Fundamentals
M7
MAINTENANCE PRACTICES

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M7.16
Aircraft Weight and Balance

EASA Part-66
CAT B1

Training Manual

Lufthansa Technical Training

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M7 MAINTENANCE PRACTICES

M7.16 AIRCRAFT WEIGHT AND BALANCE

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CENTER OF GRAVITY/BALANCE LIMITS CALCULATION: USE OF RELEVANT DOCUMENTS

Aircraft Weight and Balance

Introduction

All aircraft have design limitations. One of these limitations is weight.

The factors that must be included in determining the weight limitations are the structure, the lift forces, and the maneuvers that the aircraft is allowed to perform. Also the potential lift of the aircraft for maintenance reasons must be taken into account. For these reasons a maximum weight must be established for each aircraft during the design phase.

The distribution of weight is also of vital importance since the position of the center of gravity (Abbr. CG) affects the flight stability of the airplane. In loading an airplane, the C.G. must be within the permissible range and remain so during the flight to ensure the stability and maneuverability of the airplane during flight.

Airplane manufacturers publish weight and balance limits for their airplanes. This information can be found in two sources:

- **1. The Aircraft Weight and Balance Record (WBR)**
- **2. The Aircraft Operation Manual (AOM)**

The information in the Aircraft Operation Manual is general for the particular model of airplane.

The information in the Aircraft Weight and Balance Record is particular to a specific airplane

The airplane with all equipment installed is weighed and the C.G. limits calculated and this information is tabulated on the record that accompanies the airplane logbooks. If alterations or modifications are made or additional equipment added to the airplane, the weight and balance must be recalculated and a new record prepared.

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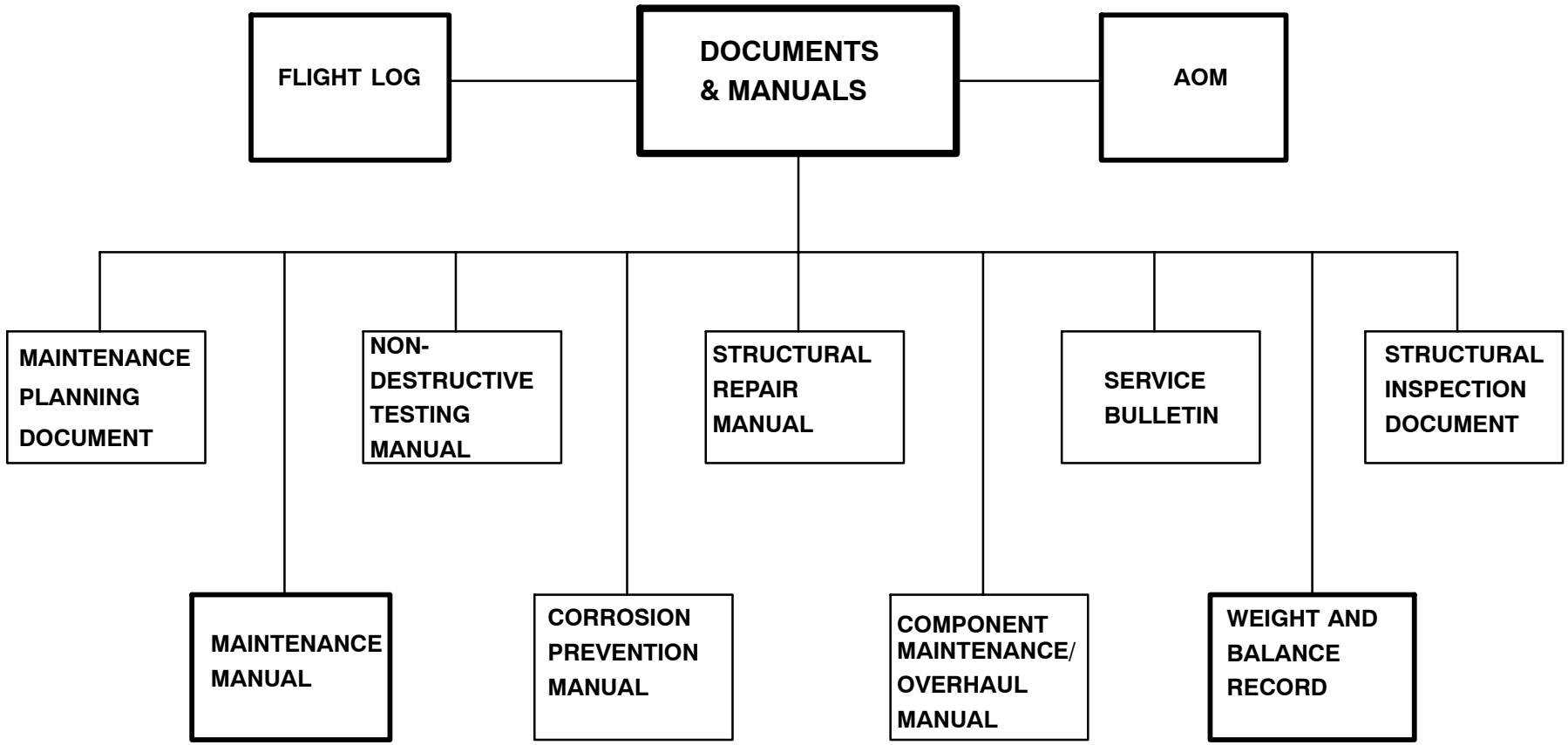


Figure 1 Manual Overview

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Overview of Technical Terms

Definitions and Terminology

The following terminology is used in the practical application of weight and balance control for weighing, maintenance and operational purposes.

Reference Datum

The reference datum is an imaginary line on a vertical plane from which all horizontal measurements on the aircraft are taken for weight and balance purposes. These measurements are taken with the aircraft in a level flight position.

It can also be used when new equipment is to be added or old equipment is to be removed from the aircraft to measure the location of the C.G.

The actual location of the datum for a particular type of aircraft can be any point selected by the manufacturer. Common places are the leading edge of the wing, the firewall and the nose for small aircrafts. For larger aircrafts it is common to place the datum forward of the nose of the aircraft.

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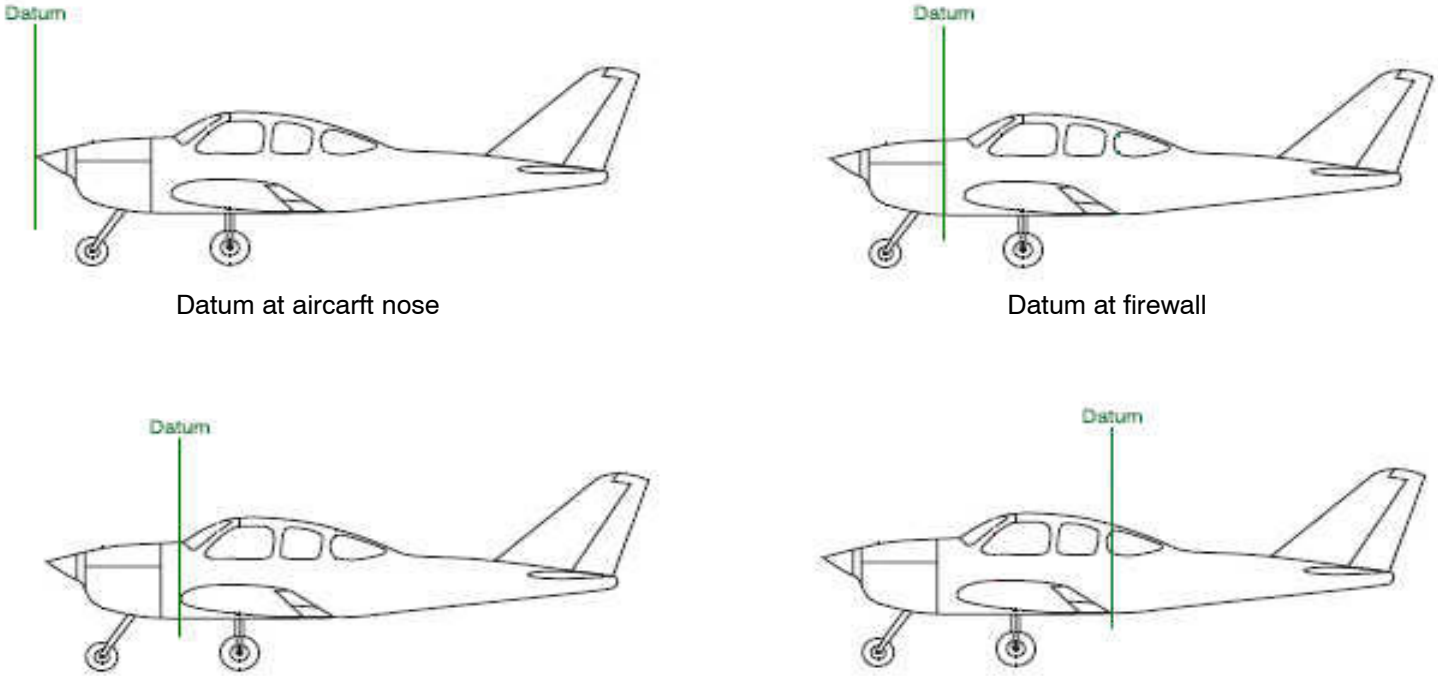


Figure 2 Aircraft Datum

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CENTER OF GRAVITY

Center of Gravity

The center of gravity (commonly abbreviated **CG**) is the point at which the total weight of the aircraft is assumed to be concentrated.

All three axes of the airplane (yaw -, longitudinal- and lateral axis) meet in the center of gravity, whereas all axes are rectangular to each other.

During flight maneuvers the aircraft always turns around one or multiple of these axes and therefore around the center of gravity.

The distribution of the single masses dictates the location of the CG. Therefore the center of gravity is the spot (geometric location), in which the concentrated mass of the whole aircraft can be imagined (center of mass). If an aircraft was hung-up freely or was supported at this point, it would be in balance.

The CG has to be in the allowable limits to ensure a safe and stable flight.

Both lateral and longitudinal balance are very important, but the prime concern is longitudinal balance.

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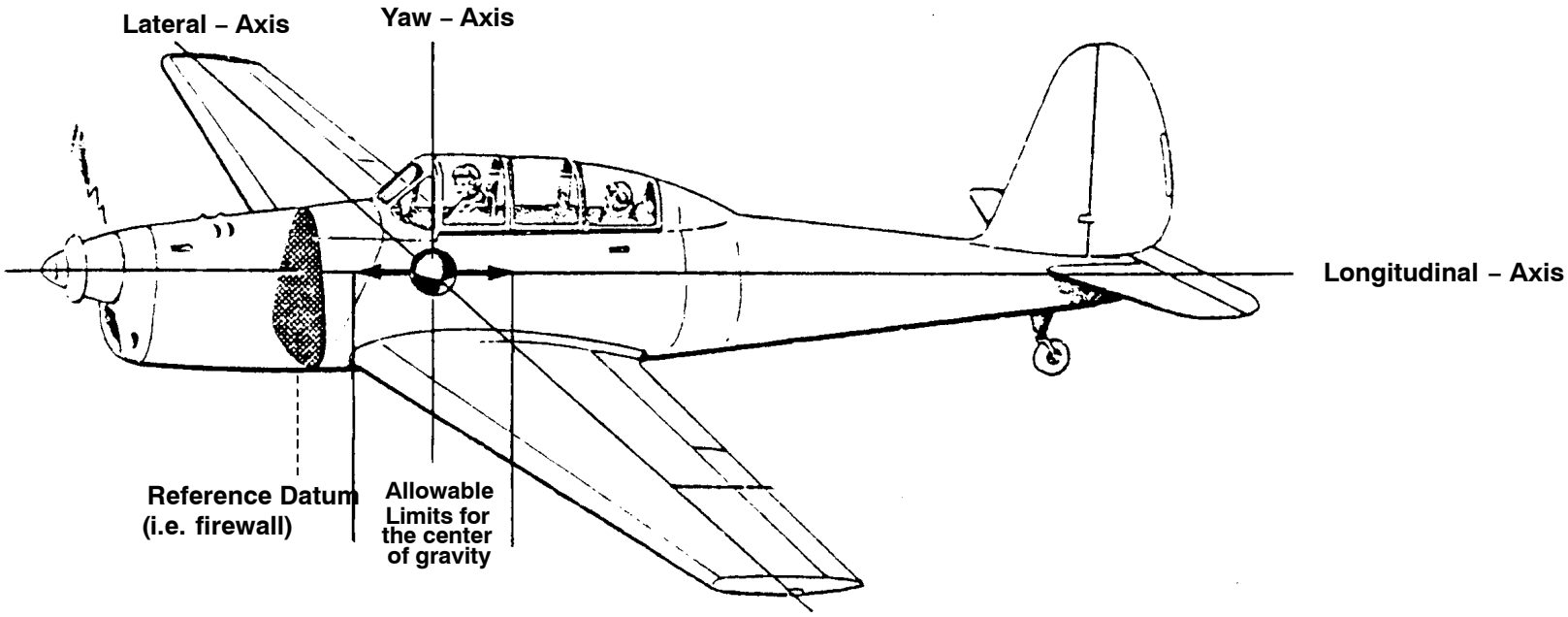


Figure 3 Center of Gravity

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LIMITS FOR THE CENTER OF GRAVITY

Influence of the CG on the Stability and Controllability

The aerodynamic characteristics of an airplane are designed in such way, that it will maintain an straight and horizontal flight after trimming even with the hands off the controls. This requirement is already introduced in the design specifications (z. B. CS-25, FAR-25).

Longitudinal stability is maintained by ensuring the CG is slightly ahead of the center of lift.

This produces a fixed nose down force independent of the airspeed (nose down moment).

The horizontal tail surfaces creates a downward force, which counteracts this nose down moment.

Self Stabilization

As said before, an aircraft in an non-accelerated horizontal flight should maintain in a stable flight attitude around all three axes.

If a vertical gust should cause the nose to pitch up, the airplane will slow down and the downward force on the tail will decrease.

So the airplane gets automatically back in the desired horizontal flight path.

If the nose should drop in flight through a vertical gust, the airspeed will increase and the increased downward tail load will bring the nose back up to level flight.

Also here the airplane gets automatically back in the desired horizontal flight path.

As long as the CG is maintained within the allowable limits for its weight, the airplane will have adequate longitudinal stability and controllability.

Limits of Stability (Center of Gravity too far aft)

If the CG is too far aft (behind the stability limit of the aircraft manufacturer), it will be unstable related to the lateral-axis.

Limits of Stability (Center of Gravity too far forward)

If the CG is too far forward, the downward tail load will have to be increased to maintain level flight., which increases the drag and the fuel consumption.

If the CG was in front of the forward limit of stability, the downward force of the tailplane could be insufficient to pitch the nose upward. The aircraft would be uncontrollable.

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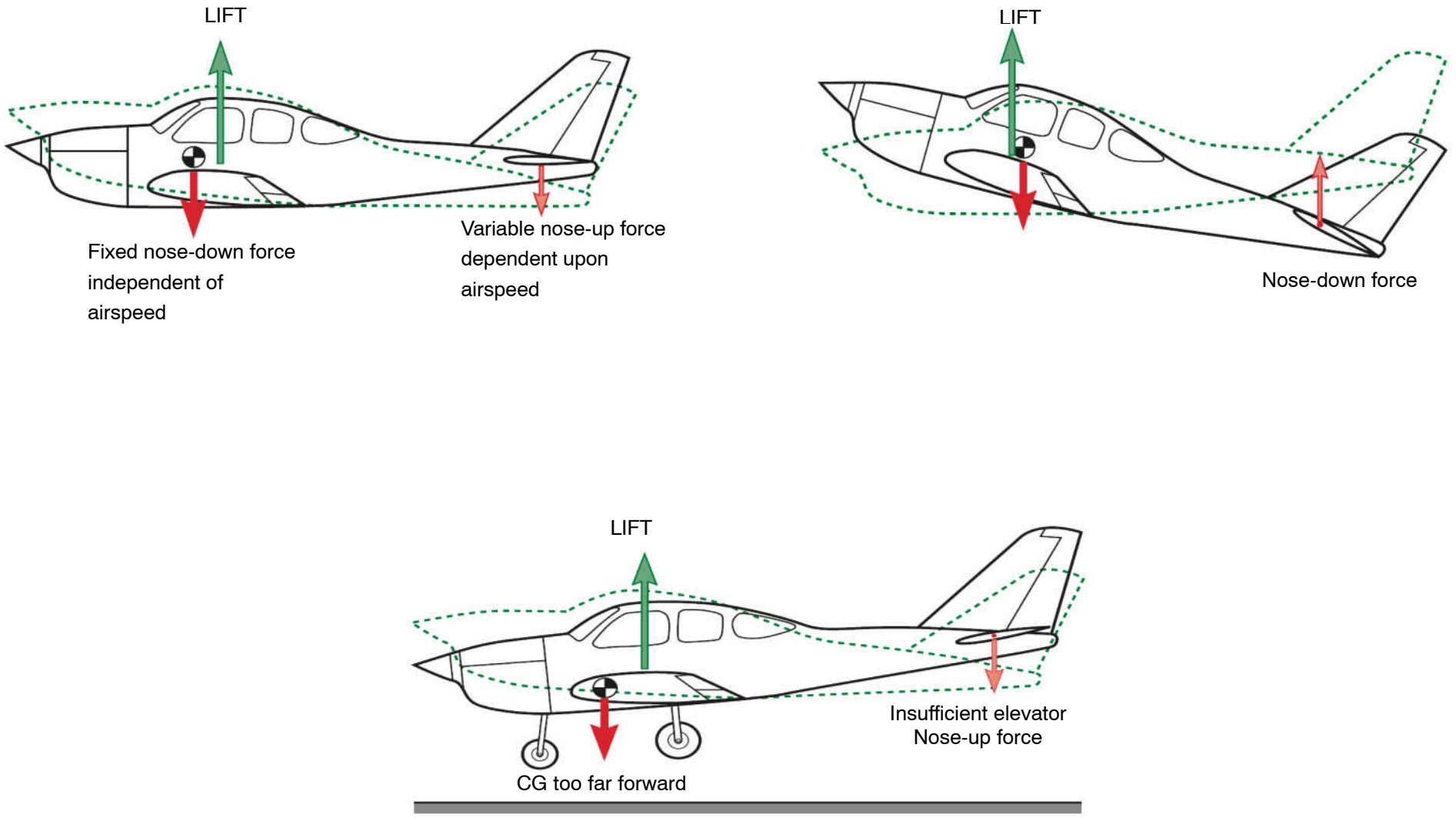


Figure 4 Center of Gravity Limits

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CENTER OF GRAVITY (CONTD.)

Limit Values of the CG

For every type of aircraft the limit values for the CG are recorded in the flight manual. Here it is made a difference (except commercial aircrafts) between normal and utility aircrafts.

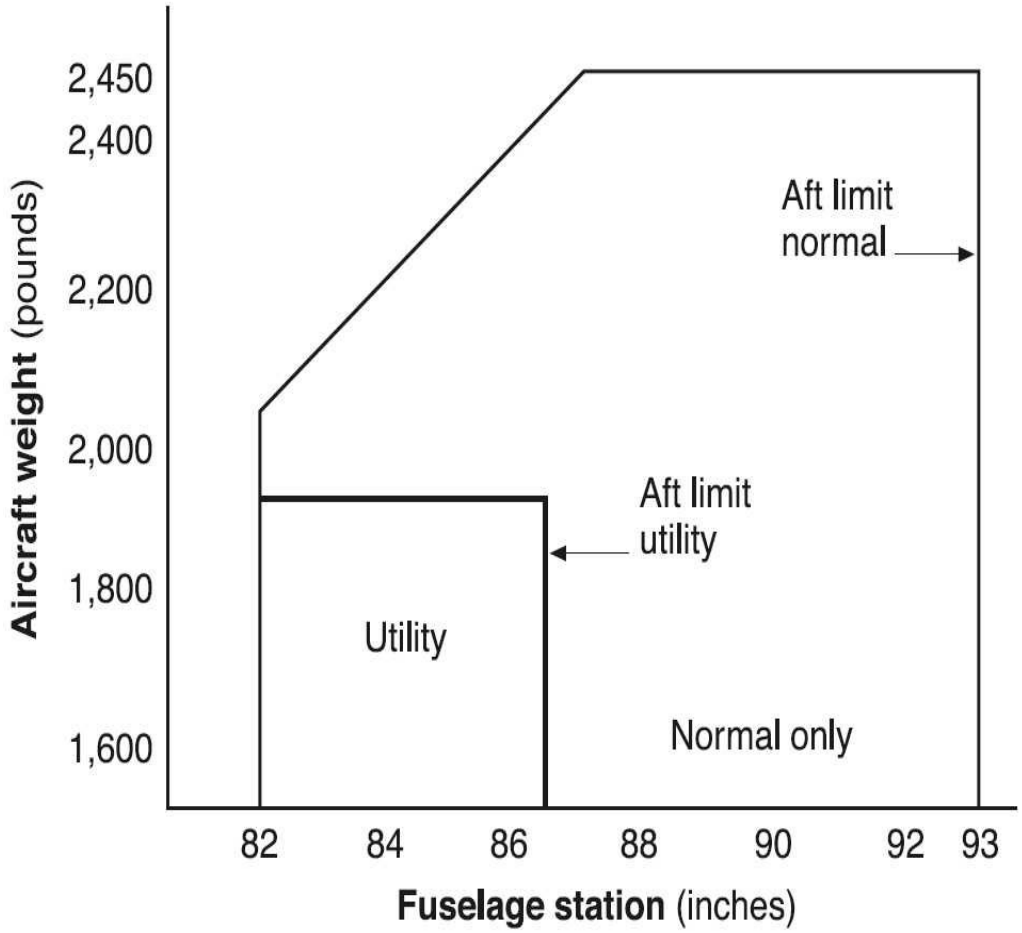
The airworthiness group ”normal aircrafts“ include all airplanes, which are not designed for acrobatic flights.

”Utility aircrafts” are allowed to take part in limited acrobatic flights (steep turn, horizontal eight, reverse turn etc.).

If you want to operate an airplane in the category ”utility aircrafts”, you have to notice that the limits for mass- and the location of the center of gravity are much more narrow.

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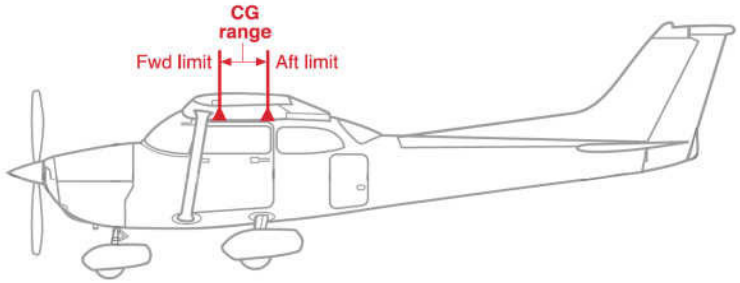


Figure 5 CG-Limits

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DETERMINATION OF THE CG

Computation of the CG

The most easy way to determine the CG on the longitudinal axis is to calculate it.

The formula for obtaining the center of gravity is the total moment divided by the total weight which may be abbreviated:

$$CG = \frac{\Sigma M}{\Sigma W}$$

Other formulas may be used to obtain the center of gravity of an aircraft, as we will discuss later, but these variations will always utilize the total moment divided by the total weight formula.

Empty Weight Center of Gravity

The empty weight CG is the CG of an aircraft in its empty weight condition, and is an important part of the **Weight and Balance Record (WBR)**.

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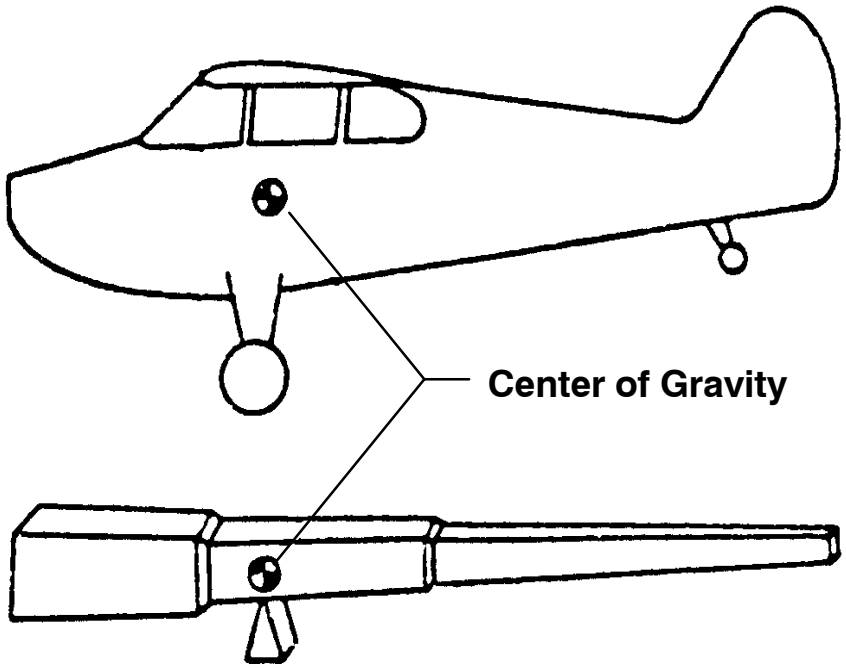


Figure 6 Center of Gravity

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Lever Principle

Forces and Moments on an Airplane

To understand the problem of forces and moments on an aircraft better, it is good to think of a balance beam which is mounted at the center of rotation in the middle.

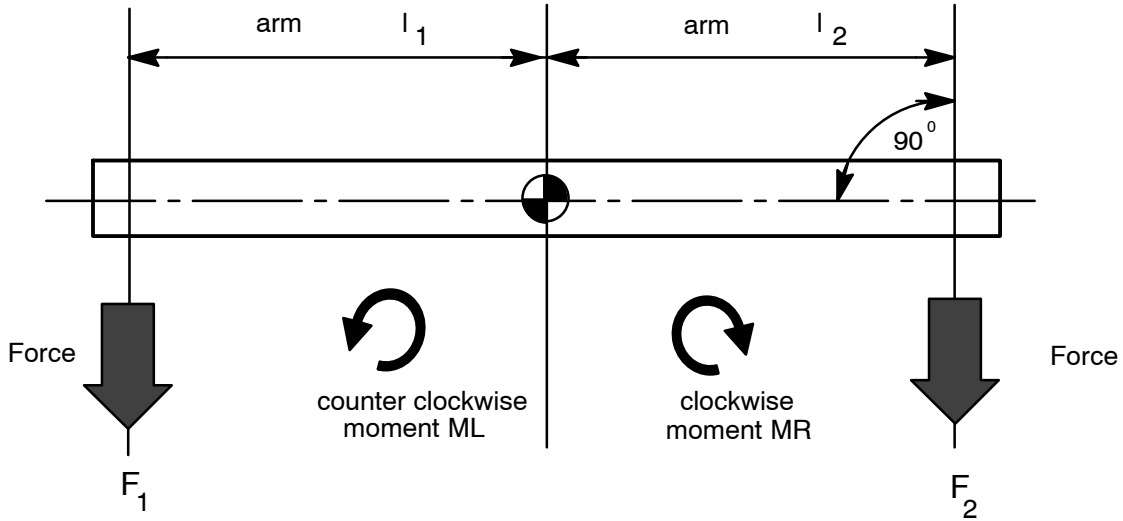
Around the center of rotation a counter-clockwise and a clockwise moment acts. Both moments have the same magnitude, if the beam is not moving (balance). The particular moment can be determined from the formula force (mass) multiplied by effective lever (distance between the mass and the center of rotation).

Since the weight force is directed downwards, the formula is mass multiplied by acceleration due to gravity. The acceleration of gravity is not being taken into account, because it is a constant in the formula.

So to determine the center of gravity the simplified formula “mass multiplied by lever arm“ can be used.

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M_L	=	M_R
$F_1 \cdot l_1$	=	$F_2 \cdot l_2$
$m_1 \cdot g \cdot l_1$	=	$m_2 \cdot g \cdot l_2$
$m_1 \cdot l_1$	=	$m_2 \cdot l_2$

Abbrevia-tions

M = Moment
F = Force
m = mass
l = arm
g = gravity

Figure 7 Arm and Moment

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DETERMINATION OF MASS-MOMENTS

All weight and balance problems are based on the physical law of the lever.

This law states that a lever is balanced when the weight on one side of the Datum multiplied by its arm is equal to the weight on the opposite side multiplied by its arm.

In other words, the lever is balanced when the algebraic sum of the moments about the Datum is zero.

This is the condition in which positive moments (those that try to rotate the lever clockwise) are equal to the negative moments (those that try to rotate the lever counterclockwise).

MASS	x	ARM	=	MOMENT	
+	x	+	=	+	Nose up
+	x	-	=	-	Nose down
-	x	+	=	-	Nose down
-	x	-	=	+	Nose up

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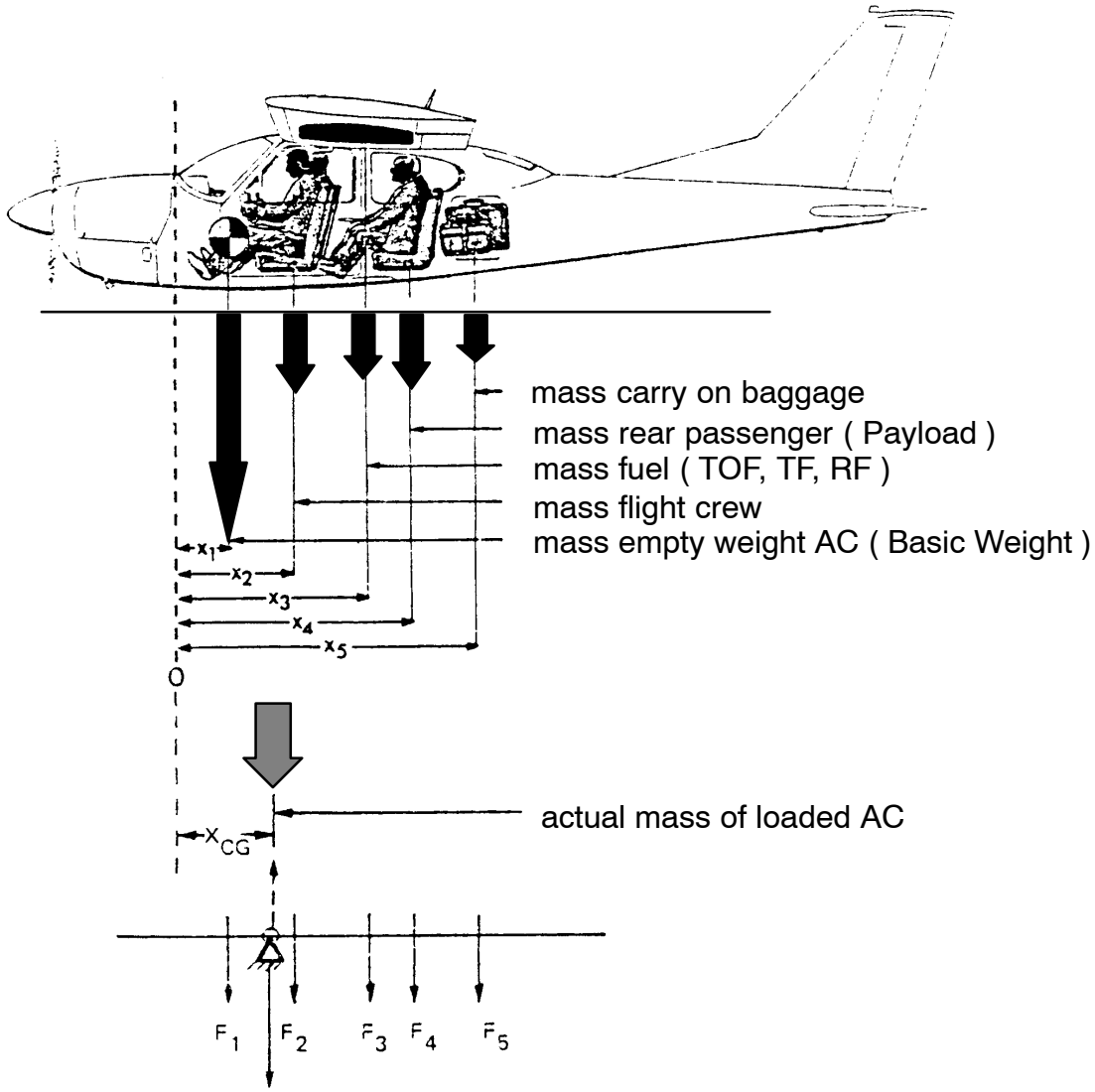


Figure 8 Mass Distribution on an Aircraft

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Center of Pressure (CP)

If the plane in a stable flight attitude it is “hung-up“ at the center of pressure (CP).

But a dynamic balance is only achieved, if a adequate high moment is applied at the stabilizer. There will be a nose down moment if the stabilizer lift is too low and a nose up moment if it is too high.

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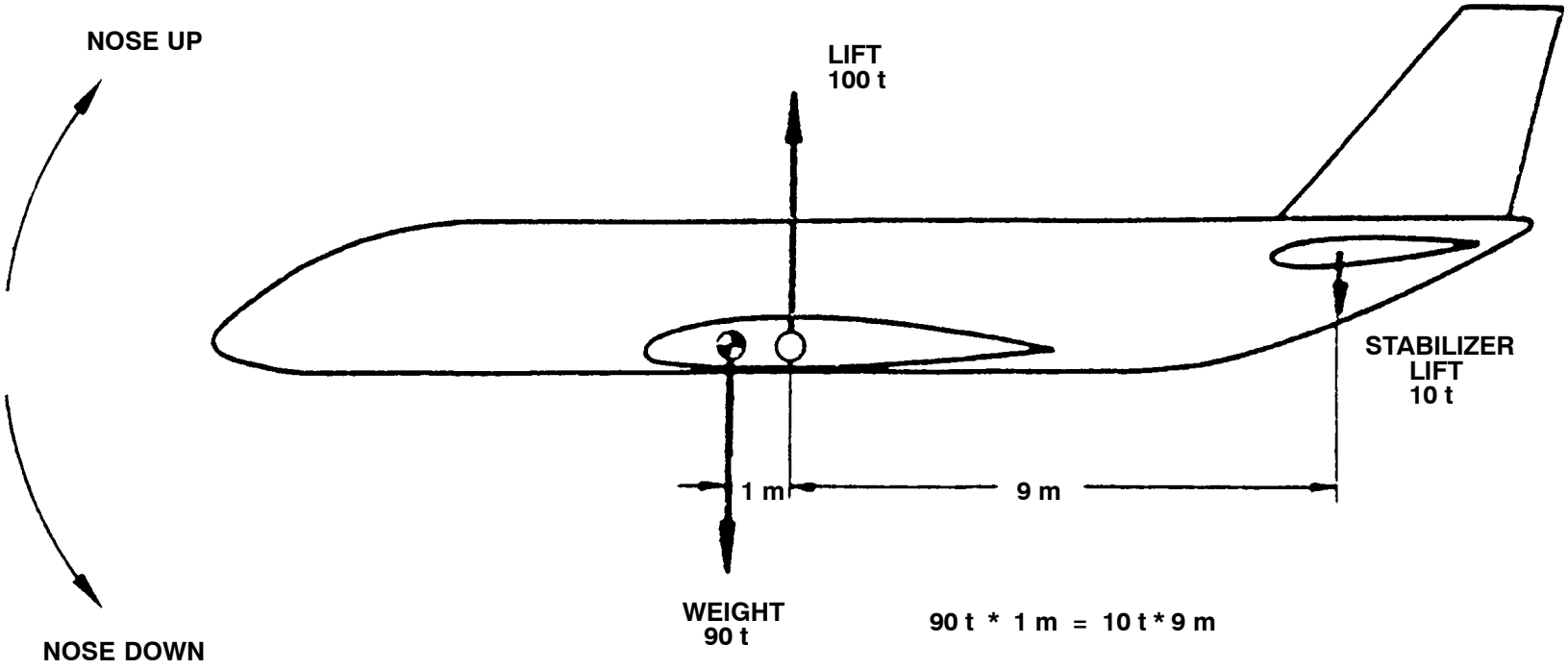


Figure 9 Loads on an Aircraft in a Stabilized Flight Condition

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Center of Pressure of a Rectangular Airfoil

The center of pressure of an airfoil can be seen as an single force, which results from the addition of all different pressure forces that are distributedover the whole airfoil.

If you take a look at the steady airfoil profile of a rectangular wing, the lift is located at the **center of pressure (CP).** The location of the CP is given in percent of the airfoil chord

So at a rectangular wing you can also determine the position of the whole lift.

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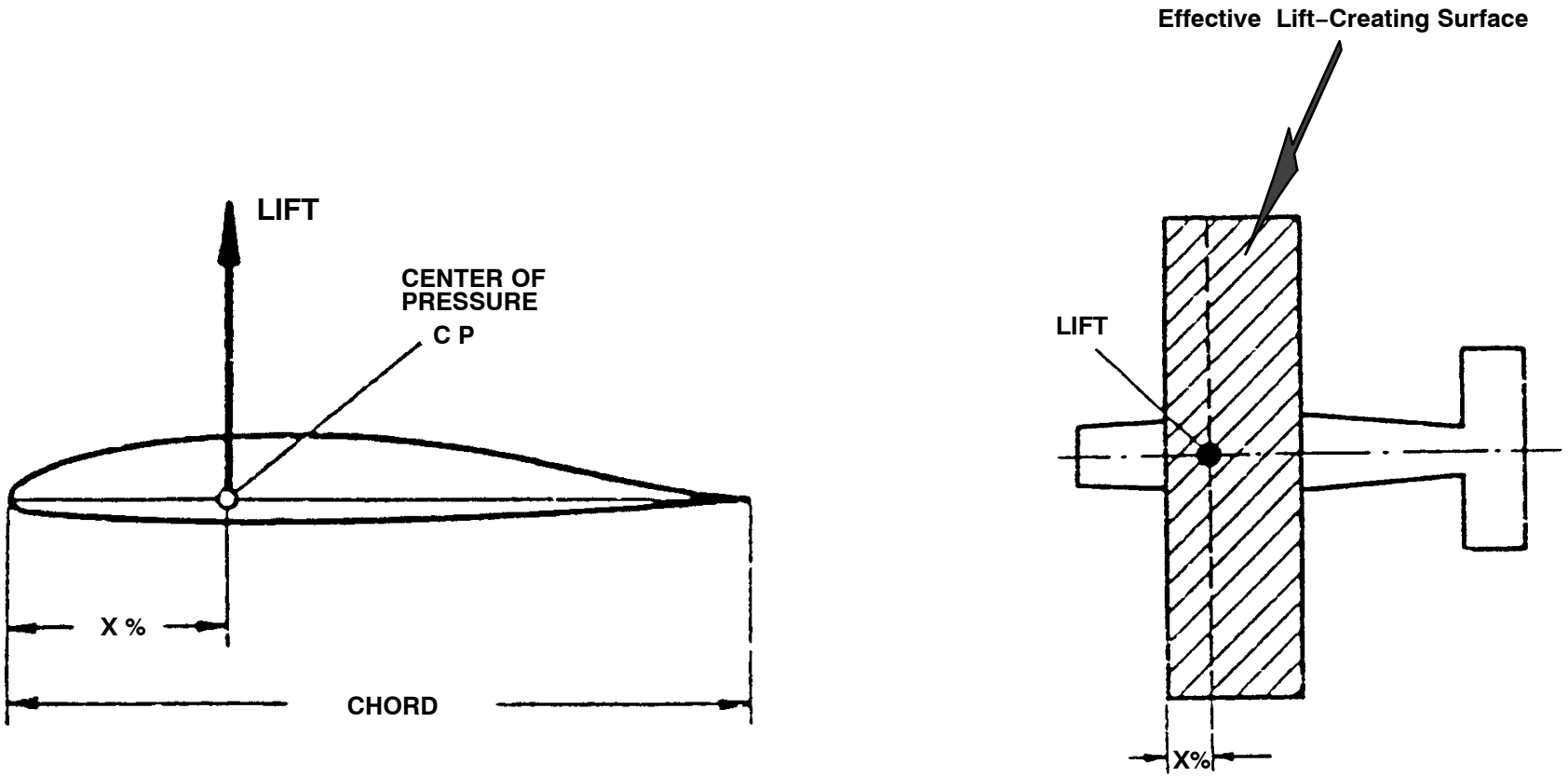


Figure 10 Area of Lift and CP

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Mean Aerodynamic Chord

Mean Aerodynamic Chord (MAC) of swept-back Wings

A swept-back wing has different profile forms at every station. These vary as well as in form as in depth.

But there can always be found a profile which creates the same lift forces as a swept-back profile, if you would choose this profile form for a rectangular wing.

The chord of this profile is called **Mean Aerodynamic Chord or MAC**.

The MAC is located parallel to the longitudinal axis of the aircraft and is conform to the depth of the wing in case of a rectangular wing.

The length of the MAC and the distance to the reference datum is always given by the aircraft manufacturer.

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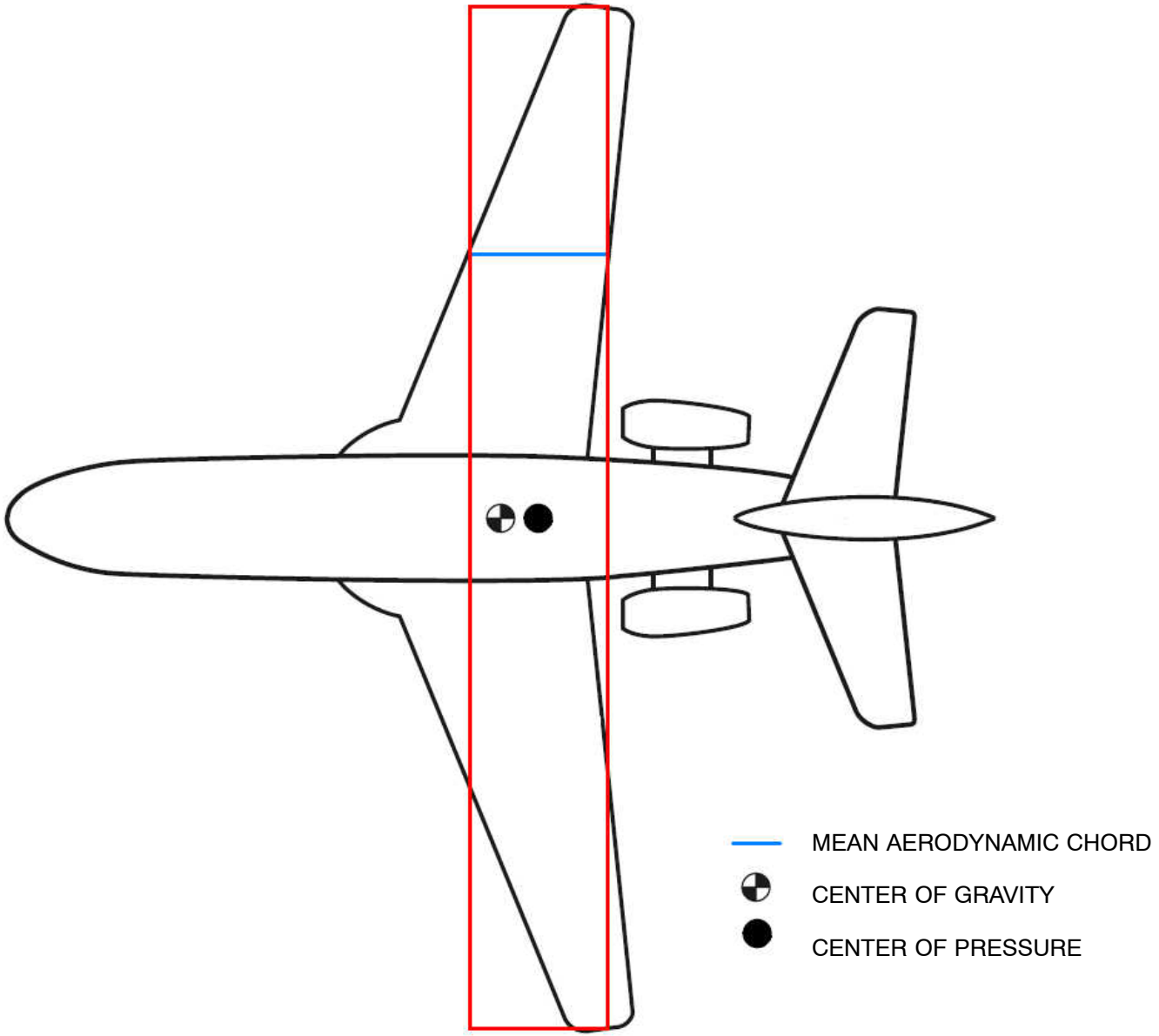


Figure 11 Mean Aerodynamic Chord (MAC)

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GRAPHICAL DETERMINATION OF MAC

To determine the MAC graphically for a swept-back wing the following approach is done:

- Draw the center line of the wing (50%-line) between chord root half (Cr/2) and chord tip half (Ct/2).
- Extend the chord root (Cr) downwards with the dimension of the chord tip (Ct).
- Extend the chord tip (Ct) upwards with the dimension of the chord root (Cr).
- Draw a diagonal between the lower point of the extended chord root and the upper point of the extended chord tip.
- The intersection point of the diagonal with the center line (50%-line, as explained in Step 1) shows the MAC, if a line is drawn which is parallel to the chord root and processes from the actual trailing edge to the actual leading edge of the wing.

The imagined rectangular wing can be determined the following way. Draw two lines which are rectangular to the MAC line and proceed from the chord tip to the chord root right through the two intersection points of the MAC and the actual leading and trailing edge.

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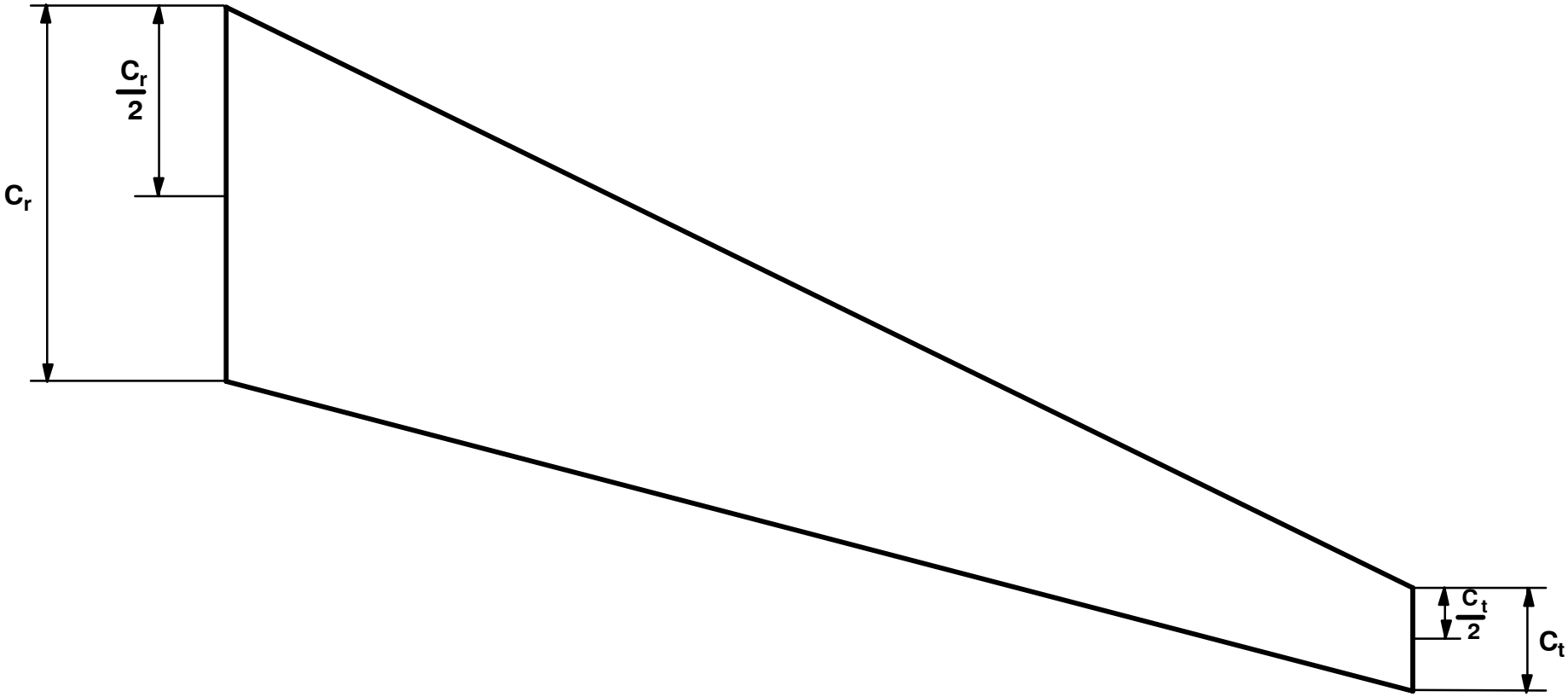


Figure 12 Graphical Determination of the MAC

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Center of Gravity

Center of gravity in X % MAC

The depicted profile has a MAC with a length of 90 inch. The actual CG is 21,7“ behind the LEMAC.

To calculate the location of the CG in percent, the following rule of proportion is applied:

100% MAC = 90“

X% MAC = 21.7“

X% MAC = 100% x 21.7“ / 90“

X% MAC = **24.1%**

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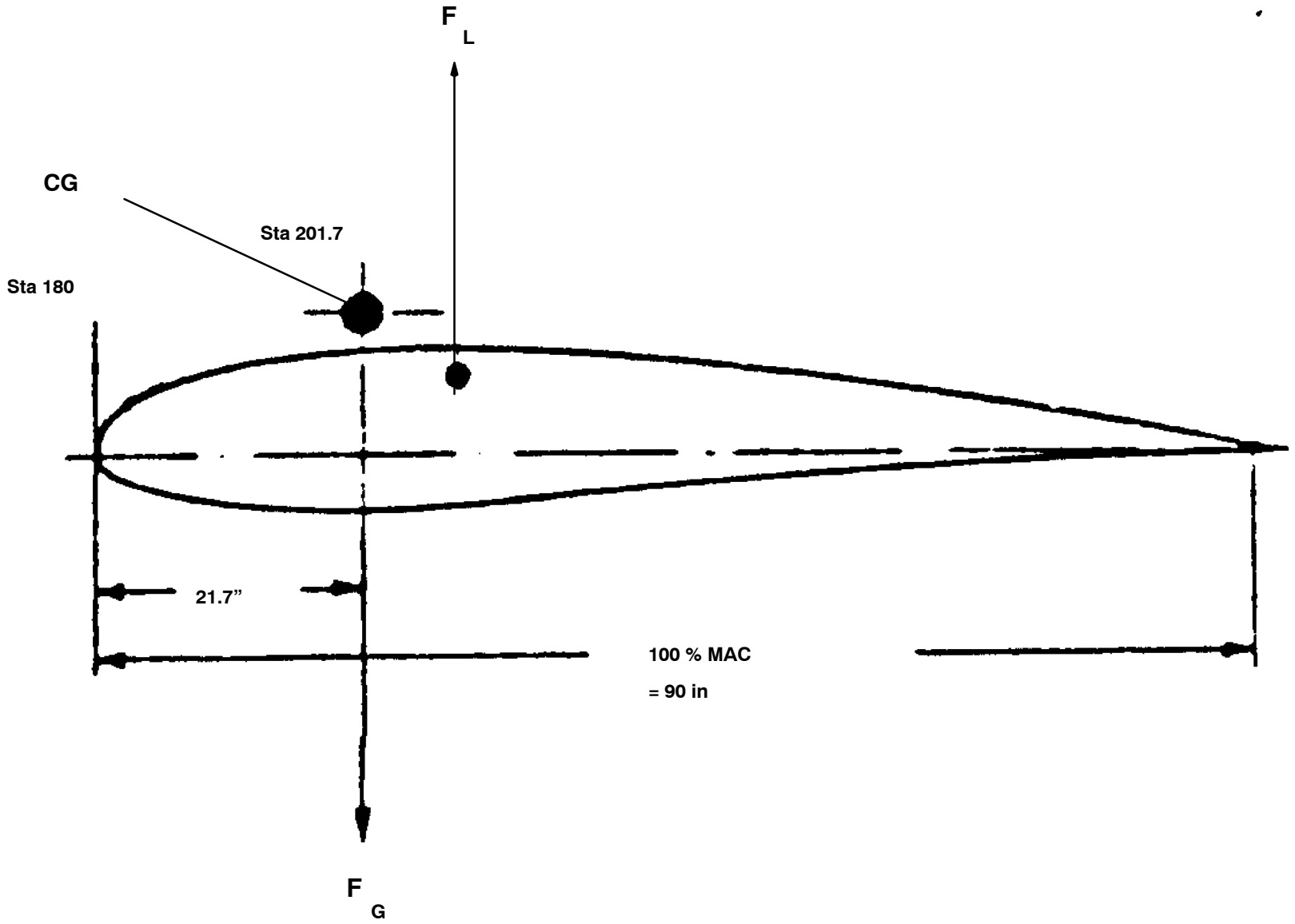


Figure 13 Mean Aerodynamic Chord

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CENTER OF GRAVITY (CONTD.)

Example Sample of Gravity Boeing 747–400

As explained before the center of gravity of the hole airplane has to be inside the limits which are given by the aircraft manufacturer.

In the documentation the manufacturer specifies the limits in **X % MAC**.

The leading edge of the MAC (station 1258) is 0% MAC, and the trailing edge (station 1586) is 100% MAC.

AOM-Data for the allowable limits of the CG B747–400:

- Forward limit: 11% MAC
- Aft limit: 34% MAC

In our Example the CG Limits are from 11 % MAC up to 34 % MAC therefore the CG limit is from STA 1294 up to STA 1333.

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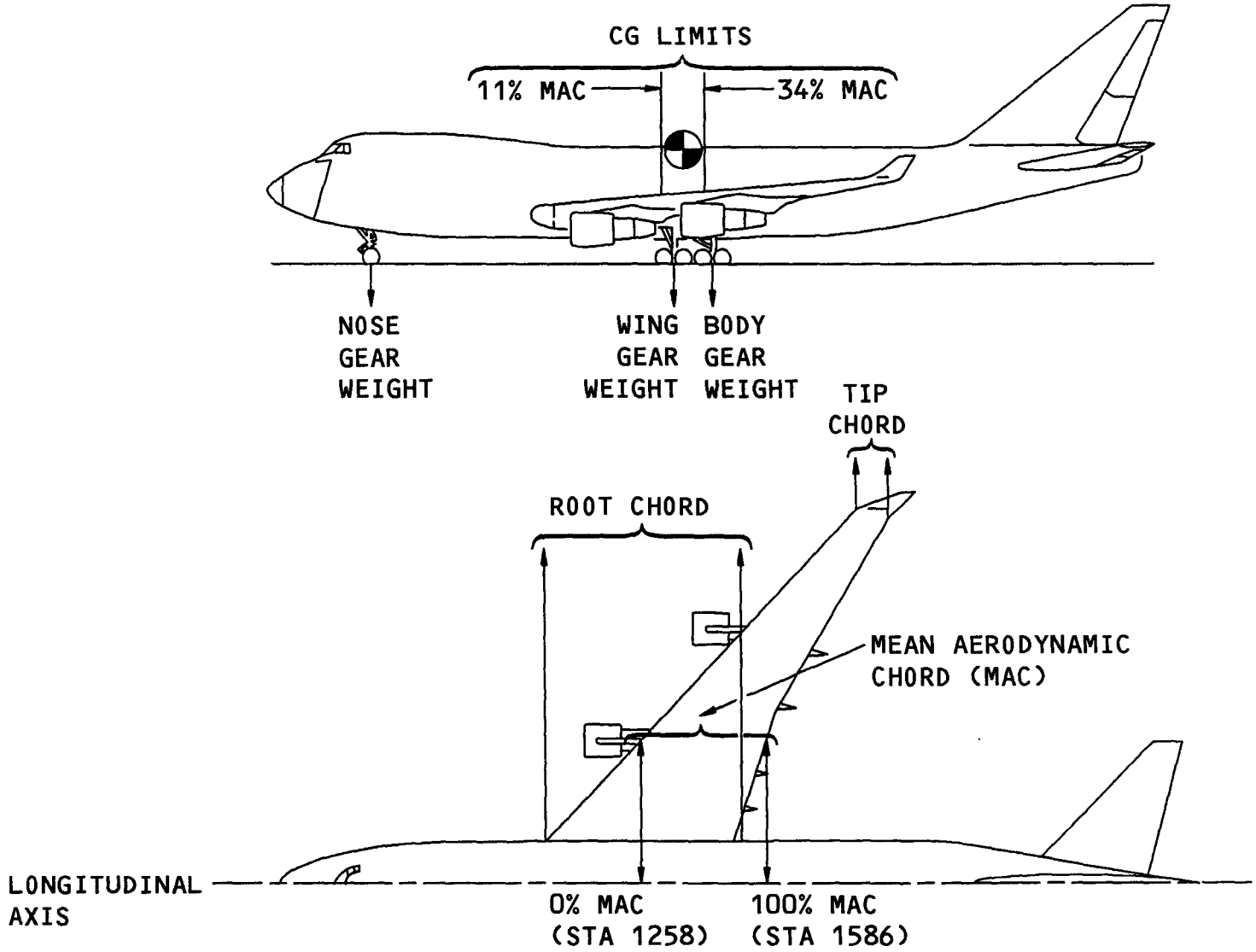


Figure 14 MAC and CG-Range Boeing 747–400

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Aircraft Mass

DENOMINATION ”WEIGHT” OR ”MASS”?

General

Already in 1980 the DIN-standard (German standard) LN 9020 was introduced. From this point on the international unit system (SI system) has to be used for all physical and measured variables according to the statuary provisions. To that effect the common term ”weight” is replaced by the term ”mass” and must be noted in the unit of ”kg”.

Only the term ”weight force” (unit Newton ”N”) is still valid to express that the mass causes a force, which is directed to the middle of the earth (weight force is mass multiplied by gravity acceleration; $\mathbf{F_G = m \times g}$). But this consideration is not important for the calculation of the center of gravity.

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Figure 15 Mass

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AIRCRAFT MASS (CONT.)

Standard Empty Mass

Another common term is the **Standard Empty Mass**. It is the empty mass of the aircraft without optional equipment. The standard empty mass is obtained from aircraft manufacturers.

Empty Mass

Standard Weight Empty: The weight of the airplane with all optional equipment included plus not usable fuel and oil.

Basic Empty Mass

The term basic empty mass is related to the mass of the standard aircraft with optional or special equipment, fixed ballast, unusable fuel and all fluids which are needed for the operation like oil, hydraulic fluid etc..

Not included are potable water, lavatory precharge water, and water intended for injection in the engines.

Dry Operating Mass

This term is conform with the total mass of the airplane for certain operations without usable fuel and traffic load. It includes:

- **Crew and crew baggage**
- **Catering and removable passenger service equipment**
- **Potable water and lavatory chemicals**

For calculation purposes the Dry Operating Weight (**DOW**) has to be used and as a corresponding value on the Load and Trim Sheet the Dry Operating Index (**DOI**).

Maximum Zero Fuel Mass (MZFM)

The maximal mass of an airplane without fuel. it is a structual mass limit in order to prevent overloads of the structure e.g. wing root.

Maximum Take Off Mass (MTOM)

The maximum mass approved for the start of the take−off run. The limit of the starting mass depends on the aircraft design and the power of the engines

Maximum Taxiing Mass (MTM or MTXM)

The maximum mass approved for ground maneuvering. It includes the mass of fuel used for start, taxi and run up.

Maximum Landing Mass (MLM/MLAM)

The maximum landing mass is in particular related to the structual design of the landing gear and the mountings.

Load Capacity

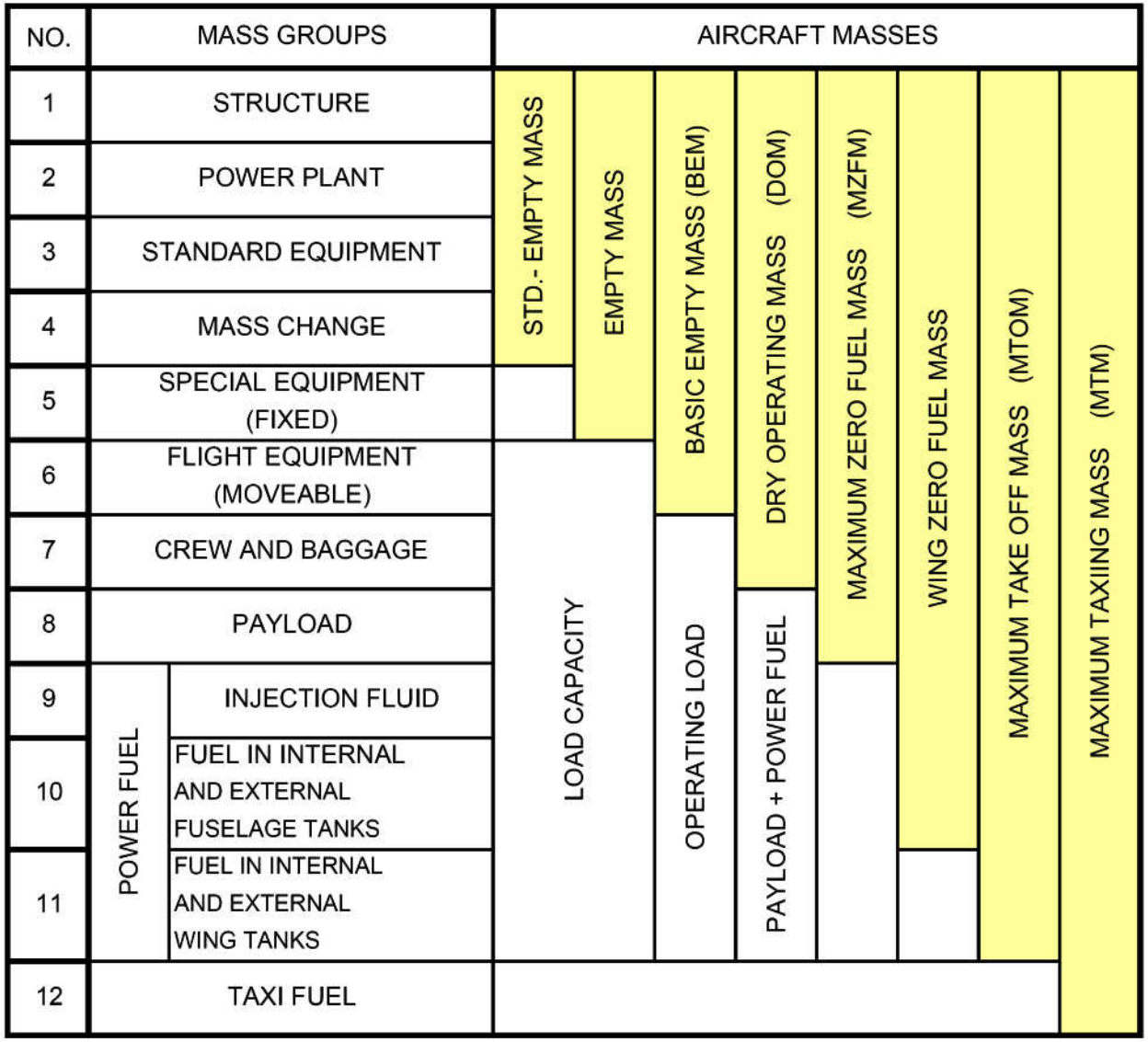
The difference between gross take−off mass and basic empty mass. It is, in other words, all the load which is removable, which is not permanently part of the airplane. It includes the usable fuel, the pilot, crew, passengers, baggage, freight, etc.

Payload

The load available as passengers, baggage, freight, etc., after the mass of pilot, crew, usable fuel have been deducted from the useful load.

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POWER PLANT INCLUDES LUBRICANTS AND NON USEABLE FUEL AND INJECTION FLUID

Figure 16 Aircraft Masses

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AIRCRAFT MASS (CONT.)

Mass Determination

The starting point for mass computation is the mass of the aircraft before passengers, cargo, and fuel are added.

Fleets or Groups of the same Aircraft Versions

For a fleet or a group of aeroplanes of the same model and configuration, an average **Dry Operating Mass** and CG position may be used as the fleet mass and CG position, provided that the dry operating weight and CG positions of the individual aeroplanes meet the tolerances of designated specifications. Tolerances up to (+/- 0,5 %) of DOW or CG are allowed.

Passenger Mass

Actual passenger mass must be used in computing the mass of an airplane with limited seating capacity. Allowance must be made for heavy winter clothing when such is worn.

Operational Mass Empty (OME)

The Basic Empty Mass of the airplane plus the mass of the pilots. Payload and usable fuel are not included.

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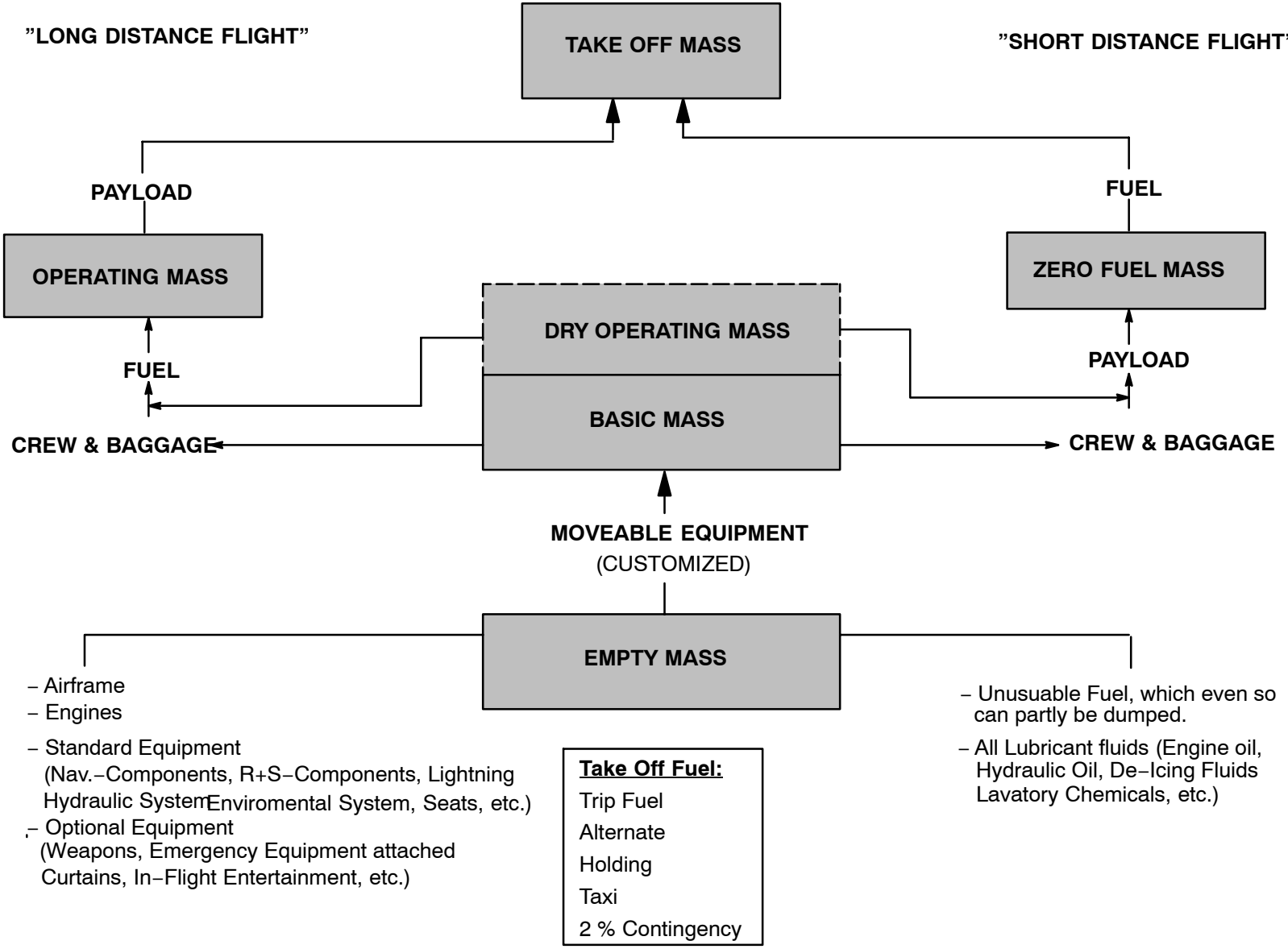


Figure 17 Take-Off-Mass Calculation

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Structual Mass Limits

General

Every airplane can only be stressed to a certain limit, which depends on the design of the structure and the material strength defined by the design engineer of the aircraft. Therefore an excess of this limit must categorically be prevented!

The first damages of the structure are often hard to find. In many cases there might be tiny fissures, which will enlarge due to the loads and will finally cause the cracking of important components. The bigger the mass due to the load is, the bigger gets the stress of the structure.

This is does apply especially for the flight attitudes, in which the load is multiplied, e.g. turning flights, recovery etc.

These values are specified in the type-certification process as operational limits and are recorded in the operation manual and the component manual.

The three most important structual mass limits, which never have to be exceeded are:

- **MTOM, Maximum Take-Off Mass**

  The Maximum Take-Off Mass depends on the aircraft design and the power of the engines.

- **MLAM, Maximum Landing Mass**

  The Maximum Landing Mass is in particular a function of the structual design of the landing gear and the mountings.

- **MZFM, Maximum Empty Fuel Mass**

  The maximal empty fuel mass is the mass of the loaded aircraft without fuel in the tanks.

  This is an important limit in airplane design, but is often not recorded in many flight manuals of small aircrafts lighter than 2000 kg take-off mass.

  For these types of airplanes the structual safety is assured, if the take-off and landing mass is in limit.

Comparison of structual mass limits of different aircraft types

A/C-Type	MTOM	MLM	MZFM
B737–300	57,6t	52,6t	49,4t
A320–200	77,0t	64,5t	61,0t
B747–400	385,6t	285,8t	256,3t
A340–600	368,0t	259,0t	245,0t

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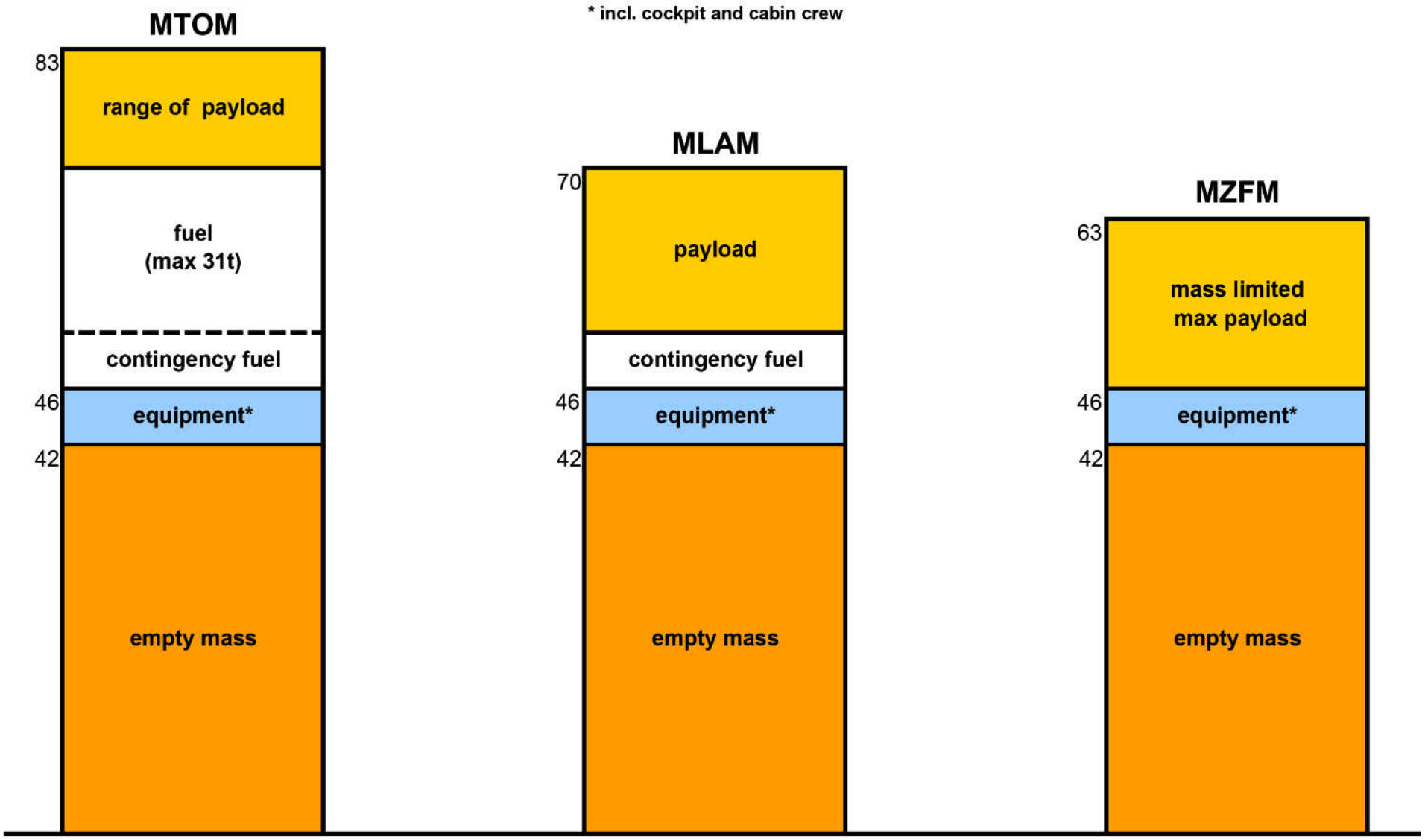


Figure 18 Comparison of Mass Limits of an Commercial Airplane (1000Kg)

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Environmental Mass Limits

General

The structual mass limits specified by the manufacturer are so called design mass limits. Environmental influences can cause a reduction of these limits (actual mass limits).

So, local conditions of the runway like

- Runway length and slope
- Airport height
- Runway conditions
- Obstacles in take off segment

or metrological conditions like

- Wind,
- Temperature,
- Density and humidity

can have such a disadvantageous influence that a aircraft loaded up to the maximum take of mass can not safely start.

The same is also valid for landings with the maximum landing mass.

In such a case the loading (payload or fuel) has to be reduced to assure a safe landing.

The maximum start or landing mass, which has been reduced about a certain loading because of the described reasons, is called *maximum allowable start or landing mass.*

Influence of the aircraft mass on the aircraft performance

With a higher mass also the performance of an airplane changes. Especially when landing at a airport with a difficult approach or a disadvantageous location this has considered.

Impact of increasing mass:

- longer take-off length
- more flat angle of climb
- lower speed of climb
- greater turning radius
- longer landing distance

The following figure shows this connection. Due to the fact that the **MZFM** is a transformable limit, it is not considered in the picture.

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Determination of the Maximal Starting Mass under consideration of the enviromental influences

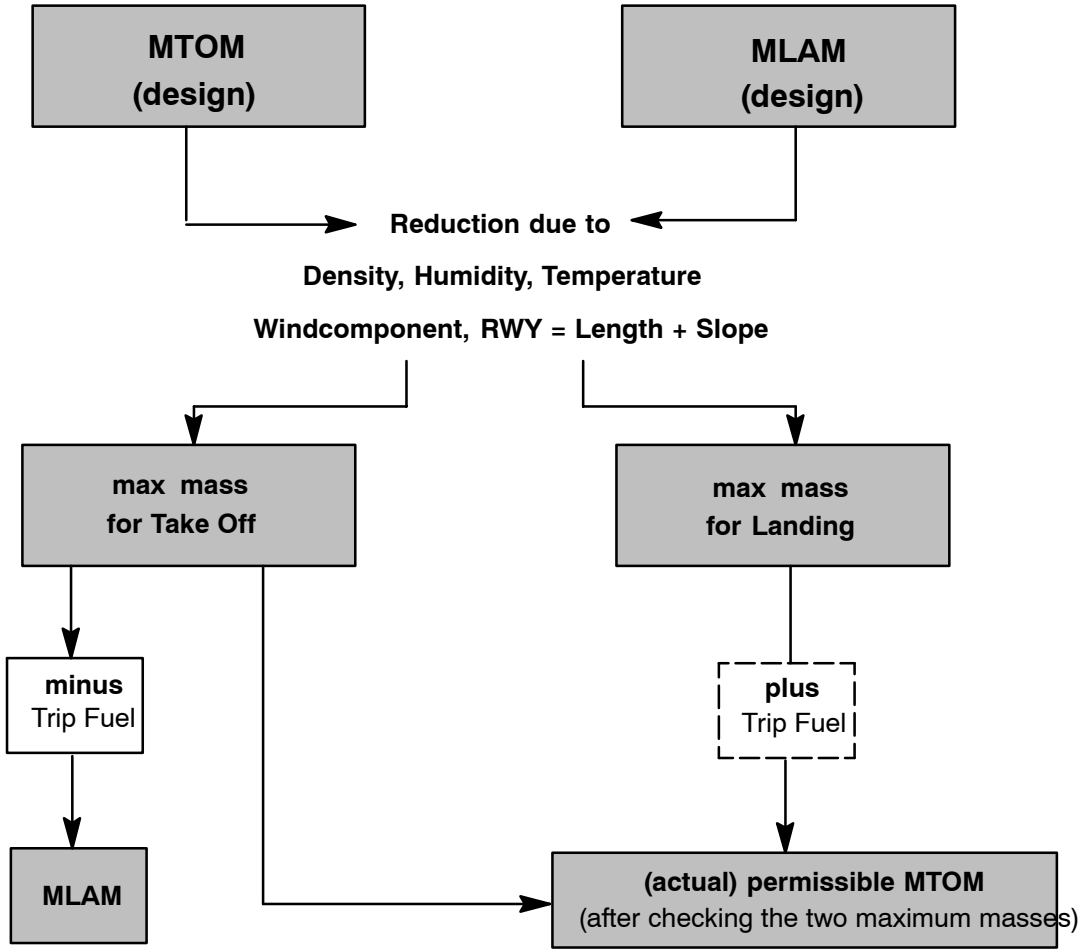


Figure 19 MTOM Calculations in Accordance to the Limitations of Ambient Conditions

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Weight and Center of Gravity Calculations

ORIGINATION OF THE CENTER OF GRAVITY FORMULA

The location of the center of gravity can **always** be determined by the following formula:

$$X_{CG} = \frac{\Sigma \text{ Moments}}{\text{Overall Weight Force}}$$

oder

$$X_{CG} = \frac{\Sigma \, M_{DL}}{F_{ges}}$$

X_{CG} = Distance from the Center of Gravity to the reference Datum DL

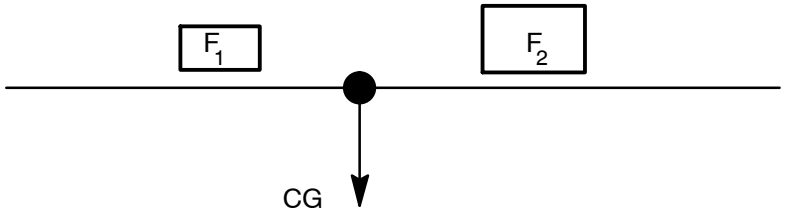
M_{DL} = Single Moment which is caused by a corresponding Mass (e.g. Cargo) with a lever arm.

$\Sigma \, M_{DL}$ = Sum of all single Moments

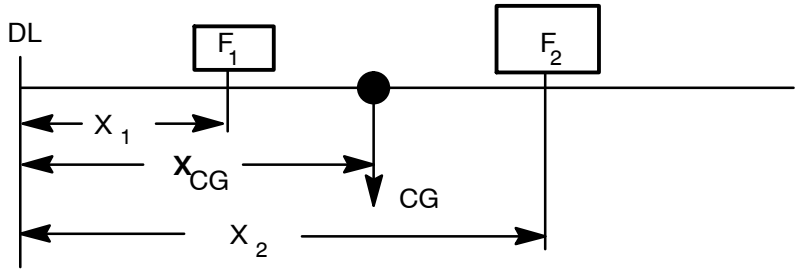
F_{ges} = Overall mass of the considered aircraft

This Formula orginates like follows:

Somewhere between F_1 and F_2 is the Center of Gravity of the sketched System:



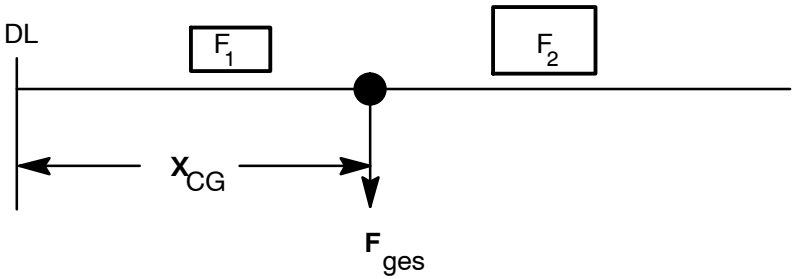
If the Reference datum for the calculation of the center of gravity is put arbitrarily left the sketch looks the following way:



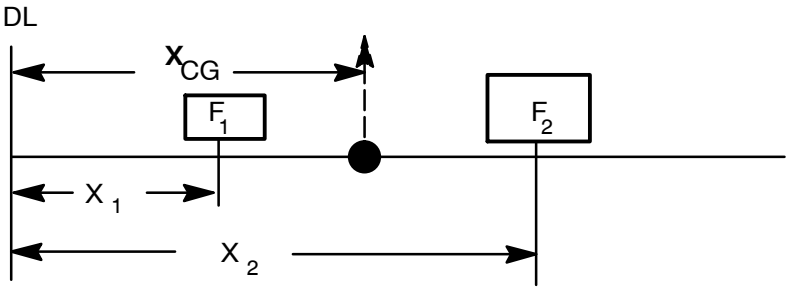
Refering to the reference Datum DL the overall weight Force F_{ges} (Sum of F_1 and F_2), which you can imagine located in the CG is also producing a moment with the lever arm X_{CG}

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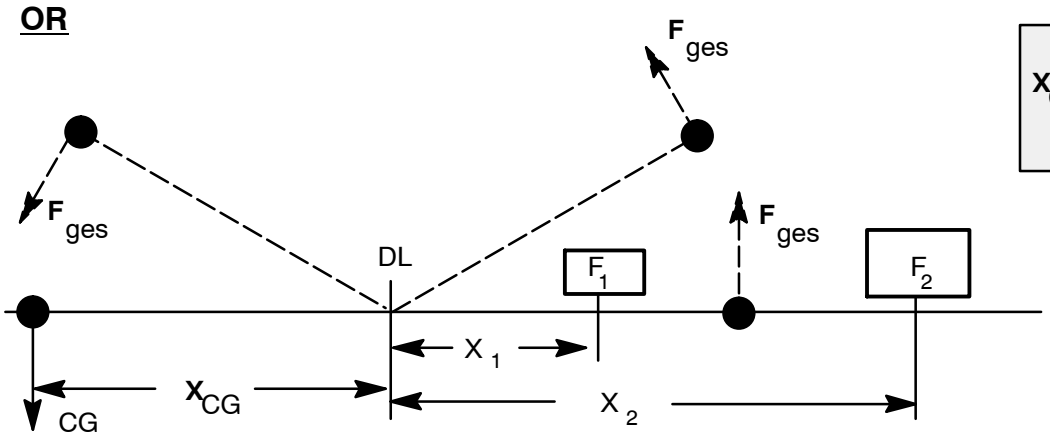
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Due to the fact that in the DL is no balance the moment $F_{ges} * X_{CG}$ must be counteracting (anticlockwise moment) to keep the balance.



OR



You can imagine F_{ges} as a reaction moment around DL which is anti−clockwise and it can be expressed matimatically in the following way:

$$M_L = M_R$$

OR

$$F_{ges} * X_{CG} = F_1 * X_1 + F_2 * X_2$$

OR

$$F_{ges} * X_{CG} = M_1 + M_2$$

OR

$$F_{ges} * X_{CG} = \Sigma M_{DL}$$

hence

$$X_{CG} = \frac{\Sigma M_{DL}}{F_{ges}}$$

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DETERMINATION OF THE CENTER OF GRAVITY VIA A TABULAR

The application of the formula for the center of gravity is done in practice (e.g. after weighing or after loading of the airplane) obviously in a tabular form, since it is easy and clear.

Therefore all forces (masses of persons, components, wheel loads, etc.) are written among each other and multiplied by the known stations, at which the forces are present. The forces and the determined moments are summed and then divided.

The following example clarify the application:

Note

After the taking out of a mass out of the airplane (unloading or fuel consumption) the missing mass appears as a negative force in the calculation.

With a positive lever arm (right of DL) a negative moment would be present. This must be considered at any case.

1. It is practical to draw a sketch with the datum DL and all forces and lever arms before starting the calculation.
2. In principle in all calculations of the center of gravity the airplane is shown with the nose directed left.
3. When determine the moment the following combinations are possible:

MASS	ARM	MOMENT
+	+	+
+	-	-
-	+	-
-	-	+

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	F	*	Station	=	M
Aircraft Empty Mass	1.000 kg	*	200 cm	=	200.000 kgcm
Equipment	100 kg	*	210 cm	=	21.000 kgcm
Fuel	300 kg	*	220 cm	=	66.000 kgcm
Payload	100 kg	*	190 cm	=	19.000 kgcm
2 Pilots	150 kg	*	180 cm	=	27.000 kgcm
	1.650 kg	*	X_{CG}	=	333.000 kgcm

With application of the center of gravity formula it is

$$X_{CG} = \frac{\Sigma M}{\Sigma F}$$

$$X_{CG} = \frac{333.000 \text{ kgcm}}{1.650 \text{ kg}} = 201{,}8 \text{ cm}$$

The overall center of gravity is at the station 201,8 cm

Figure 20 CG Calculation (Example)

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FORMULAS USED FOR WEIGHT AND BALANCE CALCULATIONS

The following formulas can be used for the calculation of the center of gravity:

$$M = F * X$$

$$M_L = M_R$$

$$M_{Ges} = M_L + M_R$$

$$F_{Ges} * X_{CG} = F1 * X_1 + F_2 * X_2$$

CG in % MAC = $\frac{\text{CG inches from LEMAC x 100}}{\text{MAC}}$

Trim Ballast = $\frac{\text{A/C weight x change in CG desired}}{\text{Ballast STA. - Arm of desired CG}}$

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Calculation of the Center of Gravity

Mathematical determination of the center of gravity

Solve the exercises 1–5 with the help of the formulary. To make the calculations easier, note which values are given and which are searched. Write down your calculations, please use the page “Exercise Calculations“ for that.

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Given: An Aircraft will be loaded at STA. 1057 with 2000kg and at STA. 2296 with 1400kg, basic mass: 34000kg

Determine: Actual position of CG after loading

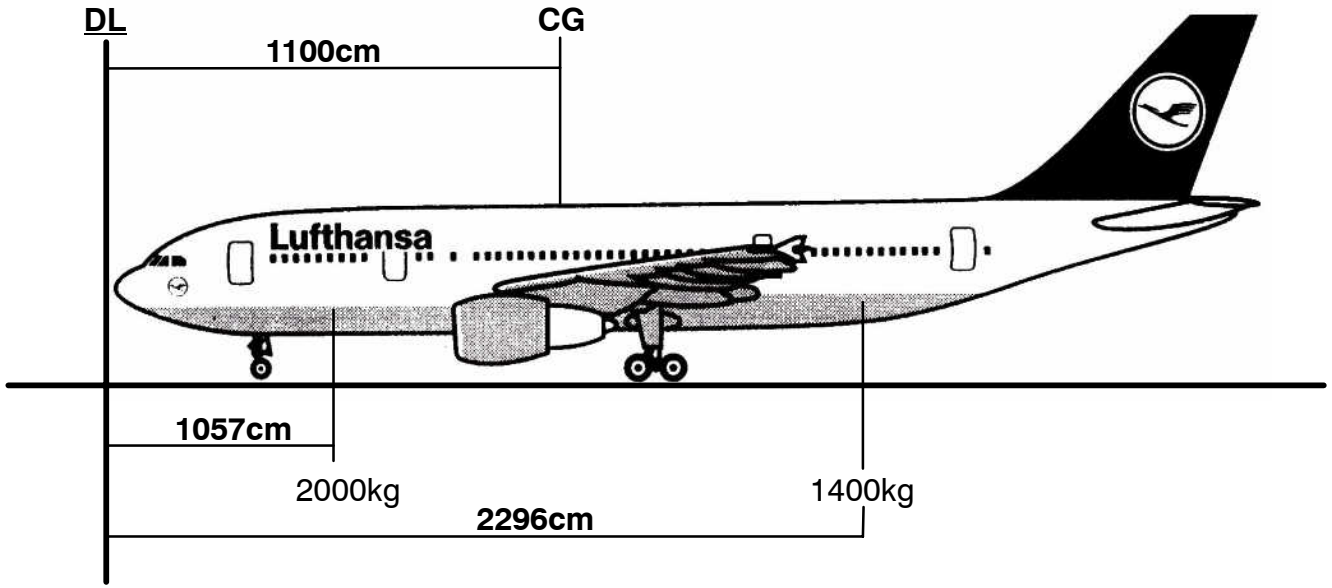


Figure 21 Exercise 1

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Exercise 1 Calculations:

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Given: An Aircraft has been weighed and the scale reading are as follows:

1) NLG = 6500kg at STA 500cm
2) MLGL = 29300kg at STA 1614cm
3) MLGR = 29200kg at STA 1614cm

All tare has been reducted.

Determine: Actual position of CG

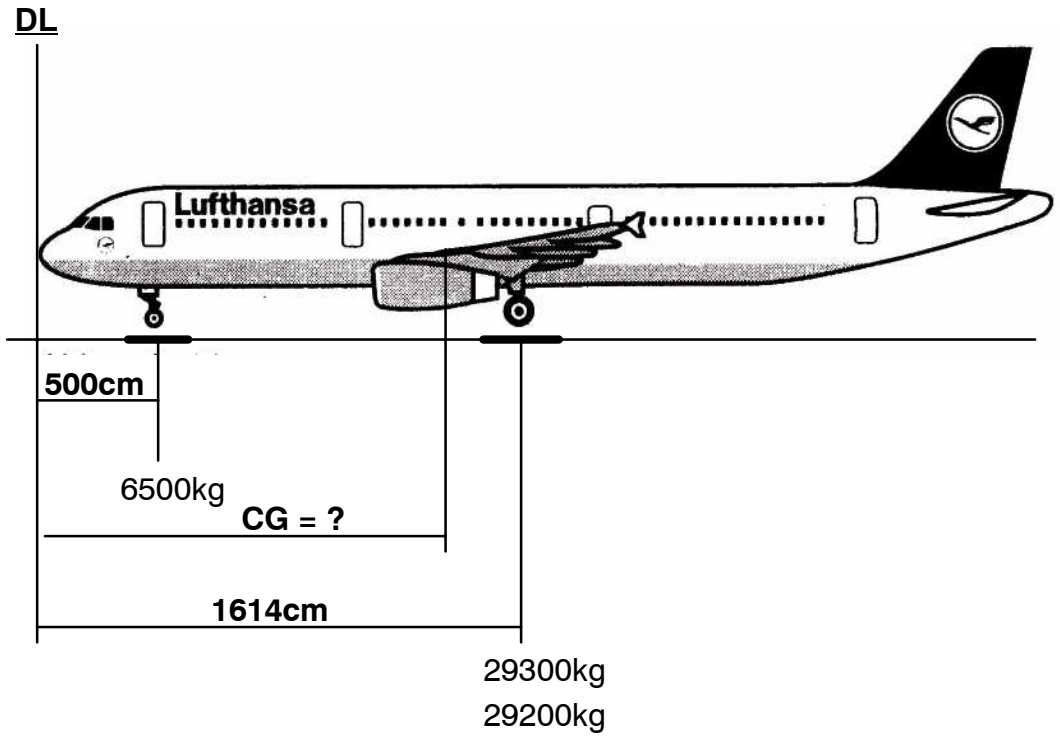


Figure 22 Exercise 2

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Exercise 2 Calculations:

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Given: An Aircraft with its empty mass of 150000kg and Empty CG at position STA 3302 has to be loaded to shift the Empty CG to STA. 3355.

Determine: How much mass has to be load at STA 5054 to reach the required CG at STA 3355?

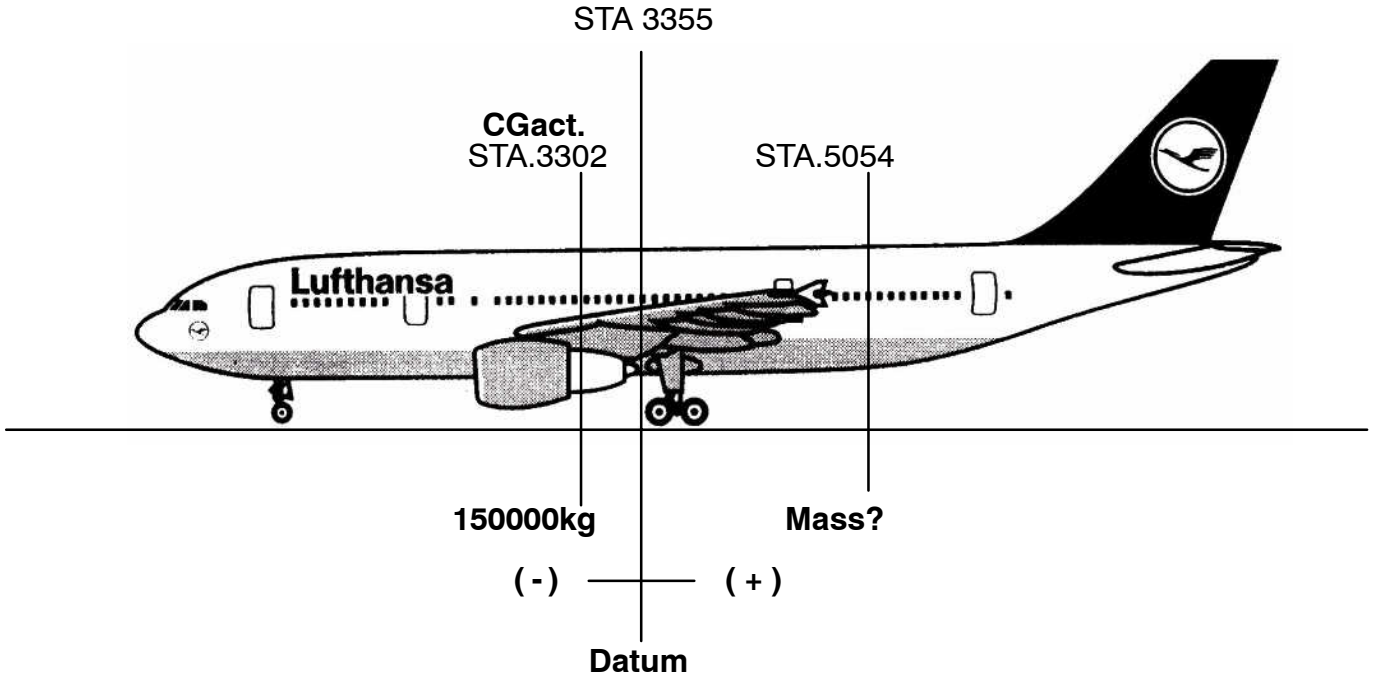


Figure 23 Exercise 3

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Exercise 3 Calculations:

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Given: An Aircraft with empty mass of 6500kg at STA.200cm + 2 Pilots with 150kg both at STA 80cm has to be loaded with:

1) CARGO 1 400kg, at STA 220cm

2) CARGO 2 200kg, at STA. 280cm

For conducting the flight they are fueling the aircraft with 1000ltr. AVGAS (**Fuel density: 0.7kg/ltr.**)

LEMAC 0% at STA 180cm, length of Chord is 90cm

Determine: Position of CG by fully loaded Aircraft in

a) cm

b) % MAC

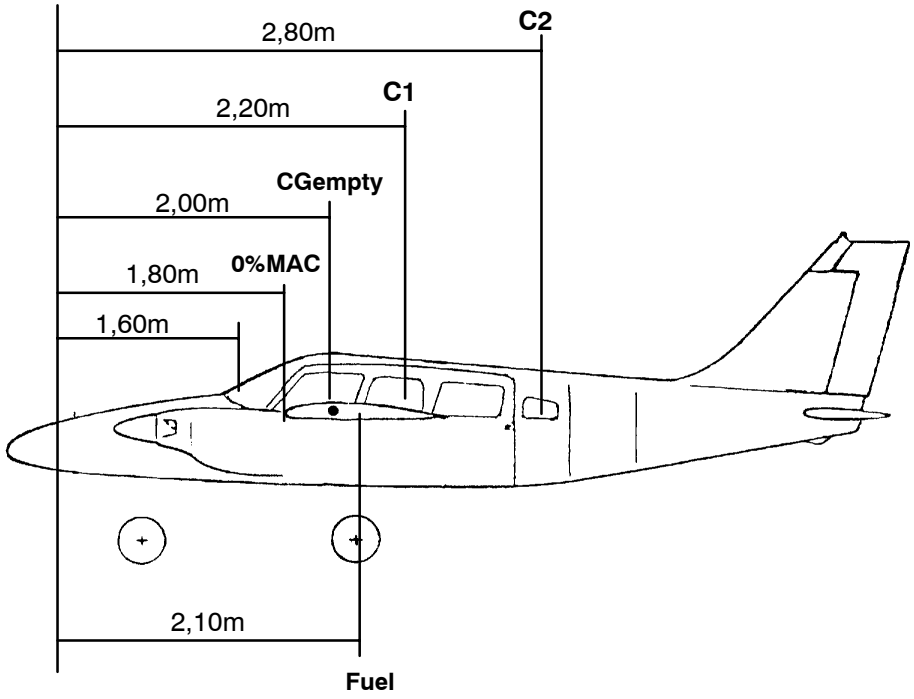


Figure 24 Exercise 4

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Exercise 4 Calculations:

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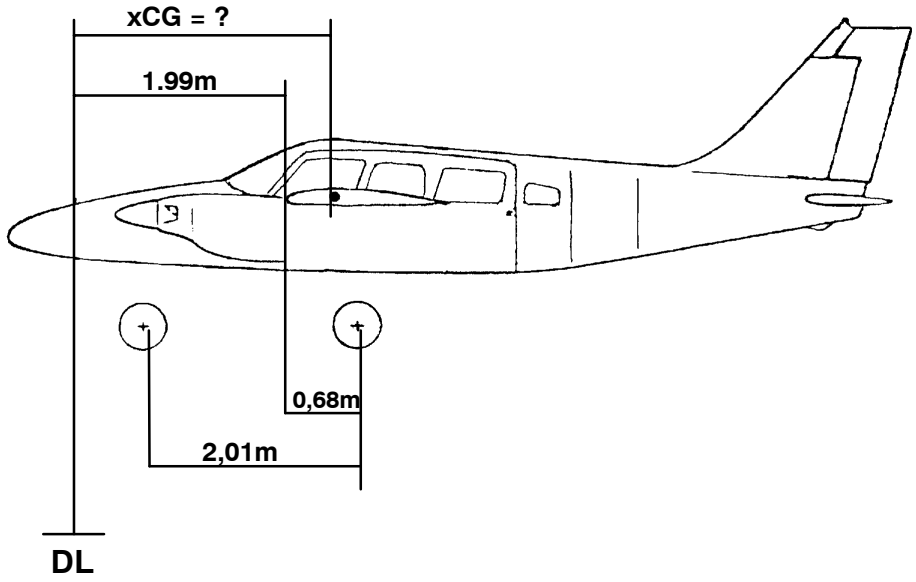
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Given: An Aircraft has been weighed, after weighing a weather radar should be installed at position 2.02m ahead of the empty mass CG.

Determine: a) Empty mass CG

b) Actual CG after installation of the radar equipment



Scale Reading

NLG	304,7 kg
MLG (L)	472,1 kg
MLG (R)	473,2 kg
Weather radar	12,0 kg

Figure 25 Exercise 5

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Exercise 5 Calculations:

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Load and Trim Sheet

Load and Trim Sheet

Everything possible is done to make flying safe, and one expedient method is to use of charts and graphs from the AOM/AFM to simplify and speed up the preflight weight and balance computations.

Some use a loading graph and moment indexes (Dry Operating Index) rather than the arms and moments.

These charts eliminate the need for calculating the moments and thus make computations quicker and easier.

Moment Indexes

Moments determined by multiplying the weight of each component by its arm result in large numbers that are difficult to handle and become a source of mathematical error. To eliminate these large numbers, moment indexes are used. The moment is divided by a reduction factor such as 100 or 1000 to get the moment index.

The Load and Trim sheet provides the moment index for each component, so you can avoid complicated calculation. The CG envelope uses moment indexes rather than arms and moments.

Masses of Persons

According to EU-OPS-1 the following masses are expected for male and female passengers (incl. hand luggage and infants under 2 years) :

Passenger Seats	30 und more
	All Adults
All Flights except Holiday Charter Flights	84 kg
Holiday Charter Flights	76 kg
Children	35 kg

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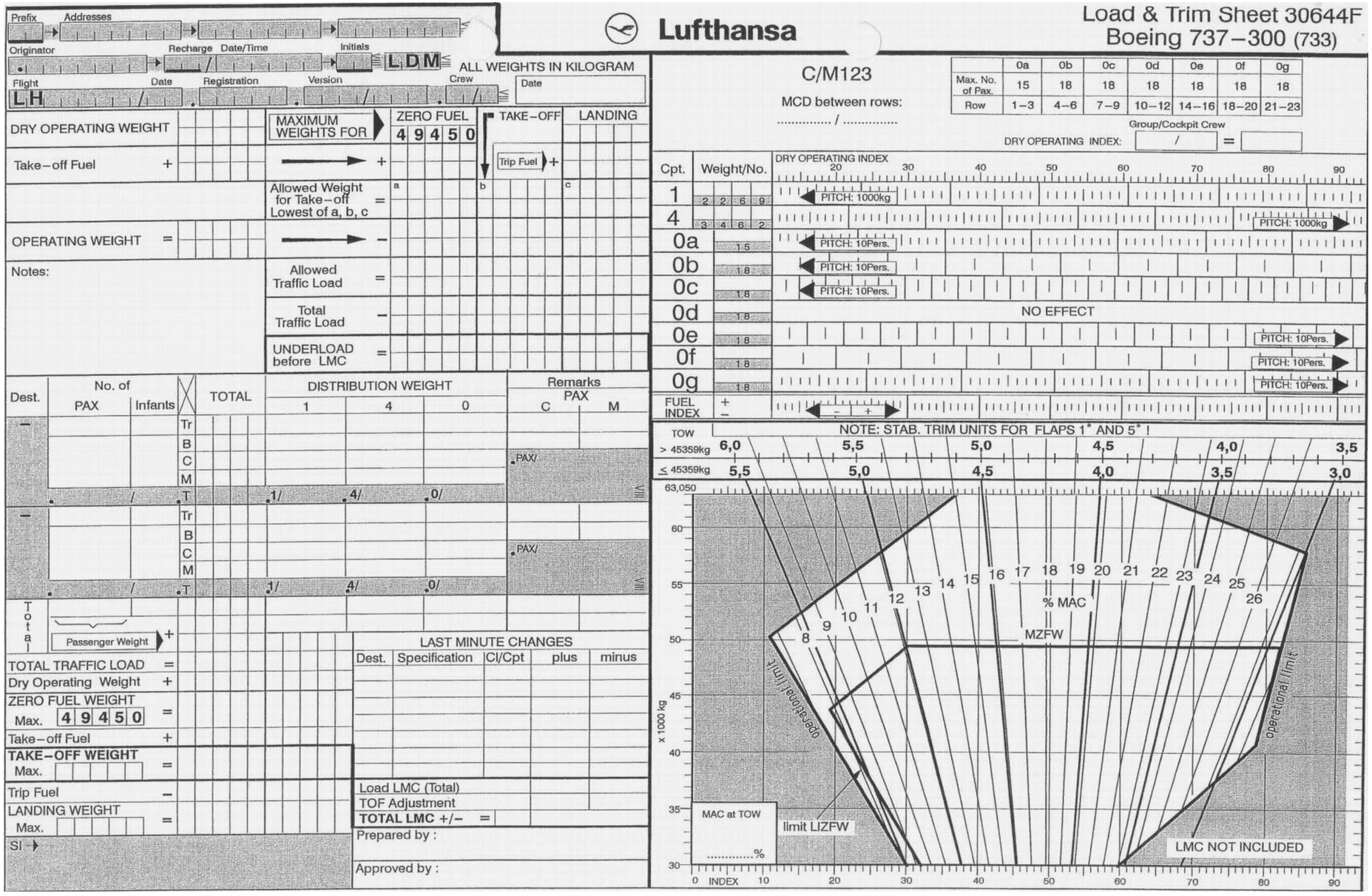


Figure 26 Load and Trim Sheet Boeing 737–300

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PREPARATION OF THE AIRCRAFT FOR WEIGHING AND AIRCRAFT WEIGHING

LEVELING OF THE AIRPLANE

Leveling Line

In order to find the CG of an aircraft it must be level.

For this purpose a leveling means is provided by the aircraft manufacturer. It may be nothing more than a door sill, or it could be two lugs built into the fuselage in order to accommodate a spirit level.

On some aircraft it consists of a point to suspend a plumb bob over a scale.

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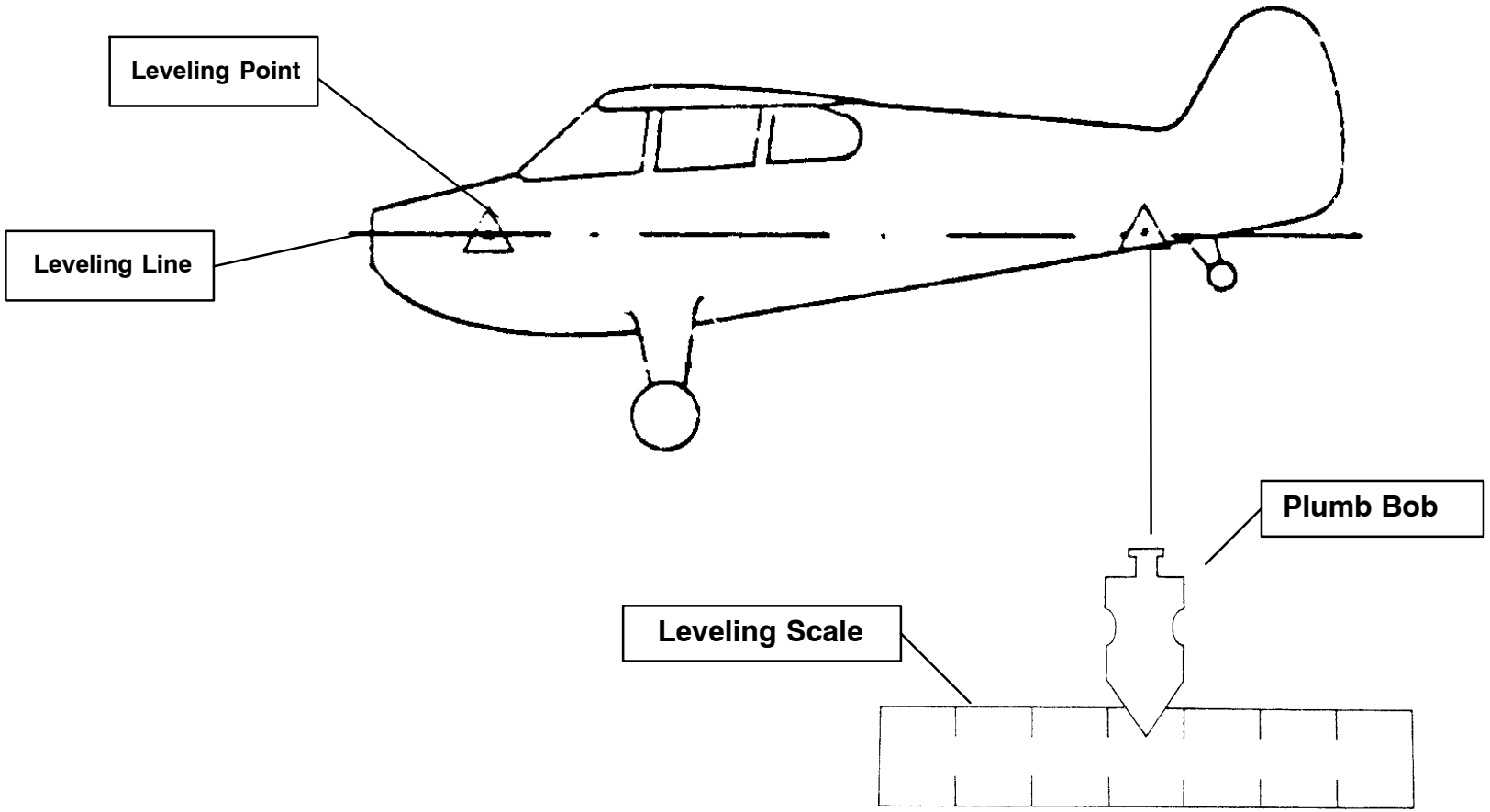


Figure 27 Leveling Line and Scale

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LEVELING OF THE AIRPLANE (CONT.)

Leveling Line Boeing 747

On large aircrafts like the B747 both the plumb bob and the spirt level system are used to level the airplane.

In the right landing-gear bay an inclinometer (spirit level) and a point to suspend a plumb bob with a scale below is located. This is used to level the airplane around the longitudinal axis (turning around the lateral axis).

The leveling around the lateral axis (turning around the longitudinal axis) is done with the inclinometer.

Other aircrafts are equipped with a attitude indicator, which is if applicable connected with the “Weight and Ballance Computer“.

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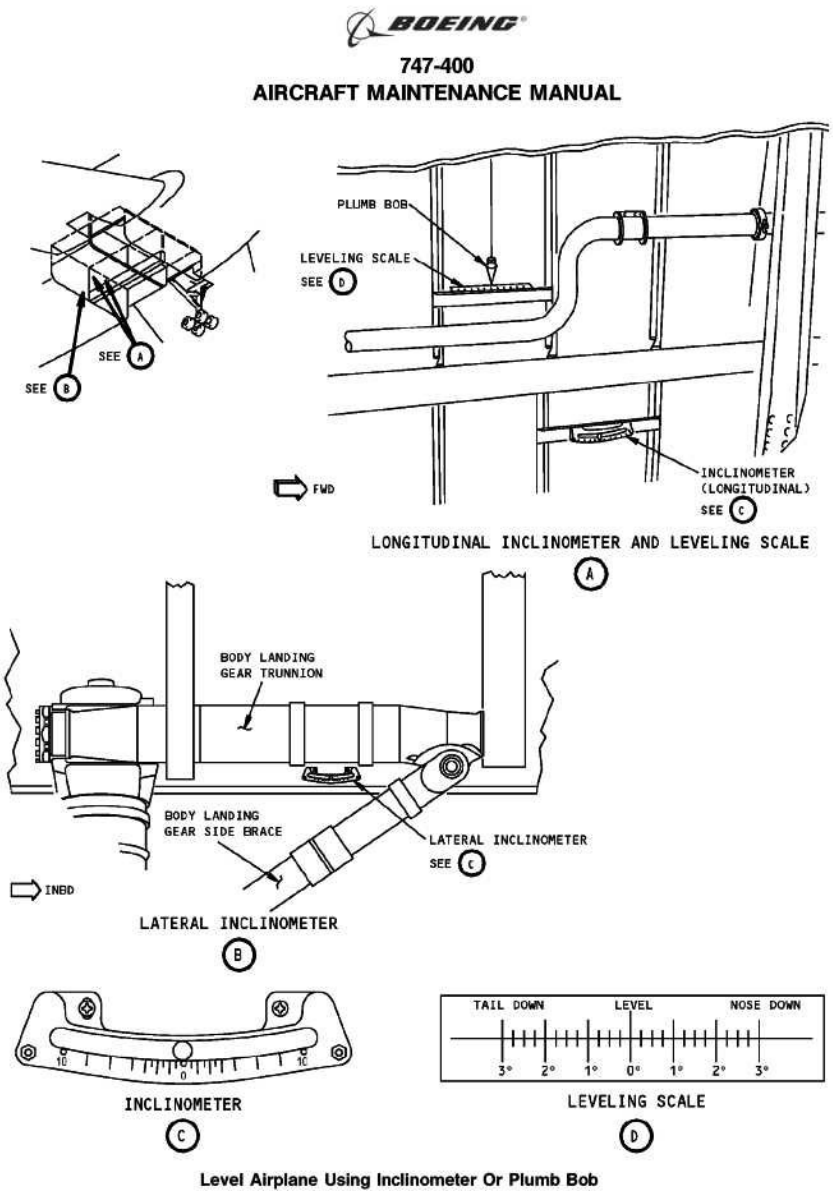


Figure 28 Leveling means B747–400

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AIRCRAFT WEIGHING

General Guidelines for Aircraft Weighing

Every aircraft manufacturer has to specify in its technical operational manuals, how and in which time periods aircraft weighing has to be done.

The basis for this specification is EU-OPS-1 Subpart J.

Weighing of Airplanes in accordance with EU-OPS-1 Subpart J

The weighing of an airplane has to be done, if the weight or the center of gravity has been changed and the data can not be calculated with the desired accuracy.

In every case a weighing is necessary:

- after major - or minor overhaul.
- if furnishing past delivery is done.
- within a time period of 4 years.

Single Airplanes

The new determination of mass and CG should be made, if the mass has changed about a certain degree, e.g. caused by changes in the equipment, or if the CG has moved about a certain value (on the MAC).

A periodically weighing should be done every 4 years.

Airplane Groups and Fleets

For airplane groups and fleets of the same type (e.g. Boeing B 737 or Airbus A340) and the same configuration there are other rules. The number of aircrafts which have to be weighed within 48 months can be determined with the following method:

Number of Airplanes in the Fleet (N)	zu wiegende Flugzeuge
2 or 3	all N
4 to 9	(N + 3)/2
10 or more	(N + 51)/10

Example: An airline possesses 29 aircrafts, hence:

(29 + 51) /10 = 8

Therefore 8 aircraft have to be weighed within 48 months.

At weighing it should be that airplane chosen, which has passed the longest period after the last weighing.

Additionally the following masses have to be considered for crew members:

Cockpit Crew, ea = 85,0 kg

Cabin Crew, ea = 75,0 kg

Another method is to weigh the actual mass of the crew members. That will be followed by a record in the load manifest (”actual weight”).

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Figure 29 Preparation for Weighing

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AIRCRAFT WEIGHING (CONT.)

Tools for Weighing

For weighing scales should be used that have a adequate range, which have to be in accordance to the calibration guidelines.

Platform Scale

Normally two scales are necessary to determine the wheel load of the main landing gear and one to determine the nose- or tail load. The scale which is used for that is called platform scale.

For leveling the aircraft the feet of the scale can be adjusted or packing plates can be used.

Load Cell Scale

A second method to weigh an aircraft is to use a load cell scale. Therefor special load cells are put on the jackscrews of the hydraulic jack and the airplane is lifted at the three jacking points. Before starting with work the load cell should acclimate about half an hour to have the same temperature as the environment.

Preparation before Weighing

The aircraft must be weighed in a clean and dry condition.

The reservoir for lubricants, hydraulic - and deicing fluids need to be filled.

The fuel tank should be empty except the fuel that can not be drained or completely filled with fuel (if the fuel mass is known from the flight manual). Fuel tanks hold “changing loads“, which have to be determined precisely.

Equipment

The equipment of the airplane must be checked according to the equipment list in the flight manual. Battery, oxygen bottles, etc. must be installed, fire extinguisher, sanitary pack, emergency axe and the other standard equipment (e. g. towbars) have to be at the intended place.

Foreign objects (tools etc.) have to be removed from the cabin and the cargo bay. Probably removed fairings covers have to be at place. Doors, flaps, cowl-doors, folding seats, etc. have to be in the standard position.

Note

At **old** aircraft it is intended due to the flight manual, that the **lubricants are not included in the empty mass.** So, it has to be proceeded the adequate way.

Since **modern** airplanes do not have an important change of mass or CG during the flight due to lubricant consumption, the **lubricant is not assigned** to the **”changing loads”**.

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Figure 30 Scales

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WEIGHING PROCESS

Requirements

All aircraft should be weighed in a closed hangar with a fairly level floor. Wind loads would change the scale readings.

Before applying the wheel load the scale has to be adjusted (plumb bob or spirit level of the scale has to be observed) and additionally to be balanced.

If wedges, supports or racks, etc. are used the ”tare mass” has to be determined carefully and subtracted from the ”gross mass”.

If small airplanes are put on the scale by jacking up them, lateral shear forces can emerge. These undesired forces are changing the scale readings and have to be prevented through adequate action (Follow the manufacturers guidelines).

Repeating the Weighing

Due to safety reasons one weighing action as to be repeated one or two times. the scales have to be balanced between the weighing actions. Are there different results for the weighings, the mean value has to be recorded into the notes.

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Figure 31 Weighing Process

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Determination of the limits for the center of gravity location

After determination of the empty mass and the empty mass moment, a check of the CG location during flight under the most extreme practical loading conditions is necessary.

The possible **forward** CG location "**Xv**" has to be determined, in which the airplane is theoretically loaded with a maximum mass at the front

The possible **aft** CG location "**Xh**" has to be identified, in which the aircraft is loaded with a maximum mass at the back.

The results are compared with the data for the allowable CG location during flight (see sketch below).

- If the values are within the limits, the empty mass and the empty mass moment can be recorded in the flight manual.

If the values are outside the limits, it has to be checked, if there are already restrictions in the flight manual for this critical loading case.

- If there are restrictions, the values are also recorded in the flight manual. Also part of this are instructions for using the fuel in the several fuel tanks in the right order to ensure that from the start (filled) on to the landing (empty) all CGs are inside the limits.

If there are no sufficient details for the loading recorded in the flight manual for the critical loading case, it has to be checked, if a better usage can be achieved with a fixed trim mass. The trim mass and the location of the trim mass have to be determined.

The safe fastening has to be checked. The trim mass is not allowed to cause failures and the fastening has to resist the acceleration forces which are described in the airworthiness directive.

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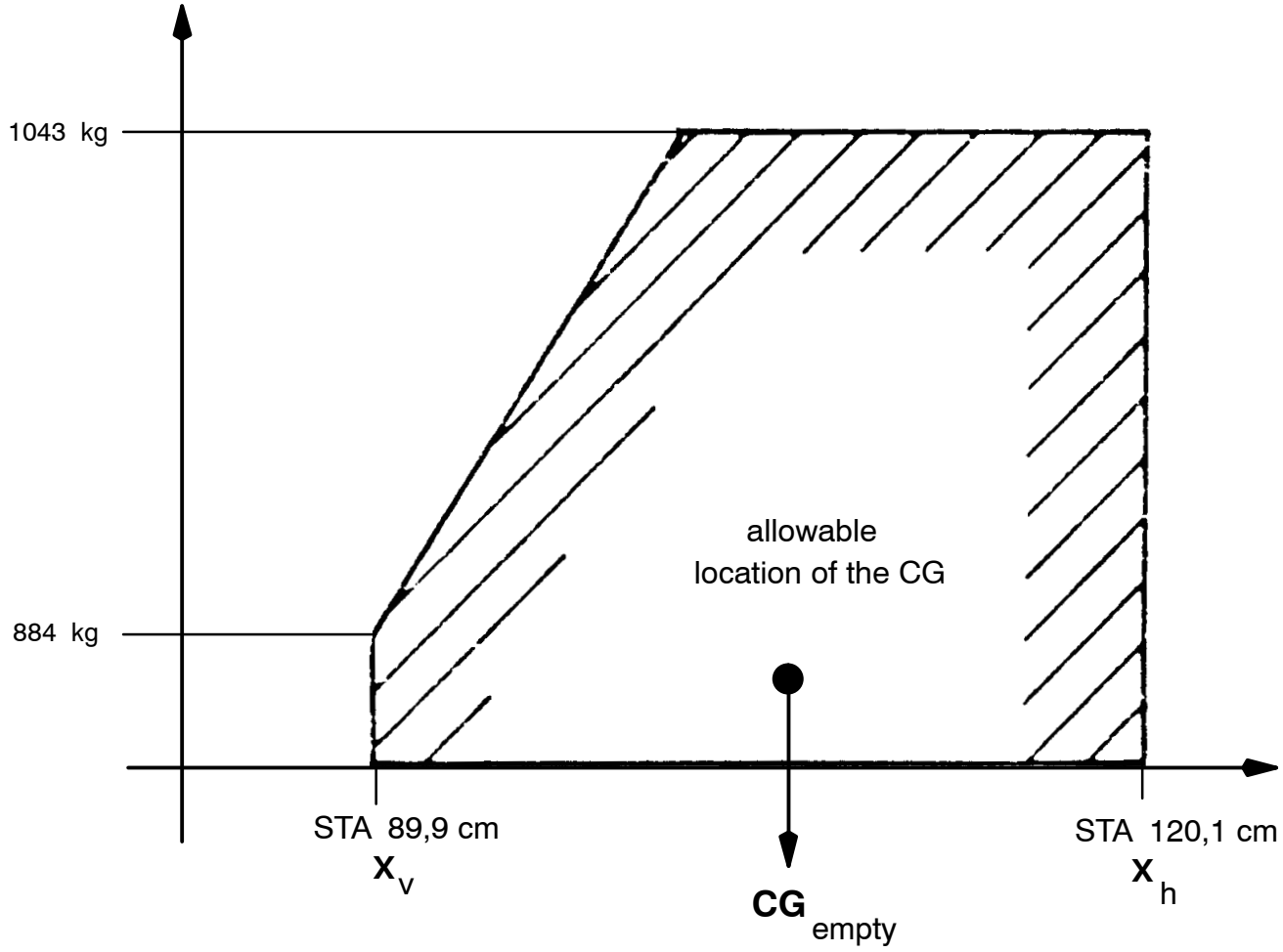


Figure 32 CG-Limit-Diagram (Typical)

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On Board Aircraft Weight and Balance System

Weight and Balance Computer (WBC)

Some large transport Aircraft have an on board aircraft weighing system called (OBAWS) that, when the aircraft is on the ground, gives the flight crew and the maintenance technician a continues indication of the aircraft gross weight and the location of the Center of gravity in % MAC.

The system consists of strain sensing transducers in each main wheel and nose wheel axle, a weight and balance computer, and indicators that show the gross weight, the CG location in % MAC, and an indicator of the ground attitude of the aircraft (leveling).

The strain sensors measure the amount each axle deflects and send this data into the computer, where signals from all of the transducers and the ground attitude sensor are integrated. The results are displayed on the indicators in the cockpit.

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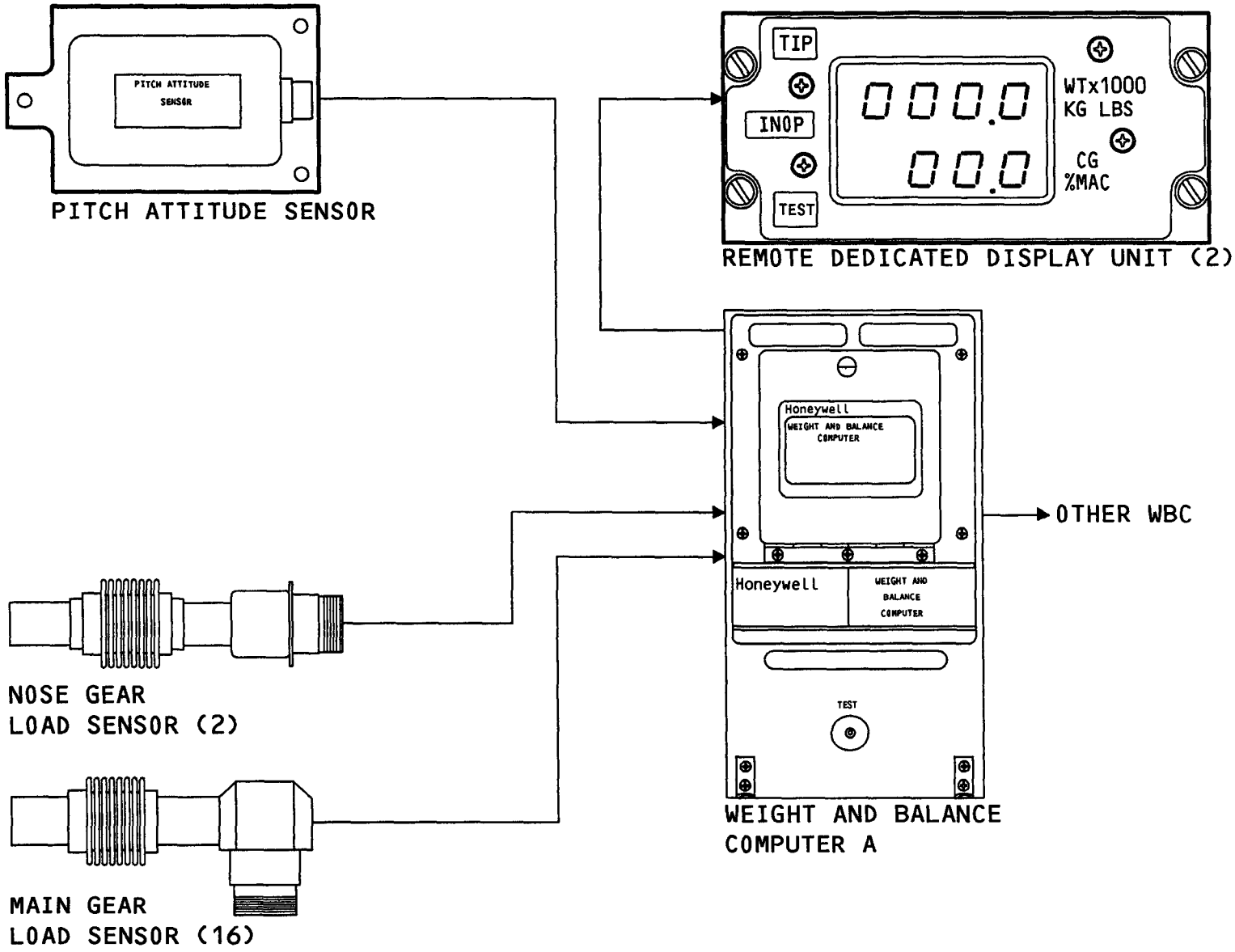


Figure 33 Weight and Balance Computer

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Weighing Procedures

General

When calculating a weight and balance record, certain procedures must be followed in order to make the report accurate.

These procedures include more than just weighing the aircraft, they include understanding weight and balance terms, knowing how to set up and use the necessary equipment. There are also different EASA regulations that apply to general aviation as compared to commercial aviation that must be adhered to.

Information on which to base the record of weight and balance changes to the aircraft may be obtained from pertinent aircraft specification as follows:

- **Type Certificate Data Sheet (TCDS)**
- **Prescribed Aircraft Operating Limitations**
- **Aircraft Operation Manual (AOM)**
- **Aircraft Weight and Balance Record**
- **Aircraft Maintenance Manual (AMM)**
- **Weight and Balance Manual (WBM)**

Removal or addition of minor items of equipment such as nuts and bolts, rivets, washers and similar standard parts of negligible weight do not require a weight and balance check.

Therefore the removal or addition of major parts or equipment, such as configuration changes, results in changes to the center of gravity and a weighing procedure must be conducted with reference to the manuals above.

These changes are often calculated by aircraft technicians and entered in the aircrafts permanent weight and balance records. Since these records stay with the aircraft forever, they must reflect current aircraft status.

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Record - No.: HAM TO/L-W 140/02

Aircraft Weighing Record

Aircraft Owner : **Lufthansa**
Aircraft Model : **B747-400**
Aircraft Registration : **D-ABTF**
Aircraft Serial No. : **24967**

Weighing Date : 01.12.2002
Weighing Place : Xianmen
Weighing Equipment : INTERCOMP AC30-6
Serial No. : ref. page 4
Last Calibration : Oct. 02

Weighing Reason : D-Check

Check Points (to be checked before/after weighing)

Aircraft checked against Equipment List	: Y	Stabilizer position [0°]	: Y
Missing Equipment	: Y	Flaps and Spoilers retracted	: Y
A/C painted and dry	: Y	Thrust/Fan reverser retracted	: Y
Fuel tanks drained	: N	All doors closed	: Y
Fuel tanks dry	: Y	All E.R.I. installed	: Y
Hydraulik oil tanks	: full	A/C attitude (+/- = nose up/down)	: -.1°
Oil tanks: engine, CSD and APU	: full	Vert. dist. of CG from main gear pivot:	: 160[inch]
Potable water tanks	: empty	Seating Version	: F16C78M274
Toilet fluid tanks/waste tanks precharged	: N		
All access doors and cowls installed	: Y		

Weight and Balance Calculation

	Average Weight [kg]	Arm [inch]	Moment [inch*kg]
Wing Gears fwd	45597,5	1313,50	59892316
Wing Gears aft	45517,5	1371,50	62427250
Body Gears fwd	40895,0	1434,50	58663877
Body Gears aft	40902,5	1492,50	61046982
Nose Gear	8497,5	395,00	3356513
Weight at weighing	181410,0	1352,67	245386938
CG-Correction due to pitch attitude		0,28	50795
Deductions	10257,6		11817900
Additions	1103,5		1673735
Lufthansa Empty Weight	**172255,9**	**1365,95**	**235293568**

CG in %MAC = (Arm - Leading Edge of MAC) / Length of MAC * 100 %

CG in %MAC = (1365,95 - 1258,00) / 327,80 * 100 % = **32,9 % MAC**

Index = 172256 * (1365,95 - 1305,00) / 200000 + 30 = **82,48**

Calculated : 11.12.2002 (Grünke)

Approved : 11.12.2002 (Wünschkowski)

Total Empty Weight

Total Empty Moment

CG position in % MAC

Empty Weight CG position (Index)

Figure 34 Weight and Balance Record

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Type Certificate Data Sheet (TCDS)

Aircraft Specification

The Type Certificate Data Sheet is a document which contains a formal description of the aircraft, including detailed specifications of the type design and the information required for type certification as well as weight and balance information as follows.

- **Center of gravity range**
- **Empty weight CG range**
- **Maximum weight**
- **Position of datum**
- **Leveling means**

The TCDS is issued by the FAA and it is the responsibility of the inspecting Aircraft technician to ensure that the aircraft adheres to them before he starts with weighing or balancing procedures.

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DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

A 45 EU
BAe/SNIAS
CONCORDE, Type 1

January 9, 1979

TYPE CERTIFICATE DATA SHEET NO. A45EU

Datum	The datum of the center of gravity computation is a vertical reference plane located 8.333 feet (2540m) forward of Fuselage Station XA.0.A reference rigging point „C“ is provided on the airframe 83.172 feet (21.570m)		
M.A.C.	The reference root chord Co is 90.748 feet (27.660m) in length; its leading edge is located 70.771 feet (21.570m) aft of the datum		
Leveling means	Clinometer on the cabin rails.		
Maximum weights	TAXI WEIGHT	86,880 kg	412,000 lb
	TAKE OFF WEIGHT	185,070 kg	408,000 lb
	LANDING WEIGHT	111,130 kg	245,000 lb
	ZERO FUEL WEIGHT	92,080 kg	203,000 lb

Figure 35 Type Certificate Data Sheet (CONCORDE)

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