longer function efficiently as a mover of loads. The operator of the vehicle and especially the pilot of an aircraft should always be aware of the consequences of overloading. An overloaded boat might sink, a truck or automobile might not be able to climb a hill, and an aircraft may not be able to leave the ground. Each vehicle has its limits, beyond which excessive weight leads to inferior operation and possible disaster. Of all common vehicles, the aircraft is most susceptible to trouble if weight considerations are disregarded; its limits are most easily exceeded. Furthermore, when the aircraft has weight problems, the initial indication of poor performance will be during takeoff; an unfortunate place for the vehicle and the pilot to be in trouble.

Excessive weight (fig. 2) reduces the flying ability of an airplane in almost every respect. The most important performance deficiencies of the overweight airplane are:

Higher takeoff speed.
Longer takeoff run.
Reduced rate and angle of climb.
Lower maximum altitude.
Shorter range.
Reduced cruising speed.
Reduced maneuverability.
Higher stalling speed.
Higher landing speed.
Longer landing roll.

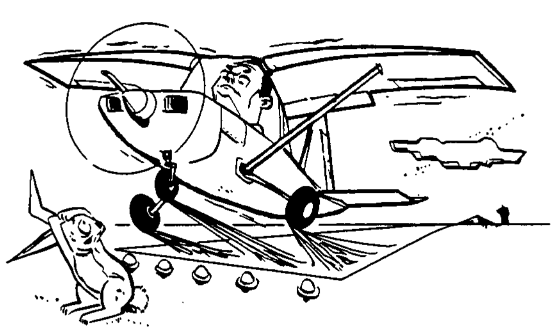


FIGURE 2. Overweight causes longer takeoff run.

The pilot must appreciate the effect of excessive weight on the performance of the aircraft. Every preflight check should include a study of performance charts to see if the aircraft weight may contribute to hazardous flight conditions. Most pilots have been trained to recognize and avoid such aircraft performance-reducing factors as: High-density altitude, frost on the wings, low engine power, and severe or uncoordinated maneuvers. Excessive weight reduces the safety margins available to the pilot when these conditions are encountered. The pilot must also consider the consequences of an overweight aircraft if emergency conditions arise. If an engine fails on takeoff or ice forms at low altitude, it is usually too late to reduce the aircraft's weight to help keep the machine in the air.

WEIGHT CHANGES

The weight of the aircraft can be changed easily by varying the payload (passengers, baggage, and cargo). But, if weight has to be decreased by reducing the payload, the flight will be less profitable. Weight can also be changed by altering the fuel load. Gasoline or jet fuel has considerable weight—30 gallons may weigh more than a paying passenger. But, if weight is lowered by reducing fuel, the range of the aircraft is shortened. Fuel burn is normally the only weight change that takes place during flight. As fuel is used, the aircraft becomes lighter and performance is improved; this is one of the few good things about the consumption of the fuel supply.

Changes of fixed equipment also have a major effect upon the weight of the aircraft. Many aircraft are overloaded to a dangerous degree by the installation of extra radios or instruments. Repairs or modifications usually add to the weight of the aircraft; it is a rare exception when a structural or equipment change results in a reduction of weight. As with people, when an aircraft ages, it just naturally puts on weight. The total effect of this growth is referred to as "Service Weight Pickup." Most service weight pickup is the known weight of actual parts installed in repair, overhaul, and modification. These parts should have been weighed or the weight calculated when they were installed. In addition, an unknown weight pickup results from the collection of trash and hardware, moisture absorption of soundproofing, and the accumulation of dirt and grease. This pickup can only be determined by the accurate weighing of the aircraft as a unit.

BALANCE, STABILITY, AND CENTER OF GRAVITY

Balance refers to the location of the c.g. (center of gravity) of an aircraft. It is of primary importance to aircraft stability and safety in flight. Pilots should never fly an aircraft if they are not personally satisfied with its loading and the resulting weight and balance condition. The c.g. is the point about which an aircraft would balance if it were possible to support the aircraft at that point. It is the mass center of the aircraft, or the theoretical point at which the entire weight of the aircraft is assumed to be concentrated. The c.g. must be within specific limits for safe flight.

The prime concern of aircraft balancing is longitudinal balance, or the fore and aft location of the c.g. along the longitudinal axis. Location of the c.g. with reference to the lateral axis, however, is also important. The design of the aircraft is such that lateral symmetry is assumed to exist as far as weight is concerned. In other words, for each item of weight existing to the left of the fuselage centerline, there is generally an equal weight existing at a corresponding location on the right. This lateral mass symmetry, however, may be upset by unbalanced lateral loading. The position of the lateral c.g. is not computed, but the operating crew must be aware that adverse effects will certainly arise as a result of a laterally unbalanced condition. Lateral unbalance will occur if the fuel load is mismanaged by supplying the engine(s) unevenly from tanks on one side of the aircraft (fig. 3). The airplane pilot can correct the resulting wing-heavy condition by the use of aileron tab adjustment or by holding a constant lateral control pressure. However, this puts the aircraft controls in an out-of-streamline condition and results in a lowered operating efficiency. Since lateral balance is relatively easy to control and longitudinal balance is most critical, further reference to c.g. in this handbook will mean longitudinal location of mass balance.

The c.g. is not necessarily a fixed point; its location depends on the distribution of items loaded in the aircraft. As variable load items are shifted or expended, there is a resultant shift in c.g. location. The pilot should realize that if the mass center of an aircraft is displaced too far forward on the longitudinal axis, a nose-heavy condition will result. Conversely, if the mass center is displaced too far aft on the longitudinal axis, a tail-heavy condition will result (fig. 3). It is possible that an unfavorable location of the c.g. could produce such an unstable condition that the pilot could lose control of the aircraft. In any event, flying an aircraft which is out of balance, either in a tail-heavy or a nose-heavy direction, may produce increased pilot fatigue with obvious effects on the safety and efficiency of flight. The pilot's natural correction for longitudinal unbalance is a change of trim to remove the excessive control pressure. However, excessive trim has the effect of reducing primary control travel in the direction the trim is applied.

EFFECTS OF ADVERSE BALANCE

Adverse and abnormal balance conditions affect the flying ability of an airplane with respect to the same flight characteristics as those mentioned for an excess weight condition (p. 2). In addition, there

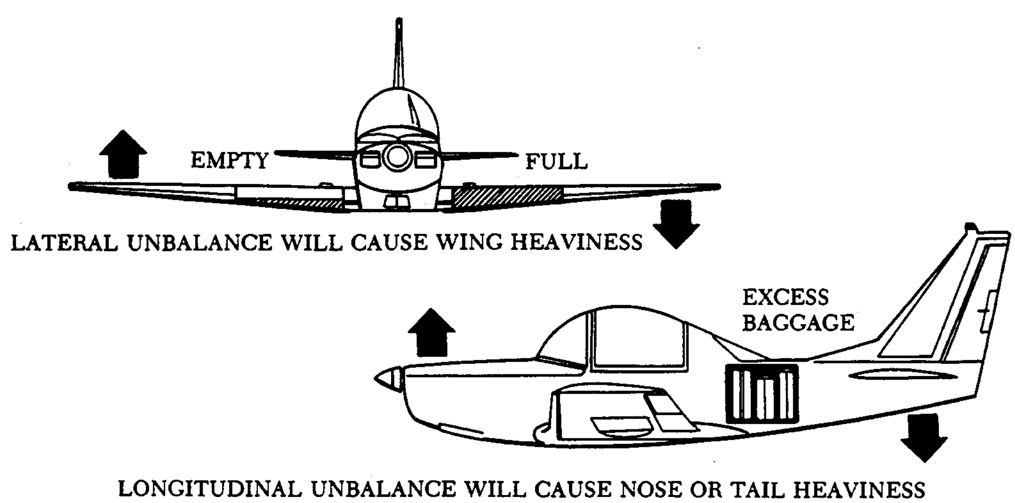


FIGURE 3. Lateral or longitudinal unbalance.

are two essential airplane attributes which may be seriously reduced by improper balance; these are *stability and control.* Loading in a nose-heavy direction causes problems in controlling and raising the nose, especially during takeoff and landing. Loading in a tail-heavy direction has a most serious effect upon longitudinal stability even to the extent of reducing the airplane's ability to recover from stalls and spins.

Limits for the location of the aircraft's c.g. are established by the manufacturer. These are the fore and aft limits beyond which the c.g. should not be located for flight. The limits are published for each aircraft in the FAA Aircraft Type Certificate Data Sheets or Specifications. If, after loading, the c.g. does not fall within the allowable limits, it will be necessary to shift loads before flight is attempted.

The forward c.g. limit is often established at a location determined by the landing characteristics of the aircraft. It may be possible to maintain stable and safe cruising flight with the c.g. ahead of the prescribed forward limit, but since landing is one of the most critical phases of flight, the forward c.g. limit is placed at a relatively rear position to avoid damage to the aircraft structure when landing (fig. 4).

FIGURE 4. Forward c.g. critical on landing.

A restricted forward c.g. limit is also specified to assure that sufficient elevator deflection is available at minimum airspeed. When structural limitations or large stick forces do not limit the forward c.g. position, it is located at the position where full-up elevator is required to obtain a high angle of attack for landing.

The aft c.g. limit is the most rearward position at which the c.g. can be located for the most critical maneuver or operation. As the c.g. moves aft, a less stable condition occurs, which decreases the ability of the aircraft to right itself after maneuvering or after disturbances by gusts (fig. 5).

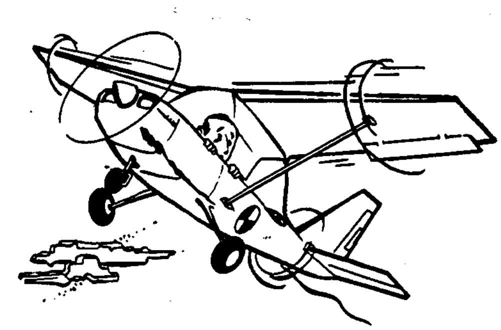
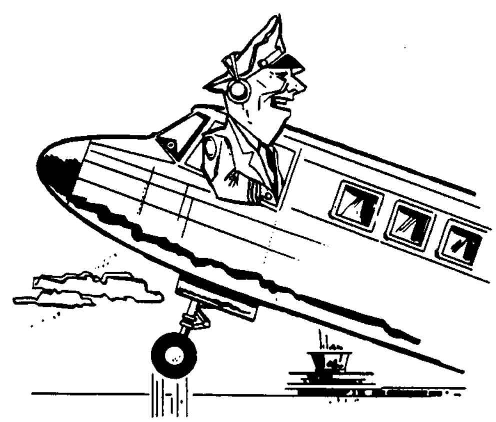


FIGURE 5. Aft c.g. critical in a stall.

For some aircraft, the c.g. limits, both fore and aft, may be specified to vary as gross weight changes. They may also be shifted for certain operational procedures, such as acrobatic flight, retraction of the landing gear, or the installation of special loads and devices that change the flight characteristics.

The actual location of the c.g. can be altered by many variable factors—usually under control of the pilot. Placement of baggage and cargo items can both determine c.g. and be used to control c.g. In addition, the assignment of seats to particular passengers can be used as a means of obtaining the most favorable balance (fig. 6). If the aircraft is tailheavy, it is only logical "horse sense" to place a heavy passenger in a front seat.

The loading and selective use of fuel from various tank locations can have a decided effect on aircraft



ALL PASSENGERS
MOVE TO THE FRONT OF THE AIR-BUS, *PLEASE!!*

FIGURE 6. If tailheavy, move passengers to front seats.

balance. Large aircraft must have fuel loaded in a particular manner determined by the total load, and then the tanks must be selected in a sequence that will keep the load in balance. Swept-wing aircraft have special problems along these lines. Fuel in outboard tanks has a tendency to rotate the aircraft in a tail-heavy direction and fuel in inboard tanks adds to a nose-heavy condition (fig. 7). The use of fuel from swept-wing tanks must be carefully managed to keep c.g. under control.

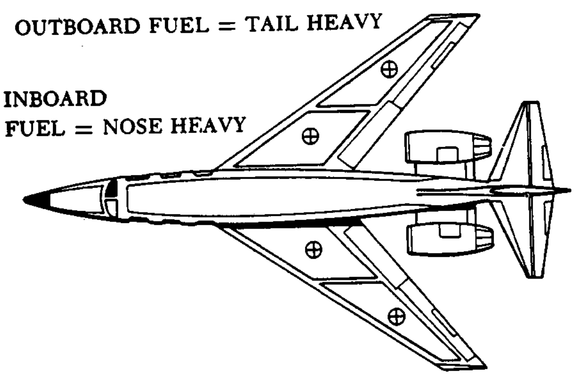


FIGURE 7. Effect of fuel in swept-wing aircraft.

SHIFTING OF LOOSE CARGO

The shifting of cargo or baggage during flight can result in several hazards, not the least of which is a dangerous balance condition. If the c.g. of an aircraft is already near the forward or aft limit, a significant longitudinal shift of cargo may make control difficult or impossible. This hazard is most likely to occur in aircraft having cargo poorly secured in the main cabin. Particular care must be taken to restrain this type load with proper tiedown devices.

MANAGEMENT OF WEIGHT AND BALANCE CONTROL

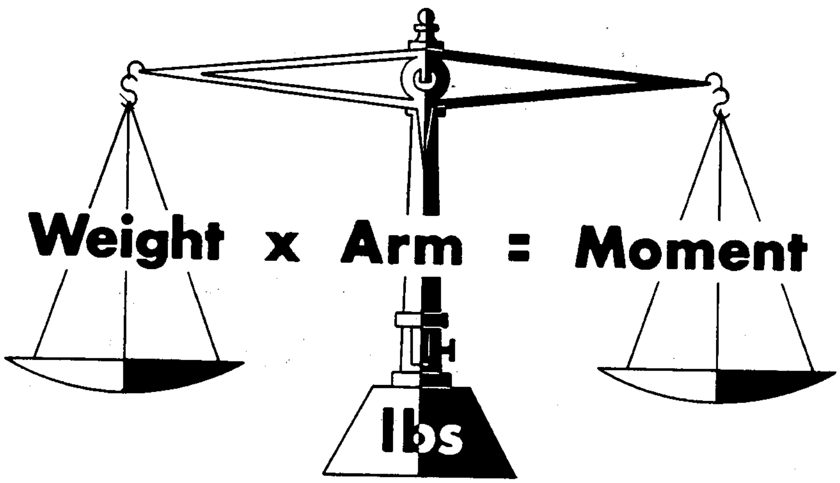
Weight and balance control is a matter of serious concern to all pilots and to many people on the ground who are involved in the support of flight. The pilot has control over the loading and fuel management within established limits for the particular aircraft. The pilot has weight and balance information available in the form of aircraft records and operating handbooks. Loading information is also available in the form of placards in baggage compartments and on tank caps. The aircraft owner or operator should make certain that up-to-date information is available in the aircraft for the pilot's use.

The owner or operator of the aircraft should insure that maintenance personnel make appropriate entries in the aircraft records when repairs or modifications have been accomplished. Weight changes must be accounted for and proper notations made in weight and balance records. Without such notations, the pilot has no foundation upon which to base calculations and decisions.

The aircraft manufacturer and the FAA (Federal Aviation Administration) have major roles in designing and certificating the aircraft with a safe and workable means of controlling weight and balance. If the prototype aircraft has weight and balance control problems which are potentially dangerous, design changes are made before the aircraft is type certificated.

Chapter 2

TERMS AND DEFINITIONS



The student of weight and balance needs to be familiar with terms used in publications related to many aspects of the subject. These terms are fairly well standardized; however, terms related to general aviation aircraft do not always apply to air carrier aircraft. Where there is a difference, the following definitions will indicate to which type of aircraft the term applies.

1. **Arm (moment arm)**—is the horizontal distance in inches from the reference datum line to the center of gravity of the item. The algebraic sign is plus (+) if measured aft of the datum, and minus (−) if measured forward of the datum.
2. **Center of gravity (c.g.)**—is the point about which an aircraft would balance if it were possible to suspend it at that point. It is the mass center of the aircraft, or the theoretical point at which the entire weight of the aircraft is assumed to be concentrated. It may be expressed in percent of MAC (mean aerodynamic chord) or in inches from the reference datum.
3. **Center of gravity limits**—are the specified forward and aft or lateral points beyond which the c.g. must not be located during takeoff, flight or landing. These limits are indicated on pertinent FAA aircraft type certificate data sheets, specifications, or weight and balance records, and meet the requirements of Federal Aviation Regulations.
4. **Center of gravity range**—is the distance between the forward and aft c.g. limits indicated on pertinent aircraft specifications.
5. **Datum (reference datum)**—is an imaginary vertical plane or line from which all measurements of arm are taken. The datum is established by the manufacturer. Once the datum has been selected, all moment arms and the location of permissible c.g. range must be taken with reference to that point.
6. **Delta**—is a Greek letter expressed by the symbol Δ. It is used in weight and balance calculations, as well as in other forms of mathematics, to indicate a change of values. As an example, Δ c.g. indicates a change (or movement) of the c.g.
7. **Fuel load**—is the expendable part of the load of the aircraft. It includes only usable fuel, not fuel required to fill the lines or that

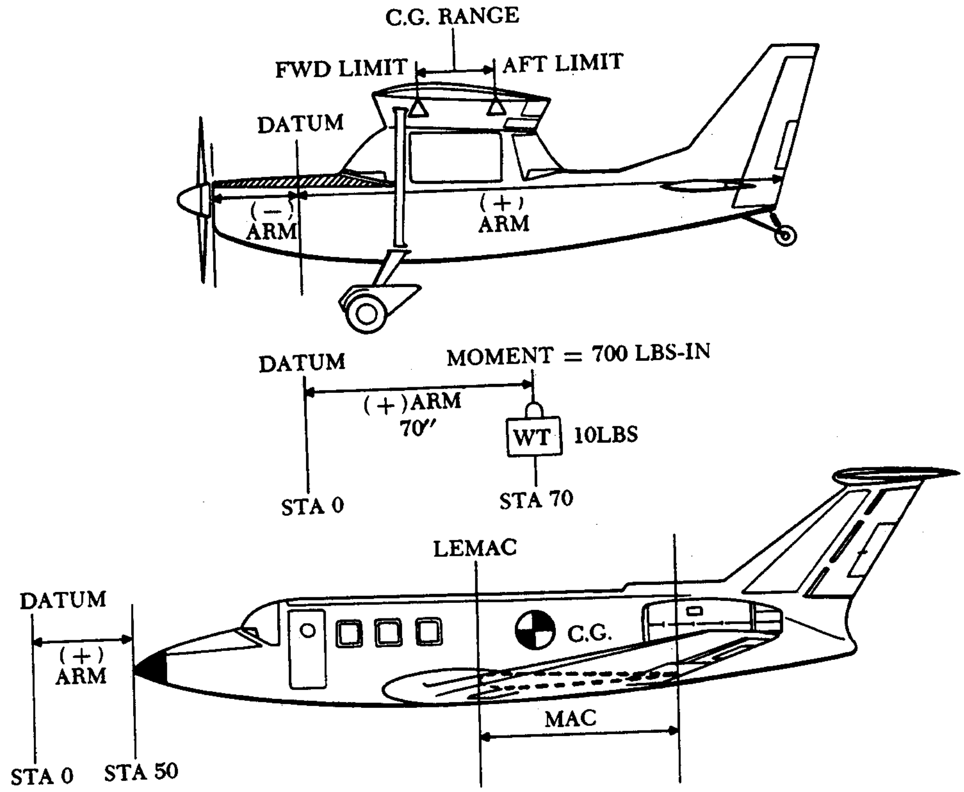


FIGURE 8. Definitions.

which remains trapped in the tank sumps.

8. **LEMAC**—is the leading edge of the mean aerodynamic chord.

9. **Moment**—is the product of the weight of an item multiplied by its arm. Moments are expressed in pound-inches (lb.-in.) or inch-pounds. Total moment is the weight of the aircraft multiplied by the distance between the datum and the c.g.

10. **Moment index (or index)**—is a moment divided by a constant such as 100, 1,000, or 10,000. The purpose of using a moment index is to simplify weight and balance computations of large aircraft where heavy items and long arms result in large, unmanageable numbers.

11. **Mean aerodynamic chord (MAC)**—is the average distance from the leading edge to the trailing edge of the wing. The MAC is specified for the aircraft by determining the average chord of an imaginary wing which has the same aerodynamic characteristics as the actual wing.

12. **Reduction factor**—is the constant which when divided into a moment results in an index. Reduction factors of 100, 1,000, or 10,000 are used to simplify weight and balance calculation processes.

13. **Standard weights**—have been established for numerous items involved in weight and balance computations. These weights are not to be used in lieu of available actual weights. Standard passenger weights should not be used in computing the weight and balance of charter flights and other special services involving the carriage of special groups; e.g., athletic groups, small foreign nationals, etc. Some of the standard weights are:

General aviation — crew and passenger	170 lb.
Air carrier — passenger (summer)	160 lb.
Air carrier — passenger (winter)	165 lb.
Air carrier — male cabin attendant	150 lb.
Air carrier — female cabin attendant	130 lb.
Air carrier — all other crewmembers	170 lb.
Air carrier — carry-on baggage	5 lb.
Gasoline	6 lb./U.S. gal.
Oil	7.5 lb./U.S. gal.
Water	8.35 lb./U.S. gal.
Jet fuel	6.7 lb./U.S. gal.

14. Station—is a location in the aircraft which is identified by a number designating its distance in inches from the datum. The datum is, therefore, identified as station zero. The station and arm are usually identical. An item located at station +50 would have an arm of 50 inches.

15. Useful load—is the weight of the pilot, copilot, passengers, baggage, usable fuel, and drainable oil. It is the empty weight subtracted from the maximum allowable takeoff weight. This term applies to general aviation aircraft only.

16. Weight, basic operating—is the weight of the aircraft, including the crew, ready for flight but without payload and fuel. This term is only applicable to transport aircraft.

17. Weight, empty—consists of the airframe, engines, and all items of operating equipment that have fixed locations and are permanently installed in the aircraft. It includes optional and special equipment, fixed ballast, hydraulic fluid, and undrainable (residual) fuel and oil. When oil is used for propeller feathering, such oil is included as residual oil.

18. Weight, maximum landing—is the maximum weight at which the aircraft may normally be landed. The maximum landing weight may be limited to a lesser weight when runway length or atmospheric conditions are adverse.

19. Weight, maximum takeoff—is the maximum allowable weight at the start of the takeoff run. Some aircraft are approved for loading to a greater weight (ramp or taxi) only to allow for fuel burnoff during ground operation. The takeoff weight for a particular flight may be limited to a lesser weight when runway length, atmospheric conditions, or other variables are adverse.

20. Weight, maximum allowable zero fuel—is the maximum weight authorized for the aircraft not including fuel load. Zero fuel weight for each particular flight is the operating weight plus the payload.

21. Weight, ramp or taxi—is the maximum takeoff gross weight plus fuel to be burned during taxi and runup.

AIRCRAFT WEIGHT NOMENCLATURE

(Transport Aircraft)

	Term	*Example (pounds)*	*Notes*
	Empty weight	65,000	Includes: Basic structure, hydraulic fluid, air conditioning fluid, and residual fuel and oil.
+	Operating items	5,000	Includes: Crew, crew luggage, oil, water, alcohol, and normal passenger service equipment.
=	Basic operating weight	70,000	
+	Payload	20,000	Includes: Passengers, baggage, and cargo.
=	Zero fuel weight	90,000	
+	Fuel load	31,000	Includes: All usable fuel.
=	Ramp or taxi weight	121,000	
−	Ramp fuel	1,000	Includes: Fuel used prior to takeoff.
=	Takeoff weight	120,000	
−	Fuel used	20,000	Includes: Fuel burned or dumped.
=	Landing weight	100,000	

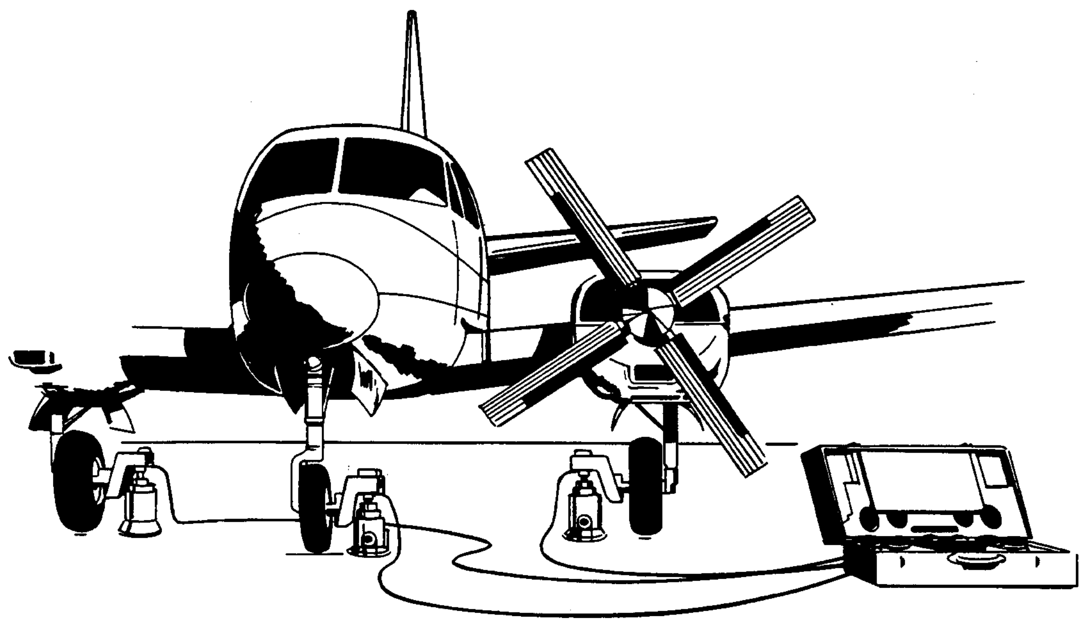
(General Aviation Aircraft)

	Empty weight	2,905	Includes: Airframe, engines, all fixed and permanent operating equipment, and residual fuel and oil.
+	Useful load	1,695	Includes: Pilot, copilot, passengers, baggage, fuel, and oil.
=	Takeoff weight	4,600	
−	Fuel used	460	Includes: Fuel burned.
=	Landing weight	4,140	

NOTE.—The weights above are used for illustration only. The actual values will vary for each aircraft and each flight.

Chapter 3

EMPTY WEIGHT CENTER OF GRAVITY



Weighing aircraft with accurately calibrated scales is the only sure method of obtaining an accurate empty weight and c.g. location. The use of weight and balance records in accounting for and correcting the aircraft weight and balance location is reliable over certain periods of time. Over extended intervals, however, unknown service weight pickup and other factors will render the basic weight and c.g. data inaccurate. For this reason, periodic aircraft weighings are desirable. Aircraft may also be weighed when major modifications or repairs are made, when the pilot reports unsatisfactory flight characteristics such as nose or tail heaviness, and when recorded weight and balance data are suspected to be in error. The pilot or owner may never actually weigh an aircraft but he should be aware of the general procedure and requirements.

WEIGHING EQUIPMENT

The type of equipment which is used to weigh aircraft will vary with the aircraft size. Light aircraft may be weighed on commercial type platform scales. Large aircraft are usually weighed with electronic weighing sets (fig. 9). In any case, the individual scale or the electronic cell should have a capacity rating suitable for the size of the aircraft—for instance, three scales with 5,000 lb. ratings would be suitable to weigh a 10,000 lb. aircraft while an electronic cell set with cells of 50,000 lb. capacity would be needed for a 100,000 lb. aircraft. Only weighing equipment that is maintained and calibrated to acceptable standards should be used to weigh aircraft.

Jacks are ordinarily used for leveling an aircraft. Care should be taken to use jacks of sufficient capacity and extension for the particular aircraft. Adapters for jack points or blocks for wheels are necessary to prevent the aircraft from moving or falling when it has been raised off the ground. Accurate spirit levels are used to assure that the aircraft is in a level position. Large aircraft are often checked

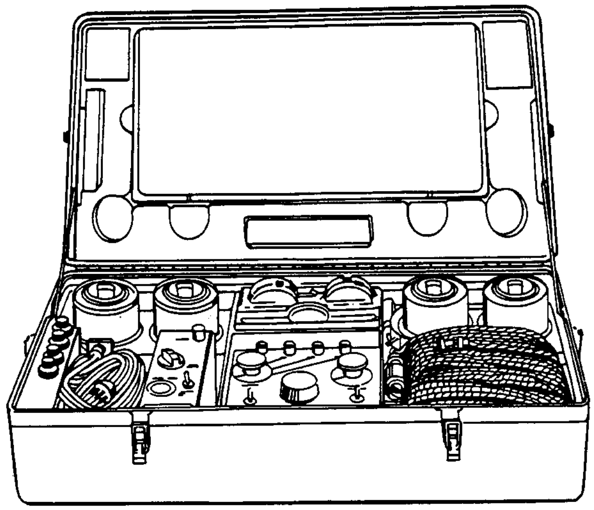


FIGURE 9. Electronic weighing kit.

for level by the use of a surveyor's transit. Plumb bobs, straight edges, and chalk lines are some other items of auxiliary equipment used during the weighing process.

WEIGHING PROCEDURE

The aircraft should be weighed in accordance with instructions in the manufacturers' manuals or other pertinent technical data. Typical procedures include:

a. The aircraft should be cleaned inside and out.
b. The aircraft equipment should be checked against the equipment list section of the weight and balance record (fig. 21). This list should have been updated to account for all equipment changes made after the list was initially established by the manufacturer. All items which are not included as fixed equipment on the updated list should be removed for the empty weight check.
c. Fuel tanks should be drained in accordance with the manufacturer's instructions. In lieu of specific instructions, the tanks can be drained until the tank quantity gauges read "zero" or empty in level flight attitude. The amount of fuel remaining in the tanks, lines, and engines is termed "residual fuel" and it is to be included in the empty weight. In certain cases, it may not be feasible to drain the fuel tanks; if this is so, fill the tanks to capacity. The weight of the fuel in the tanks should then be calculated and later subtracted from the total weight to obtain the empty weight.
d. Unless otherwise noted in the aircraft specification, the oil system should be completely drained through the normal drain ports. Under these conditions, the amount of oil remaining in the tanks, lines, and engine is termed "residual oil" and it will be included in the empty weight. When the aircraft is weighed without draining the oil, the tanks should be filled to capacity. The oil weight can then be calculated at a standard weight of 7.5 lbs./gal.
e. Reservoirs or tanks containing hydraulic fluid, anti-icing fluid and other liquids which are considered part of the empty weight should be filled to capacity.
f. Generally, all aircraft are weighed in a level position. This means the aircraft is placed in an attitude in which its longitudinal and lateral axes are parallel to a horizontal surface. Leveling devices such as leveling lugs and jig-located brackets and plates have been accurately installed on the aircraft by the manufacturer to facilitate the leveling procedure. The methods used to level specific aircraft vary with the type of aircraft and the leveling instructions provided by the manufacturer.
   1. Jacks which are used for leveling should never be employed on the aircraft other than at the specified jacking points. If wing and fuselage jacks are used to level the aircraft, it may be necessary to prevent the gear shock struts from extending when the aircraft is raised. The manufacturer's instructions will indicate the appropriate procedures in this case.
   2. During the leveling procedure, extreme care should be exercised to avoid side loads which may cause the aircraft to slip off the jacks. When raising the aircraft with two wing or two main landing gear jacks, they should be actuated simultaneously in order to maintain the aircraft in a laterally level attitude. General instructions for various types of aircraft are as follows:
      (a) Nose wheel oleo struts or tires may be inflated or deflated to level the aircraft. They may also be used to obtain an approximately level position prior to jacking the aircraft.
      (b) A hoist or jack should be employed to level tail-wheel aircraft when the aircraft is too heavy to raise the tail manually.
      (c) Normally, the smaller type of rotary-

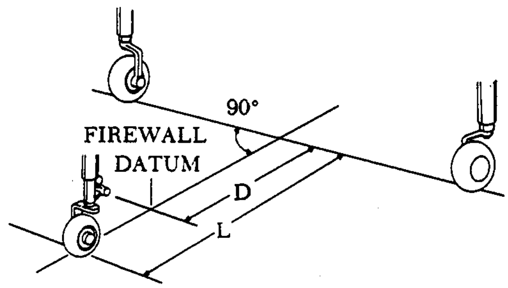


FIGURE 10. Measurement of reaction points.

wing aircraft incorporating skids rest in approximately level position. Larger rotary-wing aircraft with oleo struts may be placed in the level position by inflating or deflating the struts.

(d) A float plane may be weighed by placing the floats on four scales with suitable blocks to obtain concentrated reaction points. Care must be taken to prevent damage to the floats from this concentrated loading. Ordinarily, the normal landplane leveling points are used. The floats are not necessarily level. Amphibians can be weighed with the landing gear down and on the scales.

g. Once the aircraft is in the level position, it is necessary to measure and record dimensions. Three horizontal dimensions need to be measured to determine the horizontal location of the c.g. of the aircraft as weighed. In some cases, these dimensions can be obtained from aircraft records. When the landing gear wheels are used as weighing (reaction) points, the three dimensions to be determined are as follows (see fig. 10):

1. The horizontal distance from the reference datum to some known jig point. This dimension, for small aircraft, is usually zero because the reference datum is an easily identified location, such as the firewall or wing leading edge. It is particularly important to determine such a dimension if the datum is located ahead of the nose of the aircraft.
2. The distance from the jig point to a lateral line passing through the main gear reaction points. This measurement should be made along a line which is parallel to the longitudinal axis of the aircraft.
3. The wheel base or distance between the main and forward or aft reaction points.

Measuring these distances can be accomplished by projecting the required points to the hangar floor. To project the jig point to the hangar floor, a plumb bob may be suspended from the center of the jig point so that the plumb bob is approximately one-half inch above the floor. When the swing of the bob dampens, a cross mark is made on the floor directly under the tip of the plumb bob. The main reaction points are projected to the floor in the same manner. After marking the crosses for the two main gear points, a chalked string is stretched between them. The string is then snapped to the floor, leaving a clear straight chalkline between the main reaction points. The nose or tail reaction point is projected to the hangar floor in a similar manner (fig. 10).

After these points are projected to the floor it is a simple matter to measure the required dimensions. When measuring these distances, it is necessary that the tape be parallel to the centerline of the aircraft. Measurements made from the main reaction points

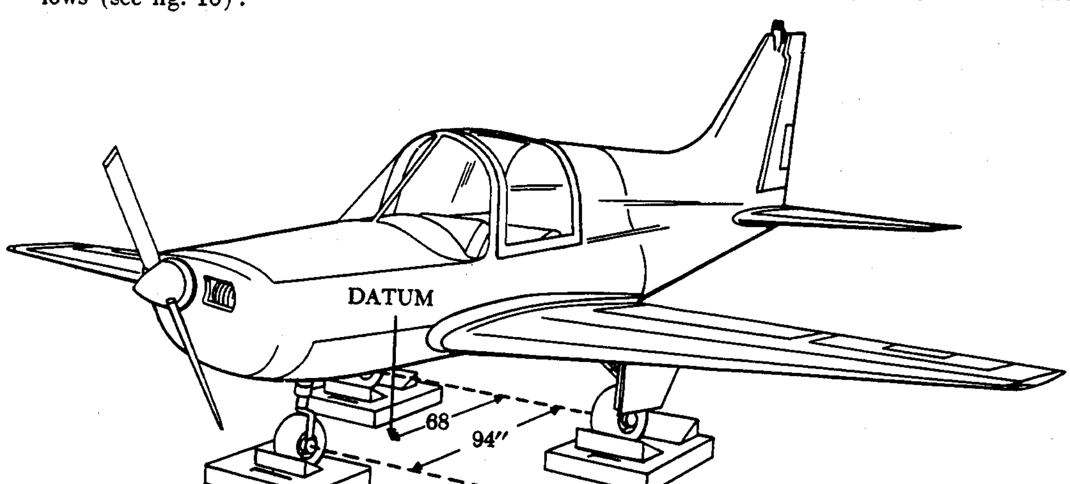


FIGURE 11. Weighing aircraft on platform scales.

are taken perpendicular to the chalkline joining these two points. When fuselage and wing jack points are used as reaction points in weighing the aircraft, it is unnecessary to measure dimensions. These points will remain fixed and their moment arms may be found in the aircraft records. Care must be taken to use the fixed reaction points indicated in the records for the particular aircraft being measured. Because of manufacturing tolerances, and minor model changes, the fixed reaction points are not necessarily identical for all aircraft of a particular type.

Weighing procedures may vary with the aircraft and the type of weighing equipment employed. The weighing procedures contained in the manufacturers' manuals should be followed for each particular aircraft. The following general instructions illustrate a common method and some of the typical precautions (see fig. 11):

a. Aircraft are weighed in closed hangars to avoid vibrations or lift forces which would otherwise be caused by air flowing over the lifting surfaces. Such vibrations or aerodynamic forces would result in fluctuating scale readings and increase the possibility of error.

b. The aircraft must be dry before it is weighed. An aircraft should never be weighed immediately after it has been washed.

c. The aircraft should be weighed in the level attitude. If the main wheels are used as reaction points, the brakes should not be set—resultant side loads on the scales or weighing units may cause erroneous readings.

d. The aircraft should be raised simultaneously on all reaction points, especially when using electronic weighing equipment. When the aircraft is supported at the weighing reaction points only, and is in the level position, scale readings may be obtained (fig. 11).

e. Several readings are taken for each reaction point and the average reading is entered on the aircraft weighing form.

f. Before the aircraft is lowered, it is necessary to make certain that all necessary measurements and scale readings have been obtained and recorded. The scales or cells should be rechecked for errors and compared to the calibration errors recorded before the weighing process. Appropriate calibration corrections or re-weighing may then be necessary.

g. When data for comparison is available, an attempt should be made to verify the results obtained from each weighing. Verification may be made by comparing results with a previous weighing of an aircraft of the same model.

FINDING CENTER OF GRAVITY

After the necessary dimensions and weights have been obtained, the empty weight and the empty c.g. can be calculated. Empty weight is the total of the three scale readings after subtracting the weight of tare items plus or minus calibration errors. This weight is important for subsequent calculation of maximum weight and also is a necessary factor in the determination of c.g.

Center of gravity computations may be accomplished by several methods. Fundamentally, the c.g. is the point at which all the weights of the aircraft can be considered to be concentrated. The average location of the weights can, therefore, be obtained by dividing the total moments (wt. × arm) by the total weight. The process then involves multiplying each measured weight by its arm to obtain a moment and adding the moments.

Example 1.

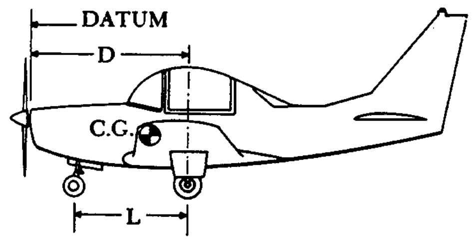
	Weight (lb.)	*Arm (in.)*	*Moment (lb.-in.)*
Right wheel ...	564	3	1,692
Left wheel	565	3	1,695
Rear wheel ...	40	225	9,000
Total ...	1,169		12,387

$$\frac{12{,}387}{1{,}169} = 10.6 \text{ in. aft of datum}$$

Extra care must be taken in these types of empty weight calculations if one or more of the arms is located ahead of the datum. In this event, the algebraic sign of the arm and moment will be negative. It should be remembered that a positive number (the weight) times a negative number (the arm) results in a negative number (the moment). Following the multiplication step, additional care must be taken when adding wheel moments to obtain total moments and when dividing total moments by total weight to obtain c.g. In all these mathematical operations, the significance of the algebraic sign must be observed.

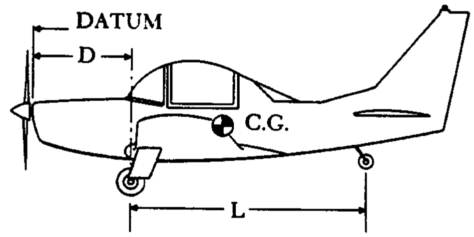
The c.g. can also be obtained by the use of a special formula:

$$\text{c.g.} = D + \frac{R \times L}{W}$$



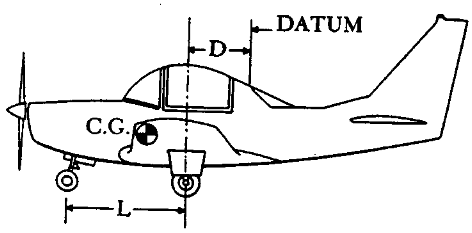
NOSE WHEEL TYPE AIRCRAFT
DATUM LOCATED FORWARD OF THE MAIN WHEELS

$$C.G. = D - \left(\frac{FxL}{W}\right)$$



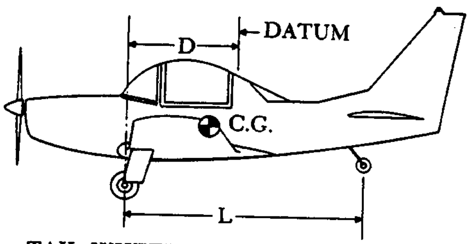
TAIL WHEEL TYPE AIRCRAFT
DATUM LOCATED FORWARD OF THE MAIN WHEELS

$$C.G = D + \left(\frac{RxL}{W}\right)$$



NOSE WHEEL TYPE AIRCRAFT
DATUM LOCATED AFT OF THE MAIN WHEELS

$$C.G. = -\left(D + \frac{FxL}{W}\right)$$



TAIL WHEEL TYPE AIRCRAFT
DATUM LOCATED AFT OF THE MAIN WHEELS

$$C.G. = -D + \left(\frac{RxL}{W}\right)$$

C.G. = Distance from datum to center of gravity of the aircraft.
W = The weight of the aircraft at the time of weighing.
D = The horizontal distance measured from the datum to the main wheel weighing point.
L = The horizontal distance measured from the main wheel weighing point to the nose or tail weighing point.
F = The weight at the nose weighing point.
R = The weight at the tail weighing point.

FIGURE 12. Empty weight c.g. formulas.

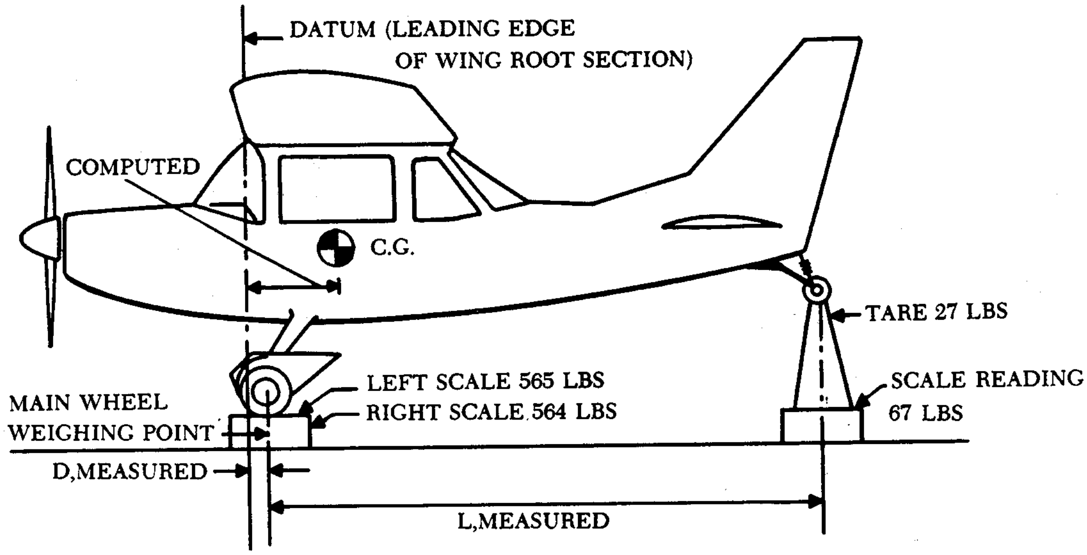
This formula and others which are applicable to nose-wheel aircraft and those with the datum located in an aft position are shown in figure 12, together with definitions of the symbols involved. The use of these formulas simplifies the calculations in several ways. In effect, the datum is mathematically moved to the main gear by this process, resulting in relatively small moments which are easy to handle in weight and balance calculations. A major benefit of the use of these formulas is the elimination of multiplication steps that involve negative arms and negative moments.

A solution to the problem in example 1 by use of the c.g. formula is shown in figure 13. The answer is the same but the process is somewhat simplified because the step of multiplication of each weight and arm has been eliminated. The solution shown in figure 13 shows how the information is entered in the empty weight c.g. part of a weight and balance report form.

An aeronautical computer (fig. 14) can be used to further simplify the problem when the formula is converted into a proportion form:

Example 2.

The computer solution (7.6 in.) is then added to the



TO FIND: EMPTY WEIGHT AND EMPTY WEIGHT CENTER OF GRAVITY

GIVEN: Datum is the leading edge of the wing.

D, Measured distance from main wheel to datum = 3″

L, Measured distance from main to tail wheel = 222″

SOLVING: EMPTY WEIGHT

Weighing Point	*Scale Reading*	*Tare*	*Net Weight*
Right	564	0	564
Left	565	0	565
Rear	67	27	40
Empty Weight (W)			1169

SOLVING: EMPTY WEIGHT CENTER OF GRAVITY

$$C.G. = D + \left(\frac{R \times L}{W}\right)$$

$$= 3 + (40 \times 222/1169)$$

$$= 3 + 7.6$$

$$= 10.6''$$

FIGURE 13. Empty weight and empty weight c.g.

$$\frac{\text{TAIL WHEEL WEIGHT}}{\text{TOTAL WEIGHT}} = \frac{\text{DISTANCE FROM MAIN WHEEL TO C.G.}}{\text{DISTANCE BETWEEN MAIN AND TAIL WHEEL}}$$

SETUP THESE NUMBERS $\frac{40}{1169}$ READ ANSWER ON OUTER SCALE $\frac{7.6}{222} = 7.6$

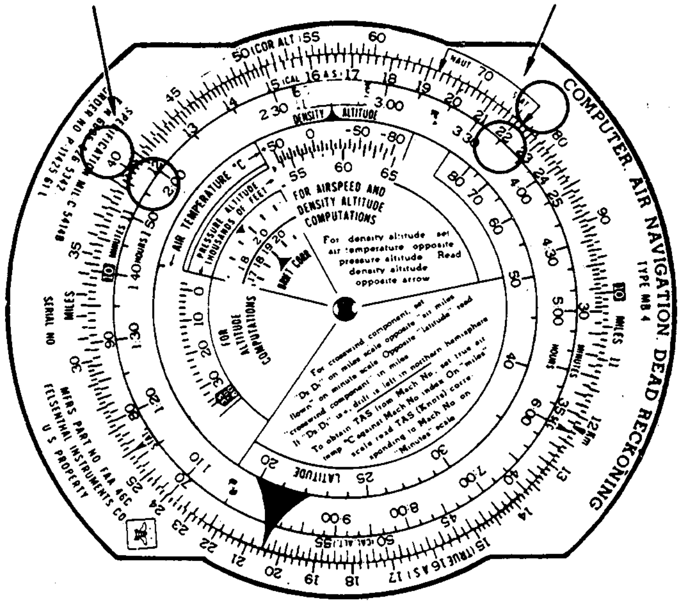


FIGURE 14. Computer solution—empty weight c.g.

arm of the main wheels (3 in.) to obtain the c.g. location (10.6 in.) aft of datum.

PERCENT OF MEAN AERODYNAMIC CHORD (MAC)

Expression of the c.g. relative to the MAC is a common practice. The c.g. position is expressed as a % MAC (percent of the mean aerodynamic chord) and the c.g. limits are expressed in the same manner (fig. 15).

The relative positions of the c.g. and the aerodynamic center or center of lift of the wing have critical effects on the flight characteristics of the aircraft. Consequently, relating the c.g. location to the chord of the wing is convenient from a design and operations standpoint. Normally, an aircraft will have acceptable flight characteristics if the c.g. is located somewhere near the 25% average chord point. This means the c.g. is located one-fourth of the total distance back from the leading edge of the average wing section. Such a location will place the c.g. forward of the aerodynamic center for most airfoils.

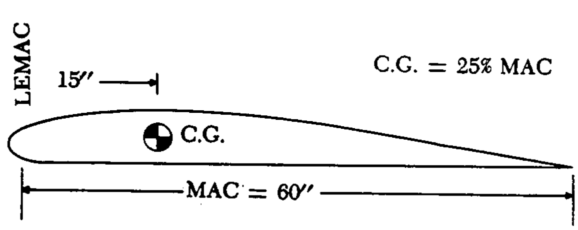


FIGURE 15. Percent of mean aerodynamic chord.

The mean aerodynamic chord is established by the manufacturer. If the wing is not swept and has a constant chord, the straight line distance from leading edge to trailing edge (the chord) would also be the MAC. However, if the wing is swept or tapered, the mean aerodynamic chord is more complicated to define, and the manufacturer's description is the only reliable description for weight and balance purposes. The MAC can be defined as the "chord of an imaginary airfoil which has the same aerodynamic characteristics as the actual airfoil."

In summary, the MAC is established by the manufacturer who defines its leading edge (LEMAC) and its trailing edge in terms of inches from datum. The c.g. location and various limits are then expressed in percentages of the MAC. The following are typical computations to use in finding the c.g. location in relation to MAC:

Example 3.

Given:

MAC—Sta. 100 to Sta. 250

c.g.—Sta. 130

Find: c.g. in % MAC

Solution:

1. MAC=250−100=150 in.
2. Distance of c.g. from LEMAC=130−100=30 in.
3. c.g. in % MAC

$$=\frac{\text{Distance of c.g. from LEMAC}}{\text{MAC}}$$

$$=\frac{30}{150}=20\%\ \text{MAC}$$

Use the following method to convert locations expressed in % MAC to locations expressed in inches from datum:

Example 4.

Given:

MAC—170 in.

LEMAC—Sta. 500

c.g.—27.5% MAC

Find: c.g. in inches from datum

Solution:

1. MAC×% MAC=inches aft of LEMAC
   170×.275=46.75 in.
2. LEMAC+46.75=c.g. aft of datum
   500+46.75=546.75 in.

Proportion formulas can be readily adapted to the conversion of % MAC to inches from datum.

A typical problem solved by the use of a proportion formula follows:

Example 5.

Given:

c.g.—Sta. 410.2

MAC—180 in.

Leading adge of MAC (LEMAC)—Sta. 390

Find: c.g. in % MAC

Solution:

1. Use the proper proportion formula:

$$\frac{\text{c.g. in inches from LEMAC}}{\text{c.g. in \% MAC}}=\frac{\text{MAC}}{100\%}$$

$$\frac{410.2-390}{\text{c.g. in \% MAC}}=\frac{180}{100\%}$$

$$\frac{20.2}{\text{c.g. in \% MAC}}=\frac{180}{100}$$

2. Cross multiply:
   180 c.g. in % MAC=2020
3. Divide both sides of the equation by 180
4. c.g. in % MAC=11.2%

NOTE.—Steps 2 and 3 can be eliminated by the use of an aeronautical computer to solve the proportion in step 1 (fig. 16).

With the use of the proportion formula presented above, the expression of a location can be easily changed from % MAC to "inches from datum." The following example illustrates a typical problem with a computer solution.

Example 6.

Given:

c.g.—20% MAC

MAC—175 in.

LEMAC—Sta. 380

Find: c.g. in inches from datum

Solution:

1. Set up the proportion on the computer (fig. 17).
2. Add to LEMAC:
   380+35=415.0 in.

NOTE.—It is easy to check the computer solution (fig. 17) by arithmetical means. The arithmetical solution is:

1. MAC×% MAC:
   175×.20=35.0 in. (c.g. aft of LEMAC)
2. Add to LEMAC:
   380+35.0=415.0 in.

FAA written tests often make use of a graphic presentation of the information needed to solve center of gravity problems (fig. 18). The following is a typical example which combines some of the principles explained in this chapter:

Example 7.

Given: The aircraft in figure 18 was weighed in the empty weight condition and was found to have the following readings at the three scales:

	Pounds
Nose wheel weight	20,500
Right wheel weight	70,000
Left wheel weight	70,500

Find: The c.g. location expressed in % MAC.

Solution:

1. Find c.g. in inches from datum using proportion formula:

$$\frac{\text{Nose wheel weight}}{\text{Total weight}}=\frac{\text{Distance from main wheel to c.g.}}{\text{Distance between main and nose wheels}}$$

$$\frac{20.500}{161,000}=\frac{\text{Distance from main wheel to c.g.}}{480\text{ in.}}$$

$$=61.1\text{ in.}$$

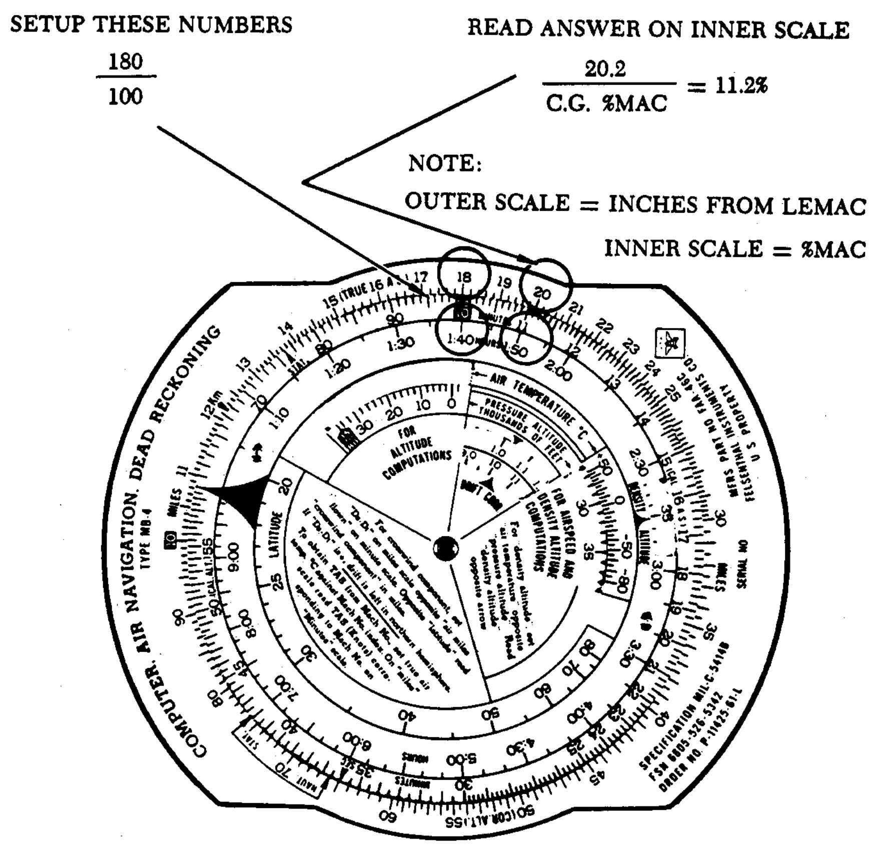


FIGURE 16. Computer solution—c.g. in percent MAC.

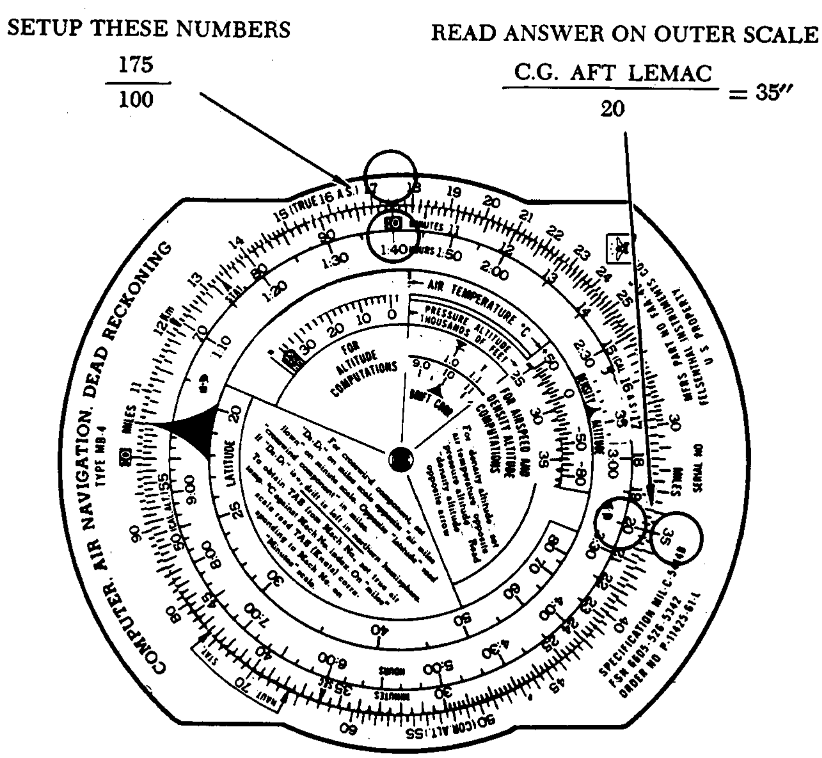


FIGURE 17. Computer solution—converting percent MAC to inches.

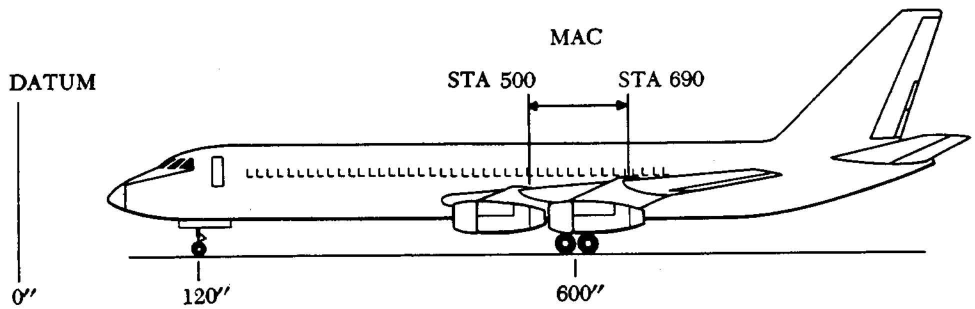


FIGURE 18. Large airplane weight and balance calculation diagram.

2. 600.0 − 61.1 = 538.9 in. aft of datum.
3. 538.9 − 500 = 38.9 in. aft of LEMAC.
4. Convert to % MAC by using the proportion formula (see example 5):

$$\frac{38.9 \text{ in.}}{\% \text{ MAC}} = \frac{190}{100\%}$$

$$\text{c.g. in } \% \text{ MAC} = 20.5\%$$

By using information on the diagram (fig. 18), we can determine c.g. limits in inches from datum when they are expressed in % MAC.

Example 8.

Given: The aircraft illustrated in figure 18 has its forward c.g. limit located at 12% MAC and its rearward c.g. limit located at 32% MAC.

Find: What are the c.g. limits of this aircraft in inches from datum?

Solution:

1. Multiply MAC times the given percentages (in decimal form):

   190 × .12 = 22.8 in.

   190 × .32 = 60.8 in.

2. Add to LEMAC:

Forward limit (500 + 22.8) = 522.8 in. aft of datum.

Aft limit (500 + 60.8) = 560.8 in. aft of datum.

AIRCRAFT MODIFICATIONS

After alteration of an aircraft or after the removal or installation of equipment, it is necessary to establish that the authorized weight and c.g. limits as shown on the FAA aircraft type certificate data sheet or specification are not exceeded when the aircraft is properly loaded. The owner should assure that this determination has been made and that the repair agency has entered appropriate changes in the weight and balance records of the aircraft. If equipment alterations are made without preparation of weight and balance records, all subsequent calculations by operating personnel would be in error. The effect of weight and balance calculation errors upon the safety of flight is potentially tragic; therefore, strict adherence to regulations and ethical practices by the owner and repair agency is essential.

The original basis for weight and balance calculations pertaining to alterations of the aircraft are the FAA aircraft type certificate data sheets or specifications. They provide the essentials for calculation of c.g. changes due to aircraft modifications: weights, arms, and limitations. These essentials are illustrated in the excerpts from a typical FAA aircraft type certificate data sheet shown in figure 19. It should be noted that all details listed in the type certificate data sheet may not be appropriate for an aircraft which has been modified.

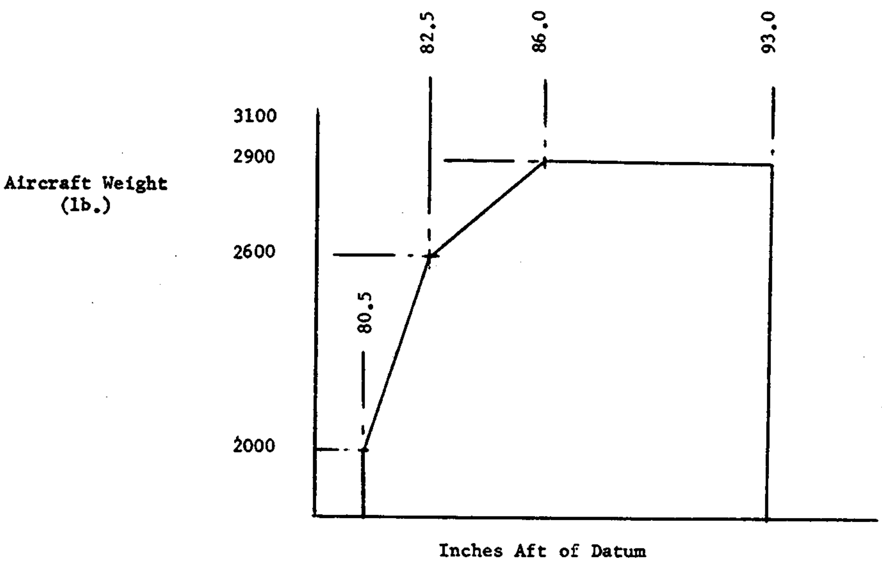
The manufacturer is required to provide documents which show the certificated empty weight and c.g. for each new aircraft. This weight and balance data may also include a schematic diagram which illustrates the fixed dimensions for all aircraft of the particular model (see fig. 20). The continued validity of weight and balance records during the life of the aircraft depends upon the maintenance of a series of similar documents which show the calculations for each successive weight change. This series of documents starts with the manufacturer's data and continues in chronological order to the latest weight and balance report. When a new weight and balance report is prepared for an aircraft, the previous report should be marked superseded and reference the date of the new document. This would preclude the necessity to search for the current report.

Data prepared by the repair agency for each modification should indicate that the maximum weight of the aircraft will be within the maximum allowable weight with anticipated loads. The new empty weight is derived from the empty weight recorded on the most recent weight and balance report plus the weight of the items added, minus the weight of items removed. When load items are added to this new empty weight, the total weight can be compared to the limit listed in the aircraft specifications.

IV - Model PA-24-260, 4 PCLM (Normal Category) Approved June 19, 1964

Engine	Lycoming O-540-E4A5 (See Item 109(f) for optional engines)			
Fuel	91/96 min. grade aviation gasoline			
Engine limits	All operations 2700 r.p.m. (260 hp.)			
Airspeed limits (CAS)	V_{ne}	Never Exceed	227 m.p.h.	(197 knots)
	V_{no}	Max. structural cruising	180 m.p.h.	(156 knots)
	V_{le}	Landing gear extended	150 m.p.h.	(130 knots)
	V_{p}	Maneuvering	144 m.p.h.	(125 knots)
	V_{fe}	Flaps extended	125 m.p.h.	(108 knots)

C.G. range (gear extended)
(+86.0) to (+93.0) at 2900 lb.
(+82.5) to (+93.0) at 2600 lb.
(+80.5) to (+93.0) at 2000 lb. or less
Straight line variation between points given.
Moment due to retracting of landing gear (1266 in.-lb.)

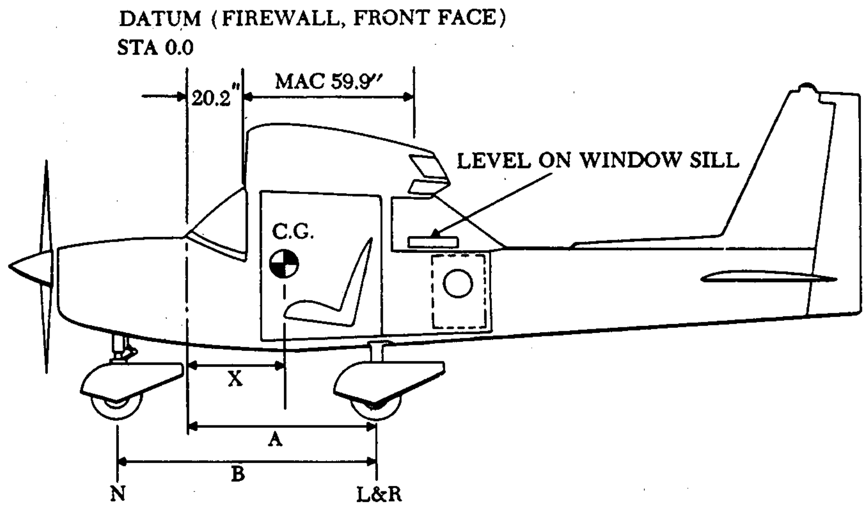


Empty Weight C.G. range	None
Maximum weight	2900 lb.
No. of seats	4 (2 at +85, 2 at +120.5)
Maximum baggage	200 lb. (Rear Compartment) (+142)
Fuel capacity	56 gal. (Two 28 gal. wing tanks) (+90) (See Note 1 for unusable fuel) (See Item 112 for auxiliary fuel tanks)
Oil capacity	3 gal. (+28)

NOTE 1. Current weight and balance report including list of equipment included in certificated empty weight and loading instructions when necessary, must be provided for each aircraft at the time of original certification. The certificated empty weight and the corresponding center of gravity location must include unusable fuel (not included in fuel capacity) as follows:
24 lb. (+90) for Model PA-24-250 Serial Nos. 24-2563, 24-2844 and up and PA-24-260, and 36 lb. (+90) for Model PA-24-400, Serial Nos. 26-2 and up.

FIGURE 19. FAA aircraft type certificate data sheet excerpts.

WEIGHT AND BALANCE DATA



SCALE POSITION	SCALE READING	TARE	SYMBOL	NET WEIGHT
LEFT WHEEL			L	
RIGHT WHEEL			R	
NOSE WHEEL			N	
AIRCRAFT EMPTY WEIGHT (AS WEIGHED)			W	

$X = \text{ARM (C.G.)} = (A) - \frac{(N) \times (B)}{W}$ $\qquad X = (\quad) - \frac{(\quad) \times (\quad)}{(\quad)} = (\quad) \text{ IN.}$

FIGURE 20. Typical weight and balance data.

WEIGHT AND BALANCE REPORT

Detailed instructions on repair and alteration procedures are contained in Advisory Circulars 43.13–1A and 43.13–2. Generally, the repair agency should prepare weight and balance data to show that the aircraft does not exceed maximum weight limits, in various load combinations, after the alteration has been made. The owner should assure that the data has been provided by the repair agency.

The repair agency also includes in the weight and balance data, information showing that the c.g. of the aircraft (usually in the fully loaded condition) falls between the specified c.g. limits when loaded in one of the extreme conditions. The weight and balance extreme conditions represent the maximum forward and rearward c.g. position for the aircraft. The computations are known as the forward and rearward extreme conditions check.

When a forward extreme condition check is made, the objective is to establish that neither the maximum weight limit nor the forward c.g. limit listed in the aircraft specifications is exceeded. Normally, in the case of a four-place airplane, this check must be made assuming both front seats are occupied and the rear seats empty. If the baggage compartment is in the rear, it is also assumed to be empty. If the fuel tanks are located forward of the forward limit, they are assumed to be full. If they are located aft of the forward limit, they are assumed to be empty. However, a minimum fuel load is always included in the calculation. This minimum fuel load for a small aircraft with reciprocating engines is calculated by:

$$\text{Minimum fuel (lb.)} = \frac{\text{METO (maximum except takeoff) horsepower}}{2}$$

For jet engine aircraft, the minimum fuel for extreme conditions check is specified by the manufacturer.

When a rearward weight and balance check is made, the objective is to establish that neither the maximum weight limit nor the rearward c.g. limit listed in the aircraft specifications is exceeded. The

ITEM	CHK	DESCRIPTION	WT	ARM
001		Engine, Continental, 0-200-A	200.0	−18.5
002		Propeller, McCauley IA 100	20.0	−32.0
003		Spinner, Propeller	1.0	−34.5
003A		Spinner, Propeller, Large	2.0	−34.5
004		Generator, 35 Amp, 14 Volt	12.5	− 6.0
005		Regulator, Voltage, 35 Amp, 14 Volt	1.0	− 1.0
006		Battery, 12 Volt, 24 AH	24.5	− 4.5
007		Filter, Carburetor Air	0.5	−23.5
008		Heating System, Carburetor and Cabin	10.5	−20.0
009		Wheel, Brake & Tire Assy, (two), 6.00×6, 4 Ply Rating, Main	35.5	48.5
010		Wheel & Tire Assy, 5.00×5, 4 Ply Rating, Nose	9.0	−10.5

FIGURE 21. Typical equipment list.

loading conditions are obviously opposite to those used for the forward check. For a typical four seat airplane, the rearward check is made with one pilot, maximum rear passengers, maximum rear baggage, and full fuel loaded in tanks behind the rear c.g. limit. After making these checks, the repair agency completes records in the form of a weight and balance report, loading schedule, or placard to inform the owner and operator about the permissible load combinations.

A list of the equipment (fig. 21) included in the aircraft during calculation of the certificated empty weight may be found in either the approved airplane flight manual or the weight and balance report. The repair agency should enter in the weight and balance report all required, optional, and special equipment installed in the aircraft at the time of weighing and when equipment changes are made. The owner should assure that the person making an equipment change completes an entry on the equipment list to indicate items added, removed, or relocated. The entry should also include the date accomplished, identity of the person making the change, and certificate number of that person.

Suggested methods of tabulating the various data and computations for determining the c.g., in the empty weight condition and the forward and aft extreme loaded conditions, are given in figure 22.

Ballast is sometimes permanently installed for c.g. balance purposes as a result of installation or removal of equipment items and is not used to correct a nose-up or nose-down tendency of an aircraft. It is usually located as far aft or as far forward as possible in order to bring the c.g. position within acceptable limits with a minimum of weight increase.

WEIGHT AND BALANCE REPORT

EMPTY WEIGHT C.G.

	Scale	Tare	Net
Left Jack Point	514	2	512
Right Jack Point	515	2	513
Nose Wheel	70	0	70
			1095

$$C.G. = D - \frac{F \times L}{W} = +37.5 - \frac{(70x\ +58.5)}{1095}$$

$$C.G. = +37.5 - 3.7$$

$$C.G. = +33.8$$

WEIGHT AND BALANCE EXTREME CONDITIONS

	Forward Check			Rearward Check		
	Wt.	Arm	Mom.	Wt.	Arm	Mom.
Airplane Empty	1095	+33.8	37011	1095	+33.8	37011
Pilot	170	+39.0	6630	170	+39.0	6630
Passenger	-	-	-	170	+39.0	6630
Fuel	50	+42.0	2100	135	+42.0	5670
Oil	11	-12.0	-132	11	-12.0	-132
Baggage	-	-	-	120	+64.0	7680
	1326		45609	1701		63489

$$\frac{45609}{1326} = 34.4''$$

Most Forward C.G. Location

$$\frac{63489}{1701} = 37.3''$$

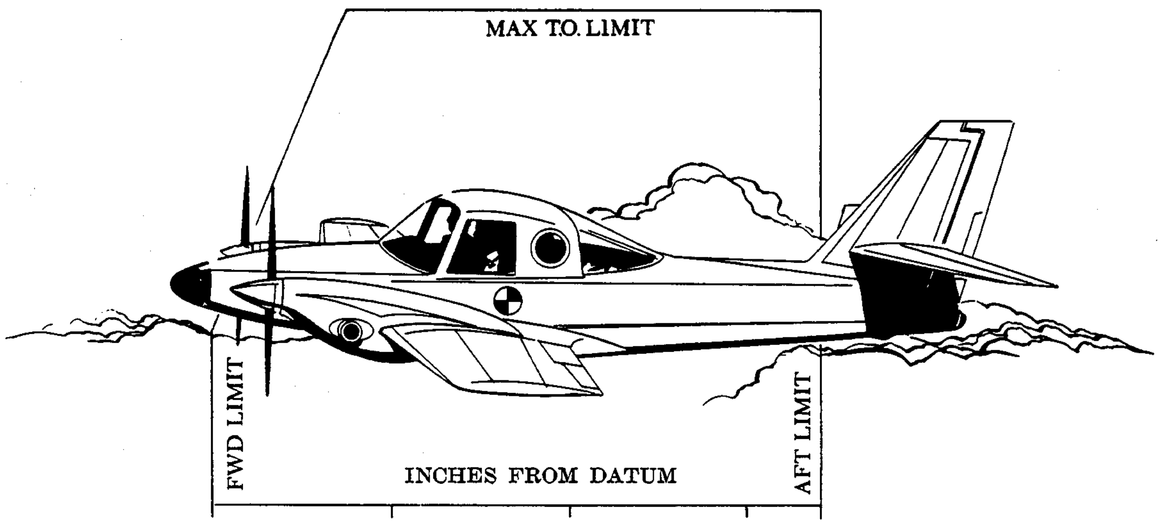
Most Rearward C.G. Location

Limits are 34.1" and 38.0"
Max. Weight - 1,750 Lbs.

FIGURE 22. Weight and balance report.

Chapter 4

INDEX AND GRAPHIC LIMITS



Aviation has been one of the most dynamic of industries since its beginning. New aircraft are continually being developed and always represent an improvement over older models. Improvements in design have, in many cases, tended to increase aircraft complexity. However, considerable effort has been spent to keep the new designs simple so that operations and maintenance procedures can be accomplished by the average airman. In accordance with this design philosophy, weight and balance engineers have developed some simplified methods, which they have applied to the weight and balance problems of most modern aircraft. Index numbers and graphic presentation of limits are features of simplified methods in common use.

INDEX NUMBERS

The use of index numbers and a reduction factor greatly simplifies weight and balance calculations, especially for large aircraft. The index is a moment divided by a reduction factor and may be found by this formula:

$$\text{Index} = \frac{\text{Weight} \times \text{Arm (moment)}}{\text{Reduction factor}}$$

The moments with which we are concerned on transport aircraft and the larger general aviation aircraft will be large numbers because of the large weights and arms which are involved. In a transport aircraft, a fuel tank located at station 500 which is loaded with 5,000 pounds of fuel would represent a moment of 2,500,000. This moment when divided (or reduced) by a reduction factor of 10,000 becomes a more manageable index of 250.0. The same problem exists to a smaller degree for general aviation aircraft. In this case, a reduction factor of 100 or 1,000 produces manageable numbers.

A simple way to change the moment into the index is to count the number of zeros in the reduction factor and move the decimal point of the moment the same number of places to the left.

Reduction factor—10,000 (4 zeros)
Moment —2,500,000 move the decimal point 4 places to the left
250.0000 = Index of 250.0

If the moment is a number with sufficient zeros, for instance a moment of 5,600,000, simply cross out the same number of zeros as you find in the reduction factor. For example:

Reduction factor—1,000 (3 zeros)
Moment —5,600,000 cross out 3 zeros
5,600,~~000~~ = Index of 5600

Follow the opposite procedure when changing from index numbers to moments:

Reduction factor—100 (2 zeros)
Index —321.2 move decimal 2 places to the right
32,120.0 = Moment of 32,120.0

You will notice that the simplified steps above would not be quite as easy if the reduction factors were not numbers such as 100, 1,000, or 10,000. If a reduction factor such as 7,750 were used, the process would be more complicated. Therefore, reduction factors are usually standardized to be either 100, 1,000, or 10,000 for a particular aircraft.

Reduction factors of 20,000 or 40,000 are used for some large aircraft in order to tailor the index numbers to a particular weight and balance system. When these reduction factors are used, the process of decimal point movement must be combined with a division or multiplication step.

Reduction factor—20,000 (4 zeros)
Moment —7,200,000—cross out 4 zeros and divide by 2

$$\frac{7{,}200{,}000}{2} = \text{Index of } 360.0$$

Reduction factor—30,000 (4 zeros)
Index —492.1—move decimal 4 places to the right and multiply by 3
4,921,000.0×3 = Moment of 14,763,000

It should be apparent that the index number system can be applied to total aircraft moments as readily as to individual load items. This principle is illustrated in the following example:

Example 9.

Given:

Aircraft total weight—105,000 lb.
c.g. (average arm) —Sta. 500
Reduction factor —10,000

Find: Total weight index

Solution:

$$\text{Use index formula} = \frac{\text{Weight} \times \text{Arm}}{\text{Reduction factor}}$$

$$\frac{105{,}000 \times 500}{10{,}000} = 5250.0$$

Total weight index = 5250.0

In typical problems involving index numbers, the weights and index numbers of particular aircraft load items are given and the fully loaded c.g. must be found.

Example 10.

Given:

Aircraft empty weight—65,000 lb.
Empty weight c.g. —Sta. 400.0
Reduction factor —10,000

Item	*Weight (lb.)*	*Index*
Crew	770	15.4
Full oil	900	27.0
Passengers	8,000	360.0
Baggage	1,000	45.2
Fuel	6,000	240.0

Find: What is the c.g. location when the aircraft is loaded with the items given above?

Solution:

1. Find empty weight index by use of formula:

$$\text{Empty weight index} = \frac{\text{Weight} \times \text{Arm}}{\text{Reduction factor}}$$

$$\text{Empty weight index} = \frac{65{,}000 \times 400.0}{10{,}000}$$

Empty weight index = 2600.0

2. Add loaded weights and index units.

Item	*Weight (lb.)*	*Index*
Aircraft empty	65,000	2600.0
Crew	770	15.4
Full oil	900	27.0
Passengers	8,000	360.0
Baggage	1,000	45.2
Fuel	6,000	240.0
Total	81,670	3287.6

3. Divide the index by the weight:

$$\frac{3287.6}{81{,}670} = .04025$$

4. To find c.g., move the decimal point to the right the same number of places as there are zeros in the reduction factor:

c.g. = 0402.5 = 402.5 in. aft of datum
(.04025×10,000 = 402.5)

The index units given for the particular items in the problem above are easily obtained from tables in the weight and balance reports for the aircraft. Tables are provided for all types of items which may be loaded on the aircraft. A typical table is shown in figure 23.

Index units may be used during flight to calculate the effect of fuel consumption upon the c.g. of the aircraft. The index units for the fuel used are subtracted from the aircraft total index which is calculated for takeoff conditions. The new c.g. is then obtained by dividing the new total index by the new

OIL TABLE

CAPACITY = 9.4 GALLONS		
ARM = 77″		
U.S. Gals.	*Weight (Pounds)*	*Moment 100*
1	7.5	6
2	15.0	12
3	22.5	17
4	30.0	23
5	37.5	29
6	45.0	35
7	52.5	40
8	60.0	46
9	67.5	52
9.4	70.5	54

FIGURE 23. Oil index table.

total aircraft weight after fuel burnoff. Fuel consumption index units may either be obtained from a table, such as that shown in figure 24, or by calculations using weight, arm, and reduction factors.

Example 11.

Given:

Aircraft total weight —125,000 lb.
Total weight index —6250.0
Reduction factor —10,000
Average fuel tank location—Sta. 550

Find: The c.g. of the aircraft after consuming 6,000 lb. of fuel.

Solution:

1. Determine the index of the fuel used:

$$\text{Index} = \frac{\text{Weight} \times \text{Arm}}{\text{Reduction factor}}$$

$$\text{Fuel index} = \frac{6{,}000 \times 550}{10{,}000}$$

$$\text{Fuel index} = 330.0$$

2. Subtract fuel weight and index from the original aircraft weight and index:

Weight (lb.)	*Index (units)*
125,000	6250.0
−6,000	−330.0
119,000	5920.0

3. Multiply index by reduction factor and divide by weight:

$$\frac{5{,}920.0 \times 10{,}000}{119{,}000} = 497.5 \text{ in. aft of datum}$$

TOTAL FUEL IN GALLONS AND INDEX Fuel = 6 lbs/gal.			
Gals.	*Index*	*Gals.*	*Index*
1200	325	3400	920
1400	379	3600	974
1600	433	3800	1028
1800	487	4000	1082
2000	541	4200	1137
2200	595	4400	1191
2400	649	4600	1245
2600	704	4800	1299
2800	758	5000	1353
3000	812	5200	1407
3200	866	5400	1461

FIGURE 24. Fuel index table.

Example 12.

Given:

Aircraft total weight—101,000 lb.

c.g.	—20.0% MAC
MAC	—Sta. 395 to Sta. 565
Reduction factor	—10,000

Find: What is the location of the c.g. in % MAC after consuming 4,000 gallons of fuel? Use the fuel index table (fig. 24):

Solution:

1. Determine original c.g. in inches from datum:

   c.g. = LEMAC + (MAC × %)

   c.g. = 395.0 + (170.0 in. × .20)

   c.g. = 395.0 + 34.0 = 429.0 in.

2. Determine total weight index:

$$\text{Total weight index} = \frac{\text{Weight} \times \text{Arm}}{\text{Reduction factor}}$$

$$\text{Total weight index} = \frac{101.000 \times 429.0}{10,000}$$

Total weight index = 4332.9

3. Find fuel burned index on table (fig. 24):

Fuel burned index for 4,000 gals. = 1082.0

4. Convert fuel gallons to pounds:

   4,000 gal. × 6.0 lb./gal. = 24,000 lb.

5. Subtract fuel burned weight and index from original total weight and index:

Weight (lb.)	*Index (units)*
101,000	4332.9
−24,000	−1082.0
77,000	3250.9

6. Multiply index by reduction factor and divide by weight:

$$\frac{3250.9 \times 10,000}{77,000} = 422.2 \text{ in. c.g. aft of datum}$$

7. Determine c.g. in % MAC:

$$\frac{\text{c.g.} - \text{LEMAC}}{\text{MAC}} = \%\ \text{MAC}$$

$$\frac{422.2 - 395.0}{170} = 16\%\ \text{MAC}$$

CENTER OF GRAVITY VARIABLE LIMIT GRAPH

Many aircraft are designed with c.g. limits which vary with changes of weight and certain other operational factors. The limits are presented in the aircraft type certificate data sheets (fig. 19) or specifications and other publications in a graphic form and are usually expressed in inches from datum or % MAC. A typical graphic presentation of aircraft c.g. limits is shown in figure 25.

It is apparent from inspection of the graph that limits for various weights would include:

Weight	*Forward*	*Aft*
70,000	20.0%	27.2%
100,000	20.0%	26.6%
130,000	23.0%	26.0%

Limits for intermediate weights may be determined by visual or mathematical interpolation of the graph. The graph should be read to the nearest one-tenth of a percent of MAC. As an example, the rear limit for a weight of 90,000 lb. is interpolated to be 26.8% MAC.

The limits may be converted to "inches from

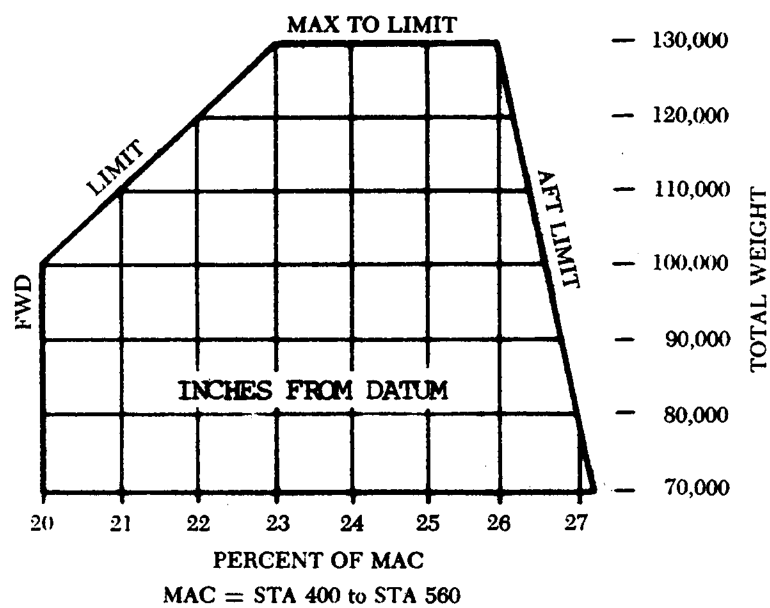


FIGURE 25. C.G. variable limit graph.

datum" by computation methods previously explained. A typical problem using the limits in the graph (fig. 25) follows:

Example 13.

Given:

Graphic c.g. limits (fig. 25)
MAC Sta. 400 to Sta. 560

Find: Forward c.g. limit for 115,000 lb. in inches from datum.

Solution:

1. Determine forward c.g. limit in % MAC by use of graph for 115,000 lb.:
   Fwd. c.g. limit=21.5% (.215)

2. Find length of MAC:
   560−400=160 in.

3. Find limit in "inches from datum":
   160×.215=34.4 in. aft of LEMAC
   400+34.4=434.4 in. aft of datum

INDEX ENVELOPE

C.G. limits may be expressed graphically in the aircraft weight and balance reports by means of an index envelope. The envelope defines the forward and aft limits and also the maximum weight limit in terms of index units.

The envelope permits the rapid determination of the weight and balance condition of an aircraft when the weight and total index units are known. Thus, the procedure of computing the c.g. location from datum or in relation to MAC is simplified. The envelope informs the pilot that the c.g. is within acceptable limits without actually locating it on the longitudinal axis. In most cases, this is all the pilot needs to know. The pilot needs only to be assured that the c.g. is within approved limits.

A typical index envelope is shown in figure 26. The similarities and differences between this graphic form and the variable limit graph (fig. 25) should be noted.

It is apparent from the envelope that a loading of 2,000 lb. with an index of 110 is within limits (point A) while a loading of 2,000 lb. with an index of 130 is not within limits (point C). Index information which the operator must gather in order to utilize the envelope is obtained from index charts or tables in the weight and balance report. Various load items and associated index numbers are added to obtain the totals.

The following is a simplified loading check making use of the index envelope:

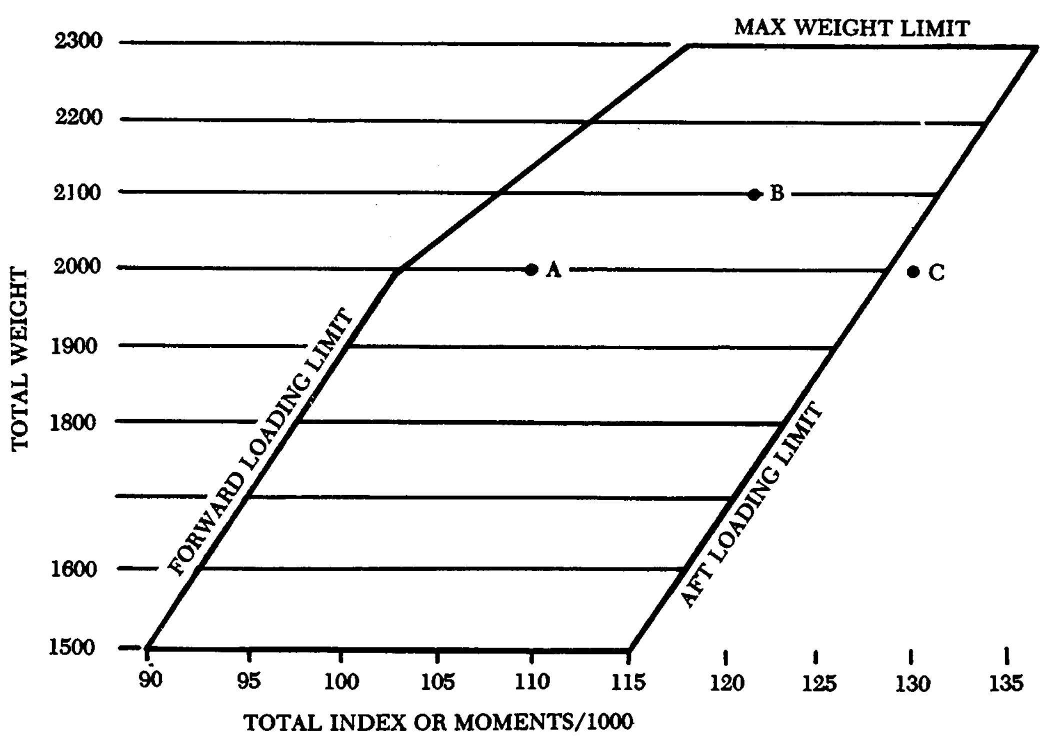


Figure 26. Index envelope.

Item	*Weight*	*Index*
Aircraft Empty	1,300	67.8
Pilot	170	10.2
Passengers	310	22.5
Fuel	210	13.6
Oil	60	2.4
Baggage	50	5.0
Total	2,100	121.5

The intersection of the above total weight and total index values falls well within the index envelope (point B), therefore, the airplane in the example is considered to be within its operating limitations as far as weight and balance is concerned.

The index number system can be modified by applying selected constant factors to the moments of load items. The selected constants are chosen to make the index system less complex, and so that the system can be used in conjunction with special loading charts. In these cases, special formulas are used to obtain index units. Typical formulas are:

Lockheed L-188—Index

$$=100\frac{-\text{Weight}\times(598.2-\text{Sta.})}{30{,}000}$$

Convair 880M—Index

$$=100\frac{+\text{Weight}\times(\text{Sta.}-849.0)}{100{,}000}$$

Douglas DC-6B—Index

$$=100\frac{+\text{Weight}\times(\text{Sta.}-430)}{20{,}000}$$

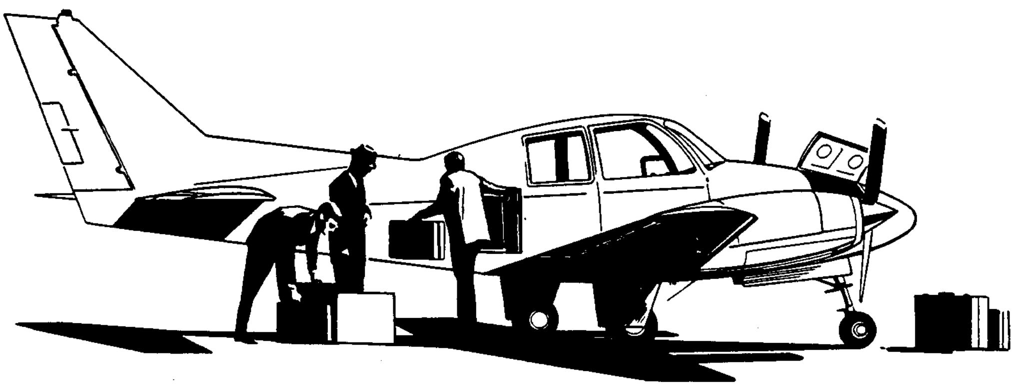
It should be noted that these special formulas are refinements of the standard formula:

$$\text{Index}=\frac{\text{Weight}\times\text{Arm}}{\text{Reduction factor}}$$

The constants that are used in the special formulas do not affect the accuracy in determining c.g. locations, as long as the same formula is applied to all weights and arms. These modifications to the index formula permit the index numbers to be related easily to other important numbers, such as % MAC and stabilizer setting.

Chapter 5

CHANGE OF WEIGHT



A pilot must be able to solve accurately and rapidly problems which involve the shift, addition, or removal of weight. For example, the pilot may load the aircraft within the allowable takeoff weight limit, then find a c.g. limit has been exceeded. The most satisfactory solution to this problem is to shift baggage, or passengers, or both. The pilot should be able to determine the minimum load shift needed to make the aircraft safe for flight. Pilots should also be able to determine if the shifting of a load to a new location will correct an out-of-limit condition. There are some standardized and simple calculations which can help make these determinations.

WEIGHT SHIFTING

When weight is shifted from one location to another, the total weight of the aircraft is unchanged. The total moments, however, do change in relation and proportion to the direction and distance the weight is moved. When weight is moved forward, the total moments decrease; when weight is moved aft, total moments increase. The moment change is proportional to the amount of weight moved. Since many aircraft have forward and aft baggage compartments, weight may be shifted from one to the other to change the c.g. If we start with a known aircraft weight, c.g., and total moments, we can calculate the new c.g. (after the weight shift) by dividing the new total moments by the total aircraft weight.

Example 14.

To determine the new total moments, find out how many moments are gained or lost when the weight is shifted.

The weight shift conditions indicated for the aircraft illustrated in figure 27 show that 100 lb. has been shifted from Sta. 30 to Sta. 150. This movement increases the total moments of the aircraft by 12,000 lb.-in.

Baggage moment when at Sta. 150
$= 100 \text{ lb.} \times 150 \text{ in.} = 15{,}000 \text{ lb.-in.}$

Baggage moment when at Sta. 30
$= 100 \text{ lb.} \times 30 \text{ in.} = 3{,}000 \text{ lb.-in.}$

Moment change $= 12{,}000$ lb.-in.

By adding the moment change to the original moment (or subtracting if the weight had been moved forward instead of aft), we obtain the new total moments. We can then determine the new c.g. by dividing the new moments by the total weight:

$$\text{Total moments} = 616{,}000 + 12{,}000 = 628{,}000$$

$$\text{c.g.} = \frac{628{,}000}{8{,}000} = 78.5 \text{ in.}$$

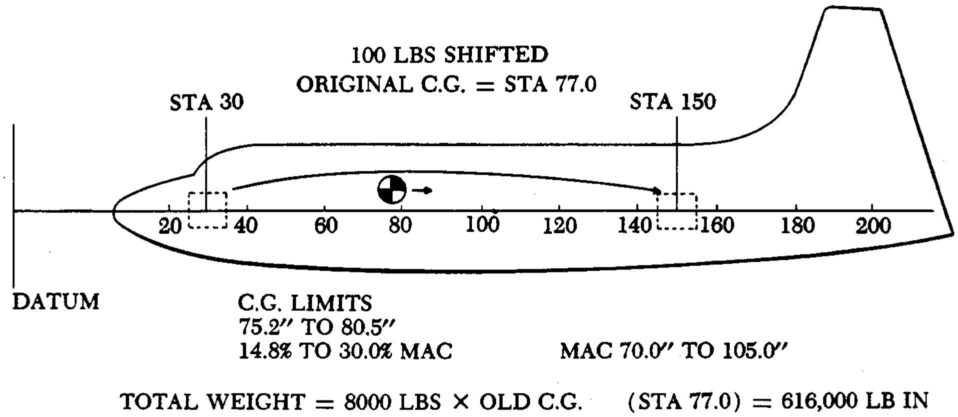


FIGURE 27. Weight shifting diagram.

The shift of the baggage has caused the c.g. to shift to Sta. 78.5.

A simpler solution may be obtained by using the aeronautical computer and a proportion formula (fig. 28). This can be done because the c.g. will shift a distance which is proportional to the distance the weight has shifted.

Example 15.

1.

$$\frac{\text{Weight shifted}}{\text{Total weight}} = \frac{\Delta\text{c.g. (change of c.g.)}}{\text{Distance weight is shifted}}$$

$$\frac{100}{8{,}000} = \frac{\Delta\text{c.g.}}{120}$$

$$\Delta\text{c.g.} = 1.5 \text{ in.}$$

2. The change of c.g. is added to (or subtracted from) the original c.g. to determine the new c.g.:

$$77 + 1.5 = 78.5 \text{ in. aft of datum}$$

A possible point of difficulty arises in the computer-type solution when an attempt is made to locate the decimal point in the answer. How do we make sure the Δc.g. in the above problem is not .15 in. or 15.0 in.? The answer you get can always be checked by cross multiplying. Substitute the answer in step 1 (example 15):

$$1.5 \times 8{,}000 = 12{,}000$$

$$100 \times 120 = 12{,}000$$

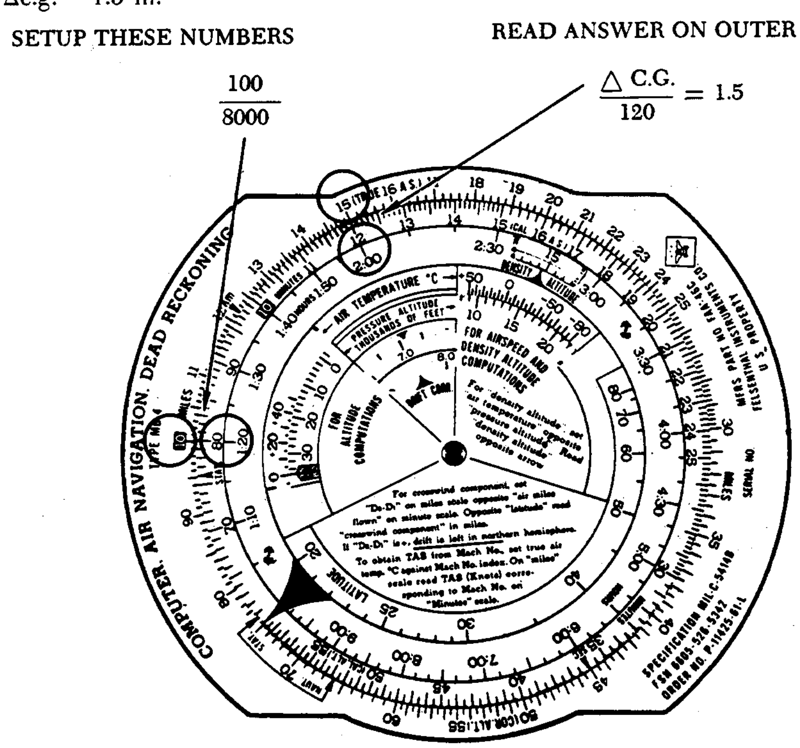


FIGURE 28. Computer solution—shifting weight.

If the cross multiplication answers are not the same, you have selected the wrong decimal location for the Δc.g. and the decimal should be relocated accordingly.

Finding the decimal location is primarily a matter of observation; remember that the proportions on either side of the equal sign (example 15, step 1) are similar.

The shifting weight proportion formula can also be used to determine how much weight must be shifted to achieve a particular shift of the c.g. The following problem illustrates a solution of this type.

Example 16.

Given:

Aircraft total weight—7,800 lb.
c.g. —Sta. 81.5 in.
Aft c.g. limit —80.5 in.

Find: How much cargo must be shifted from the aft cargo compartment at Sta. 150 to the forward cargo compartment at Sta. 30 to move the c.g. to exactly the aft limit?

Solution:

1. Use the shifting weight proportion:

$$\frac{\text{Weight shifted}}{\text{Total weight}} = \frac{\Delta\text{c.g.}}{\text{Dist. wt. shifted}}$$

$$\frac{\text{Weight (to be) shifted}}{7{,}800} = \frac{1.0 \text{ in.}}{120 \text{ in.}}$$

Weight to be shifted = 65 lb.

2. Cross multiply to check for accuracy of decimal point location in the answer.

$$7{,}800 \times 1.0 = 7{,}800$$
$$65 \times 120 = 7{,}800$$

A combination problem may involve the shifting of weight when the c.g. and the c.g. limits are expressed in % MAC.

Example 17.

Given:

Aircraft total weight—7,200 lb.
c.g. —12% MAC
Fwd. c.g. limit —14.8% MAC
MAC —Sta. 70 to Sta. 105 = 35 in.

Find: How much cargo must be shifted from the front baggage compartment at Sta. 30 to the aft baggage compartment at Sta. 150 to move the c.g. to exactly the forward limit?

Solution:

1. Convert the % MAC locations to inches from datum by using the aeronautical computer (fig. 29).

c.g. = LEMAC (70 in.) + % MAC in inches (4.2 in.) = 74.2 in.

Fwd. limit = LEMAC (70 in.) + % MAC in inches (5.2 in.) = 75.2 in.

SETUP THESE NUMBERS

READ ANSWER ON OUTER SCALE

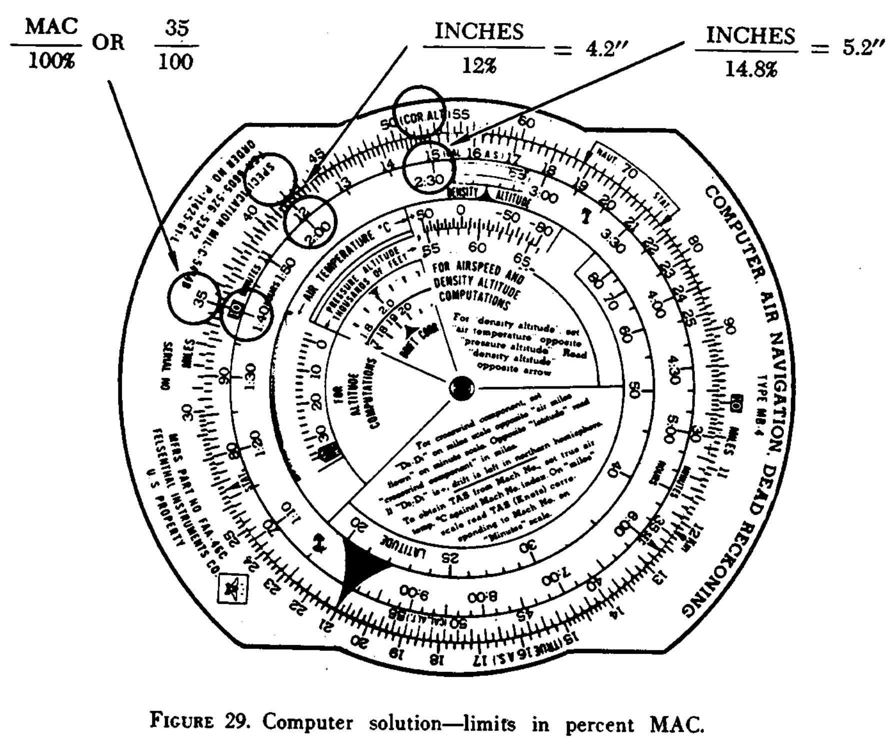


FIGURE 29. Computer solution—limits in percent MAC.

2. Determine Δc.g. (distance c.g. must be moved):

$$75.2-74.2=1.0$$
$$\Delta c.g.=1.0 \text{ in. aft}$$

3. Use the shifting weight proportion:

$$\frac{\text{Weight shifted}}{\text{Total weight}}=\frac{\Delta c.g.}{\text{Dist. wt. shifted}}$$

$$\frac{\text{Weight (to be) shifted}}{7{,}200}=\frac{1.0}{120}$$

Weight to be shifted = 60 lb.

WEIGHT ADDITION OR REMOVAL

In many instances the weight and balance of the aircraft will be changed by the addition or removal of weight. When this happens a new c.g. must be calculated and checked against the limitations to see if the location is acceptable. This type of weight and balance problem is commonly encountered when the aircraft burns fuel in flight, thereby reducing the weight located at the fuel tanks. Most aircraft are designed with the fuel tanks positioned close to the c.g., therefore, the consumption of fuel does not affect the c.g. to any great extent. However, large jet aircraft with fuel tanks located in the swept-back wings require careful planning on each flight to prevent the c.g. shifting out of limits due to the consumption of fuel.

The addition or removal of cargo presents a c.g. change problem which may have to be calculated rapidly before flight. The problem may always be solved by calculations involving total moments. However, a shortcut formula which can be adapted to the aeronautical computer may be used to simplify computations:

$$\frac{\text{Weight added (or removed)}}{\text{New total weight}}=\frac{\Delta c.g.}{\text{Distance between wt. and old c.g.}}$$

In this formula the terms "new" and "old" refer to conditions before and after the weight change.

It is often more convenient to use another form of this formula when required to find the weight change needed to accomplish a particular c.g. change (Δc.g.). In this case we use:

$$\frac{\text{Weight (to be) added (or removed)}}{\text{Old total weight}}=\frac{\Delta c.g.}{\text{Distance between wt. and new c.g.}}$$

Notice that the terms "new" and "old" are **not** found on both sides of the equation in either of the above proportions. If the "new" total weight is used, the distance must be calculated from the "old" c.g. Just the opposite is true if the "old" total weight is used.

A typical problem may involve the calculation of a new c.g. for an aircraft which, when loaded and ready for flight, receives some additional cargo or passengers just before departure time.

Example 18.

Given:

Aircraft total weight—6,860 lb.
c.g. —Sta. 80.0

Find: What is the location of the c.g. if 140 lb. of baggage is added to station 150?

Solution:

1. Use the added weight formula:

$$\frac{\text{Added weight}}{\text{New total weight}}=\frac{\Delta c.g.}{\text{Dist. between wt. and old c.g.}}$$

$$\frac{140}{6{,}860+140}=\frac{\Delta c.g.}{150-80}$$

$$\frac{140}{7{,}000}=\frac{\Delta c.g.}{70}$$

$$\Delta c.g. = 1.4 \text{ in. aft.}$$

2. Add Δc.g. to the old c.g.:

New c.g. = 80.0 in. + 1.4 in. = 81.4 in.

Example 19.

Given:

Aircraft total weight—6,100 lb.
c.g. —Sta. 78

Find: What is the location of the c.g. if 100 lb. is removed from station 150?

Solution:

1. Use the removed weight formula:

$$\frac{\text{Weight removed}}{\text{New total weight}}=\frac{\Delta c.g.}{\text{Dist. between wt. and old c.g.}}$$

$$\frac{100}{6{,}100-100}=\frac{\Delta c.g.}{150-78}$$

$$\frac{100}{6{,}000}=\frac{\Delta c.g.}{72}$$

$$\Delta c.g. = 1.2 \text{ in. forward}$$

2. Subtract Δc.g. from old c.g.:

New c.g. = 78 in. − 1.2 in. = 76.8 in.

NOTE.—In the above two examples, the Δc.g. is either added to or subtracted from the old c.g. Deciding which to accomplish is best handled by mentally calculating which way the c.g. will shift for the particular weight change. If the c.g. is shifting aft, the Δc.g. is added to the old c.g.; if it is shifting forward, the Δc.g. is subtracted from the old c.g. To summarize c.g. movement:

Weight added fwd. of old c.g. } c.g. moves fwd.
Weight removed aft of old c.g. }
Weight added aft of old c.g. } c.g. moves aft
Weight removed fwd. of old c.g. }

Example 20.

Given:

Aircraft total weight—7,000 lb.
c.g. —Sta. 79.0
Rear c.g. limit —Sta. 80.5

Find: How far aft can additional baggage weighing 200 lb. be placed without exceeding the rear c.g. limit?

Solution:

1. Use the added weight formula:

$$\frac{\text{Added weight}}{\text{New total weight}}=\frac{\Delta\text{c.g.}}{\text{Dist. between wt. and old c.g.}}$$

$$\frac{200}{7{,}200}=\frac{1.5}{\text{Dist. between wt. and old c.g.}}$$

Distance between wt. and old c.g. = 54 in.

2. Add to old c.g.:

79 in. + 54 in. = 133 in. aft of datum

When the 200 lb. is located at Sta. 133, the new c.g. will be exactly on the aft limit; if the weight is located any further to the rear, the aft c.g. limit will be exceeded.

Example 21.

Given:

Aircraft total weight—6,400 lb.
c.g. —Sta. 80.0
Aft c.g. limit —Sta. 80.5

Find: How much baggage can be located in the aft baggage compartment at station 150 without exceeding the aft c.g. limit?

Solution:

Use the added weight formula.

Note.—In this problem, the new total weight is not given, therefore, it is more convenient to use the version of the formula which makes use of the old total weight.

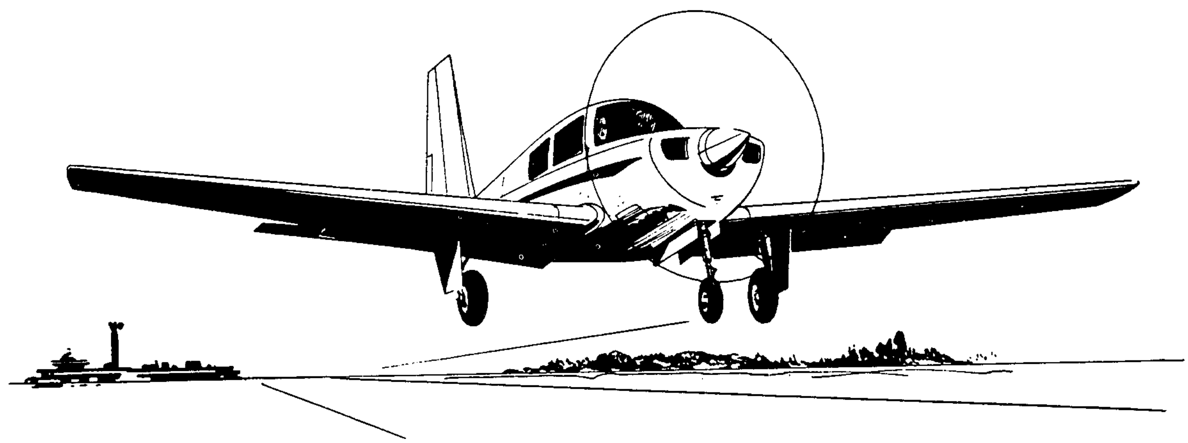
$$\frac{\text{Added weight}}{\text{Old total weight}}=\frac{\Delta\text{c.g.}}{\text{Dist. between wt. and new c.g.}}$$

$$\frac{\text{Added weight}}{6{,}400}=\frac{.5}{150-80.5}=$$

Added weight = 46 lb.

Chapter 6

CONTROL OF LOADING—GENERAL AVIATION



Before any flight, the pilot should determine the weight and balance condition of the aircraft. In the early days of flying, aircraft were loaded by guess and intuition. On occasion, the results were grim. Through trial and error the early pilots learned about weight and balance. Today there is no excuse for following this method. Simple and orderly procedures based on sound principles have been devised by aircraft manufacturers for the determination of loading conditions. The pilot, however, must use these procedures and exercise good judgment. In many modern aircraft, it is not possible to fill all seats, baggage compartments, and fuel tanks and still remain within the approved weight and balance limits. If the maximum passenger load is carried, the pilot must often reduce the fuel load or reduce the baggage.

USEFUL LOAD CHECK

A simple and fundamental weight check should always be made by general aviation pilots before flight. This check should determine if the useful load is exceeded. The check may be a mental calculation if the pilot is familiar with the aircraft's limits and knows that unusually heavy loads are not aboard. But when all seats are being occupied, fuel tanks are full, and some baggage is aboard, the pilot should do some careful calculations.

The pilot needs to know the useful load limit of the particular aircraft. This information may be

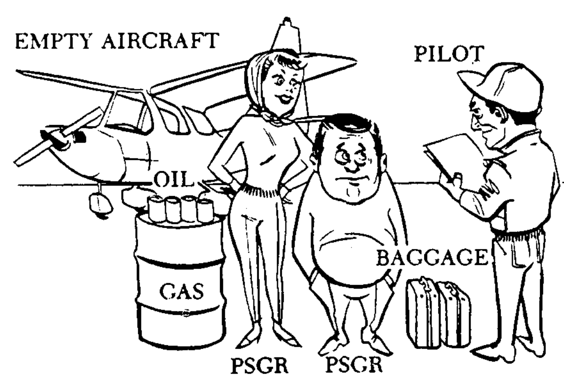


FIGURE 30. Empty weight + useful load = takeoff weight.

WEIGHT & BALANCE DATA

AIRCRAFT SERIAL NO. 15556480 FAA REGISTRATION NO. N3248X

ITEM	WEIGHT ×	ARM =	MOMENT
STANDARD AIRPLANE	975.0	32.0	31200.0
OPTIONAL EQUIPMENT	89.0	26.1	2322.9
PAINT	15.5	85.3	1322.2
UNUSABLE FUEL	20.0	43.0	860.0
LICENSED EMPTY WEIGHT	1099.5	32.5	35705.1

(GROSS WT)–(LICENSED EMPTY WT) = USEFUL LOAD
(1800 LB)–(1099.5 LB) = 700.5 LBS

IT IS THE RESPONSIBILITY OF THE OWNER AND PILOT TO ENSURE THAT THE AIRPLANE IS PROPERLY LOADED. THE DATA ABOVE INDICATES THE EMPTY WEIGHT, C.G., AND USEFUL LOAD WHEN THE AIRPLANE WAS RELEASED FROM THE FACTORY. REFER TO THE LATEST WEIGHT AND BALANCE RECORD WHEN ALTERATIONS HAVE BEEN MADE.

SAMPLE LOADING PROBLEM

ITEM	WEIGHT (LBS)	ARM (IN)	MOMENT (LB-IN/1000)
LICENSED EMPTY WEIGHT	1099.5		35.7
OIL	12	−15.0	-0.2
PILOT & PASSENGER	340	40.0	13.6
FUEL	188.5	43.0	8.1
BAGGAGE	160	65.0	10.4
TOTAL LOADED AIRPLANE	1800		67.6

FIGURE 31. Weight and balance data.

found in the latest weight and balance report, in a log book, or on a major repair and alteration form, located in the aircraft. If useful load is not stated directly, simply subtract empty weight from maximum takeoff weight. Be especially weight conscious of aircraft which have a limited useful load because they are the ones which cause weight and balance troubles.

The check is simple enough—just be sure to include all the load items included in the useful load—then check the total against the limit. The calculations might look like this:

Example 22.

	Pounds
Mr. Jones (instructor)	175
Pilot	180
Fuel—30 gallons	180
Oil—8 quarts	15
Baggage	5
Total	555

Useful load limit is 575 lbs.

The calculations indicate that the useful load is not exceeded and the flight can take place.

Now suppose that Mr. Jones, in the example, is replaced by a new instructor who weighs 210 lb. A useful load check will show that the aircraft is too heavy. The pilot in our example must reduce the load to the specified useful load limit. There is no alternative in this small aircraft but to reduce the fuel load, even if all the baggage has been removed.

Pilots should be aware of, and on the alert for, unusual loadings. They should remember that the manufacturer's initial weight and balance calculations and some examples in the owner's manual make the assumption that the pilot and passengers weigh a standard 170 lb. each. Heavyweight passengers can overload a small aircraft seriously. A student and instructor may easily weigh 220 lb. each in winter clothing; this represents a potential overload of 100 lb. The baggage compartment is another place where pilot vigilance should be directed—the maximum compartment load placard must be obeyed. Frequently, a restriction is placed on rear seat occupancy with the maximum baggage aboard.

WEIGHT AND BALANCE RESTRICTIONS

Be sure to follow your aircraft's weight and balance restrictions. The loading conditions and empty weight of your particular aircraft (fig. 31) may differ from those in the owner's manual due to modifications or equipment changes. Sample loading problems in the owner's manual are intended for guidance only; each aircraft must be treated separately for weight and balance. The pilot should understand that although the aircraft is certified for a specified maximum gross weight, it will not safely take off with this load under all conditions. Conditions which affect takeoff and climb performance such as high elevations, high temperatures, and high humidity (high-density altitudes), may require operation at reduced weight. Other factors to consider are runway length, runway surface, runway slope, surface wind, and the presence of obstacles. Pilot experience and proficiency should always be considered—if in doubt, reduce the load.

Some small aircraft are designed so that it is not possible to load them in a condition which will place the c.g. outside the fore or aft limits if standard load schedules are observed. These aircraft have the seats, fuel, and baggage accommodations located very near the c.g. limits. They also have special empty weight c.g. limits listed in their specifications. Loads can be added to or removed from any location within the c.g. range with complete freedom from concern about c.g. movement. Such action cannot cause the c.g. to move beyond the c.g. limits of these aircraft (see fig. 32), but maximum weight limits can still be exceeded.

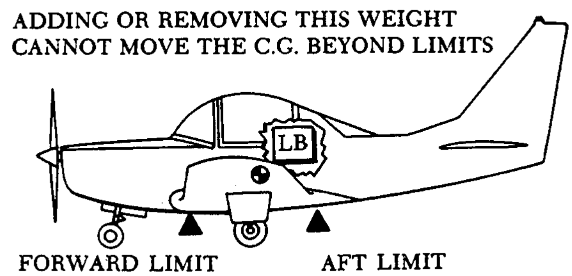


FIGURE 32. Changing weight between c.g. limits.

Most aircraft, however, can be loaded in a manner which will place the c.g. beyond limits. Even though the useful load is not exceeded, an out-of-balance condition is serious from a stability and control standpoint. The pilot can quickly determine if the load is within limits, if the aircraft is simple enough to make use of a loading schedule. This schedule may be found in the weight and balance report, the aircraft log book, the owner's manual, or may be posted in the form of a placard. A typical placard may appear similar to the one shown in figure 33.

LOADING SCHEDULE

FUEL	PASSENGERS	BAGGAGE
FULL	2 REAR	100 LBS
39 GAL	1 FRONT AND 2 REAR	NONE
FULL	1 FRONT AND 1 REAR	FULL

INCLUDES PILOT AND FULL OIL

FIGURE 33. Loading schedule placard.

The loading schedule should be treated as a suggested loading plan only. The pilot should make a check by means of weight and balance calculations to see if limitations are not being exceeded. The assumption in the use of the loading schedule is that each passenger weighs approximately the standard weight of 170 lb. It is obvious that passenger weights could vary widely from the assumed standard.

AIRPLANE FLIGHT MANUAL

Each airplane of over 6,000 lbs. maximum weight is furnished with an airplane flight manual. An airplane of less than 6,000 lbs, may have information furnished in the form of placards, markings, or manuals. When an airplane flight manual is furnished, the following is included:

a. Limitations and data:
   (1) The maximum weight.
   (2) The empty weight and c.g. location.
   (3) The useful load.
   (4) The composition of the useful load, including the total weight of fuel and oil with full tanks.

b. Load distribution:
   The established c.g. limits are furnished in the airplane flight manual. If the available loading space is adequately placarded or arranged so that no reasonable distribution of the useful load will result in a c.g. outside of the stated limits, the airplane flight manual may not include any information other than the statement of c.g. limits. In other cases, the manual includes enough information to indicate loading combinations that will keep the c.g. within established limits.

LIGHT SINGLE-ENGINE AIRCRAFT LOADING PROBLEMS

Aircraft manufacturers use one of several available systems to provide the aircraft loading information. The following weight and balance problems will show how the pilot can determine if the maximum weight limit is exceeded or the c.g. is located beyond limits.

Assume you are a pilot planning a flight in a light single-engine, four-place aircraft. Your load consists of yourself, one front seat passenger and two rear seat passengers, full fuel and oil, and 60 lb. of baggage (fig. 34). Here is how the critical weight and balance problems are solved for this case by two different methods (examples 23 and 24).

Example 23.

Solution by index table:

1. From the manual or weight and balance report, determine the empty weight and empty weight c.g. (arm) of the aircraft.
2. Determine the arms for all useful load items.
3. Determine the maximum weight and c.g. range. (For this case—Max. TOGW= 2,400 lb., c.g. range - Sta. 35.6 to 45.8.)
4. Calculate the actual weights for the useful load items.
5. Construct a table as follows (pg. 39), and enter the appropriate values. Multiply each individual weight and arm to obtain moments.

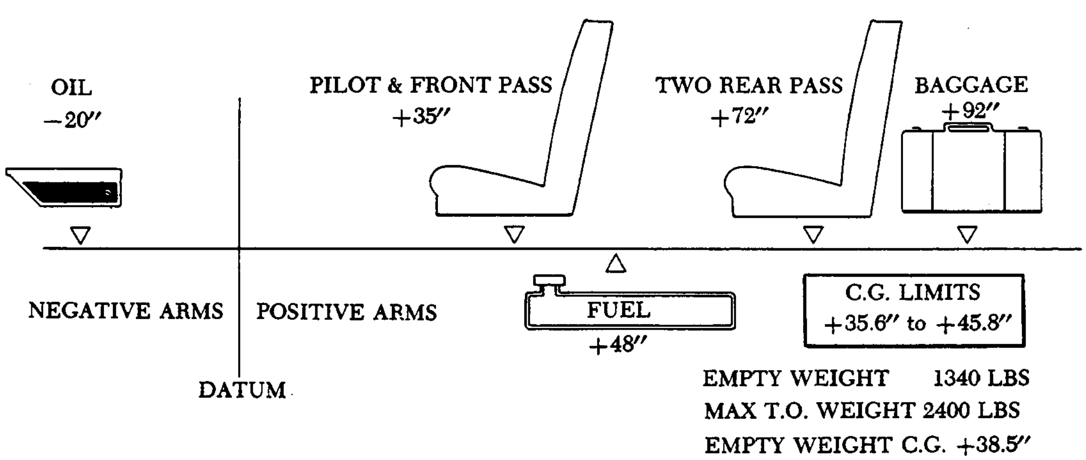


FIGURE 34. General aviation aircraft—weight and balance diagram.

	Weight	× *Arm*	= *Moment (lb.-in.)*
Aircraft (empty) ..	1,340	38.5	51,590
Oil	15	−20.0	−300
Pilot and front passenger ..	320	35.0	11,200
Fuel	241	48.0	11,568
Rear passengers .	300	72.0	21,600
Baggage	60	92.0	5,520
Total	2,276	....	101,178

NOTE.—Observe that the oil tank for this aircraft is located forward of the datum. Care must be taken to subtract the negative oil moment when totaling the moment column.

6. Adding the weights produces a total of 2,276 lb., and adding the moments produces a total of 101,178 lb.-in. The c.g. is calculated by dividing the total moment by the total weight:

$$\frac{101{,}178}{2{,}276} = 44.5 \text{ in. aft of datum}$$

7. The total weight of 2,276 lb. does not exceed the maximum weight of 2,400 lb., and the computed c.g. of 44.5 falls within the allowable c.g. range of 35.6 to 45.8 in. aft of datum.

Weight and balance computations are greatly simplified by two graphic aids—the loading graph and the center of gravity moment envelope. The loading graph (fig. 35) is typical of those found in general aviation aircraft owner's manuals. This graph, in effect, multiplies weight by arm giving moment, then divides the moment by a reduction factor, giving an index number. Weight values appear along the left side of the graph. The moment/1,000 or index numbers are along the bottom. In this example, each line representing a load item is labeled. To determine the moment of any load item, find the weight along the left margin, then project a line right to a point of intersection with the appropriate load item line. For example, the index number of a pilot weighing 170 lb. is 6.1. The c.g. moment envelope (fig. 36) allows the pilot to bypass the computation of a c.g. number. It gives an acceptable range of index numbers for any aircraft weight from minimum to maximum. If the lines from total weight and total moment intersect within the envelope, the aircraft is within weight and balance limits. In solving the sample problem, follow this procedure:

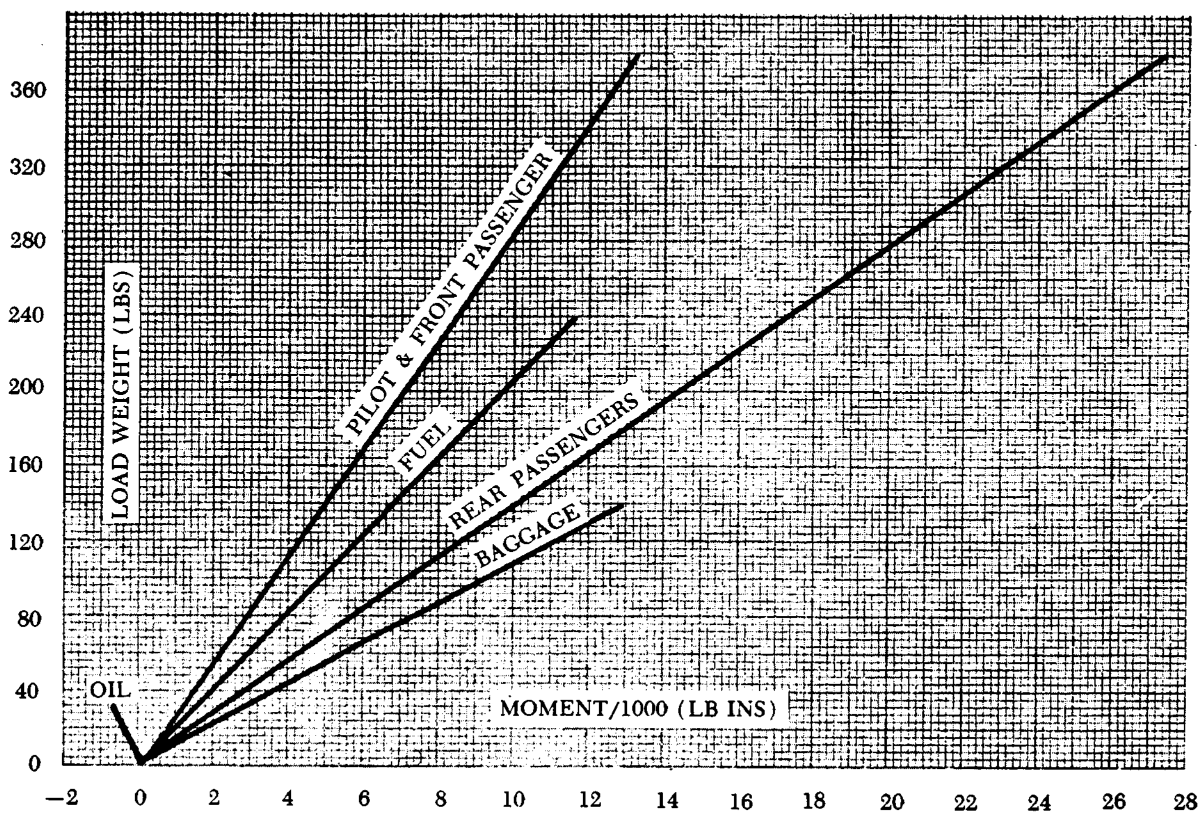


FIGURE 35. Loading graph.

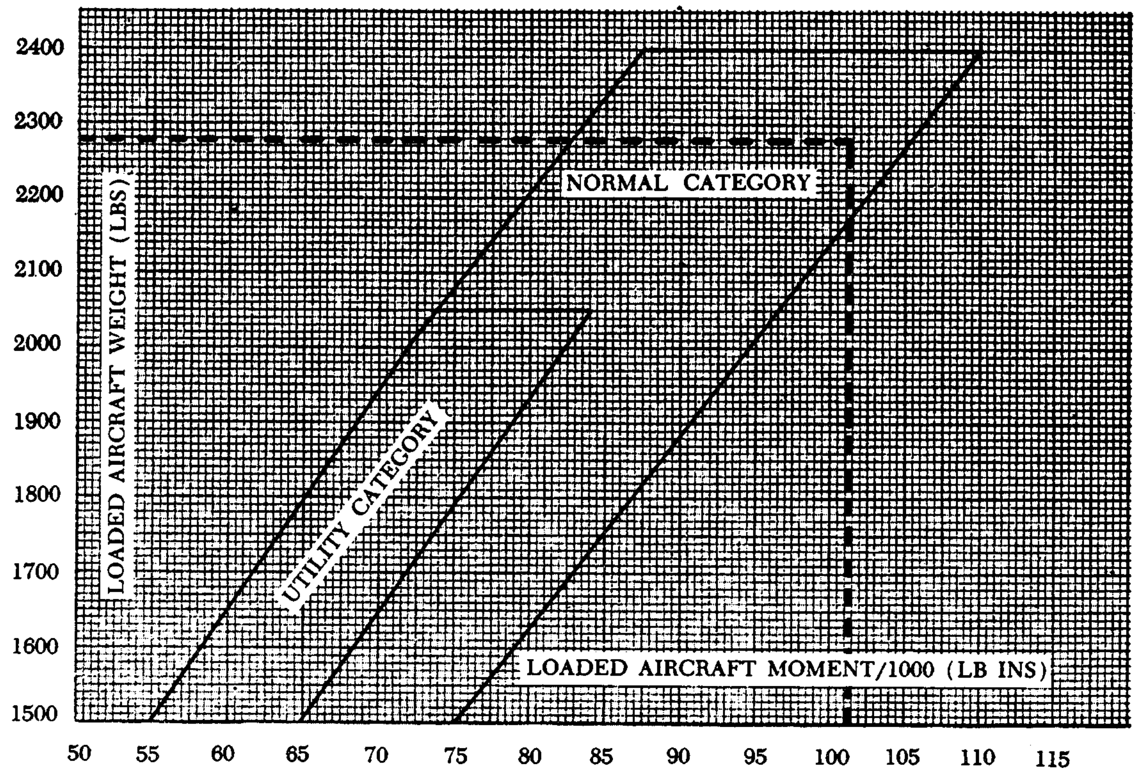


FIGURE 36. C.G. moment envelope.

Example 24.

1. Determine the aircraft empty weight and the empty weight index from the weight and balance report.
2. Construct a table such as the one that follows. In the left column, enter the actual weights of the empty aircraft, oil, pilot and front seat passenger, fuel, rear seat passenger, and baggage. In the right column, enter the aircraft empty weight index (moment/1,000).
3. From the loading graph, fig. 35, determine the index number (moment/1,000) of each useful load weight item and enter it in the table.
4. Add the weight and moment columns and write in the totals.
5. Refer to the c.g. moment envelope, fig. 36, and find the point of intersection of a line projected right from total weight (2,276 lbs.) and of a line projected up from total moment/1,000 (101.2).
6. The point of intersection falls within the envelope, therefore, the weight and c.g. are within limits.

Sample Loading Problem

Item	*Weight*	*Moment/1,000*
1. Empty aircraft weight	1,340	51.6
2. Oil	15	−0.3
3. Pilot and front passenger	320	11.2
4. Fuel	241	11.6
5. Rear seat passengers	300	21.6
6. Baggage	60	5.5
7. Total aircraft weight	2,276	101.2

LIGHT TWIN-ENGINE AIRCRAFT

Modern light twin-engine aircraft are larger than most single-engine aircraft; accordingly, their useful load is almost always greater than that found in the smaller aircraft. In these aircraft, it is possible to have many different loading combinations. Their large baggage compartments may be full or empty, and there may be wide variations in the number of seats being occupied. These variations are to be expected and are normal for the types of operations for which the aircraft are used. However, the c.g. is bound to range backward and forward as the loads are varied; therefore, weight and balance control is essential.

If a variety of loads can be placed aboard an aircraft in a number of locations, the pilot must be especially aware of duties regarding weight and balance control. Pilots should use a reliable weight and balance system, preferably the type recommended by the manufacturer, to assure that the weight and balance is within limits for each flight. They should insist that passengers are assigned to the correct seat from a weight distribution standpoint. They should also be sure that passenger baggage or miscellaneous cargo is properly loaded.

The weight and balance systems used on light twin-engine aircraft are essentially the same as those used for single-engine aircraft. Weights, arms, and moments are the basic factors, and the final c.g. computation must fall within the allowable c.g. limits. Many twin-engine aircraft make use of the loading graph and moment envelope system (figs. 35 and 36). Other models make use of index tables similar to those explained earlier for single-engine aircraft (fig. 24).

Some light twin-engine aircraft have weight and balance control systems which make use of a special weight and balance plotter. The typical plotter is made of plastic material similar to an aeronautical computer. It consists of several movable parts which can be adjusted over a plotting board on which is printed a c.g. envelope. The reverse side of the typical plotter contains general loading recommendations for the particular aircraft. The recommendations may suggest that occupants be loaded progressively from front to rear. In other words, the forward and center seats should be occupied before passengers are assigned to the rear seats. A pencil line plot can be made directly on the envelope imprinted on the working side of the plotting board. This plot can be erased and recalculated anew for each flight. The plotter is to be used only for the aircraft for which it was designed. This weight and balance control system is very similar to one used on air carrier aircraft as explained on page 60 and illustrated by figure 57.

A typical weight and balance plotter should contain this reminder: "It is the responsibility of the owner and pilot to ascertain that the aircraft always remains within the allowable weight versus c.g. envelope while in flight." This note should serve as a precaution to the pilot to be sure to check the weight and balance condition before takeoff and to be sure that any shift in passenger seating locations does not adversely affect the location of the aircraft center of gravity.

HIGH-DENSITY-SEATING AIRCRAFT

Many light twin-engine aircraft are being used for transportation of passengers, cargo, or mail in the form of commuter or air-taxi service to supplement the scheduled and unscheduled air carriers. An increasing number of twin-engine aircraft are being used to carry mail on a scheduled basis. Many commuter and air-taxi operators carry passengers to and from small cities to make connections with trunk carriers at airports in large cities. The aircraft used for this purpose are in some cases fitted with a large number of seats in relation to fuselage size and are called high-density-seating aircraft. The aircraft may contain seats for eight to 15 passengers and some of the larger types may seat over 25 passengers. The loading problems are relatively more complex than for aircraft which carry only six passengers. The complexity of the loading situation approaches that encountered in air carrier operations. Weight and balance limits for high-density-seating aircraft must be respected. The passenger, cargo, or mail load on high-density-seating aircraft may vary considerably from flight to flight. Some trips may be made with a full load and others with a minimum load. Some of the high-density-seating aircraft have special weight and balance problems because they have been modified and modernized from older aircraft which originally did not have a great number of seats. Some of these modified aircraft are very sensitive as far as loading toward the rear limit is concerned. The recommended weight and balance checking procedures for modified aircraft must be carefully followed and operators should be sure to make a thorough analysis of weight and balance records to assure currency.

An operator's manual, when required for high-density-seating aircraft, should contain procedures for assuring compliance with weight and balance limits, including periodic reweighing of the aircraft. The weight and balance procedures contained in the manual should:

1. Be based on sound principles, using standardized terminology, and be compatible with the type(s) of aircraft operated.
2. When followed, assure that the aircraft is properly loaded and will not exceed authorized weight and balance limitations during operation.
3. Provide for blocking off seats or compartments when necessary to remain within c.g. limits. Effective means should be provided to assure that those seats and compartments are not occupied during operations specified.
4. Provide crewmembers, cargo handlers, and other personnel concerned complete information regarding distribution of passengers, fuel, and other items, and should give com-

COMMUTER TAXI AIRLINE INC.

PASSENGER AND CARGO MANIFEST

PASSENGER – CARGO LIST	WEIGHT	SEAT-COMPT	INDEX
	180	1	
	170	2	
	140	3	
PASSENGER NAMES	150	4	
	200	5	
ENTERED HERE	160	6	
	210	7	
	130	8	
	120	9	
	140	10	
	130	11	
PASSENGER – CARGO – MAIN CABIN TOTAL			

	FUEL	
WEIGHT	TANK	INDEX
300	R–MAIN	
300	L–MAIN	
120	R–AUX	
120	L–AUX	
	NOSE	
	TOTAL	

BAGGAGE COMPT	100	NOSE	
BAGGAGE COMPT	200	REAR	
PILOT – COPILOT	330	–	
OIL	85	–	
FUEL		TOTAL	
EMPTY WEIGHT	6,150	–	5842.5
TAKEOFF WEIGHT		–	
TAKEOFF LIMITS	10,000	–	

AIRCRAFT ....N 123 QC........

FLIGHT ....45........

ROUTE ....OKC-MKC........

DATE ....

I HEREBY CERTIFY THAT THE ABOVE TAKEOFF WEIGHT AND INDEX IS WITHIN LIMITS AS SPECIFIED IN THE FLIGHT OPERATIONS MANUAL

....

PILOT IN COMMAND

FIGURE 37. Passenger manifest.

OCCUPANTS – MOMENTS/100

Weight	*Pilot & Co-Pilot*	*Seats 1 & 2*	*Seats 3 & 4*	*Seats 5 & 6*	*Seats 7 &8*	*Seats 9 & 10*	*Seat 11*
100	50.0	70.0	90.0	110.0	130.0	150.0	170.0
110	55.0	77.0	99.0	121.0	143.0	165.0	187.0
120	60.0	84.0	108.0	132.0	156.0	180.0	204.0
130	65.0	91.0	117.0	143.0	169.0	195.0	221.0
140	70.0	98.0	126.0	154.0	182.0	210.0	238.0
150	75.0	105.0	135.0	165.0	195.0	225.0	255.0
160	80.0	112.0	144.0	176.0	208.0	240.0	272.0
170	85.0	119.0	153.0	187.0	221.0	255.0	289.0
180	90.0	126.0	162.0	198.0	234.0	270.0	306.0
190	95.0	133.0	171.0	209.0	247.0	285.0	323.0
200	100.0	140.0	180.0	220.0	260.0	300.0	340.0

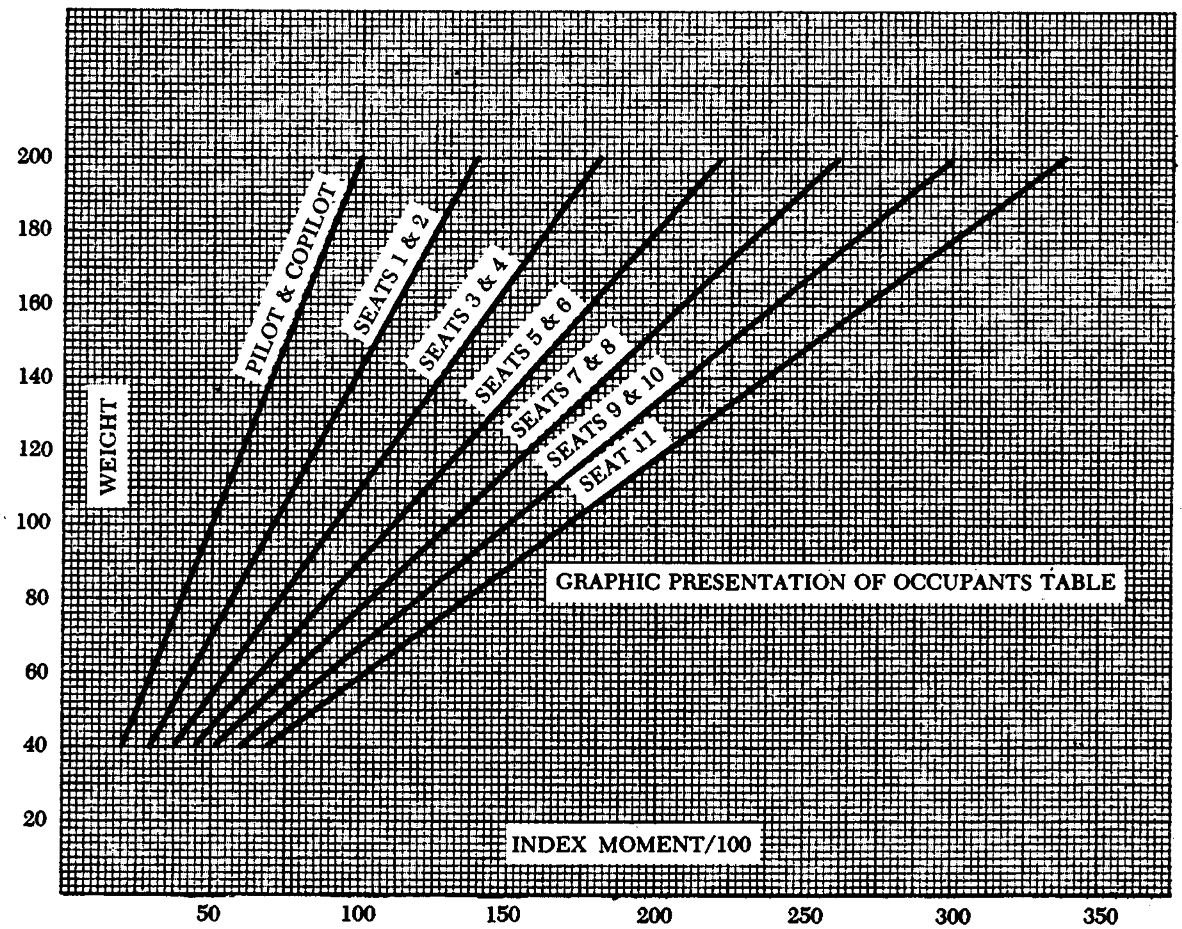


FIGURE 38. Occupants loading moments.

BAGGAGE OR CARGO MOMENTS/100

Weight	*Nose Baggage*	*Compt. A*	*Compt. B*	*Compt. C*	*Compt. D*	*Compt. E*	*Rear Baggage*
20	4.0	16.0	20.0	24.0	28.0	32.0	38.0
40	8.0	32.0	40.0	48.0	56.0	64.0	76.0
60	12.0	48.0	60.0	72.0	84.0	96.0	114.0
80	16.0	64.0	80.0	96.0	112.0	128.0	152.0
100	20.0	80.0	100.0	120.0	140.0	160.0	190.0
120	24.0	96.0	120.0	144.0	168.0	192.0	228.0
140	–	112.0	140.0	168.0	196.0	224.0	266.0
160	–	128.0	160.0	192.0	224.0	256.0	304.0
180	–	144.0	180.0	216.0	252.0	288.0	342.0
200	–	160.0	200.0	240.0	280.0	320.0	380.0
300	–	240.0	300.0	360.0	420.0	480.0	–
400	–	320.0	400.0	480.0	560.0	640.0	–
500	–	400.0	500.0	600.0	700.0	800.0	–

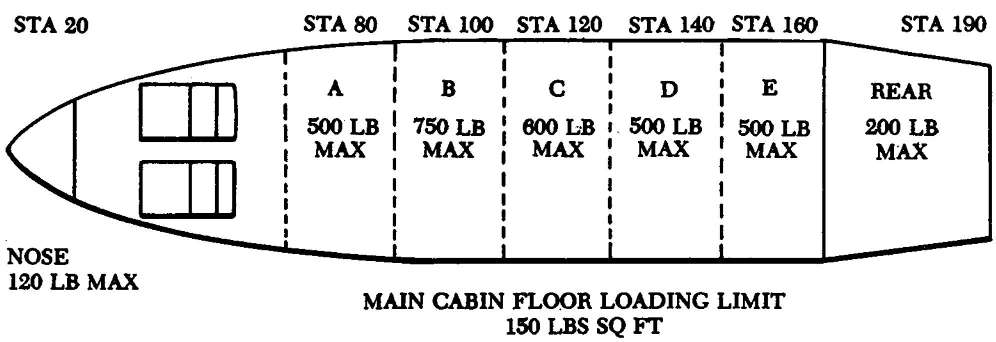


FIGURE 39. Baggage and cargo loading moments.

plete information regarding the distribution and security of cargo to prevent the shifting of weight in flight.

5. Provide other information relative to maximum weights, capacities, and other pertinent limitations affecting the weight and balance of the aircraft.

Pilots of these high-density-seating aircraft must be aware of the effect of passenger and cargo location on c.g., and they must have a personal knowledge of the means of correcting an out-of-limits condition. They often have no one to assist them with loading problems; they act as pilot, dispatcher, and loading agent in many cases.

In commuter or air taxi operations, pilots are confronted with the problem of frequent trips with varying loads. They need to have a positive, accurate, and fast way to compute the weight and balance. They must have reliable empty weight and c.g. information readily available for use. This information must be updated to account for all the modifications performed on the aircraft.

A load manifest, when required for air-taxi or commercial operations, should contain the following information concerning the aircraft loading at takeoff time:

1. The weight of the aircraft, fuel and oil, cargo (including mail and baggage), and passengers;

FUEL – MOMENTS/100

Weight	Nose	Main	Aux.	Weight	Nose	Main	Aux.
30	6.0	27.0	36.0	330	66.0	297.0	396.0
60	12.0	54.0	72.0	360	72.0	324.0	432.0
90	18.0	81.0	108.0	390	78.0	351.0	468.0
120	24.0	108.0	144.0	420	84.0	378.0	504.0
150	30.0	135.0	180.0	450	90.0	405.0	540.0
180	36.0	162.0	216.0	480	96.0	432.0	576.0
210	42.0	189.0	252.0	510	102.0	459.0	612.0
240	48.0	216.0	288.0	540	108.0	486.0	648.0
270	54.0	243.0	324.0	570	114.0	513.0	684.0
300	60.0	270.0	360.0	600	120.0	540.0	720.0

OIL – MOMENTS/100

Gallon	Weight	Moment
2	17	1.5
4	34	3.1
6	51	4.6
8	68	6.1
10	85	7.7

FIGURE 40. Fuel and oil loading moments.

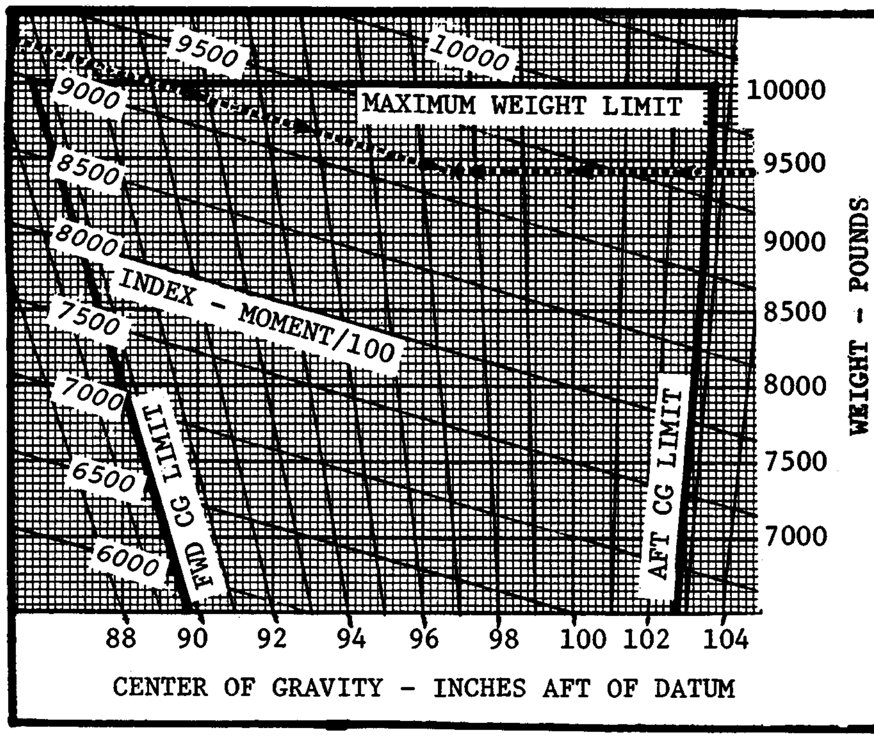
2. The maximum allowable weight for that flight;
3. The total weight computed under approved procedures;
4. Evidence that the aircraft is loaded according to an approved schedule that insures that the c.g. is within approved limits.

The execution of a load manifest is always a highly recommended procedure from the standpoint of making a uniform preflight check of the weight and balance condition. A typical load manifest may be a simple form similar to that illustrated in figure 37. This form provides a record of passengers and of all useful loads for the particular flight. The major advantage of such a form is that the pilot has a standardized means of calculating and recording the weight and balance condition of the aircraft for each flight. If care is taken to carry forward or make proper record of the empty weight and c.g., the pilot can be spared the task of a search through aircraft records for this vital information. The form may also be used as a record of passenger identification as may be needed for administrative purposes.

One typical weight and balance control system for high-density-seating aircraft is based upon the utilization of useful load index tables and a total weight index limit envelope or table. With these tables (figs. 38–41), it is possible to determine if weight and balance is within limits even in a situation where the passenger, cargo, or fuel loads change fairly rapidly. The tables can be read for intermediate weights by interpolation of values. To simplify and speed up calculations, use the nearest listed weight, but be conservative when checking against particular limits. The system is generally similar to those discussed on smaller aircraft. The pilot adds the weight and moments (index) of the empty aircraft and the useful load items. Then, checks are made against the published limits—in this case the index limit envelope or table. Care must be taken to use the empty weight and moments or index from the latest weight and balance report. The pilot must be sure to use the same

TOTAL WEIGHT INDEX LIMIT

ENVELOPE



INDEX TABLE

Weight	Min. Index	Max. Index
9100	8167	9350
9150	8212	9402
9200	8257	9453
9250	8302	9504
9300	8347	9556
9350	8392	9607
9400	8437	9659
9450	8481	9710
9500	8526	9761
9550	8571	9813
9600	8616	9864
9650	8661	9915
9700	8706	9967
9750	8751	10018
9800	8796	10070
9850	8840	10121
9900	8885	10172
9950	8930	10224
10000	8975	10275

FIGURE 41. Total weight index limits.

reduction factor for all moments in the calculations. Sufficient accuracy is obtained by rounding off index numbers to the nearest tenth.

Example 25.

Assume you are a pilot planning a flight in an air-taxi aircraft. Your load consists of yourself, your copilot, 11 passengers, 300 pounds of fuel in each of the main tanks, 120 pounds of fuel in each of the auxiliary tanks, 75 pounds of oil, 100 pounds of baggage in the nose compartment, and 200 pounds of baggage in the rear compartment. The sample manifest form in figure 37 has been completed to show the useful load and empty weight items. Use the loading tables and total weight index limit table shown in figures 38 through 41 to determine if the aircraft is properly loaded for takeoff. The intersection of the dotted weight and moment/100 lines in figure 41 shows that limits are not being exceeded.

TWIN-ENGINE CARGO AIRCRAFT

Small twin-engine aircraft can be used effectively for carrying cargo into airports where operations would not be practical with transport aircraft. Cargo which is particularly suitable for twin-engine aircraft are high-value items or items which must reach local destinations quickly. The scheduled transportation of mail to small cities and towns is an example of the type service these aircraft provide.

Light twin-engine aircraft can be designed for more effective cargo operations if some special loading and handling features are employed. Large size cargo doors are a great help when bulky packages are to be loaded. Without the use of large doors, the cargo space may be restricted because big packages cannot be maneuvered through the passenger type doors. Provisions for securing the cargo to the aircraft structure are also needed. Normally, tiedown rings are attached to the floor and to structural members of the side walls for this purpose.

Many of the high-density twin-engine aircraft can be quickly converted from passenger to cargo use by removing the seats from the main cabin area (fig. 42). In some cases, cargo is carried in the passenger seats and secured by the regular seat belt. It is also

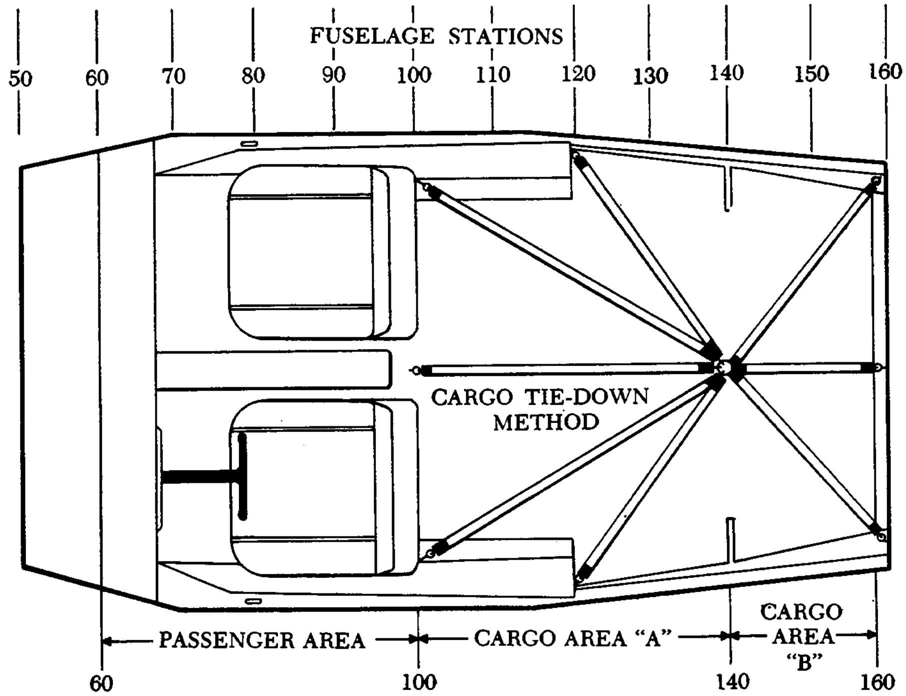


FIGURE 42. Cabin tiedown diagram.

possible that only one or two passenger seats will be removed, resulting in a mixture of cargo and passengers in the main cabin. Measures must be taken in this case to protect the passengers from possible cargo movement.

The following are recommended for the loading of cargo in other than approved cargo compartments or bins:

a. If passengers are carried, the cargo must be carried forward of the foremost passenger.
b. The cargo should be properly secured by a safety belt or other tiedown device to prevent it from becoming a hazard by shifting.
c. The cargo must not impose any load on seats or the floor structure that exceeds the load limitations for these components.
d. The location of the cargo must not restrict access to or use of any required emergency or regular exit by any passenger, or access to an emergency exit by a pilot if a regular exit is not accessible to the pilot.
e. The location of the cargo must not obscure any passenger's view of any required sign, unless an auxiliary sign or other approved means for proper instruction or notification is provided.

Cabin cargo is in danger of shifting if the deck angle (floor attitude) is not level as during the rotation and initial climb at takeoff. Unrestrained cargo will shift rearward in this event and cause a tail-heavy condition which may lead to a dangerous takeoff stall. Cabin cargo is also subjected to inertia forces resulting from turbulence, acceleration, deceleration, vibration, and hard landings. These inertia forces act more strongly in some directions than in others and tend to shift the cargo unless it is properly restrained. A forward force is the one most likely to act on cargo. This force may result from a sudden application of brakes, landing on a soft sod runway, or a crash landing. That is why cargo should be located forward of all passengers in a mixed-load configuration. Cargo must also be secured from moving aft, from side to side (laterally), or up and down (vertically).

Cargo may be secured by means of tiedown devices such as straps, ropes, or nets. These devices, when properly used, will restrain the cargo from moving in any direction. Tiedown fittings should be adequate in number and strength to restrain a cargo of any allowable weight and size. Floor structure, particularly where the tiedown fittings are anchored, must be strong enough to resist any anticipated load without distortion. Cargo floor loading limits are usually expressed as maximum weight in pounds per square foot. If a cargo item is loaded in a seat, the pilot would be wise to limit its weight to that of an average passenger. A tiedown or safety belt should

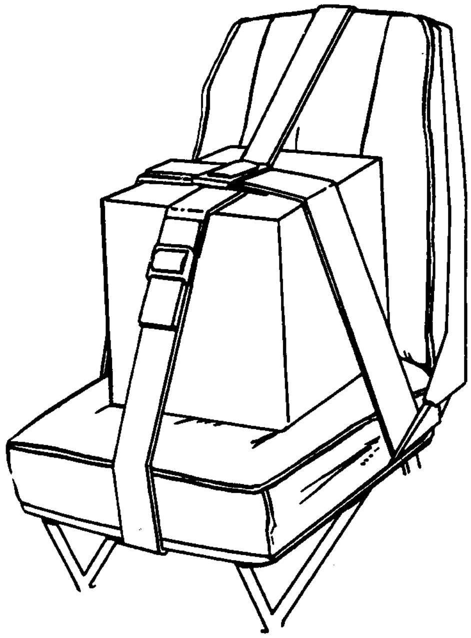


FIGURE 43. Securing cargo in seat.

restrain its movement in the seat (fig. 43). A single cargo item on the cabin floor should be secured in a manner similar to that shown in figure 44. Its center of gravity may be determined by the method shown in figure 45.

The following general precautions should be observed when actually loading the cargo:

1. In a tailwheel aircraft, cylindrical items on their sides should be chocked until lashed down.
2. Liquid containers should be placed with their outlets at the top.

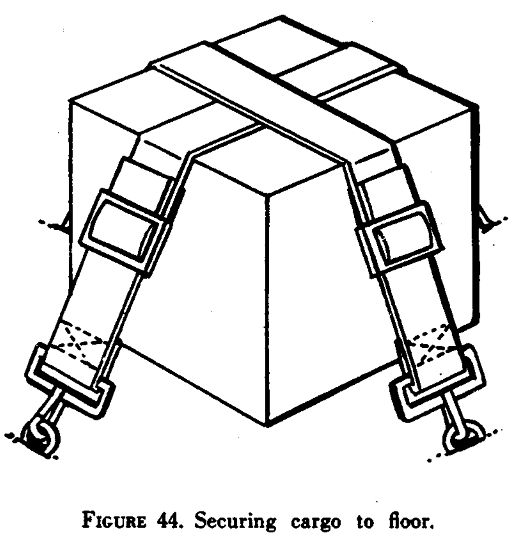


FIGURE 44. Securing cargo to floor.

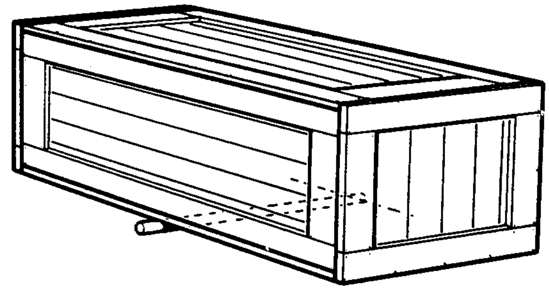


FIGURE 45. Determining c.g. by means of a roller.

3. Lightweight items should be stacked on heavier items, or stacked separately.
4. Shoring or planking must be used when the contact area is likely to exceed the floor-strength limitations.

Many cargo loads carried in air-taxi aircraft will consist of a variety of boxes, crates, sacks, drums, etc. This type of composite cargo may be secured with the type devices shown in figures 46 and 47. Sufficient restraint should be used to prevent shifting because of high deck angle or inertia forces. In

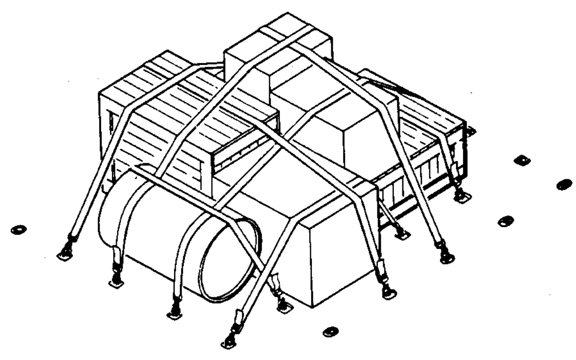


FIGURE 46. Securing composite cargo with straps.

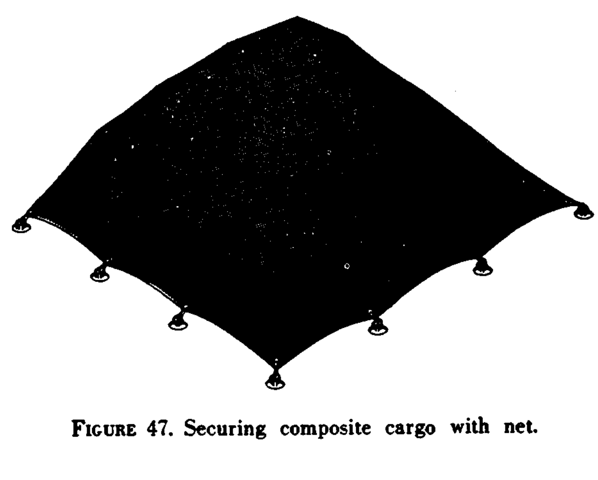


FIGURE 47. Securing composite cargo with net.

COMMUTER TAXI AIRLINE INC.

PASSENGER AND CARGO MANIFEST

PASSENGER – CARGO LIST	WEIGHT	SEAT-COMPT	INDEX
	670	B	
CARGO DESCRIPTION	600	C	
	500	D	
ENTERED HERE	500	E	
PASSENGER – CARGO – MAIN CABIN TOTAL			

WEIGHT	FUEL TANK	INDEX
200	R–MAIN	
200	L–MAIN	
400	R–AUX	
400	L–AUX	
	NOSE	
	TOTAL	

BAGGAGE COMPT		NOSE	
BAGGAGE COMPT	200	REAR	
PILOT – COPILOT	340	–	
OIL	75	–	
FUEL		TOTAL	
EMPTY WEIGHT	5655	–	5271.0
TAKEOFF WEIGHT		–	
TAKEOFF LIMITS	10,000	–	

AIRCRAFT N123QC

FLIGHT 46

ROUTE MKC-DEN

DATE

I HEREBY CERTIFY THAT THE ABOVE TAKEOFF WEIGHT AND INDEX IS WITHIN LIMITS AS SPECIFIED IN THE FLIGHT OPERATIONS MANUAL

PILOT IN COMMAND

FIGURE 48. Cargo manifest.

arranging composite loads, cargo items should not be arranged so the load is topheavy. If possible, the height of the load should not exceed its length. Particular care should be taken to secure this type load against slipping out from under the tiedown device. If the individual items of this type cargo are comparatively light, a net type tiedown device is adequate. Heavy items will require ropes or straps.

Cargo should be placed as near to the c.g. of the airplane as possible, roughly at the 30% chord point; but limitations of particular areas should be observed to prevent overloading the structure. Care must also be taken not to block access to an exit in the rear of the cabin or to cut off an aisle needed for inflight inspection of the main cabin cargo.

Example 26.

This problem is an example of the use of a manifest form to determine the weight and balance condition of a cargo flight. The airplane is the same one used in example 25 with the seats removed from the main cabin. Notice that the empty weight and moments have been changed due to the removal of the seats. This change must be carefully noted according to the manufacturer's recommendations. The sample manifest form in figure 48 has been completed to show the useful load and empty weight items.

Using the loading tables and total weight index table shown in figures 38 through 41 to determine the loading condition of the aircraft, you should obtain a moment of 10038.7 index units. It is apparent when the index limit table is checked that the cargo is loaded too far to the rear. The aircraft is not safe or legal to fly in this loaded condition. The maximum index limit (rear c.g. limit) has been exceeded by 20.7 index units (2070.0 lb.-in.). If the cargo in compartment *E* consists of cartons, each weighing 20 pounds, how many cartons must be moved to compartment *A* to bring the index within the maximum limit?

The baggage or cargo table can be used to help determine how much cargo must be shifted. At least two methods are available:

1. Select the cargo weight which would make a difference of at least 20.7 index units when compartments *A* and *E* are compared. (40 lb.$=64.0-32.0=32.0$ index units)
2. Determine the difference in arms between compartments *A* and *E* (Sta. 160$-$Sta. 80$=$80 in.). Divide the excessive moments by this arm ($2070.0\div80=25.9$ lb.).

By use of either method we can see that the movement of 40 lb. (two ea. 20-lb. cartons) would be required to reduce the index by at least 20.7. A new passenger and cargo manifest should now be executed to prove that the c.g. is within limits with the proposed new load distribution. Of course, it would be possible to shift a greater number of cartons than the minimum to be on the safe side. In any case, care must be taken to remain within the compartment maximum weight limit, the floor loading limit, and the minimum and maximum index limits.

HELICOPTER WEIGHT AND BALANCE

The weight and balance principles and procedures which have been described in connection with airplanes apply generally to helicopters. Each model helicopter is certificated for a specific maximum gross weight. However, it is not safe to operate at this maximum weight under all conditions. Combinations of high altitude, high temperature, and high humidity determine the density altitude at a particular location. This, in turn, critically affects the hovering, takeoff, climb, autorotation, and landing performance of a helicopter. Additional factors to be considered are wind, obstacles, type of surface, and space available for takeoff and landing. Just because a helicopter can take off with a heavy load does not mean that flight with that load will be safe. A heavily loaded helicopter has less ability to withstand shocks and additional airloads caused by turbulence. The greater the weight, the less the margin of safety for the supporting structures such as the main rotor, fuselage, and landing gear.

Most helicopters have a much more restricted c.g. range than do airplanes. In some cases this range is less than 3 inches. The exact location and length of the c.g. range is specified for each helicopter and usually extends a short distance fore and aft of the main rotor mast or the centroid of a dual rotor system. Ideally, the helicopter should have such perfect balance that the fuselage remains horizontal while in a hover and the only cyclic adjustment required should be that made necessary by the wind. The fuselage acts as a pendulum suspended from the rotor. Any change in the c.g. changes the angle at which it hangs from this point of support. Many recently designed helicopters have loading compartments and fuel tanks located at or near the balance point. If the helicopter is not loaded properly and the c.g. is not very near the balance point, the fuse-

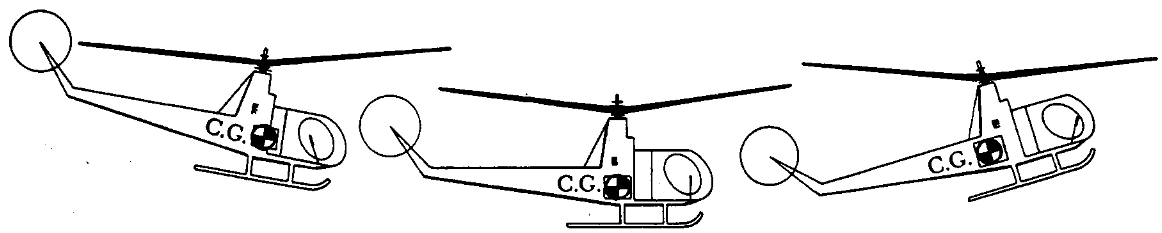


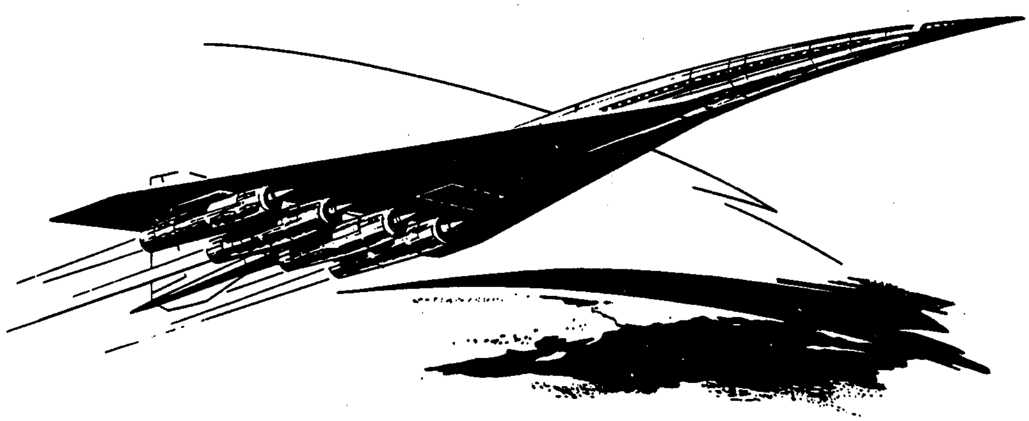
FIGURE 49. Effect of c.g. on helicopter attitude in hover.

lage does not hang horizontal in a hover. If the c.g. is too far aft, the nose tilts up and excessive forward cyclic is required to maintain a stationary hover. Conversely, if the c.g. is too far forward, the nose tilts down and excessive aft cyclic is required (fig. 49). In extreme out-of-balance conditions, full forc or aft cyclic may be insufficient to maintain control. Similar lateral balance problems may be encountered if external loads are carried.

Upon delivery by the manufacturer, the empty weight, empty weight c.g., and the useful load are noted on the weight and balance data sheet in the helicopter flight manual. If, after delivery, additional fixed equipment is added or removed, or if a major repair or alteration is made which may affect the empty weight, empty weight c.g., or useful load, the weight and balance data must be revised. All weight and balance changes should be entered in the appropriate aircraft record. The helicopter flight manual includes directions for solving loading problems. The procedures are similar to those already described for airplanes. For further information, read the FAA Basic Helicopter Handbook, AC 61–13A.

Chapter 7

CONTROL OF LOADING—LARGE AIRCRAFT



The principles of weight and balance which have been discussed in previous chapters apply to large aircraft used by the air carriers and commercial operators as well as to small aircraft used by general aviation pilots and operators. The general concept of weights, arms, and moments apply regardless of aircraft size. The location of the c.g. can always be found by dividing total moments by total weight.

Large aircraft have the same dangerous flight characteristics as small aircraft when weight and balance limits are exceeded. It is not safe to assume that a large aircraft, because of its apparent abundance of engine power and spacious passenger and cargo compartments, cannot be loaded in an adverse manner. Any aircraft can be overloaded or loaded out of balance if weight and balance control procedures are not followed.

Aircraft which have a large number of passenger seats potentially possess great flexibility of loading configurations. From a utilization standpoint, such flexibility is desirable; but unless due consideration is given to weight and balance control, such an aircraft may easily be loaded in a nose-heavy or tail-heavy condition.

Large aircraft, particularly those operated by air carriers, are flown and maintained by a large number of people. No one pilot or mechanic may be fully and personally familiar with the loading or weight and balance condition of a particular aircraft. A properly documented weight and balance control system which is understood by flight, maintenance, and dispatch personnel is necessary for safe and orderly flight operations.

Weight control has a direct relationship to the profit or loss made by air carrier and commercial operator aircraft. When extra fuel is required for long trips or to allow for delays, the payload (passengers, baggage, cargo) must be proportionately reduced to prevent exceeding maximum weight limits. When trips are short and the payload is high, there are frequent changes of passenger and cargo load. Under these conditions, a quick, accurate method must be available to keep account of the aircraft weight and balance condition.

WEIGHT AND BALANCE CONTROL PROCEDURES

The operator should develop a method and procedure by which it can be shown that the aircraft is properly loaded and will not exceed authorized weight and balance limitations during operation. The large aircraft operator should also account for all probable loading conditions which may be experienced in service and devise a loading schedule which will provide satisfactory weight and balance control. Loading schedules may be applied to individual aircraft or to a complete fleet. When an operator utilizes several types or models of aircraft, the loading schedule should be identified with the type or model of aircraft for which it is designed.

CENTER OF GRAVITY TRAVEL DURING FLIGHT

The operator's flight manual should show procedures which fully account for the extreme variations in c.g. travel during flight caused by all or any combination of the following variables:

1. The movement of passengers and cabin attendants from their normal seat position in the aircraft cabin to the lounge or lavatory.
2. Possible change in c.g. position due to landing gear retraction.
3. The effect of the c.g. travel during flight due to fuel used.

RECORDS

The operator's weight and balance system should include methods by which responsible personnel will maintain a complete, current, and continuous record of the weight and c.g. of each aircraft. Such records should reflect all alterations and changes affecting either the weight or balance of the aircraft, and will include a complete and current equipment list. When fleet weights are used, pertinent computations should also be available in individual aircraft files.

The operations specifications of each air carrier should also contain the procedures used to maintain control of weight and balance of all aircraft operated under the terms of the carrier's operating certificate. The procedures should assure that the aircraft, under all operating conditions, is loaded within the gross weight and c.g. limitations. They should include a reference to the procedures used for determining weight of passengers and crew, weight of baggage, periodic aircraft weighing, type of loading devices, and identification of the aircraft concerned.

WEIGHT AND BALANCE SYSTEMS

The large aircraft operator's weight and balance control system may be in any form that proves workable. Several systems have been devised and many variations of the required documents are in use. All the systems strive for a rapid method of determining if the aircraft's weight and balance is within the stated tolerances. The systems are more sophisticated than those used for general aviation aircraft, however, they are subject to some of the same errors. Simple arithmetic errors and errors in updating necessary records after equipment changes are common sources of trouble. The latest systems are designed to eliminate the human error factor while speeding up the process of getting weight and balance information to the pilot and others who are responsible.

Weight and balance control systems are primarily based upon information contained in official sources, such as the Airplane Flight Manual, Type Certificate Data Sheets, etc. Ultimately, all systems are designed to provide values for a load manifest which in turn shows that the weight and balance condition is within limits for the flight.

AIRPLANE FLIGHT MANUAL

The airplane flight manual may be found in several forms—variations of the manuals are the result of the slight differences in operations by the various aircraft operators. Some manuals contain all the essential weight and balance information together with flight performance information in one volume, others utilize a separate volume for loading information.

A typical manual contains an explanation of the approved weight and balance system. It also provides limitations as they apply to the aircraft under various operating conditions. Fuel-loading charts are included, these charts indicate fuel-load arrangements and also the moments or index which apply to a particular fuel load.

The loading section of the manual also contains information about passenger and cargo loading. It includes tabulated charts which indicate the index value for normal payloads. Instructions are also contained in the manual concerning procedures to use when the load is other than normal. For example, the manual explains the adjustments to make in passenger compartment index calculations when cargo containers are placed in passenger seats.

Typical information from the weight and balance section of the manual is shown in the crewmember table, figure 50. It will be noted that the table provides the normal weight and balance information (weight, arm, and moment/1,000) which is to be used in the load manifest.

Title	*Weight Lb.*	*Arm In.*	*Moment 1000*
Captain	170	229	39
First Officer	170	229	39
Flight Engineer	170	263	45
First Observer	170	263	45
Second Observer	170	290	49
Fwd. Cabin Attendant – Female	130	311	40
Fwd. Cabin Attendant – Male	150	311	47
Aft Cabin Attendant – Female	130	1169	152
Aft Cabin Attendant – Male	150	1169	175

FIGURE 50. Crewmember index table.

LOAD MANIFEST

The load manifest (fig. 51) is completed by use of information from the manual as it pertains to the particular flight. Basic operating weight is either calculated or carried forward from previous records. Payload and fuel-load indexes are obtained from load tables. When the weight and index items are totaled on the load manifest, such factors as zero fuel weight, taxi gross weight, and c.g. in % MAC are indicated. The load manifest makes provisions for last minute corrections such as would be necessary when cargo or additional passengers are added just before takeoff. Weights on the load manifest may be indicated in kilograms (kilo or kg.), or pounds, or both. Forms used for international operations will usually have weights indicated in kilograms.

TYPICAL SYSTEMS

Loading summary chart. A typical approach to the problem of finding c.g. quickly is found in the use of a loading summary chart. Representative loading summary charts are shown in figures 52 and 53. These charts provide a means for determining c.g. position with some of the arithmetic steps omitted. Generally, the charts are entered at the top with basic operating weight and its index. Then a line is drawn downward and corrections are made to the right or left as appropriate for loads in each compartment. When all the compartment loads are considered, the line will indicate the zero fuel weight index. Continuing the line downward, a right or left adjustment is made for fuel load. The line is then terminated in the grid section of the chart at a horizontal line which represents the total weight. The terminal point of the line is an indication of c.g. in % MAC or index. Many turbojet aircraft load summary charts will provide an answer directly in stabilizer setting increments.

Load adjusters. Military aircraft have for many years made use of load adjusters for weight and balance computations. The load adjuster is a balance computer similar in form to the conventional slide rule. It consists of a base, a slide and a transparent, movable indicator. A representative load adjuster is illustrated in figure 54.

Load adjusters should never be interchanged between aircraft of different series or models. Although the method of using all load adjusters is generally the same, the scales that appear on a load adjuster are designed for use with one specific type of aircraft.

Generally, the load adjuster is used in a manner similar to the procedure explained for the load summary chart. The process begins with the basic operating weight and index. The index is always placed under the cursor or hairline of the load adjuster. Then the cursor is moved to the right or left a distance determined by the weight and index units for each load item added to the basic operating weight. As each load item is considered, the cursor is moved until all load items, including fuel, have been accounted for. After the final movement of the cursor, the total weight index will appear under the cursor hairline.

The load adjuster also has a c.g. grid which permits quick conversion of the answer from total weight index to c.g. in % MAC. Inasmuch as the load adjuster is designed for one model airplane, the fore and aft limits are indicated on special scales. After determining total weight index, the

FLIGHT LOADING MANIFEST

MODEL ____________ AIRPLANE NO. ______________ FLIGHT NO. ____________

REMARKS

INDEX UNITS = WEIGHT (BAL ARM - 463) / 10,000

ITEM		WEIGHT POUNDS	INDEX UNITS
BASIC WEIGHT (FROM WT. & BAL. LOG)	LB	C.G.	% MAC
OIL	(GAL)		
CREW	(NO.)		
CREW BAGGAGE			
WASH & DRINK WATER	(GAL)		
PASSENGER SERVICE EQUIPMENT			
EMERGENCY EQUIPMENT			
SPECIAL EQUIPMENT			
BASIC OPERATING WEIGHT	LB	C.G.	% MAC
PASSENGERS			
BAGGAGE - FWD. COMPT.			
BAGGAGE - AFT COMPT.			
CARGO - FWD. COMPT.			
CARGO - AFT COMPT.			
ZERO FUEL WEIGHT	LB	C.G.	% MAC

TANK	DRIP STICK (IN)	DRIPSTICK GALLONS	DRIPSTICK POUNDS	GAGE LB	GAGE DIFF. + OR − LB.	INDEX UNITS
RESERVES NO. 1 & 4						
OUTBD. MAINS NO. 1 & 4						
INBD. MAINS NO. 2 & 3						
CENTER WING						
TOTALS						
LB/GAL.		TOTALIZER →				

CORRECTIONS

ITEM	CHANGES WT.	CHANGES INDEX UNITS
TOTAL ADDED	+	+
TOTAL REMOVED	−	−
NET DIFFERENCE		

ITEM		WEIGHT - LB	INDEX UNITS
TOTAL FUEL	GAL LB/GAL		
TAXI GROSS WEIGHT (UNCORRECTED)	LB	C.G.	% MAC
CORRECTIONS (IF REQUIRED)			
TAXI GROSS WEIGHT (CORRECTED)	LB	C.G.	% MAC

COMPUTED ______________ DATE ____________

CHECKED ______________ DATE ____________

PILOT ______________ DATE ____________

FIGURE 51. Flight loading manifest form.

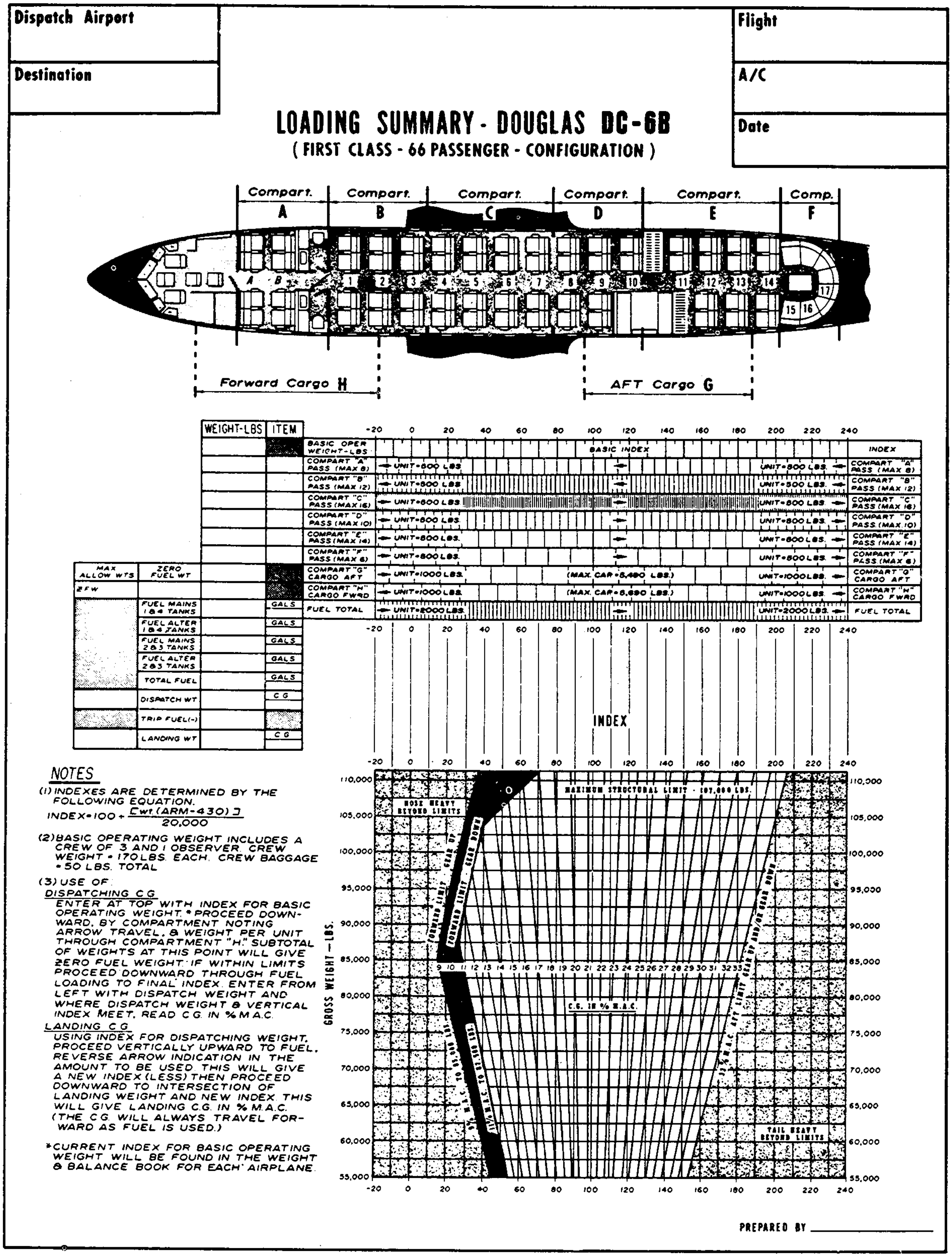


FIGURE 52. Loading summary chart—DC-6B.

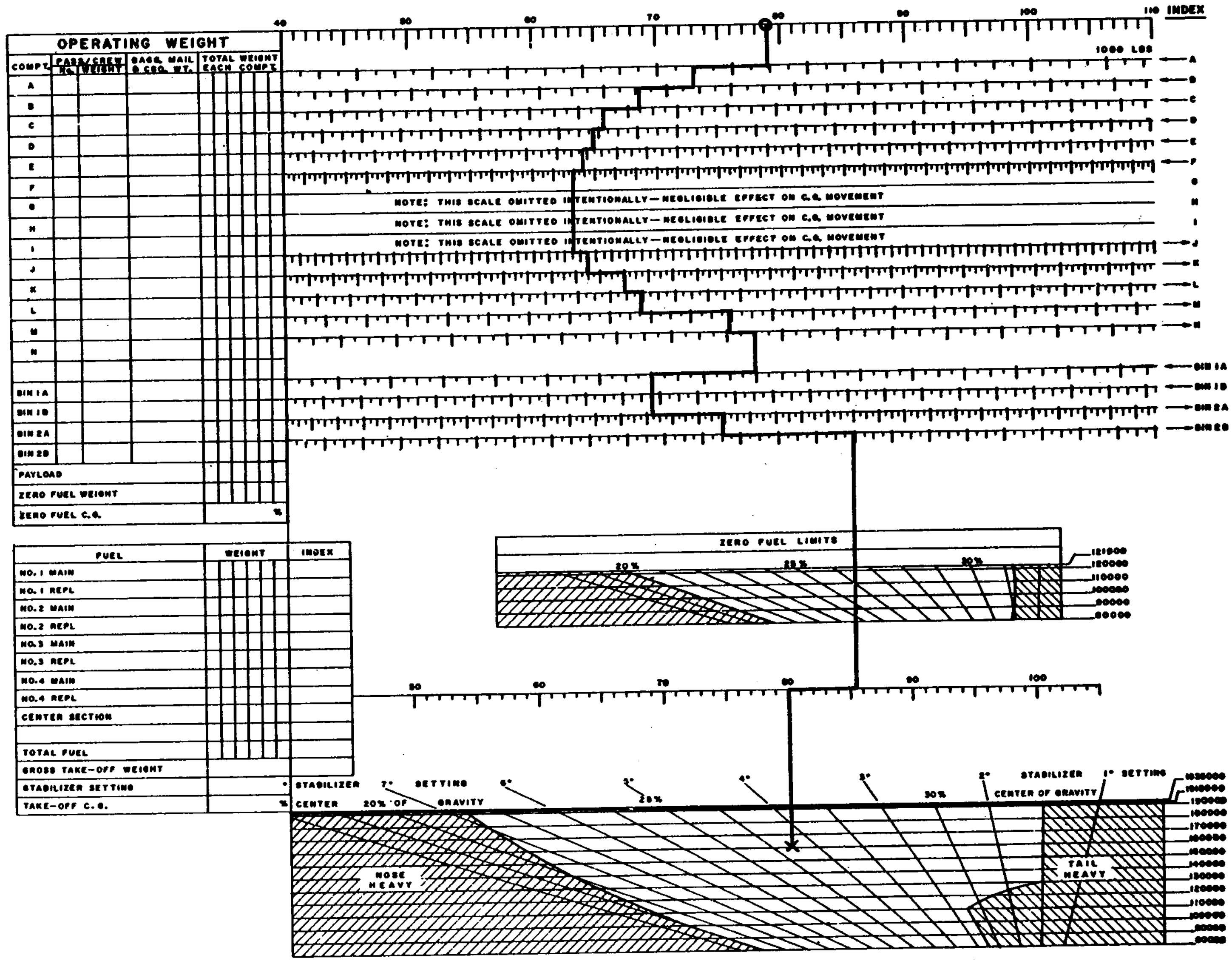


FIGURE 53. Loading summary chart—CV-880M.

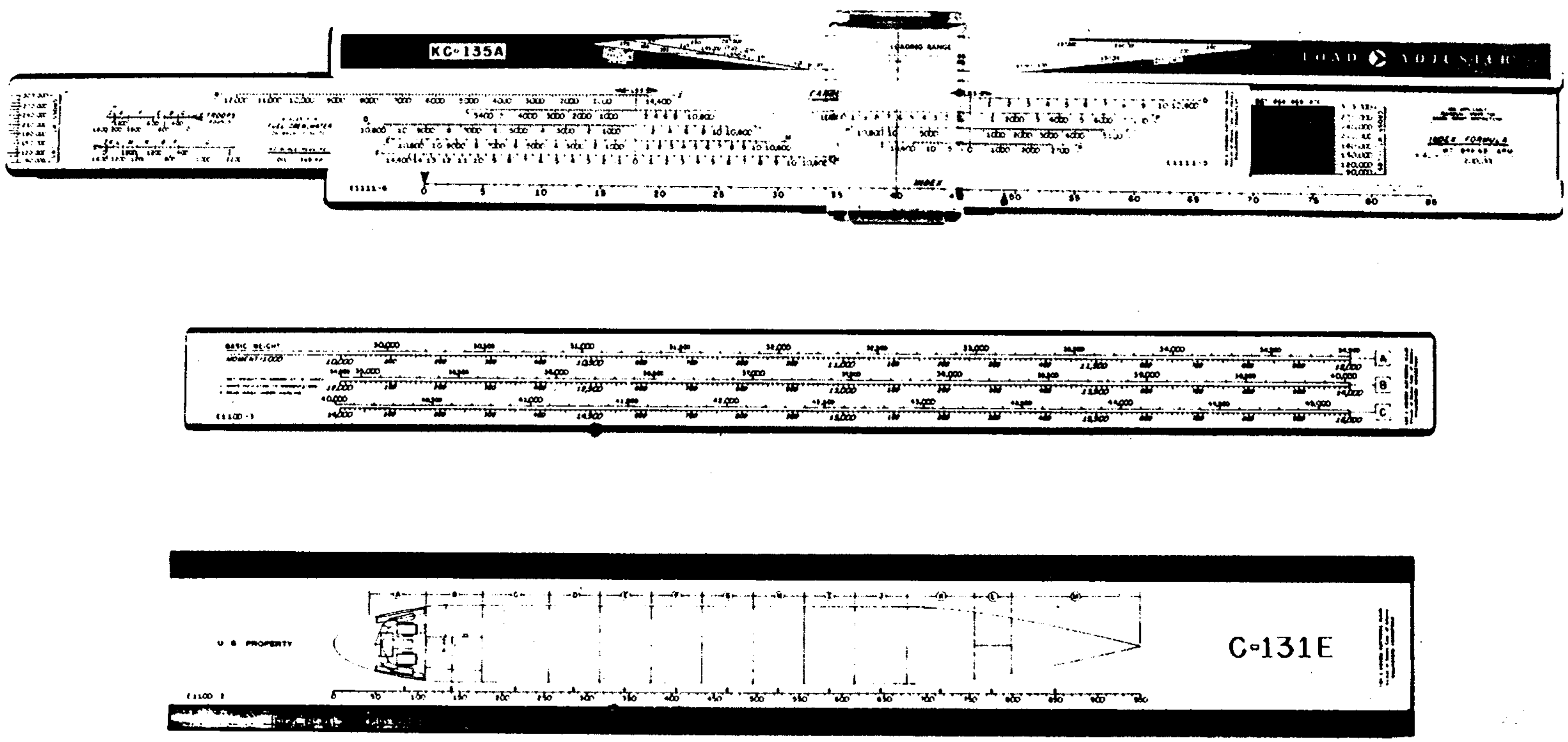


FIGURE 54. Load adjuster.

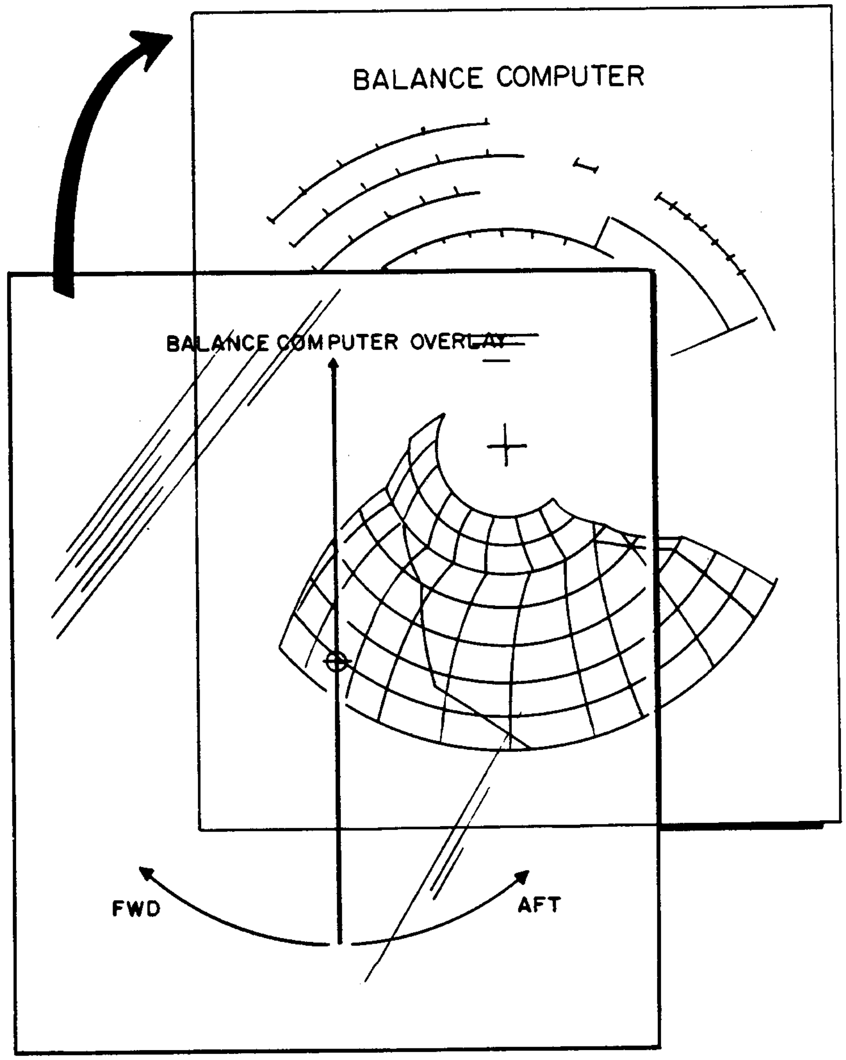


FIGURE 55. Balance computer and overlay.

location of the c.g. relative to its limits can easily be seen.

A diagram of the aircraft fuselage is normally included on the load adjuster. This diagram is used to help identify various compartment locations.

Balance computer. A slide rule can be circular as well as linear in construction—the aeronautical computer is an example of the circular type. Circular slide rules or computers have been adapted to the solution of weight and balance problems. Essentially, these balance computers are circular load adjusters, and like the linear type, can be used only for an aircraft of one make, model, and configuration. The identification markings of a balance computer should be carefully checked to insure its correct use.

The circular balance computer consists of a card on which are printed curved scales for load items and a curved c.g. grid. A different card is provided for each configuration aircraft and can be included in the weight and balance section of the aircraft flight manual. A transparent plastic overlay sheet with a simple straight line similar to the cursor on the load adjuster is used on top of the balance computer card (fig. 55).

The procedure for use of the circular balance computer is similar to that used on the slide rule type load adjuster. Starting with basic index units, progressive movements of the overlay are made in clockwise or counterclockwise directions. A pencil mark is made on the overlay before making each adjustment for a load item. After the final fuel item adjustment is accounted for, the line on the plastic overlay indicates the c.g. location where it crosses

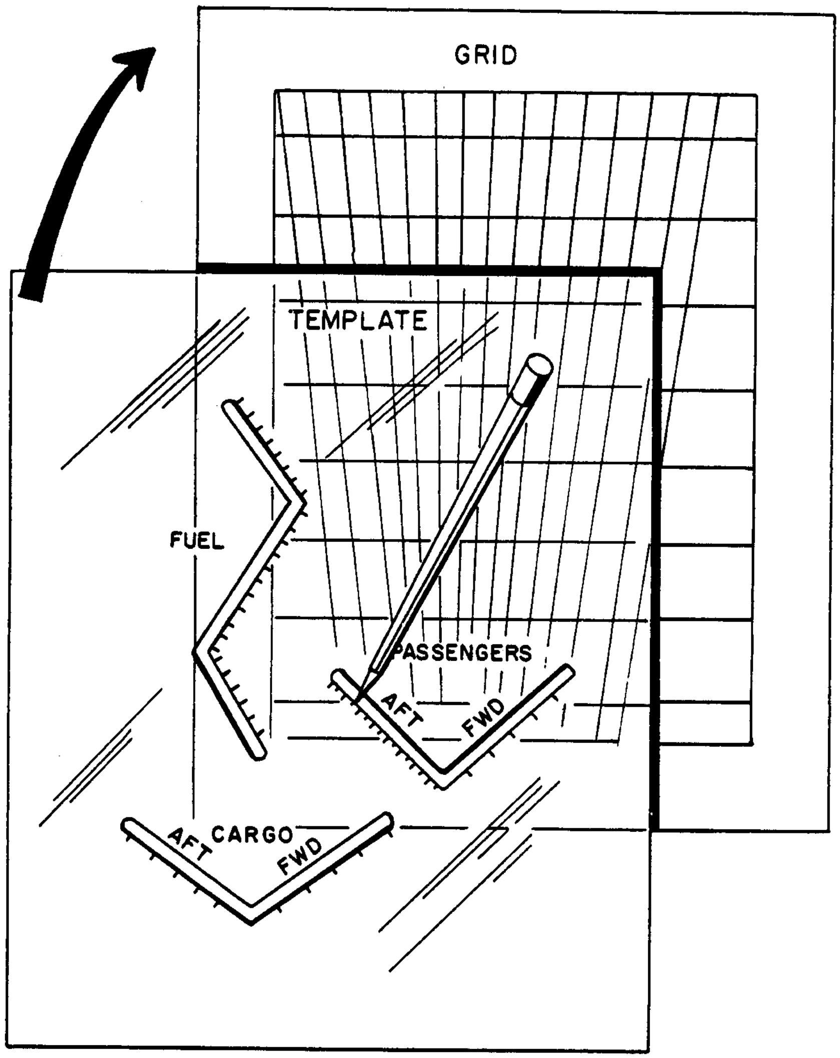


FIGURE 56. Template and grid.

the gross weight line on the c.g. grid. The c.g. is indicated in % MAC on the grid and the grid itself is a limit envelope (fig. 55).

The design of the circular balance computer takes into account several general assumptions pertaining to the normal operation of the aircraft. Among these is the assumption that passengers will have a preference for empty seats next to the windows and that the fuel will be loaded and consumed according to standard schedules.

If standard practices are followed, the computer allows omission of the intermediate steps of calculating moments and indexes for the load items.

Template and grid. A similar system makes use of a large weight and balance grid upon which the weight items are directly plotted. The grid indicates the weight and balance limits of the aircraft as expressed in % MAC. The grid can be printed on a hard plastic material from which the plot is erased after use or on a paper form which is kept as a record for each flight. The values for the load items are plotted progressively by the use of a plastic template (fig. 56). The final plot of the fuel load terminates at the intersection of the total weight and c.g. in % MAC.

As in all other systems, this system relies upon getting off to a good start with a reliable basic operating weight and basic operating c.g. in % MAC. Since the final plot represents the fuel load, the plotted fuel line can be followed down the chart as fuel is consumed in flight to get a continuous graphic indication of c.g. location during flight (fig. 57).

Advanced systems. New systems of weight and

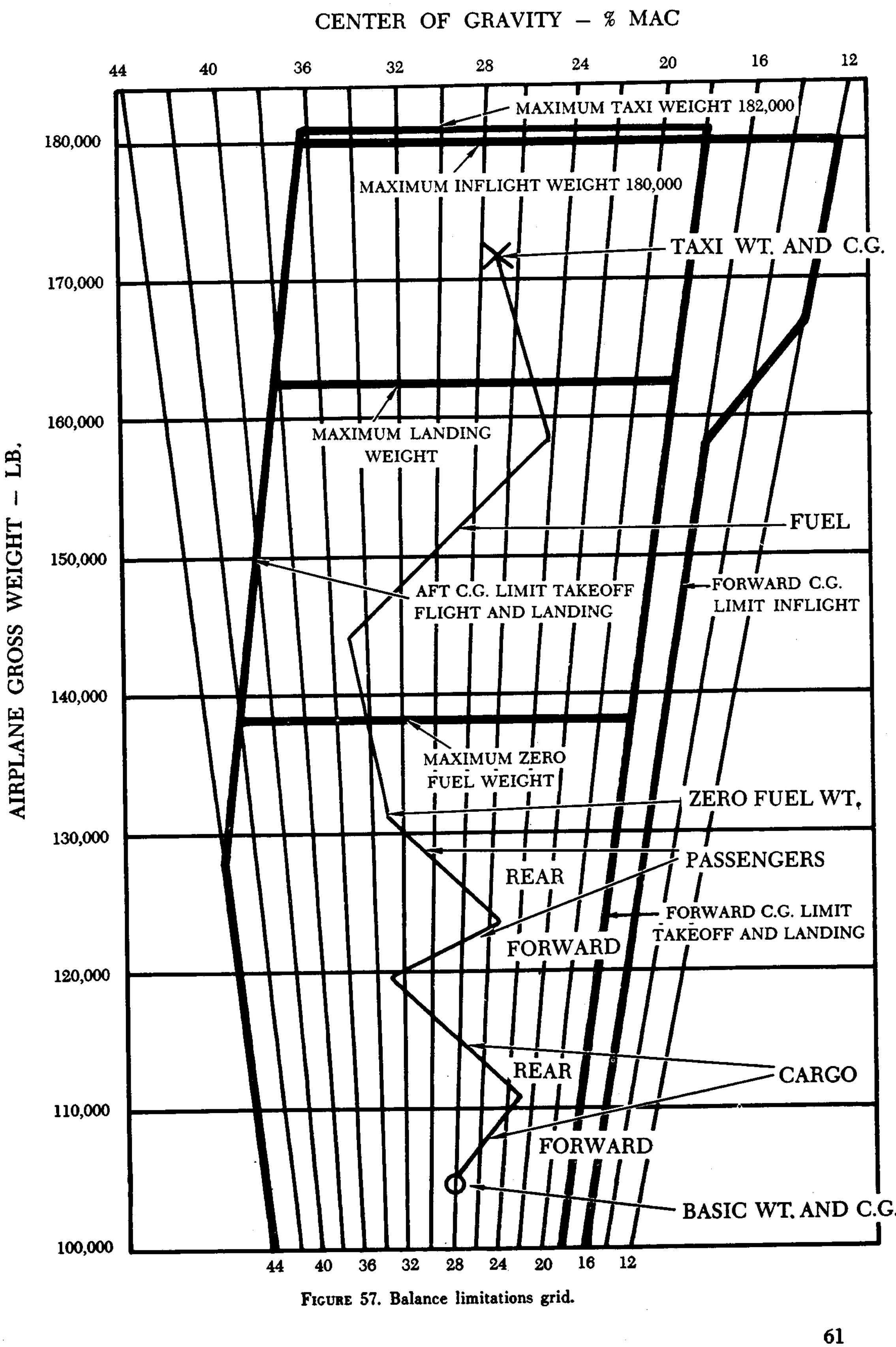


FIGURE 57. Balance limitations grid.

WEIGHT AND BALANCE MANUAL

5-10-61	Equipment List	N-113

Chk	*Description and Identification*	*Quantity*	*Weight*	*Balance Arm*
	Compressor—Air Fuel Starter ABC Co. 4056728	1	50.0	875.6
	Pressure Regulating Shutoff Valve Jones Inc. 1726001-10 Jones Inc. 1726001- 9 (Optional)	1	7.5	835.4
	Boost Pump, Fuel, High Pressure Smith Co. HD 309721-1	2	7.8	756.3
		2	7.8	779.2
		2	7.8	801.5
		2	7.8	835.7
	Boost Pump, Fuel, High Pressure Lotco Inc. XX45678-9	1	10.2	753.0

FIGURE 58. Large aircraft equipment list.

balance control are being devised and will undoubtedly be adopted in the future by the large aircraft operators. Electronic computers can be used to calculate and print out the weight and balance answers; the computer input possibly being based upon passenger and cargo reservation information.

Other systems have been investigated utilizing devices which measure the weight applied to each landing gear when the airplane is on the ground. These devices are installed in the landing gear system and produce a numerical read out of gross weight and c.g. position. The read out could be located in a convenient location in the flight compartment.

LARGE AIRCRAFT WEIGHT AND BALANCE RECORDS

It is apparent when a study is made of the weight and balance control systems introduced in this chapter, that the use of a valid Basic Operating Weight (BOW) is essential for accurate results. Operating personnel must rely upon BOW information in the aircraft records. Maintenance personnel must assure that the recorded BOW is correct.

BOW is defined as the weight of the aircraft as loaded ready for payload and fuel. The BOW, therefore, includes the empty aircraft with all permanently installed equipment, normal oil and fluids (except fuel), crew and crew baggage, passenger service equipment, emergency equipment, and special equipment.

The aircraft is weighed to establish the empty weight and c.g. before it is put into service. When a record is made of this weighing, an equipment list is established which shows each item of installed equipment included in the empty weight. From then on, the condition for empty weight can be duplicated by assuring that this same equipment is installed An excerpt from the equipment list of an FAA aircraft is shown in figure 58.

When equipment changes take place, an appropriate entry is made on a weight and balance log or the equipment list itself is amended so that the empty weight and c.g. are properly corrected. It is essential that any change in structure or equipment be entered in the records, otherwise all other calculations will be inaccurate. Part of a weight and balance log for an FAA aircraft is shown in figure 59.

The use of "empty fleet weights" and "basic operating fleet weights" are explained in FAA Advisory Circular 120–27. When fleet weights are used,

ACTUAL WEIGHT AND BALANCE LOG

Serial: 18066 Registration: N 113

Item and Description	*Weight*	*Balance Arm*	*Moment*	*CG %MAC*	*Index Units*
SUMMARY					
Pre-flight Weighing	98,320	847.3	83355696	25.5	+3,783
Additions	+978		+795556		
Deductions	-429		-338838		
BASIC WEIGHT —	98,869	(847.7)	83812414	25.4	+3,803

FIGURE 59. Weight and balance log.

weight and balance procedures can be standardized and periodic weighings reduced; these advantages are possible when a large number of similar aircraft are used by a particular operator.

The term "zero fuel weight" indicates the maximum authorized weight of an aircraft without fuel—this weight is the sum of BOW and payload. It should be understood that passengers or cargo are included in zero fuel weight. When the zero fuel weight is high because of a large payload, the fuel load must be proportionately low to prevent exceeding maximum takeoff or landing weights. On the other hand, if a large fuel load is needed for a long-range flight or for low-altitude operation, IFR holding, or traffic delays, a reduction of payload and zero fuel weight may be required.

Average weights of adult passengers are assumed to be 160 pounds in summer (May 1—Oct. 31) and 165 pounds in winter (Nov. 1—Apr. 30). Children under 2 are considered "babes-in-arm" and children 2 through 12 are averaged at 80 pounds each. Passenger carry-on baggage is calculated at 5 pounds each. Most weight and balance control systems assume that passengers will select the window seats first, the aisle seats second, and the center of three-abreast seating last. With these assumptions, passenger index tables are calculated. Allowances are made for those loading situations where passengers happen to group in extreme forward or aft locations. In flight, movement of passengers or crewmembers is also considered and load adjustments made. Any such allowances have the effect of reducing the load-carrying flexibility of the aircraft.

A typical passenger load index chart is shown in figure 60. It should be noted that this chart assumes that passengers are seated in the normal distribution around the center (centroid) of the forward and aft passenger compartments. A separate table in figure 60 provides information about cargo loads. The assumption is again made that the cargo is loaded evenly around the centroid of the cargo hold.

Fuel is loaded in large aircraft according to a schedule presented in the FAA approved manuals. Such a procedure distributes the fuel among the fuel tanks in a manner which will cause a minimum of difficulty with weight and balance (fig. 61). Personnel involved with weight and balance are, therefore, able to determine the fuel moments or index from standard tables or by calculating the moment of the fuel in each tank.

Fuel is used according to procedures given in the flight manual. Besides ensuring structural integrity, an important reason for following a standard sequence of fuel tank selection is to control the c.g. location. The flight crew has a much less complex

PASSENGER LOADING TABLE		
Number of Pass.	*Weight Lb.*	*Moment 1000*
FWD. COMP. CENTROID 486.3		
5	850	413
10	1,700	827
15	2,550	1,240
20	3,400	1,653
25	4,250	2,067
29	4,930	2,397
AFT. COMP. CENTROID 928.8		
5	850	789
10	1,700	1,579
15	2,550	2,368
20	3,400	3,158
25	4,250	3,947
30	5,100	4,736
35	5,950	5,526
40	6,800	6,315
45	7,650	7,105
50	8,500	7,894
54	9,180	8,526

CARGO LOADING TABLE		
	Moment 1000	
Weight Lb.	*Forward Hold Arm 581*	*Aft Hold Arm 1066*
6,000		6,396
5,000	2,905	5,330
4,000	2,324	4,264
3,000	1,743	3,198
2,000	1,162	2,132
1,000	581	1,066
900	523	959
800	465	853
700	407	746
600	349	640
500	290	533
400	232	426
300	174	320
200	116	213
100	58	107

FUEL LOADING TABLE

Weight	*Tank 1 and 3*		*Tank 2 (3 Cell)*		*Weight*
Lb.	*Arm*	*Moment 1000*	*Arm*	*Moment 1000*	*Lb.*
8,500	892.1	7,583	817.5	6,949	8,500
9,000	893.0	8,037	817.2	7,355	9,000
9,500	893.9	8,492	817.0	7,762	9,500
10,000	894.7	8,947	816.8	8,168	10,000
10,500	895.4	9,402	816.6	8,574	10,500
11,000	896.1	9,857	816.5	8,982	11,000
11,500	896.8	10,313	816.3	9,387	11,500
12,000	897.5	10,770	816.1	9,793	12,000
18,500	906.8	16,776	815.1	15,079	18,500
19,000	907.8	17,248	815.0	15,485	19,000
19,500	908.9	17,724	814.9	15,891	19,500
20,000	910.1	18,202	814.9	16,298	20,000
20,500	911.7	18,690	814.8	16,703	20,500
21,000	913.4	19,181	814.7	17,109	21,000
21,500	915.5	19,683	814.6	17,514	21,500

FIGURE 60. Loading tables.

STANDARD FUEL LOADING

Total Fuel Load	*Outboard Tanks 1 & 3*	*Center Tank 2*
29,550	9,850	9,850
30,000	10,000	10,000
30,600	10,200	10,200
31,050	10,350	10,350
31,500	10,500	10,500
32,100	10,700	10,700
32,550	10,850	10,850
33,000	11,000	11,000
33,600	11,200	11,200
34,050	11,350	11,350
34,500	11,500	11,500
35,000	11,600	11,800
35,500		12,300
36,000	″	12,800
36,500		13,300
37,000		13,800
37,500	″	14,300
38,000		14,800
38,500		15,300
39,000	″	15,800
39,500		16,300

Total Fuel Load	*Outboard Tanks 1 & 3*	*Center Tank 2*
40,000	11,600	16,800
40,500		17,300
41,000		17,800
41,500		18,300
42,000	″	18,800
42,500		19,300
43,000		19,800
43,500	″	20,300
44,000		20,800
44,500		21,300
45,000	″	21,800
45,500		22,300
46,000		22,800
46,500	″	23,300
47,000		23,800
47,500		24,300
48,000	″	24,800
48,500		25,300
49,000		25,800
49,700	11,600	26,500
50,000	11,750	26,500
50,526	12,013	26,500

FIGURE 61. Fuel load distribution table.

job in determining in-flight c.g. travel if standard burn-out procedures are followed.

When the aircraft is loaded ready for takeoff, the total weight of the aircraft is called taxi gross weight or ramp gross weight. Because of high fuel consumption during ground operation, this weight may be 500 to 1,000 pounds more than takeoff weight. Maximum takeoff weight is the maximum allowable just before brake release. This weight may be limited to a lesser weight for any particular takeoff by many factors related to aircraft performance. The actual takeoff weight limit is calculated by the use of various performance charts, taking into account such factors as: Runway length, temperature, density altitude, runway slope, and wind conditions.

Maximum landing weight is a structural limit and is the maximum weight authorized at touchdown. All weight in excess of maximum landing weight must consist of disposable fuel. A fuel dumping system is required on the aircraft if the maximum takeoff weight is more than 105 percent of maximum landing weight.

Conditions may arise during flight, such as engine failure or an aircraft system failure, which may require a landing sooner than originally planned. In this event, fuel may have to be dumped to reduce weight to maximum landing weight. If the fuel dumping procedures contained in the aircraft flight manual are followed, c.g. travel will remain within prescribed limits. Calculations of the effects of fuel dumping are similar to those used for fuel burn. Use of the fuel-load table moments makes the calculations simple. Some manuals will provide a fuel-tank centroid as a single arm, then the effect of fuel dumping can be calculated by a single remove weight formula such as the one which follows:

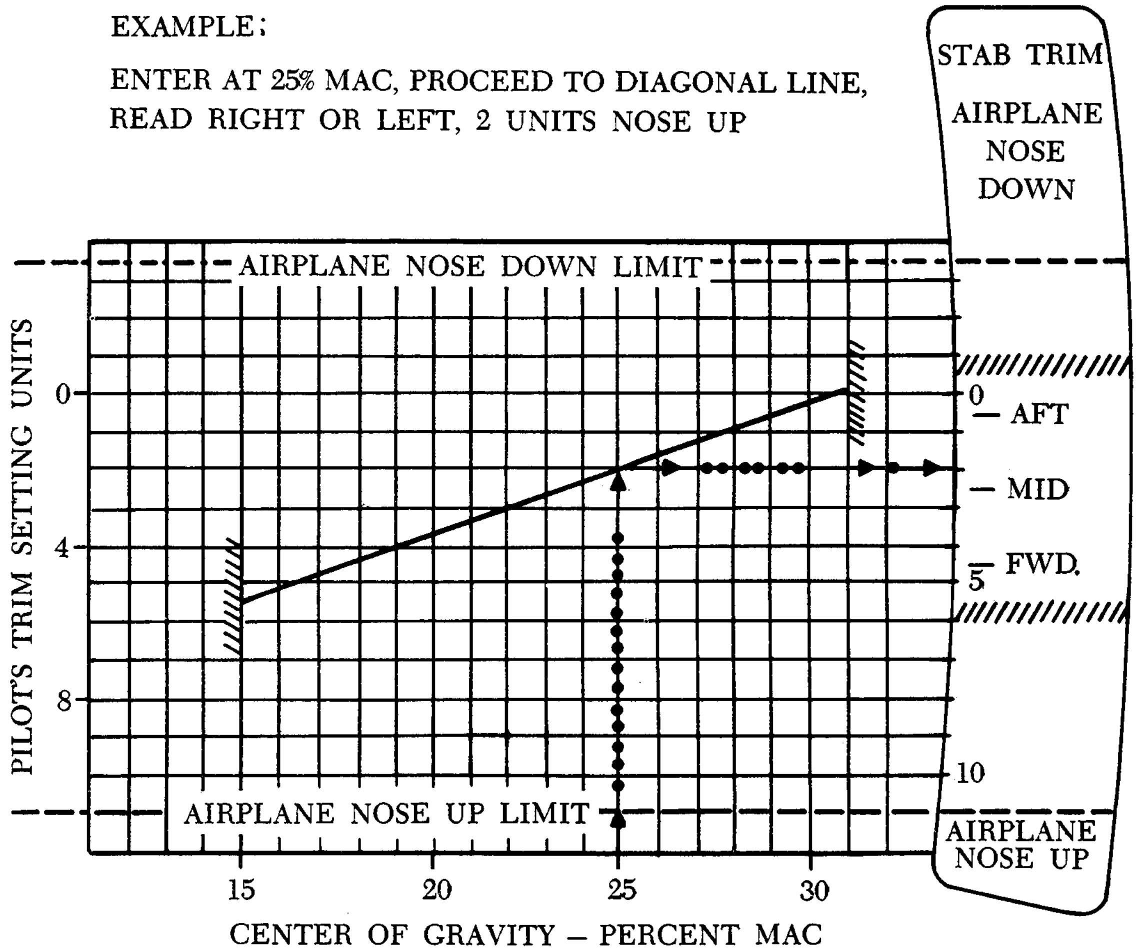


FIGURE 62. Stabilizer trim.

Weight before dumping—160,000 lb.
c.g. before dumping —Sta. 615.5
Fuel to dump —40,000 lb.
Centroid of fuel tanks —Sta. 750.2

Find c.g. after dumping.

Use remove weight formula:

$$\frac{\text{Wt. removed}}{\text{New total wt.}} = \frac{\Delta\text{c.g.}}{\text{Dist. from c.g. to tank}}$$

$$\frac{40{,}000}{120{,}000} = \frac{\Delta\text{c.g.}}{134.7}$$

$$\Delta\text{c.g.} = 44.9$$

c.g. after dumping $= 615.5 - 44.9 = 570.6$ in.

STABILIZER TRIM SETTING

Before starting a takeoff in a large turbojet aircraft, the stabilizer trim must be placed in a position dictated by the c.g. location. An improperly set stabilizer trim may have such a powerful effect that it cannot be overcome by elevator control. During takeoff, it may be difficult to raise the nose (rotate at V_R) ; or on the other hand, the nose may pitch up uncontrollably depending on which direction the stabilizer is out of trim. Once the aircraft is airborne, the trim is adjusted by the pilot to a setting which will enable him to fly with minimum control pressure. The only acceptable procedure for takeoff is to set the trim according to c.g. location before the takeoff roll is started.

Some of the c.g. control systems previously explained (see Convair 880M loading summary, fig. 53) provide a stabilizer setting directly when the total weight c.g. is calculated. Other systems require the use of a simple chart to convert from c.g. in % MAC to stabilizer setting for a particular takeoff weight. A typical chart from an aircraft flight manual is illustrated in figure 62.

When the c.g. is determined to be located at a particular station, that location must first be converted to % MAC to use the stabilizer trim chart. A typical problem follows:

Given:

Takeoff c.g.—Sta. 575.0
MAC —Sta. 540.0 to Sta. 745.0
Stabilizer trim chart (fig. 62)

Find: Stabilizer trim setting for takeoff

Solution:

1. Determine c.g. in % MAC:

$$\text{c.g. \% MAC} = \frac{\text{c.g.} - \text{LEMAC}}{\text{MAC}}$$

$$= \frac{575.0 - 540.0}{205.0}$$

$$= \frac{35}{205} = 17.1\% \text{ MAC}$$

2. Determine stabilizer setting to nearest ½ unit:
   Enter chart at bottom on 17.1 % line.
   Proceed upward to diagonal line.
   Read stabilizer setting = 5 nose up.

LARGE AIRCRAFT LOADING PROBLEM

Given: An air carrier aircraft has the following load condition:

	Weight	Index moment/1,000
1. Basic operating weight	85,000	65720.0
2. Cargo:		
Fwd.	3,000	
Aft	900	
3. Passengers:		
Fwd. 20		
Aft 40		
(Winter wt. = 165 + 5 lb. carry-on baggage)		
4. Fuel load:		
Tank 1	20,000	
Tank 2	20,000	
Tank 3	20,000	

5. Average fuel consumption to point of first intended landing—3,600 lb./hr./engine. Three-engine operation for 2:30 hours. Straight tank to engine fuel management for entire flight.
6. Limitations:
   a. Max. ramp wt.—165,000 lb.
   b. Max. zero fuel wt.—110,000 lb.
   c. Max. landing wt.—135,000 lb.
   d. c.g. limits—15% to 35% MAC
   e. MAC—Sta. 750.0 to Sta. 955.0

Find:

Ramp and landing weights and c.g.
Investigate if limitations are exceeded.
Stabilizer trim setting.

Solution:

Use loading tables—figure 60.
Use stabilizer trim setting chart—figure 62.

Complete the loading form below:

Takeoff conditions check

Load item	*Weight*	*Index*
Basic operating weight Payload: Cargo: Fwd. Aft Passengers Fwd. Aft		
Sub total (zero fuel weight)		
Fuel load: 1 Main 2 Main 3 Main		
Total (ramp and takeoff wt.)		

Ramp c.g.—% MAC	
Stabilizer trim setting	

Landing conditions check

Load item	*Weight*	*Index*
Zero fuel weight Remaining fuel load: 1 Main 2 Main 3 Main		
Total (landing wt.)		

Landing c.g. % MAC	

Notice that the fuel arms (fig. 60) vary with weight because the aircraft used in the problem is a swept-wing type. The correct procedure is to add a new fuel index to the ZFW index. Subtraction of index units for fuel burned will not properly account for the change in arm.

Using the principles explained in the preceding chapters, you should be able to solve the sample problem. As a spot check, here are several answers:

1. No limits are exceeded.
2. Stabilizer trim for takeoff is one-half nose up.
3. C.G. at landing weight is 22.2% MAC.

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