getting to grips with
weight and balance

AIRBUS

SYSTEMS

WEIGHT AND BALANCE ENGINEERING

LOADING OPERATIONS

CARGO SYSTEMS INTRODUCTION

Airbus aircraft are designed for passenger civil air transport with a passenger cabin on the upper deck. The lower deck of the airplane is dedicated to passenger luggage as well as additional freight transportation. So at the end of the 60's, the A300 was originally designed to accommodate, with a semi-automatic, electrically powered cargo loading system, the Unit Load Devices that were already standardized at that time for the B747, considering that the cargo area was too great for it to be loaded manually. This solution was later used for to all the other long-range programs. On the single aisle family two cargo loading solutions are proposed to the operators either manual bulk loading or semi-automatic, electrically powered cargo loading system accommodating Unit Load Devices derived from the larger aircraft ULDs.

The following chapter describes the cargo loading areas on Airbus aircraft and the systems related to cargo holds.

As an introduction the first paragraph is dedicated to Unit Load Devices description.

A. CARGO SYSTEMS

1. TYPE OF ULDS AND CONFIGURATION

1.1. History

When the first Boeing 747 went into service in 1970, the air transport industry faced a dramatic change of ground-handling culture.

In fact, the lower-deck capacity of the 747 was too great for it to be loaded manually. Baggage and cargo had to be accommodated in Unit Load Devices (ULDs), which had previously only been used for freighter aircraft.

The 747 was originally designed to accommodate the 96in square cross-section of the ISO standard 'marine' containers on the main deck, which determined the overall shape and size of the fuselage. The space remaining in the lower deck, after satisfying the main deck requirement determined the basic dimensions and shape of the lower-deck containers.

Most carriers at that time used 88in x 125in pallets on freighter aircraft. The 747s lower-deck system was required, therefore, to be able to accept the 125in dimension across the width of the lower deck. Then the lower deck height dictated the maximum height for ULDs (64in).

For ease of handling, the new baggage containers were smaller than cargo containers and were loaded in pairs, each unit occupying half the width of the compartment floor. The baseplate dimensions of the half-width container were set at 60.4 x 61.5in.

Having been of such service to the industry in developing a 'standard' for lower deck ULD equipment, Boeing then, unaccountably, introduced the 767, which first flew in 1981, which used several completely different sizes of ULD.

With this background of evolution and airframe manufacturer influence, although many of the ULD sizes in use are 'standard' in terms of certain critical dimensions, incompatibilities do still exist and many different ULD types are in service.

The basic reference document for ULD base sizes is a National Aerospace Standard produced by the Aerospace Industries Association of America, in accordance with the requirements of federal Aviation Regulation-Part25 (FAR25)-Airworthiness Standards: Transport Category Aeroplanes.

This document, drafted with input from the major U.S. airframe manufacturers, was designated NAS3610. The document was approved by the Federal Aviation Administration (FAA) in 1969 and entitled: minimum Airworthiness requirements and test conditions for Certified Air Cargo Unit Load devices.

The primary objective was to provide requirements designed to ensure the ability of ULDs and their in-aircraft restraint-systems to contain their load under the influence of in-flight forces. Although NAS3610 is an airworthiness certification document, the fact that it reflects mandatory requirements and details the baseplate dimensions of all ULDs types dictate that all ULD standards should refer to it.

NAS3610 only considers the ULD baseplate. There are a variety of different contours that may be attached to any one baseplate size.

It is the responsibility of the owner of an aircraft ULD to have provisions for the maintenance of such units to the effect that they are kept in an airworthy condition.

Airbus does not differentiate between so-called certified or non-certified containers. It is not required that a container actually undergoes a certification process, however the container has to fulfil the same requirements as a certified container.

1.2. IATA identification code for Unit Load Devices (ULDs)

There is a large number of ULDs in operations today. Taking into account all the characteristics corresponding to a particular ULD has therefore developed an identification Code.
This Code contains essential data to describe each ULD and for further technical information the reference is the **IATA ULD Technical Manual**.
The purpose of the following paragraph is to explain quickly the method of ULD marking and numbering.

- **IATA Identification Code**

The Identification Code gives each unit an individual identification and allows the easy exchange of the information contained in the marking of units.

The IATA Identification Code consists in nine characters composed of the following elements:

Position	Type description
1	ULD Category
2	Base Dimensions
3	Contour and Compatibility
4,5,6 and 7	Serial number
8 and 9	Owner/Registrant

Only the three first letters are necessary to identify the ULD.

- **TYPE CODE (Positions 1,2 and 3)**

- **Position 1**

Position 1 is used to describe the general type of the unit considering only the following characteristics:
- Certified as to airworthiness or non-certified.
- Structural unit or non-structural.
- Fitted with equipment for refrigeration, insulation or thermal control or not fitted for refrigeration, insulation or thermal control.
- Also considering specific units: containers, pallets, nets, pallet/net/non-structural igloo assembly.

Code Letter	ULD Category
A	Certified aircraft container
D	Non-Certified aircraft container
F	Non-Certified aircraft pallet
G	Non-Certified aircraft pallet net
J	Thermal non-structural igloo
M	Thermal non-certified aircraft container
N	Certified aircraft pallet net
P	Certified aircraft pallet
R	Thermal certified aircraft container
U	Non-structural container
H	Horse stalls
K	Cattle stalls
V	Automobile transport equipment
X	Reserved for airline internal use
Y	Reserved for airline internal use
Z	Reserved for airline internal use

- **Position 2**

This position makes reference to the Base Dimensions of the ULD.

Series	Base dimensions (and compatible nets when applicable)			
	length × width mm		length × width in	
A	2235 x 3175 mm		88 x 125 in	
B	2235 x 2743 mm		88 x 108 in	
E	1346 x 2235 mm		53 x 88 in	
F	2438 x 2991 mm		96 x 117.75 in	
G	2438 x 6058 mm		96 x 238.5 in	
H	2438 x 9125 mm		96 x 359.25 in	
J	2438 x 12192 mm		96 x 480 in	
K	1534 x 1562 mm		60.4 x 61.5 in	
L	1534 x 3175 mm		60.4 x 125 in	
M	2438 x 3175 mm		96 x 125 in	
N	1562 x 2438 mm		61.5 x 96 in	
P	1198 x 1534 mm		47 x 60.4 in	
Q	1534 x 2438 mm		60.4 x 96 in	
R	2438 x 4938 mm		96 x 196 in	
X	Miscellaneous sizes largest dimension between 2438 mm and 3175 mm (between 96 in and 125 in)			
Y	Miscellaneous sizes largest dimension lower than 2438 mm (96 in)			
Z	Miscellaneous sizes largest dimension above 3175 mm (125 in)			

- **Position 3**

The Position 3 corresponds to the type of contour and describes if the ULD is forklift compatible or not. The loading contours have been sequentially numbered and the individual aircraft ULDs are coded and marked according to the type of aircraft in which they can be carried. A full description of the aircraft contours is contained in the **IATA ULD Technical Manual**.

Here are the main contours and their letters.

48in (1219mm)

A / B

M

90in (2286mm)   96in (2438mm)
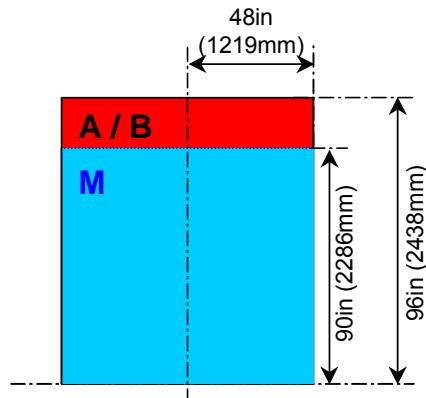
A - Non-Forkliftable
B - Forkliftable
M

92 in(2337mm)

79 in(2007mm)

E / N

G   **C**

46in (1168mm)   64in (1626mm)

2.12 in(54mm)
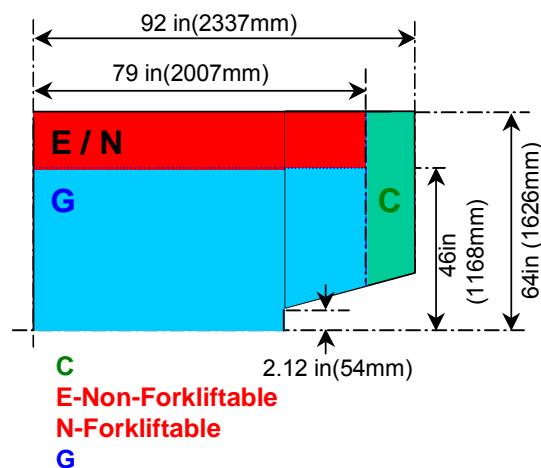
C
E-Non-Forkliftable
N-Forkliftable
G

93 in(2362mm)

80 in(2032mm)

96 in(2438mm)

F   **H**   **U**

46in (1168mm)   64in (1626mm)

U / F / H

2.12 in(54mm)
or
4.25 in (108mm)

62.5 in(1588mm)

P

64 in(1626mm)

P

62.5 in(1588mm)

41.3 in (1049mm)

15.3 in (389mm)

Z

K

64 in(1626mm)

82 in(2083mm)

Z / **K**

SYSTEMS
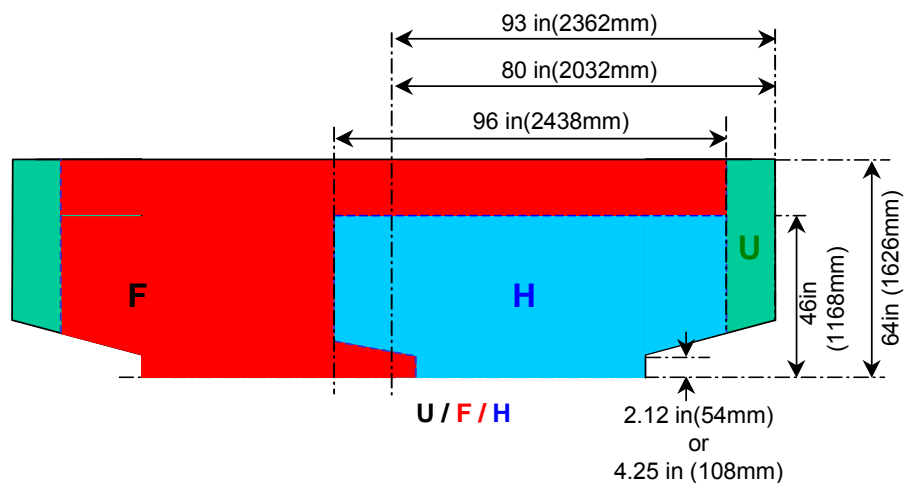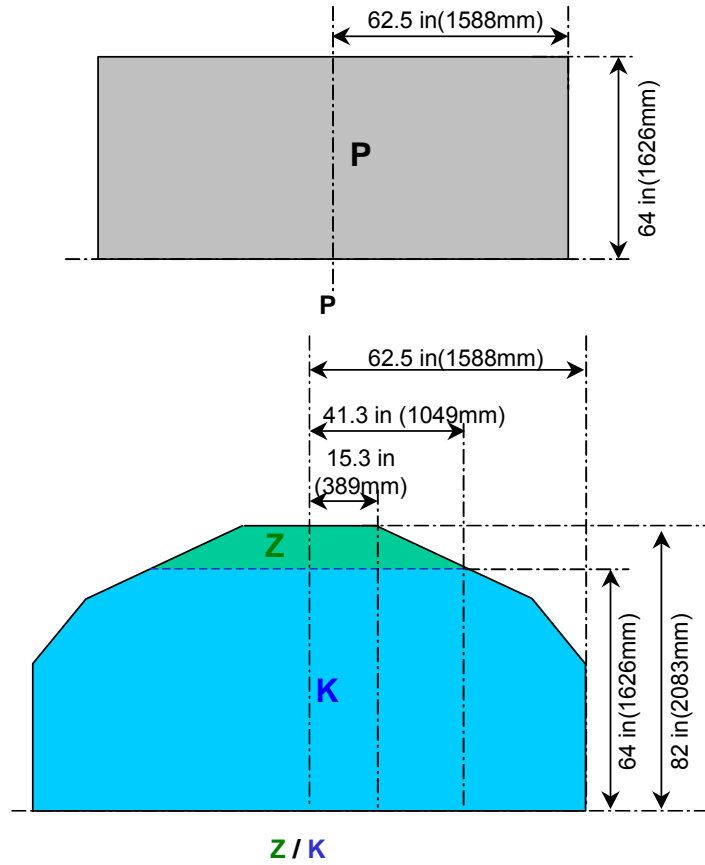
1.3. ULDs among the AIRBUS fleet

ULD Type					
CONTAINERS					
	ATA	IATA	**Base Dimension**		Height	Typical Volume (without shelves)
			Length	Width		
standard	LD3	AKE (V3)	60.4 in (1534 mm)	61.5 in (1562mm)	64 in (1626mm)	4.3 m³ - 151 ft³
standard	LD3-46	AKG	60.4 in (1534 mm)	61.5 in (1562mm)	46 in (1168mm)	3.1 m³ - 109 ft³
standard	LD3-46W	AKH	60.4 in (1534 mm)	61.5 in (1562mm)	46 in (1168mm)	3.68 m³ – 130 ft³
standard	LD1	AKC (V1)	60.4 in (1534 mm)	61.5 in (1562mm)	64 in (1626mm)	4.7 m³ - 166 ft³
standard	LD6	ALF (W3)	60.4 in (1534 mm)	125 in (3175 mm)	64 in (1626mm)	8.9 m³ - 314 ft³
standard	LD3-40/45	H	39.75 in (1010mm)	61.5 in (1562mm)	40 - 45 in (1016-1143mm)	2.42 m³ - 96 ft³
option	LD2	DPE	60.4 in (1534 mm)	47 in (1194 mm)	64 in (1626mm)	120 ft³
option	LD4	DQP	60.4 in (1534 mm)	96 in (2432 mm)	64 in (1626mm)	202 ft³
option	LD8	DQF	60.4 in (1534 mm)	96 in (2432 mm)	64 in (1626mm)	245 ft³

PALLETS					
	ATA	IATA	**Base Dimension**		Height	Vol.
			Length	Width		
standard	LD9	PMx	96 in (2438 mm)	125 in (3175 mm)	64 in (1626mm)	10.9 m³ - 385 ft³ (contour P) 14.6 m³ - 515 ft³ (contour F)
standard	LD7	PAx (A2)	88 in (2235 mm)	125 in (3175 mm)	64 in (1626mm)	10 m³ - 353 ft³ (contour P) 13.4 m³ - 473 ft³ (contour F)
standard		PLx	60.4 in (1534 mm)	61.5 in (1562 mm)	64 in (1626mm)	7.2 m³ - 254 ft³ (contour F)
standard		PKx	60.4 in (1534 mm)	61.5 in (1562 mm)	46 in (1168mm)	3.5 m³ - 123 ft³ (contour P)

ULD	ATA/IATA	Number of ULD per cargo hold FWD/AFT/BULK Max weight										
		A318	A319	A320	A321	A310	A300-600	A330-200	A330-300 A340-300	A340-200	A340-500	A340-600
standard	LD3 / AKE (V3)					8/6/1*	12/10/1*	14/12/1*	18/14/1*	14/12/1*	18/12 18/10****	24/18
						3500lb (1587kg)						
	LD3-46 / AKG		2/2**/0	3/4**/0	5/5**/0	8/6/1*	12/10/1*	14/12/1*	18/14/1*	14/12/1*	18/12 18/10****	24/18
						2500 lb (1134kg)						
	LD3-46W / AKH		2/2**/0	3/4**/0	5/5**/0	4/3/1*	6/5/1*	7/6/1*	9/7/1*	7/6/1*	9/6 9/5****	12/9
						2500lb (1134kg)						
	LD1 / AKC (V1)					4/3/0	6/5/0	7/6/0	9/7/0	7/6/0	9/6 9/5****	12/9
						3500lb (1587kg)						
	LD6 / ALF (W3)					4/3/0	6/5/0	7/6/0	9/7/0	7/6/0	9/6 9/5****	12/9
						7000lb (3174kg)						
	LD3-40/45 / H		0/1**									
			1660lb (753kg)									
option	LD2 / DPE							0/8***	0/10***	0/8***		
								2700lb (1224kg)				
	LD4 / DQP							0/4***	0/5***	0/4***		
								5400lb (2449kg)				
	LD8 / DQF							0/4***	0/5***	0/4***		
								5400lb (2449kg)				
PALLET	PMx					3/0	4/0	4/4	6/4	5/4	6/4 6/3****	8/6
						11250lb (5103kg)						
	Pax (A2)					3/0	4/0	4/4	6/5	5/4	6/4 6/3****	8/6
						10200lb (4626kg)						
	PLx					4/3/0	6/5/0	7/6/0	9/7/0	7/6/0	9/6 9/5****	12/9
						7000lb (3174kg)						
	PKx	2/2	3/4	5/5		8/6	12/10	14/12	18/14	14/12	18/12 18/10****	24/18
						3500lb (1587kg)						

*option : additional container in bulk cargo compartment.
**option : the basic version is designed for bulk loading.
***option : eight (or ten) containers plus four LD3 in aft compartment.
****option : for A340-500 equipped with 7 frames Rear Center Tank (RCT)

CONTAINER AKG

IATA ULD Code: AKG
Classification ATA: LD3-46
Aircraft: A320 family and interlining
Volume: 110 ft³ (3.1m³)
Weight limitations: 2500 lb (1134 kg)

79 in (2007mm)
*46 in (1168 mm)
61.5 in (1562mm)
60.4 in (1534mm)
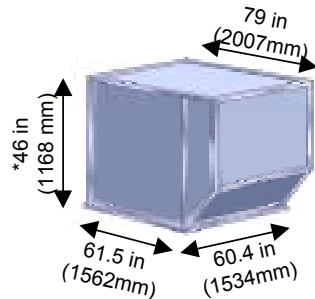
CONTAINER AKH

IATA ULD Code: AKH
Classification ATA: LD3-46W
Also known as DKH.
Aircraft: A320 family and interlining
Volume: 127 ft³ (3.6m³)
Weight limitations: 2500 lb (1134 kg)

96 in (2438mm)
*46 in (1168 mm)
61.5 in (1562mm)
60.4 in (1534mm)
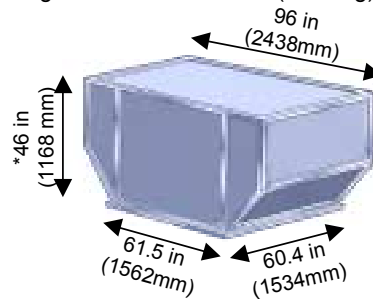
Additional CONTAINER A319

IATA ULD Code: H
Classification ATA: LD3-40/45
Aircraft: A319
Volume: 80 ft³ (2.25m³)
Certified MGW limit: 1660 lb (753 kg)

96 in (2438mm)
45 in (1168 mm)
61.5 in (1562mm)
39.75 in (1010mm)
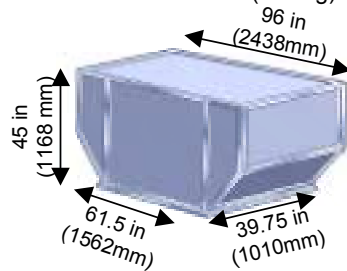
CONTAINER AKE

IATA ULD Code: AKE
Classification ATA: LD3
Also known as AVA, AVB, AVC, AVK, DVA, DVE, DVP, XKS, XKG.
Aircraft: A310, A300, A330, A340.
Volume: 145 to 158 ft³ (4.1 to 4.47m³)
Weight limitations: 3500 lb (1587 kg)

79 in (2007mm)
64 in (1626mm)
61.5 in (1562mm)
60.4 in (1534mm)
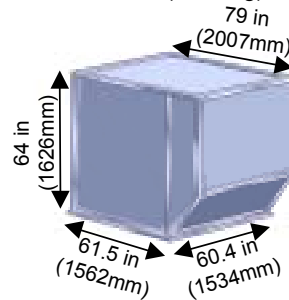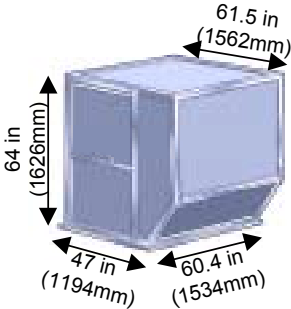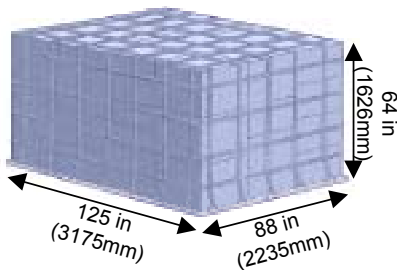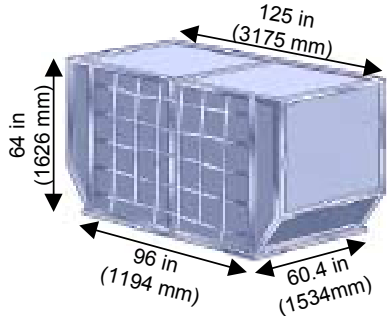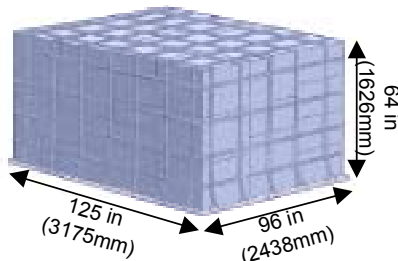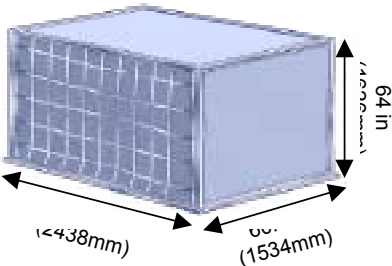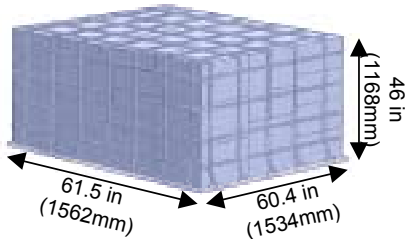
CONTAINER ALF

IATA ULD Code: ALF.
Classification ATA: LD6
Aircraft: A310, A300, A330, A340.
Volume: 316 ft³ (8.9m³)
Weight limitations: 7000 lb (3175 kg)

160 in (4064mm)
64 in (1626 mm)
125 in (3175mm)
60.4 in (1534mm)
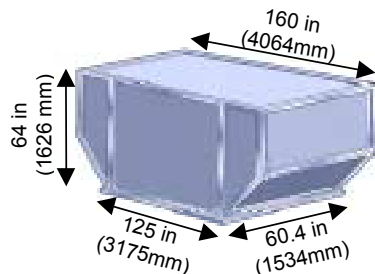
CONTAINER AKC

IATA ULD Code: AKC
Classification ATA: LD1
Also known as AVC, AVD, AVK, AVJ.
Aircraft: A310, A300, A330, A340.
Volume: 159 to 173 ft³ (4.5 to 4.9m³)
Weight limitations: 3500 lb (1587 kg)

94 in (2337mm)
64 in (1626mm)
61.5 in (1562mm)
60.4 in (1534mm)
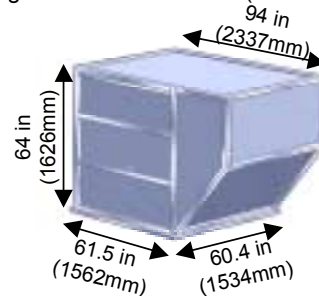
NB: * means that, for those two containers, this dimension varies between 44 in and 46 in. Some airlines prefer the 45 in container.

CONTAINER DPE

IATA ULD Code: DPE
Classification ATA: LD2.
Also known as APA, DPA.
Aircraft: A330, A340.
Volume: 120 ft³(3.4m³)
Weight limitations: 2700 lb (1224 kg)

61.5 in
(1562mm)
64 in
(1626mm)
47 in
(1194mm)
60.4 in
(1534mm)

PALLET PAx

IATA ULD Code: Pax
Classification ATA: LD7
Also known as PAA, PAG, PAJ, PAP, PAX, P1A, P1C, P1D, P1G.
Aircraft: A310, A300, A330, A340.
Volume: 372 ft³(10.5m³)
Weight limitations: 10200 lb (4626 kg)

64 in
(1626mm)
125 in
(3175mm)
88 in
(2235mm)

CONTAINER DQF

IATA ULD Code: DQF.
Classification ATA: LD8
Also known as ALE, ALN, DLE, DLF, DQP.
Volume: 245 ft³(6.9m³)
Weight limitations: 5400 lb (2449 kg)

125 in
(3175 mm)
64 in
(1626 mm)
96 in
(1194 mm)
60.4 in
(1534mm)

PALLET PMx

IATA ULD Code: PMx
Classification ATA: LD9
Also known as P6P, P6A, P6Q, PMA, PMC, PMP, PQP.
Aircraft: A310, A300, A330, A340.
Volume: 407 ft³(11.5m³)
Weight limitations: 11250 lb (5103 kg)

64 in
(1626mm)
125 in
(3175mm)
96 in
(2438mm)

CONTAINER DQP

IATA ULD Code: DQP
Classification ATA: LD4
Volume: 202 ft³(5.7m³)
Weight limitations: 5400 lb (2449 kg)

64 in
(2438mm)
60.
(1534mm)

PALLET PKx

IATA ULD Code: PKx
Volume: 85 ft³(2.4m³)
Aircraft: A320 family
Weight limitations: 2500 lb (1134 kg)
Certified MGW limit: 3500 lb (1587 kg)

46 in
(1168mm)
61.5 in
(1562mm)
60.4 in
(1534mm)

2. CARGO HOLDS DESCRIPTIONS

All Airbus aircraft lower decks are divided into 3 cargo holds : forward (FWD), AFT and BULK.
FWD and AFT holds are divided into 1 or 2 compartments, each compartment being made of several loading positions defining the position of each type of ULD or the position of bulk cargo loads.
The cargo holds position arrangement depends on the aircraft fuselage length.

2.1. Bulk cargo system

For the A320 family aircraft the basic way to load cargo is to load it in bulk. For any Airbus aircraft the most rear cargo hold (BULK : compt 5) is also loaded in bulk.
These holds are equipped with adequate cargo and lining components.

2.1.1. Cargo components

a) Partition nets

These nets are used for cargo loading areas separation. They have fixed locations in each cargo hold and dedicated attachment points on the ceiling and side-wall linings and on the floor panels. There is also a divider net separating AFT and BULK cargo holds. This divider net has to be linked with a tarpaulin.

Partition net

Tarpaulin

Partition net
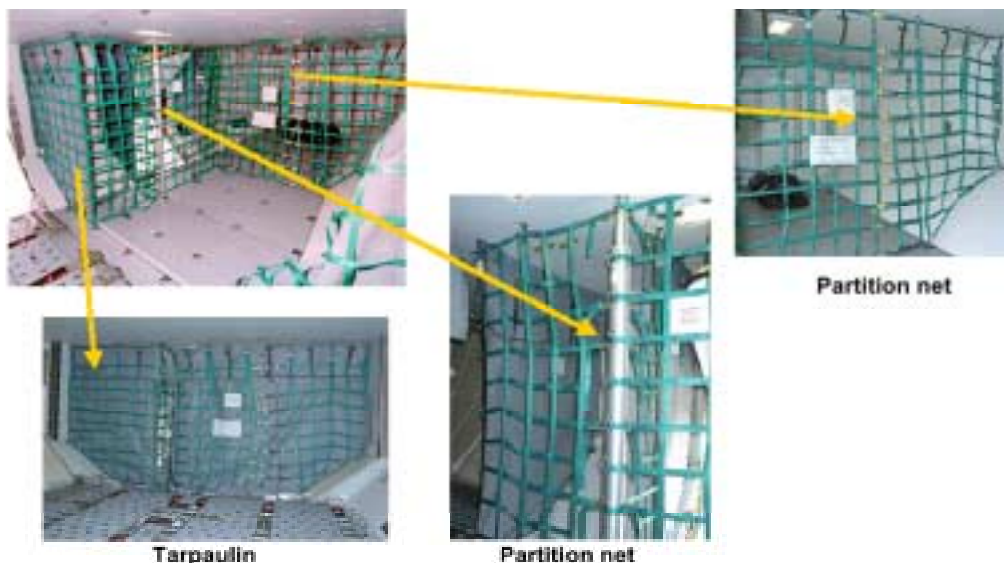
b) Door net

These nets are used to delimit the entrance door area which must remain unloaded.

c) Attachment point

Attachment points are used to fasten the nets. They are located on the ceiling and side-wall linings and on the floor panels.
Attachment points in the side-wall and ceiling linings are for nets fastening only.
Attachment points on the floor panels that are not used for nets fastening can be used for load restraint.

d) Tie-down point

Tie-down points are used to restraint cargo item(s) movement in the cargo hold.

2.1.2. Lining components

a) Floor panel

b) Side wall lining

c) Ceiling

d) Partition wall

Each panel has a defined maximum static area load. These loads are not exceeded if the maximum loads per position and per holds are not exceeded and if loads, which due to their geometry or weight may damage the panel, are tied down at loading.

2.2. Cargo Loading Systems (CLS):

The 2-aisle aircraft family is equipped with a semi-automatic, electrically powered cargo loading system in the FWD and AFT cargo holds.
For A320 family, except for the A318, an option is available to have the cargo loading system installed.

This cargo loading system is compatible with ULDs designed to meet the class II requirements of the specification NAS3610 and provides individual ULD baseplate restraint.
It offers a real flexibility for loading as any position can be loaded or remain empty. Locking and unlocking of ULDs inside the cargo compartments is carried out manually.

ULDs which do not fit into the restraint system due to their geometry can be loaded but they must be handled in such a manner that neither the ULD nor the items loaded on it will endanger the aircraft during the whole flight.
The cargo loading system allows manual loading and offloading of the ULDs if the power drives are inoperative for any reason.
Simultaneous loading and offloading of the FWD and the AFT holds is possible provided that the stability criteria are met.

The cargo loading system is equipped with rollertrack mounted self-lifting electrical Power Drive Units (PDU) installed for the lateral and longitudinal movement of ULDs and controlled by a joystick located in the doorway.
The following paragraphs provide detailed information about conveyance components, guides and restrains, power drive and control component.

2.2.1. Conveyance components:

a) Ballmats and Ball Transfer units in entrance area:

Ballmats and ball strips are installed in the forward and aft cargo door entrance area. The ballmats and strips are equipped with ball transfer units installed in a framework, they allow multi-directional and low friction movements of ULDs in the cargo door area.

Ballmats and Ball Transfer units in entrance area of A330/A340

b) Roller tracks:

The roller tracks are installed in longitudinal direction, used for longitudinal transport of ULDs. The roller tracks are extruded profiles, equipped with transport rollers, endstops and XZ-latches. At certain position, the roller tracks are additionally equipped with power drive units and proximity switches below the XZ-latches allowing powered transportation of ULDs. In these roller tracks braking rollers are also installed to prevent inadvertent ULD movement.

Transport roller

Roller track
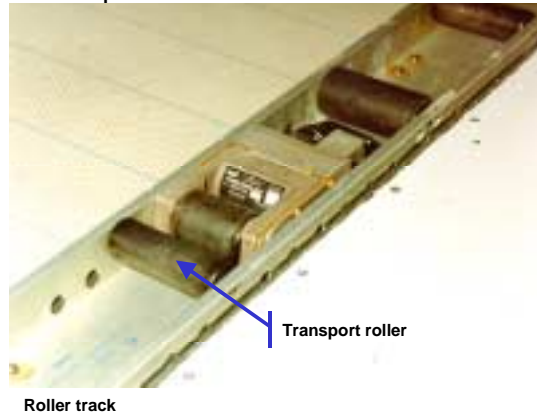
2.2.2. Power drive and control components:

a) Power drive units:

The Power Drive Unit (PDU) consists of an electrical motor, a gear drive and a rubber coated roller, mounted on a rolling axle.
It is used to move the ULDs in longitudinal and lateral direction. All PDUs are activated via signal from the control system.
It provides a towing force, sufficient to drive the ULDs in different directions. When the PDU is switched off, the drive roller lowers automatically to its rest position, 3 mm below system height.

PDU

Drain outlet

Roller track

PDU sensor
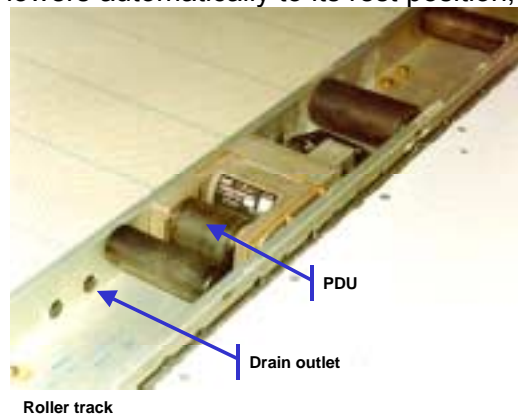
Ball mat PDU, "Self - lift" type

Outside ball mat PDU, "Spring - Lift" type

b) Control components and control panel:

Loading and offloading with the lower deck cargo loading system is managed by control panels located at FWD and AFT cargo doors, that are equipped with a power ON-OFF switch to activate the CLS and a joystick to determine the direction of movement of the PDUs.
On A340-500 and A340-600 aircraft an additional joystick is installed on the roof of the entrance area. From this joystick it is possible to control the all PDUs except those in the ballmat area.

In order to avoid any unexpected or dangerous ULD movement in the cargo hold some limitation systems are available :

- limit switches below the XZ-latches stopping the PDU power when the ULD has reached its limit.
- a switch at each door sill latch interrupting power supply for the CLS each when the latch is raised and preventing door operations when the latch is lowered.

FWD control panel

Additional joystick

SYSTEMS

2.2.3. Guides and restraints:

a) Door sill:

Door sill latch units are installed in the FWD and AFT cargo door areas. Each door sill latch consists of:

- a YZ-latch, which allows to latch the ULDs positioned in the door entrance area.
- an overrideable Y-latch which prevents inadvertent roll out of ULDs during loading and off-loading.
- a guide roller which is used to transfer of ULDs between the loader and the ballmat area.

Guide roller

Overrideable Y-latch
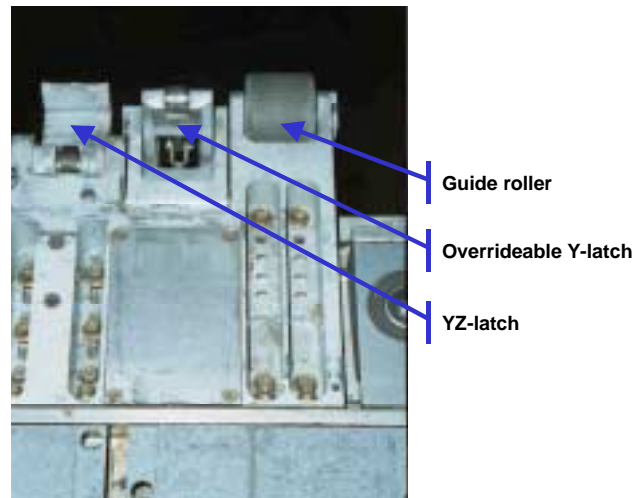
YZ-latch

The **YZ-latch** is operated manually. It can be lowered by pressing a red lever at the side of the unit and can be raised by being pulled up by hand. Each lever of the door sill latch units is electrically monitored by a limit switch to ensure that the cargo door cannot be closed when the YZ-latch is in its lower position and that the CLS is not powered closed when the YZ-latch is in its up position.

YZ-latch lowered

YZ-latch in up position
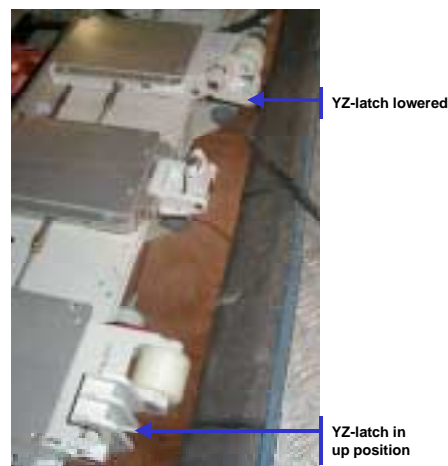
The **overrideable Y-latches** are spring loaded and operated automatically or manually. They are overrideable in loading direction, returning to the raised position once the ULD has passed over, to prevent inadvertent roll out. Before ULD offloading, the Y-latch has to be lowered manually by means of a handle located on the cargo loading system control panel. When the handle is pushed down, a hydraulic damper delays the Y-latch raising to allow ULD unloading.

b) Entrance guides:

The door entrance guides provide a correct guidance on the ballmat during loading or offloading of ULDs and prevent impact to the doorframe.
Entrance guides system is made of guides acting in different directions :

- a mechanical **Z-guide** is installed for guidance of ULD baseplates under the endstops.
- a spring loaded **Y-guide** is installed with a guide roller, which provides sufficient clearance between ULD's baseplate and the door frame during loading and offloading.
- **retractable Y-guides** prevent the ULD's from turning while entering the compartment. To transport the ULDs to their final position those guides have to be unlocked by operating a toggle switch on the entrance control panel.
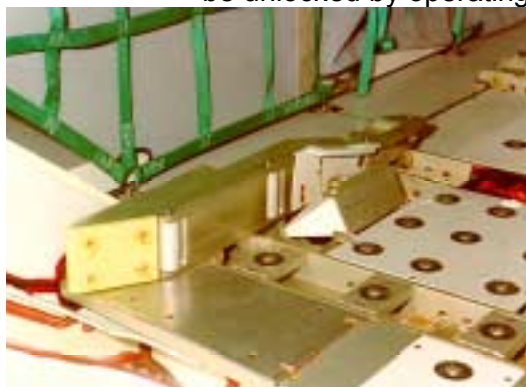
Entrance guides AFT door   **Entrance guides FWD door**   **Retractable Y-guides**

c) Fixed YZ-latches and side guides opposite of cargo door:

The fixed YZ-latches serve to guide in X-direction and to lock ULDs in Y- and Z-direction. These latches are located at each frame on both sides of the cargo compartments. A vertical guide roller is installed in the YZ-latch. Each YZ-latch is equipped with a tie-down point, designed to a maximum load of 2000 lbs (890daN) or 4000 lbs for A340-500 and A340-600 in any direction. Additional side guides are basically installed opposite of each cargo door to align ULDs and optional continuous side guides are installed all along the cargo holds.

Tie down point
Fixed YZ-latch
Optional Continuous Side Guides
Tie down point

Fixed YZ-latch

SYSTEMS
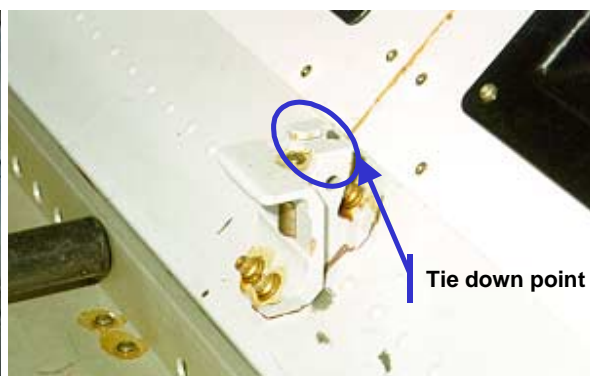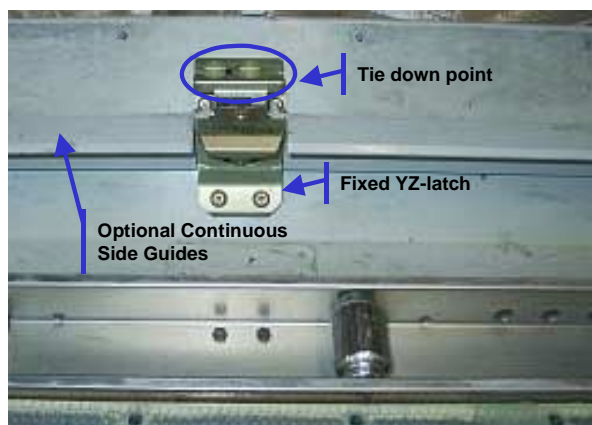
d) Overrideable YZ-latches (A310, A300, A330, A340):

Overrideable YZ-latches, also known as "butterfly", are provided to lock half-size containers in Y- and Z-direction. These latches are attached to the structure at aircraft centerline. During loading of full size containers the latches are overridden. The two latch claws are spring loaded so they raise again when the ULD has moved on.
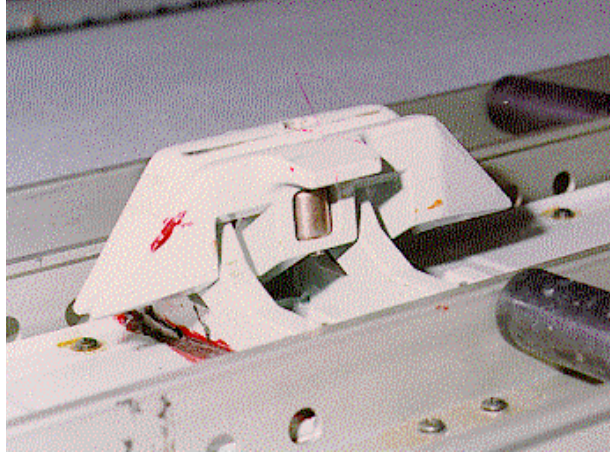
Overrideable YZ-latches

e) Overrideable Y-guide (splitter):

The overrideable Y-guides are used to separate half-size ULDs during loading and offloading. They are located in the entrance area of AFT and FWD holds.
When loading ULDs they can be lowered manually by foot beneath the level of the cargo loading system then when half size containers are loaded they can be pulled up using the control panel joystick in order to separate the ULDs.
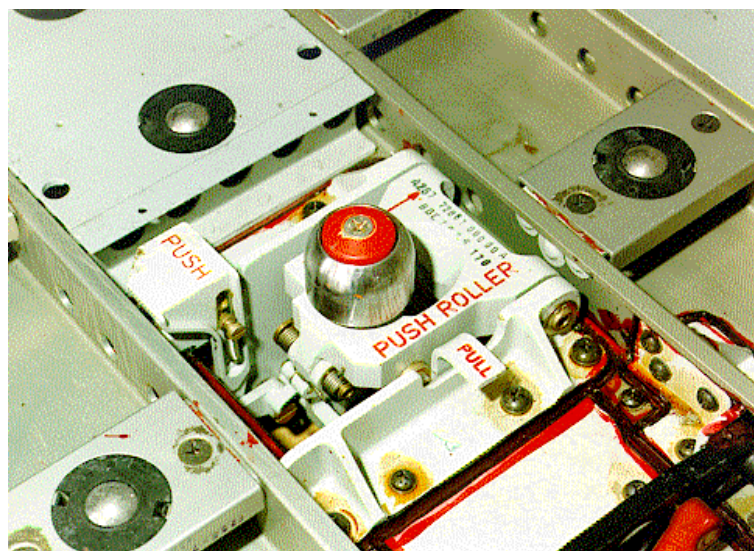
Overrideable Y-guide

f) XZ-latches:

The XZ-latches are used to lock the ULDs in X- and Z-direction. They are fitted to the roller tracks.

They are spring loaded and operated manually. Limit switches are installed underneath some of the XZ-latches. These switches serve to cut off the power supply of the associated PDUs when the applicable latch is in the locked (up) position and to restore PDU power supply when the latch is in lowered position.

To unlock/lower the latch the pawl marked "Press to unlock" needs to be pressed this can be achieved by foot pressure.

The latch is locked by hand by pulling the pawl upwards.

Depending on the cargo hold configuration single, double or triple latches may be installed in order to accommodate any kind of ULD loading.

Single latch	Double latch	Triple latch

g) Endstops:

The fixed XZ-endstops at the extremities of each cargo hold are used to lock ULDs in the X- and Z-direction.

2.3. Cargo loading system failure cases

In case of failure or malfunctions of some of the cargo loading system equipments: nets; tie down points, latches; …, some limitations in the allowed cargo weight per position may appear.
The WBM details these different limitations in chapter 1.10.
In case of malfunctioning ULD's and aircraft structure.
Malfunctioning equipment should be replaced as soon as possible.

Failure of a latch may require weight reduction of the ULD forward and aft of the latch of LH and RH of the latch.

Example :
A330-200 : In case of XZ-latch failure between position 13L and 21L, ULD weight must be reduced to 0 kg on both position.

LATCH TYPE	FRAME POSITION OF LATCH	ULD CONCERNED POSITION	LATCH FAILURE	ULD WEIGHT REDUCED TO (kg)	(lb)	REMARK
■	20/21 RH	11R	1 unit	0	(1)	
	20/21 LH	11L	1 unit	No Reduction		
			2 or more units	0	(1)	
①	26/29 31/32 37.1 37.4	12R/L and 13R/L 13R/L and 21R/L 22R/L and 23R/L 23R/L and 24R/L	1 unit	0	(1)	
ⅢⅢ	23/24 RH	11R and/or 12R (2)	1 unit on Y=-0.140	No Reduction		
			1 unit on Y=-0.805 or more	0	(1)	
ⅢⅢⅢ	34/35 RH	21R and/or 22R (2)	1 unit on Y=-1.470	No Reduction		
			1 unit on Y=-0.805 or more	0	(1)	

2.4. Additional Cargo holds related systems

2.4.1. Cargo hold doors

In most Airbus aircraft there are three cargo doors: one for the forward compartment, one for the aft cargo compartment and one for the bulk compartment. However the shorter A318 and A319 do not have the bulk cargo door.The forward and the aft cargo doors open to the outside and the bulk cargo door opens to the inside.

Aft Cargo Door

Bulk Cargo Door

CLEAR OPENING DIMENSIONS

		A318	A319	A320	A321	A310/A300	A330/A340
FWD DOOR		1.24 x 1.28 m (48.8x50.5 in)	1.23 x 1.82 m (48.6x71.5 in)	1.23 x 1.82 m (48.6x71.5 in)	1.23 x 1.82 m (48.6x71.5 in)	1.69 x 2.70 m (66.8x106 in)	1.70 x 2.70 m (66.9x106 in)
AFT DOOR		1.23 x 1.28 m (48.6x50.5 in)	1.23 x 1.82 m (48.6x71.5 in)	1.2 x 1.82 m (48.6x71.5 in)	1.23 x 1.82 m (48.6x71.5 in)	1.68 x 1.81 m (66.3x71.3 in)	1.68 x 2.72 m (66.1x107 in)
BULK DOOR		No door	No door	0.81 x 0.95 m (32 x 37 in)	0.88 x 0.95 m (34 x 37 in)	0.64 x 0.95 m (25.1x37.4 in)	0.64 x 0.95 m (25x37.4 in)

2.4.2. Lining and decompression (All Airbus aircraft):

The ceiling, sidewalls and floors of the cargo compartment have fire and impact resistant linings complying with "JAR/FAR 25 Amendment 60".
The floor panels and the linings are of sandwich type, manufactured from honeycomb, prepreg layers and protection foil or metal sheet.
The installed linings and floor panels are designed for the following:

- Handling loads from loading personnel.
- Surface finish in light color.
- Quick release features necessary for accessibility.
- Rapid decompression requirements according to FAR/JAR.
- Leak proof requirements for class C compartments according to FAR/JAR.
- Flammability requirements according to FAR/JAR.
- Low smoke and toxicity requirements.

The sidewalls and partitions are equipped with rapid decompression panels. Each decompression panel is enclosed within a frame and is held in place by decompression assemblies.

Decompression panels
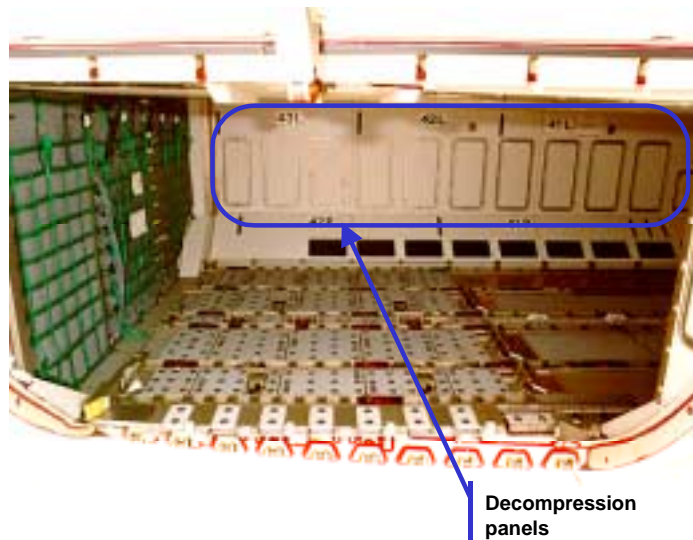
In case of "blow in" spring loaded snappers are pushed back, in case of "blow out" the frame of the decompression panel brakes to allow decompression panel displacement.

"Blow out" case

"Blow in" case
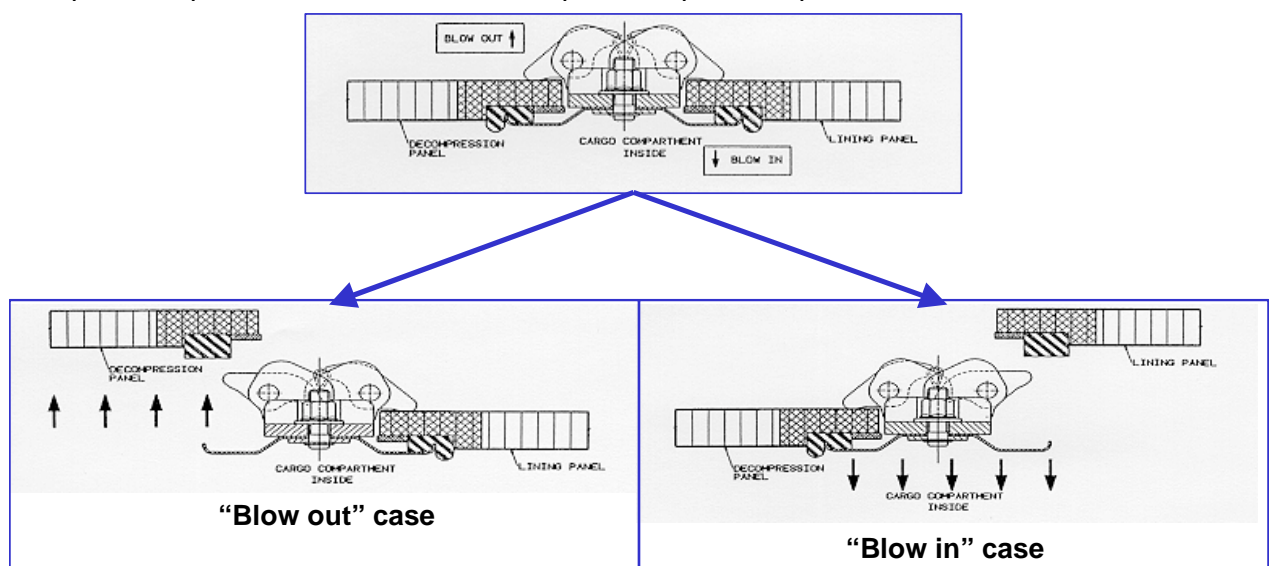
2.4.3. Drainage (All Airbus aircraft):

To prevent accumulation of water in the cargo compartments, numerous drain-outlets are provided in forward and aft cargo compartments and in the bulk compartment floor. Drain funnels are installed in the roller tracks, in sumps and in the floor in front of slushing dam.

The drain outlets consist of a mounting housing, acting as a coarse filter, which contains a sponge filter element. Hoses are connected to the drain outlets, leading to the bilge area, which is provided, with drain valves.
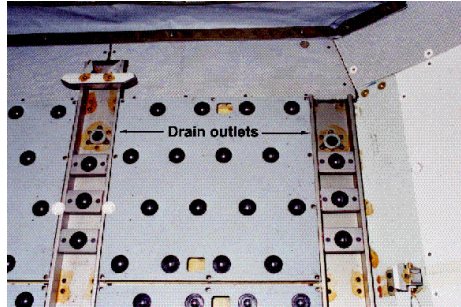
2.4.4. Cargo compartment lighting (All Airbus aircraft):

A separate lighting system is installed in each cargo compartment. All lights are manually controlled by means of switches. The control switch is installed adjacent to the cargo door for the respective compartment. Each cargo hold is provided with a minimum light level of 50 lux at the hold floor. For the lighting of the loading area, a spotlight is installed in each door ceiling area. The loading area light is sufficient to allow reading of labels on the ground loading equipment, placed near to the cargo door.
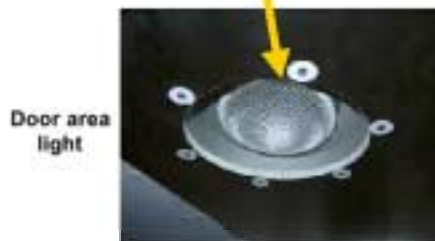
Door area light

Compartment light

SYSTEMS
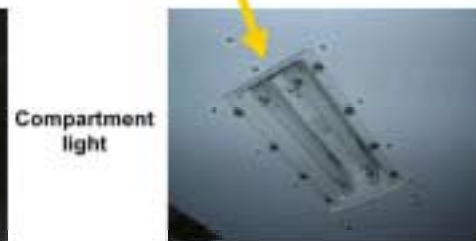
2.4.5. Heating and ventilation

a) in bulk cargo compartment (A310/A300/A330/A340):

Cabin ambient air is supplied to the bulk cargo compartment through a distribution duct along the left-hand side of the compartment. On request, an electrical heater can heat the air.
The air is extracted from the bulk compartment by an electrical fan through vents near ceiling on the right-hand side. The extracted air from the bulk cargo compartment is passed under the bulk compartment floor to provide floor heating.
In the bulk cargo compartment, isolation valves are fitted in the inlet and outlet ducts to isolate the cargo compartment in case of smoke warning.

Air Extraction Fan

BULK

Overboard

Inlet Isolation Valve

ELECTRICAL FAN HEATER

Cabin Ambient Air
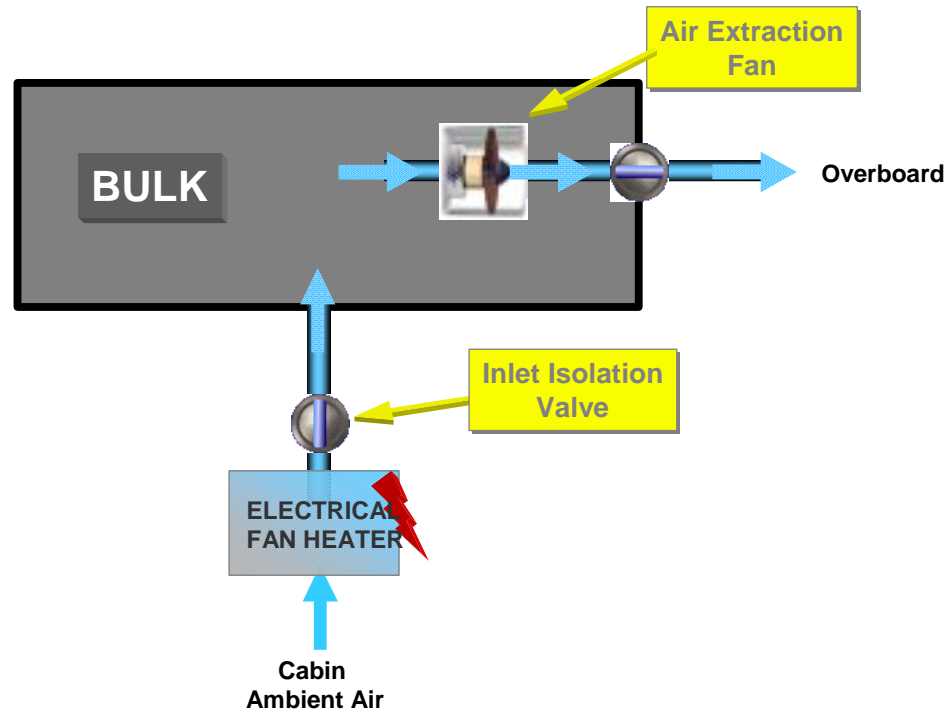
b) in FWD and/or AFT cargo compartment (all aircraft, optional):

Ventilation system is based on air suction provided by an extraction fan or by a venturi tube in flight when the pressure difference is sufficient. In the case of temperature regulation, the air enters pressurized and conditioned.

The air enters the compartment through one side wall and ceiling and is extracted on the other side. Temperature control is provided on top of the ventilation by adding cold or hot air respectively from the packs or hot air manifold. The hot air supply is controlled by a trim valve which regulates the temperature in the compartment. To decrease the compartment temperature, the cabin ambient air can be mixed with cold air from the packs via a cold air valve. This valve has three positions to adjust the quantity of cooled conditioned air.

In the event of smoke detection, the isolation valves, trim air valve, cold air valve are automatically closed and the extraction fan is switched OFF.

A cockpit temperature selector and a cockpit cooling mode selector control temperature. It is possible to select temperatures within the range of 5 DEG C and 25 DEG C (41 DEG F and 77 DEG F).
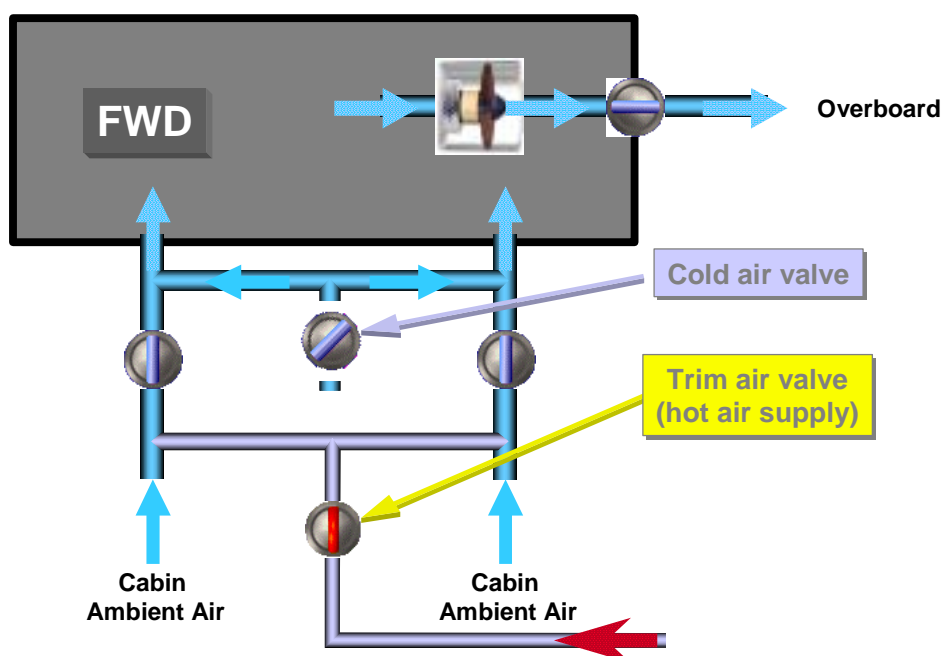
An additional option is available which ensures proper ventilation in the bulk and main cargo compartments during ground time when respective cargo doors are open.

In the bulk cargo compartment, the basic fan heaters can be controlled by an ON/OFF switch on the aft compartment servicing panel in order to activate the blowing function when the aircraft is on ground and the cargo compartment door is fully open. The heating function is deactivated in this operation.

In the main cargo compartment, this option uses the same ventilation as in flight nevertheless; the following aircraft conditions and activities are necessary:

- Packs running
- Forward cooling selector in cockpit overhead panel in "NORM" position.

SYSTEMS

2.4.6. Fire protection:

We consider two airworthiness requirements:
  – **Class "C" (FAR 25.857(c)):**
A class "C" cargo or baggage compartment is one in which:

1- **There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station**

2- **There is an approved built-in fire-extinguishing system controllable from the pilot or flight engineer station**

3- **There are means to exclude hazardous quantities of smoke, flames or other noxious gases from any compartment occupied by the crew or passengers**

4- **There are means to control ventilation and drafts within the compartment so that the extinguishing agent used can control any fire that may start within the compartment.**

5- *{Reserved}*

To sum up, it is a compartment, which has a smoke detection and an automatic fire extinguishing system and burn through resistant lining.

- **The fire protection system consists of two sub-systems:**

a) <u>A dual loop smoke detection system:</u>

Ionization-type smoke detectors are installed in cavities in the ceiling of each compartment. Each cavity contains two detectors. Detectors are controlled and operated by the Smoke Detection Control Unit (SDCU) as a dual loop system using and/or logic principle requiring that, in each compartment, signaling from two detectors is required to produce a smoke warning. With a detector failure, the system reverts to a single-loop operating condition.

Note: Smoke detectors: When combustion gazes enter the detector, they change the voltage of an ionization chamber, which the sampled air passes through. An electronic circuit inside the detector estimates this change, amplifies it and transmits the information to the flight deck)

Smoke detectors and Extinguishing nozzle

b) <u>A Fire extinguishing system:</u>

This system consists of two fire suppression bottles (just one bottle for the A320 family) which are installed behind the sidewall lining, one without flowmeter and the second with flowmeter. The discharged cartridges are electrically ignited by guarded switches located on the overhead panel. When the bottle content is discharged, a pressure switch activates lamps in the cockpit to confirm that the agent has been discharged. The extinguishing agent (Halon 1301) is discharged to either the forward or aft lower deck holds.(see picture above).
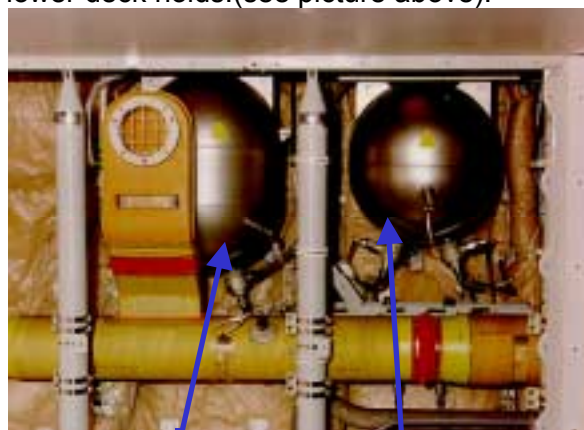
Discharge cartridges without flowmeter

Discharge cartridges with flowmeter

FUEL SYSTEMS INTRODUCTION

This part describes general aspects of the aircraft fuel systems such as fuel capacities, fuel control computers as well as the impact on CG position (CG movement during refueling and CG movement in flight).

All Airbus aircraft fuel systems described in this part have some common characteristics, the most obvious being the location of the fuel tanks. These tanks are located in the wings, in the fuselage (center tank and additional center tanks – ACT) and in a trim tank located in the THS (except for A320 family and some A300/A310 aircraft). Due to some structural issues common to all aircraft, the refueling and defueling sequences follow the same guidelines. Fuel computers on board the aircraft manage the fuel sequence.

B. FUEL SYSTEMS

1. GENERALITIES

The main part of the aircraft weight and most particularly the payload is located in the fuselage. In flight, this weight is balanced by the lift created mainly on the wings. This distribution generates a bending moment around the wing root. This has a strong impact on the aircraft structure and leads to define a Maximum Zero Fuel Weight (MZFW) in order to limit the stress at these locations.

Bending moments

$\dfrac{\text{Lift}}{2}$ $\dfrac{\text{Lift}}{2}$

Important structural strain
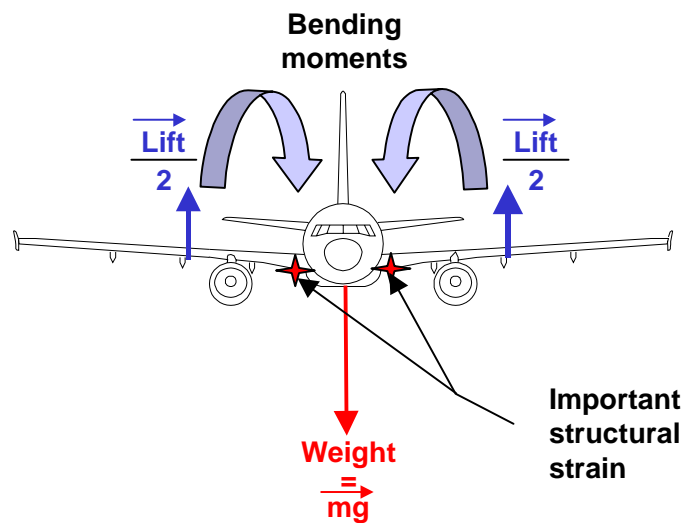
$$\text{Weight} = mg$$

On the one hand, the weight of the fuel tanked in the wings balances the effect of the lift and thus reduces the bending moment. On the other hand, the fuel in the fuselage is an extra load the wings have to create lift for. So, fuel has to be kept in the wing as long as possible.

Bending moments

$\dfrac{\text{Lift}}{2}$ $\dfrac{\text{Lift}}{2}$

$m_{fuel}g$ $m_{fuselage}g$ $m_{fuel}g$
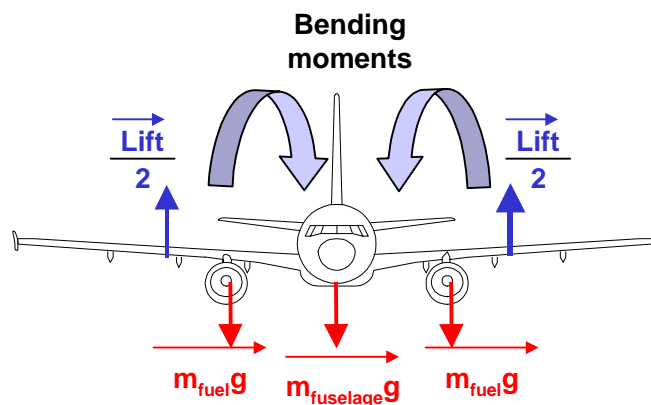
This is the reason why the wing tanks are the first tanks to be filled and the last ones to be emptied and this no matter the aircraft type.

Moreover, as the wing tanks are generally divided into outer and inner wing tanks (except on A321), the outer tank is filled first in order to bring the $m_{fuel}g$ vector further out. However, it is worth pointing out that this rule is only applicable to a certain extent : too much weight in the outer tanks creates some structural strain on the wings on ground (ie when not balanced by the lift).

On top of this general considerations, each aircraft family (ie. A318/A319/A320/A321, A330/A340 and A300-600/A310) has its own characteristics. That is why this part presents the following aspects for each aircraft family separately:

- **Fuel tanks:** location and capacities

- **Fuel systems:** engine feed system, control and indication

- **CG travel during refueling:** refueling sequence and resulting fuel vector

- **In-flight CG travel**: defueling sequence, in-flight fuel transfers

- **CG control system** (when applicable)

SYSTEMS

2. THE SINGLE-AISLE FAMILY (A318/A319/A320/A321)

2.1. Tanks and capacities

Compared with A318/A319/A320, A321 wings have been modified in order to support higher weights. As a consequence, contrary to all the other Airbus aircraft, there is no separation between outer and inner tanks on A321.
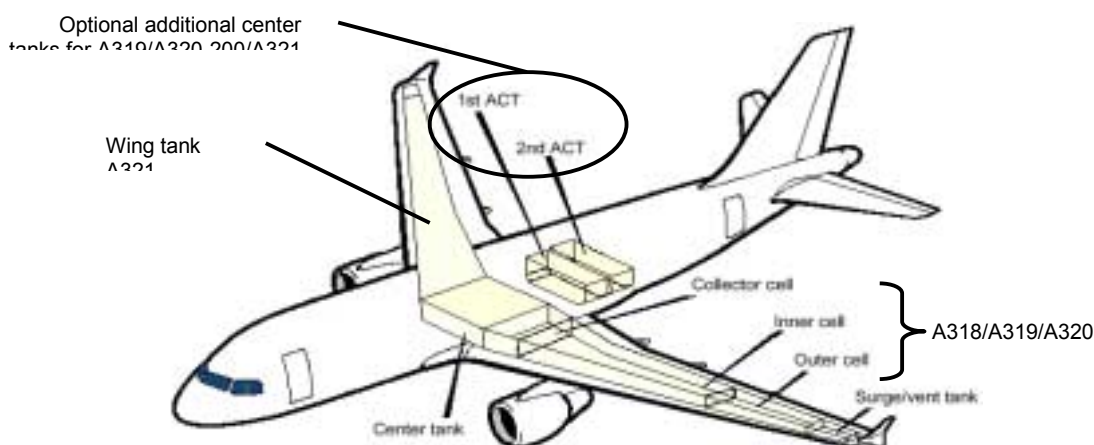
2.1.1. A318/A319/A320
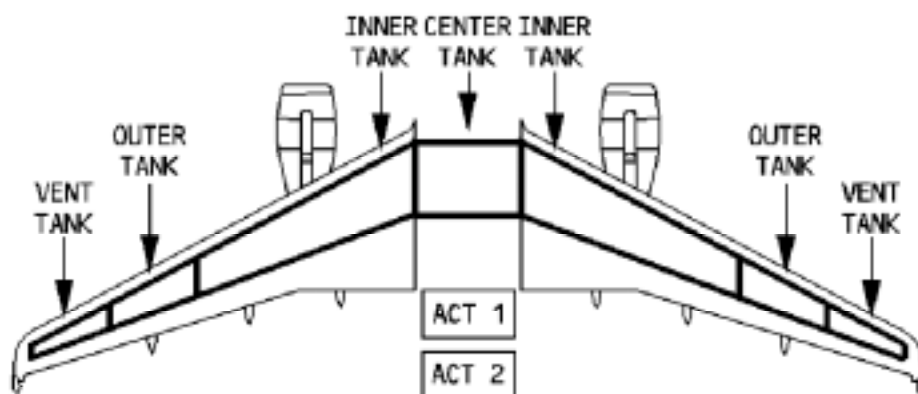
Note : One or two optional additional center tanks can be fitted (on the A319 and A320-200 only)

Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Outer Tanks (x 2)	Inner Tanks (x 2)	Center Tank	**Total without ACT**	ACT	**Total with 1 ACT**	**Total with 2 ACTs**
Volume	Liters	880	6925	8250	**23860**	2992	**26852**	**29844**
	US Gal	232	1830	2180	**6304**	790	**7094**	**7885**
Weight	Kg	691	5436	6476	**18730**	2349	**21079**	**23428**
	Lb	1523	11984	14277	**41292**	5179	**46471**	**51649**

Note: this does not apply to the A320-100, which has no center tank and slightly dissymmetrical inner tanks. Please refer to Weight and Balance Manual for relevant information.

2.1.2. A319 Corporate Jet

The A319 CJ can be fitted with up to six additional center tanks. Due to specific issues raised by this configuration, applicable information will be presented separately from other A319 aircraft.
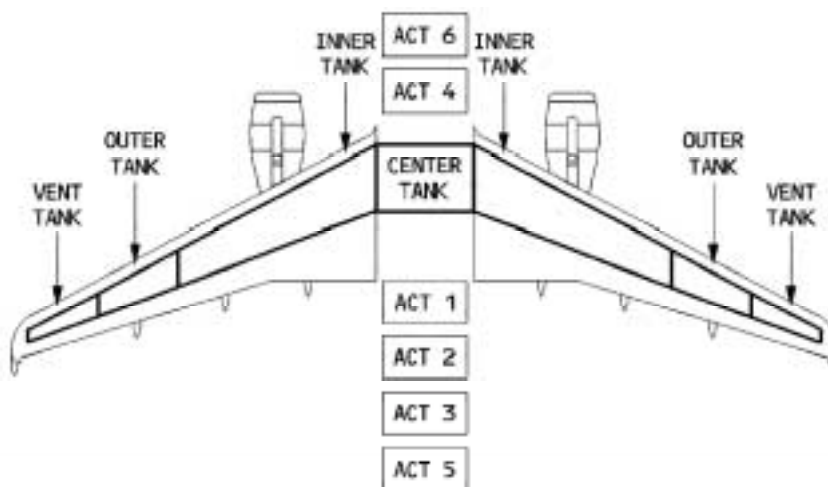
Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Outer Tanks	Inner Tanks	Center Tank	Total without ACT
Volume	Liters	880 (x2)	6925 (x2)	8250	**23860**
	US Gal	232 (x2)	1830 (x2)	2180	**6304**
Weight	Kg	691 (x2)	5436 (x2)	6476	**18730**
	Lb	1523 (x2)	11984 (x2)	14277	**41292**

		ACT 1	ACT 2	ACT 3	ACT 4	ACT 5	ACT 6	Total with 6 ACTs
Volume	Liters	3104	2180	2180	3036	3104	3104	**40568**
	US Gal	820	576	576	802	820	820	**10718**
Weight	Kg	2437	1711	1711	2383	2437	2437	**31846**
	Lb	5372	3773	3773	5254	5372	5372	**70207**

Note: Two fuel operating sequences are available on A319 CJ. ACTs are fueled in the following order :
- *Seq A: 1, 2, 3, 4, 5 and 6*
- *Seq B: 1, 2, 4, 6, 3 and 5*

and defueled in the reverse order.
Please refer to the Weight and Balance Manual for applicable information.

2.1.3. A321
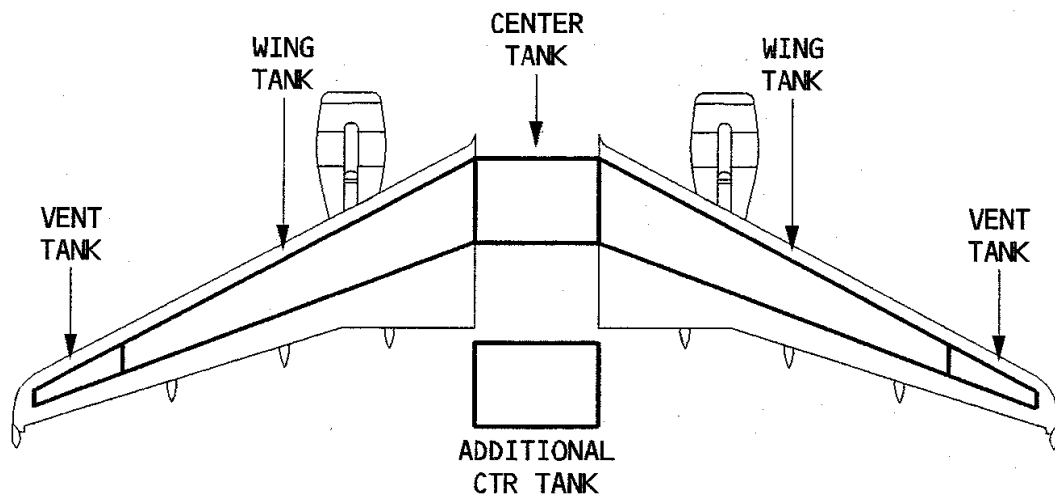
Note : One or two optional additional center tanks can be fitted (on A321-200 only)

Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Wing Tanks	Center Tank	Total without ACT	ACT	Total with 1 ACT	Total with 2 ACTs
Volume	Liters	7745	8210	**23700**	2992	**26692**	**29684**
	US Gal	2046	2169	**6261**	790	**7052**	**7842**
Weight	Kg	6080	6445	**18605**	2349	**20954**	**23302**
	Lb	13404	14208	**41015**	5178	**46193**	**51371**

2.2. Fuel System

The standard body family has the simplest fuel systems, as it is neither equipped with a CG control system nor a trim tank. Indeed, the benefits of a CG control system on the much shorter missions of the A320 family aircraft would be negligible compared with the cost related to the installation of a CG control system (maintenance costs and extra weight on board). So, the fuel system only deals with fuel quantities and tank transfer issues. As explained above, some differences can be observed depending on the aircraft type and on the modifications fitted on the aircraft (e.g. ACTs)

2.2.1. Engine feed and fuel transfer

On A318, A319 and A320 aircraft, there are six main pumps: two pumps in the center tank (except A320-100 which has no center tank) and two pumps in each inner tank. Each engine is fed with one pump in the center tank and with the two pumps in its own side inner tank. When inner tanks reach low level, valves between outer and inner open and an automatic gravity transfer occurs.

On A321, each engine is supplied from two pumps in its own side wing tank. Fuel transfers from center tank to wing tanks are managed through a transfer valve.

When aircraft are equipped with ACTs (Additional Center Tanks), fuel transfer is made by pressurization. ACTs are emptied one by one into the center tank.

2.2.2. Control and indication

The A320 family aircraft are fitted with a Fuel Quantity Indication (FQI) system and three Fuel Level Sensor Control Units (FLSCU).

The FQI provides the crew with information regarding fuel (total fuel mass, quantity and temperature in each tank) via the ECAM and based on data from:
- A set of capacitance probes in each tank measuring fuel level and temperature,
- One densitometer (cadensicon) sensor in each wing inner tank (in wing tank for A321) to measure density of fuel and,
- One CIC (capacitance Index Compensator giving the dielectric constant of the fuel) to give the density in case of cadensicon failure.
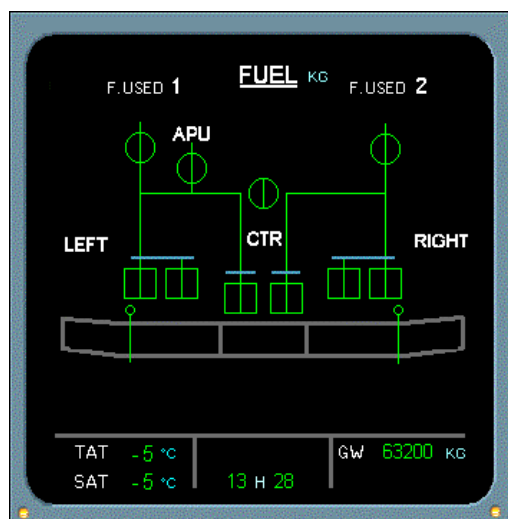
A318/319/320 ECAM fuel page
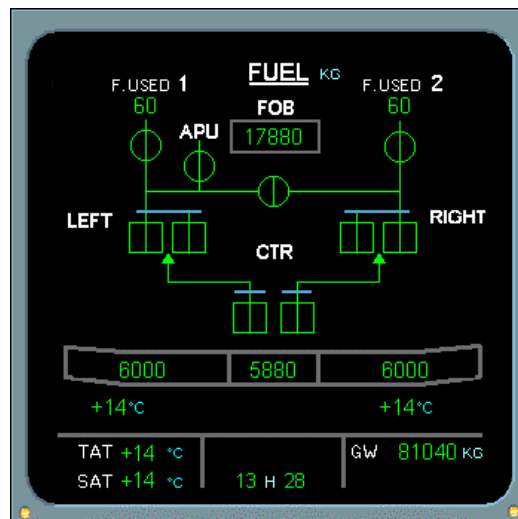
A321 ECAM fuel page

B. FUEL SYSTEMS

The FQI also controls the automatic refueling by determining the target levels in each tank.

The FLSCUs include probes and temperature sensors located in the tanks during refueling and transfer to detect low and high fuel levels in tanks. They generate signals that are used to operate the valves during refueling and transfers (from center tank to wing tanks as well as from ACTs to center tank).

On A319CJ, which can be fitted with up to 6 ACTs, specific units (AFMC - Auxiliary Fuel Management Computer and ALSCU - Auxiliary Level Sensor Control Unit) are dedicated to ACT fuel management.

The following diagram presents the fuel system architecture:

```
                        ┌──────────────────┐
                        │   WING TANK      │
                        │   PROBES &       │
                        │   SENSORS        │
                        └────────┬─────────┘
                                 ↓
                        ┌──────────────────┐
                        │   FLSCU (FUEL     │
                        │   LEVEL          │
                        │   SENSOR         │
                        │   CONTROL        │
                        │   UNIT)          │
                        └────────┬─────────┘
    ┌──────────┐                 ↓
    │ REFUEL   │←────────────────┤
    │ VALVES   │        ┌──────────────────┐   ┌─────────────┐
    └────┬─────┘        │                  │   │   ECAM      │
         ↑              │                  │──→│   UPPER     │──┐
    ┌──────────┐        │                  │   │   DISPLAY   │  │  ┌──────────┐
    │ REFUEL   │←───────│                  │   └─────────────┘  │  │          │
    │ CONTROL  │        │   FQI            │   ┌─────────────┐  ├─→│ FLIGHT   │
    │ PANEL    │───────→│   COMPUTER       │──→│ ECAM FUEL   │──┤  │ CREW     │
    └──────────┘        │                  │   │ DISPLAY     │  │  │          │
    ┌──────────┐        │                  │   └─────────────┘  │  └──────────┘
    │ ADIRS    │───────→│                  │   ┌─────────────┐  │
    └──────────┘        │                  │──→│   FMGS      │──┘
                        └────────┬─────────┘   └─────────────┘
                                 ↑
                        ┌──────────────────┐
                        │   WING TANK      │
                        │   PROBES &       │
                        │   SENSORS        │
                        └──────────────────┘
```
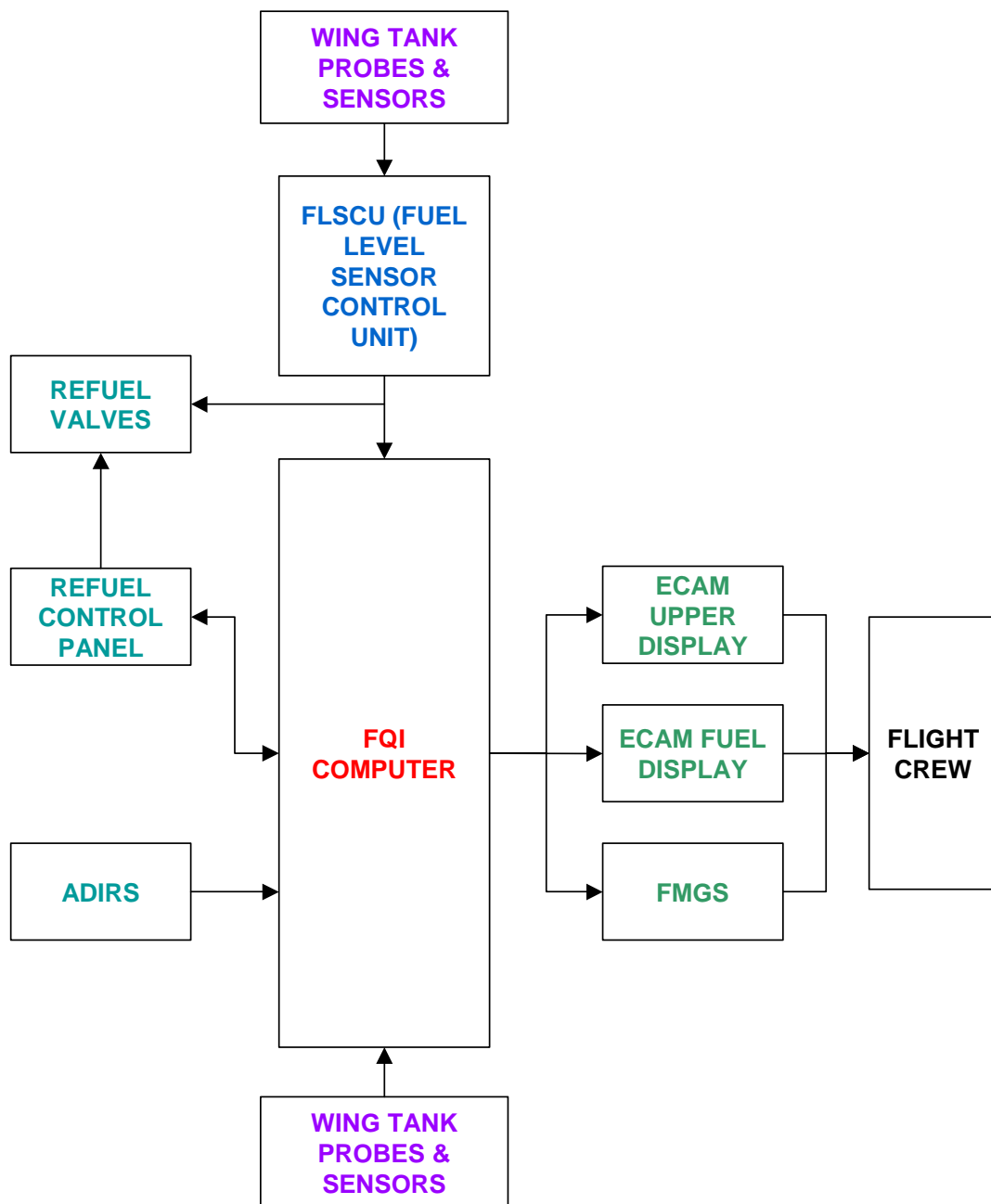
2.3. CG travel during refueling

2.3.1. A318/A319/A320

The refueling sequence and the resulting fuel vector are the same for A318, A319 and A320 aircraft:
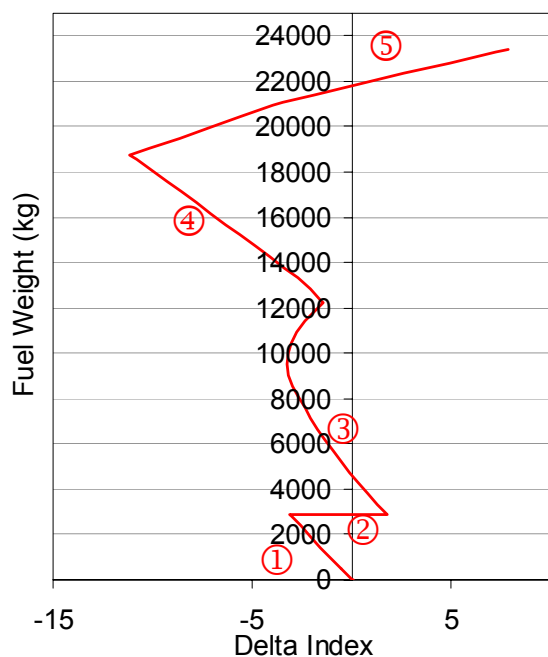
① Outer tanks (full). If an inner tank contains less than 750 kg of fuel, valves between the outer and inner tanks open and fuel spills from the outer to the inner tanks (②).

③ Inner tanks (full)

④ Center tank (full)

⑤ ACT1 then ACT 2 (if applicable)

The graphs below illustrate examples of the fuel vector impact on the certified CG envelopes:

A318

A319 (no ACT)
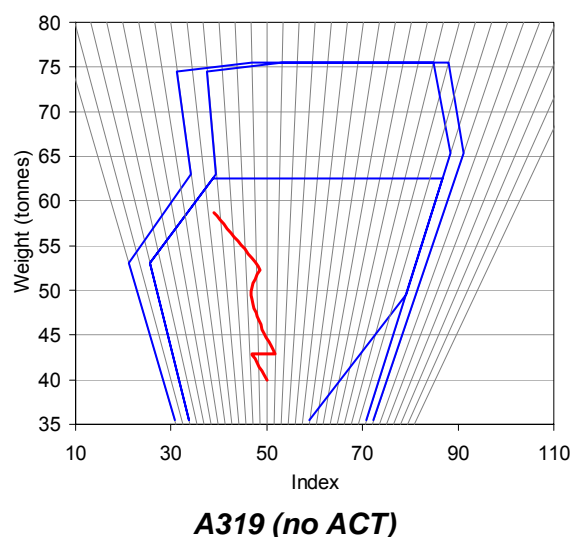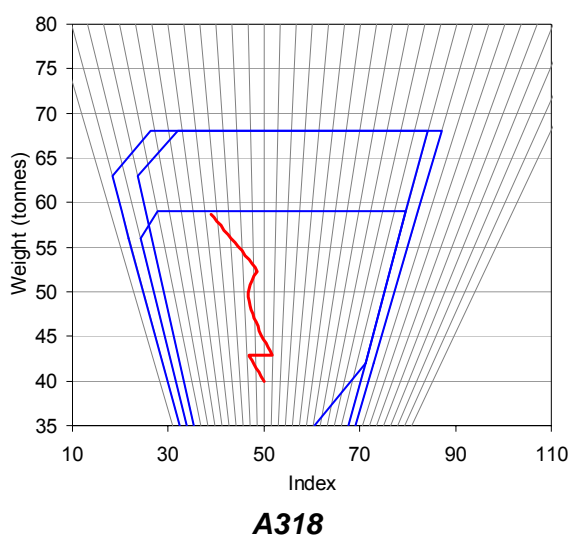
B. FUEL SYSTEMS
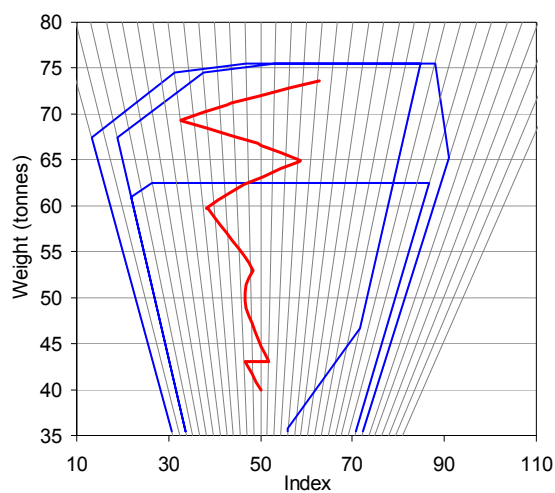
A319 CJ (with 6 ACTs – Seq B)
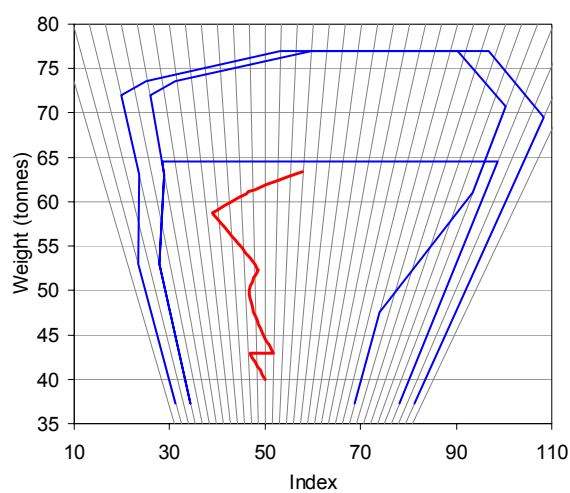
A320 (with 2 ACTs)

Note: On A319CJ, due to the range of the fuel vector, specific ZF envelopes have been certified in order to ensure that CG is kept inside the limits in case of failure of the fuel transfer function from the ACTs to the center tanks.

2.3.2. A321

The refueling sequence for the A321 and the resulting fuel vector are the following:

① Wing tanks (full)

② Center tank (full)

③ ACTs (if applicable)
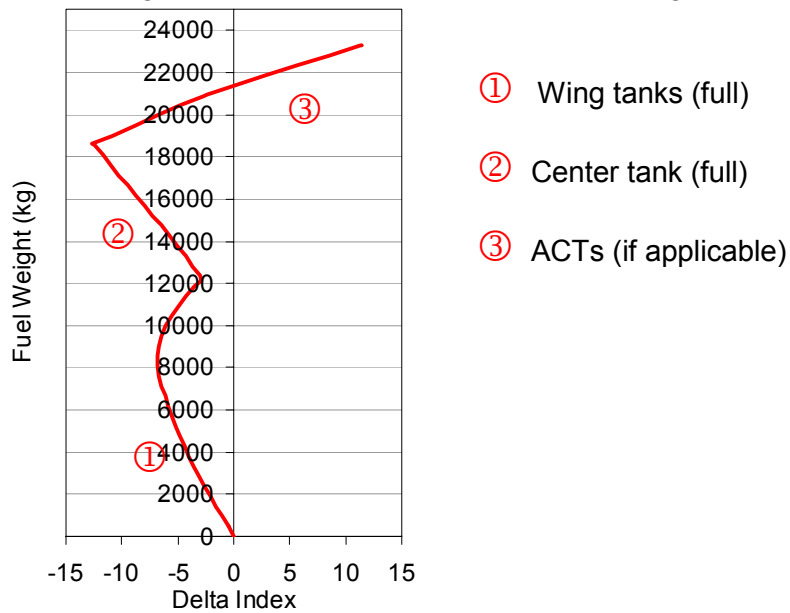
The following chart presents the impact of the refueling vector on the certified CG envelopes.
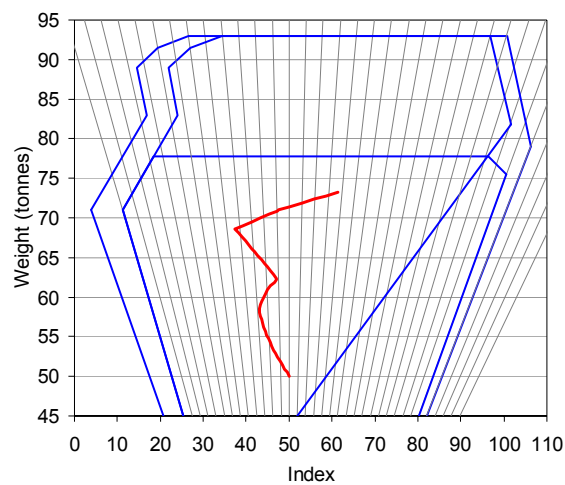
2.4. In-flight CG travel

2.4.1. A318/A319/A320

The fuel burn sequence for the A318, A319, A320 is as follows:

1/ ACTs (ACT2 then ACT1) – fuel transferred into the center tank (if applicable)
2/ center tank (until empty)
3/ inner tanks (until 750kg left in each tank)
4/ outer tanks – all the fuel transferred to the inner tanks from where it is fed to the engines
5/ inner tanks (until empty)

The only transfer that takes place is the transfer of fuel from the outer to the inner tanks when the fuel quantity in the inner tanks reaches a low level of 750kg. The valves between the outer tanks and the inner tanks open and are latched open until the next refueling. This does not necessarily occur simultaneously in both wings. This transfer brings the CG forward.

As a consequence, the fuel vector for defueling is the same as for the refueling.

2.4.2. A321

On A321, only the wing tanks are fitted with engine feed pumps. All the fuel located in the center and auxiliary tanks have to be pumped into the wing tanks in order to be burnt.
The fuel burn sequence is therefore the following:

1/ ACTs (ACT2 then ACT1) – fuel transferred to the center tank (if applicable)
2/ center tank – fuel transferred to the wing tanks
3/ wing tanks

So, the fuel vector is the same for refueling and defueling.

3. **The Long-Range Family (A330/A340)**

3.1. Tanks and capacities

3.1.1. A330-200/-300

As far as fuel is concerned, the main difference between the models is that the A330-200 is fitted with a center tank in order to cover longer-range missions than the A330-300
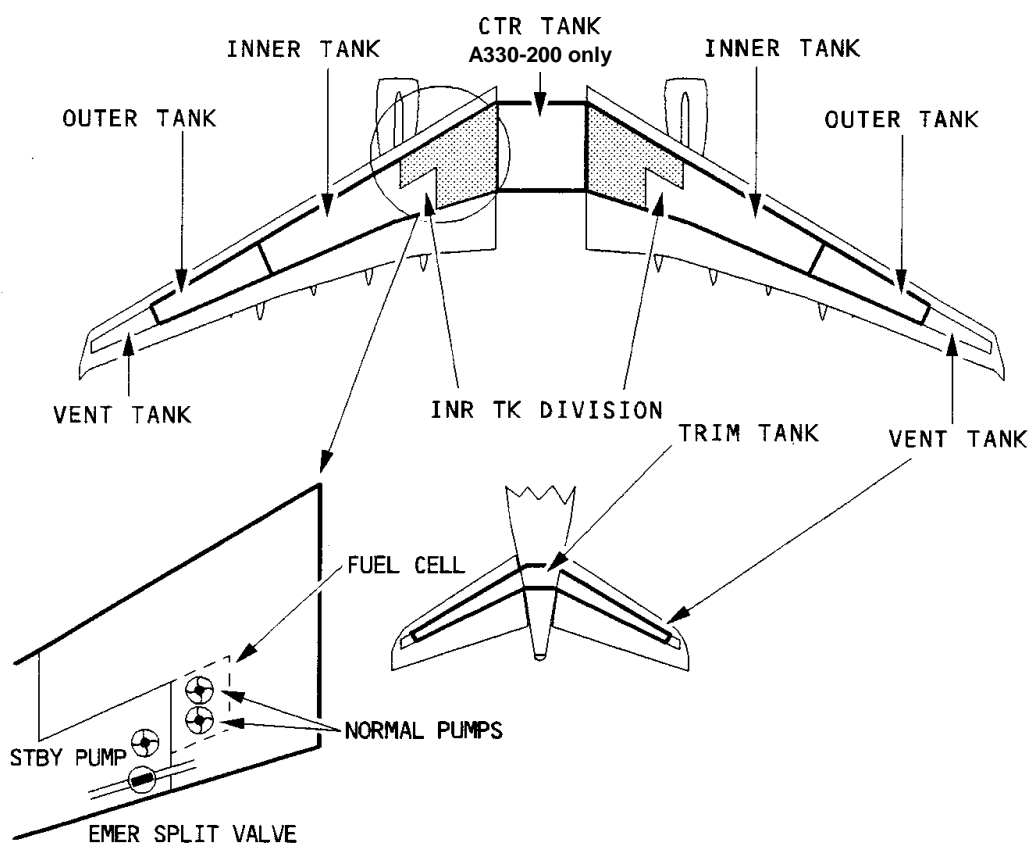
The following table gives the detail of fuel tanks capacity on the A330.

Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Outer Tanks (x2)	Inner Tanks (x2)	Trim Tank	Total A330-300	Center Tank	Total A330-200
Volume	Liters	3650	42000	6230	**97530**	41560	**139090**
	US Gal	964	11096	1646	**25767**	10980	**36748**
Weight	Kg	2865	32970	4890	**76560**	32625	**109185**
	Lb	6316	72686	10780	**168784**	71925	**240709**

Note: These values are applicable to for all A330-200 and for A330-300 from MSN 256 and above. For relevant information, please refer to the Weight and Balance Manual or to the Aircraft Flight Manual.

3.1.2. A340-200/-300
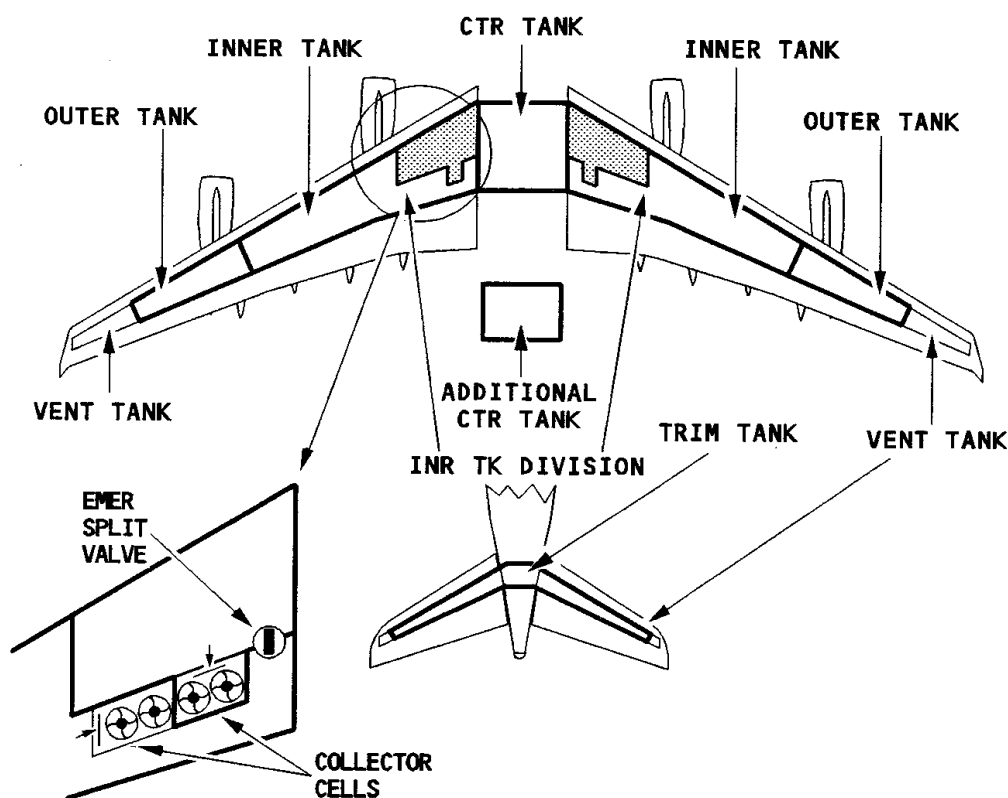
Note: One optional additional center tank can be fitted.

Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Outer Tanks (x2)	Inner Tanks (x2)	Trim Tank	Center Tank	Total
Volume	Liters	3650	42775	6230	42420	**141500**
	US Gal	964	11301	1646	11207	**37384**
Weight	Kg	2865	33578	4890	33300	**111076**
	Lb	6316	74026	10780	73413	**244878**

		ACT	**Total with ACT**
Volume	Liters	7200	**148700**
	US Gal	1902	**39287**
Weight	Kg	5652	**116728**
	Lb	12460	**257339**

Note: These values apply for all aircraft from MSN 179 and above and to some previous MSNs. For relevant information, please refer to the Weight and Balance Manual or to the Aircraft Flight Manual.

3.1.3. A340-500/-600

Compared with A340-200/-300, A340-500/-600 inner tanks have been split into two inner tanks per wing, mainly for engine burst considerations. Moreover, an extra tank (rear center tank) has been installed on A340-500
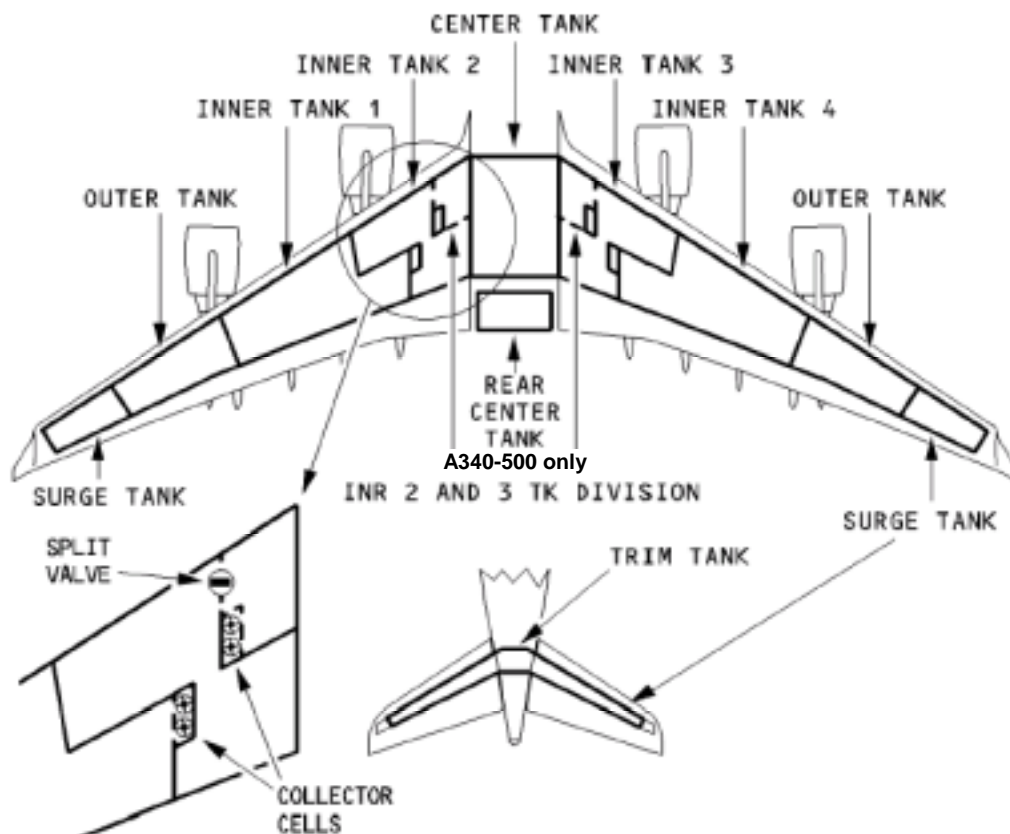
Fuel Capacity (Usable fuel) – density: 0.785kg/L

		Outer Tanks (x2)	Inner Tanks 1 & 4 (each)	Inner Tanks 2 & 3 (each)	Center Tank	Trim Tank	**Total A340-600**	Rear Center Tank	**Total A340-500**
Volume	Liters	6310	24716	34805	55133	7986	**194781**	19873	**214654**
	US Gal	1667	6530	9195	14566	2110	**51461**	5250	**56712**
Weight	Kg	4953	19402	27322	43279	6269	**152903**	15600	**168503**
	Lb	10920	42774	60234	95413	13821	**337088**	34392	**371480**

Note: Some aircraft modifications may affect the tanks capacity on A340-500/-600. Particularly, two RCT sizes are available on A340-500 (5 or 7 frame). The information presented in this brochure is applicable to 5-frame RCT. Please refer to Weight and Balance Manual or to the Aircraft Flight Manual for relevant information.

3.2. Fuel systems

All the aircraft of the long-range family basically follow the same guidelines in terms of fuel system. The main differences between the models mainly result from the number of engines and from the tanks that actually equip the aircraft.

In order to take advantage of the large amount of fuel on board and of the possible influence that this fuel position may have on the aircraft CG position, A330/A340 aircraft are fitted with a CG control system involving trim tank transfers that enables to keep the CG as aft as possible during the flight to optimize the fuel consumption.

3.2.1. Engine feed

A dedicated collector cell located in the inner wing tanks feeds each engine:
- On A330, there is one collector cell per inner tank. Each cell includes two main fuel pumps. One standby pump is installed in the inner tank outside the collector cell.
- On A340-200/-300, two collectors cells are located in each inner tank. On A340-500/-600, there is one collector cell in each of the four inner tanks. For all A340s, each collector cell consists in one main fuel pump and one standby fuel pump.

Each collector cell contains about 1000 kg and is maintained full in order to protect the engine feed. A cross feed valve is associated with each engine. When the cross feed valves are open, any pump is able to supply any engine.

3.2.2. Fuel transfers

This paragraph aims at briefly describing how the various fuel transfers are performed during the flight.

The collector cells located in the inner tanks ensure the engine feed. That implies that the fuel from the other tanks has to be transferred in the inner tanks:
- Two pumps enable the transfer from center tank (when applicable). They run continuously as long as there is fuel in the center tank.
- Fuel transfer from outer tanks is done by gravity and controlled by transfer valves.

For ACT (when fitted) and for RCT on A340-500, the fuel is transferred to the center tank by pressurization.

The CG control system generates trim tank transfers during the flight:
- Forward transfers:
  Some aircraft are equipped with one trim tank forward transfer pump for the fuel transfers from trim tank to the inner tanks or to the center tank. In case of the pump failure or if the aircraft is not fitted with it, these transfers are done by gravity.
  A340-500/-600 aircraft are basically fitted with two forward transfer pumps.
- Aft transfers:
  Fuel is provided from the center tank through the two center tank pumps mentioned above
  The fuel from inner tank is transferred using the two engine feed pumps
  On A340-500/-600 aircraft, transfers to trim tank are performed via six dedicated aft transfer pumps (two in the center tank and one per inner tank).

3.2.3. Control and indication

On long range family aircraft, the fuel system (FCMS : Fuel Control and Monitoring System) is controlled by two Fuel Control and Monitoring Computers (FCMCs). Their main functions are:

- Fuel transfer control
- Aircraft gross weight and CG position calculation
- Center of gravity control
- Refuel control
- Fuel quantity measurement and indication on ECAM and on refuel control panel.

A340-200/-300 ECAM fuel page

A340-500 ECAM fuel page

In normal operation, one FCMC is active while the other is in stand-by.
Fuel quantity calculation performed by FCMC is based on the following information:

- Fuel volume from tank probes
- Fuel density from densitometers
- Horizontal stabilizer angle
- Aircraft attitude
- Fuel electrical characteristics from compensators

On A340-500/-600, the tank data (volume, density, electrical characteristics and temperature) is provided to the FCMCs via two Fuel Data Concentrators (FDC).

Fuel level sensors also provide the FCMC with information used to control transfers and to trigger warnings independently of the fuel quantity indication.

B. FUEL SYSTEMS

AIRBUS

The following diagram presents the fuel system architecture:
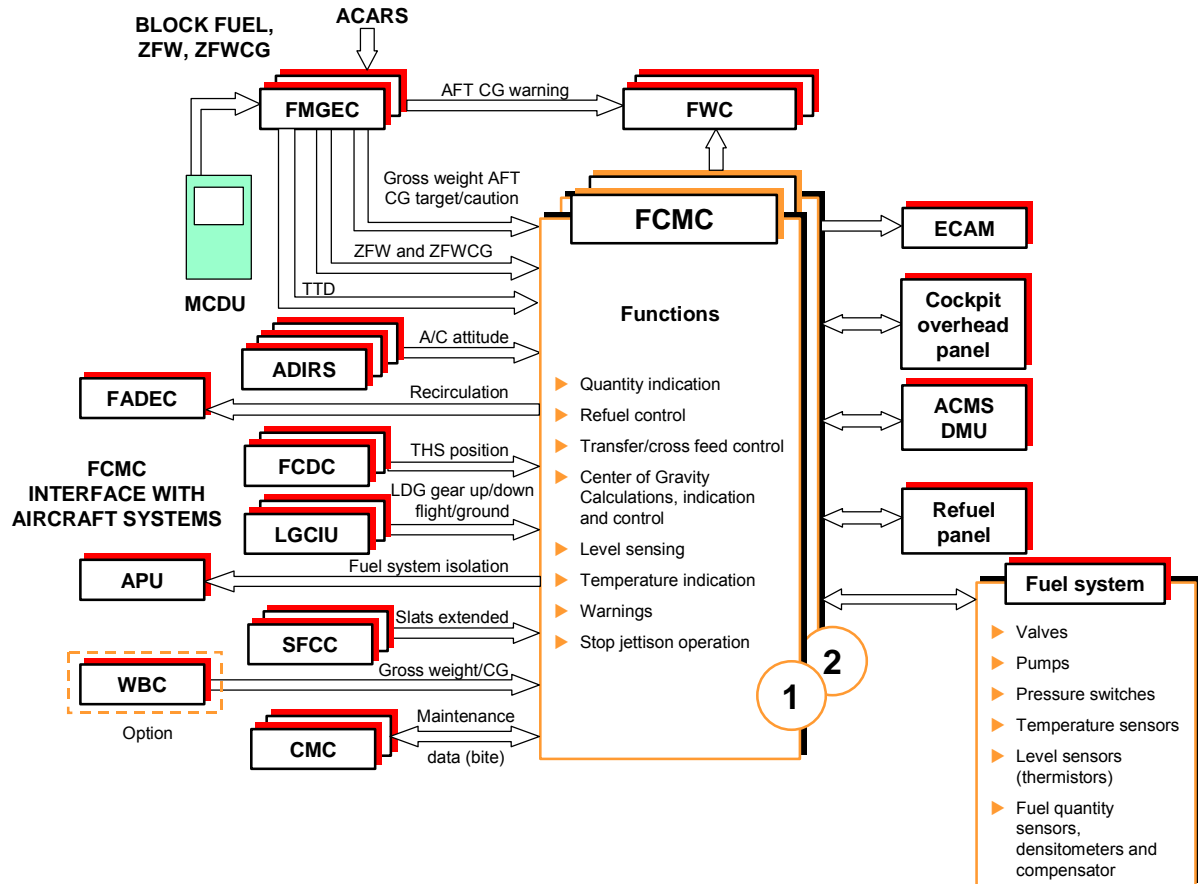
3.3. CG travel during refueling

During automatic refueling, once a fuel quantity has been selected, all the tanks are filled simultaneously according to a given fuel distribution. The following graph is published in FCOM 2.01.30 and enables to determine the fuel distribution in each tank at the end of refueling as a function of the total fuel quantity:
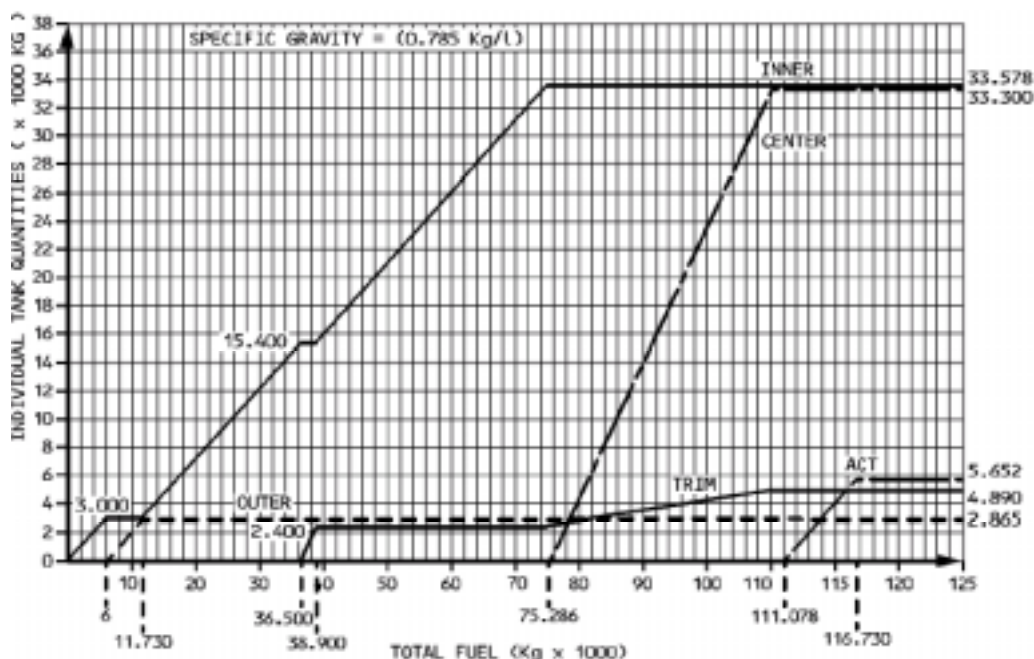

Refueling distribution A340-300 FCMS 7.0

FCMS modifications have been introduced in order to optimize the fuel sequences by reducing the fuel vector range. The following information is based on FCMS 9.0 (10.0), which is the production standard at the date of the publication, and on the fuel tank capacities mentioned above. Please refer to the Weight and Balance Manual for applicable information.

3.3.1. A330-200-300 and A340-200/-300

The refueling sequence for A330 and A340-200/-300 is as follows:
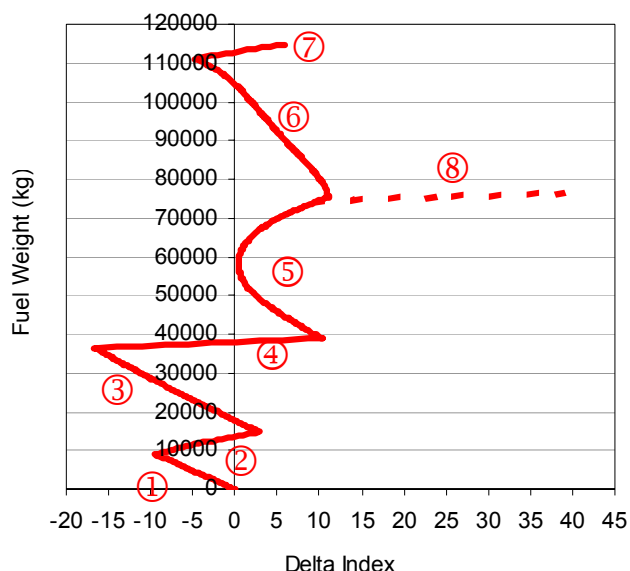
① inner tanks up to 4500 kg per side (to fill in the collector cells)

② outer tanks (full)

③ inner tanks up to total fuel equals 36500 kg

④ trim tank up to 2400 kg

⑤ inner tank (full)

⑥ A330-200, A340: simultaneously trim tank (full) and center tank (full)

⑦ A340: ACT (if applicable)

⑧ A330-300: trim tank (full)

B. FUEL SYSTEMS

The graphs below illustrates the fuel vector impact on the certified CG envelopes:
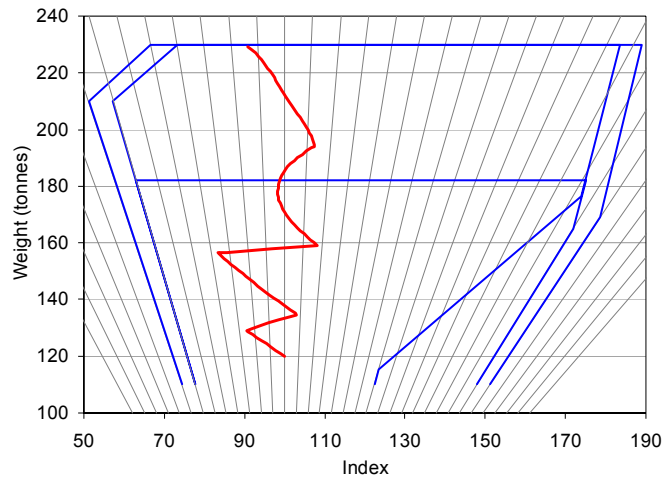
A330-200
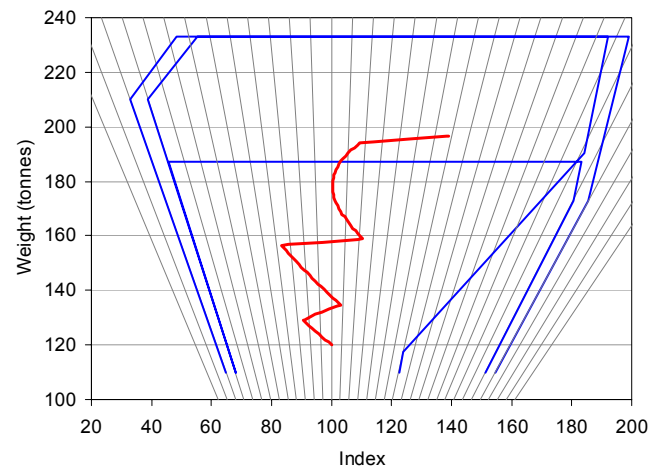
A330-300
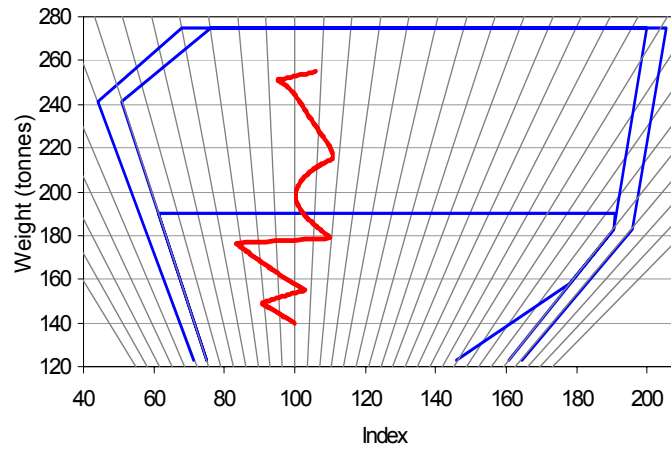
A340-200/-300 (1 ACT)

3.3.2. A340-500/-600

A340-500 and A340-600 have similar refueling sequences:

① Inner tanks 1,2,3 and 4 up to up to 3000 kg per tank, Total fuel = 12000 kg (to fill in the collector cells)

② Outer tanks up to up to 4500 kg per tank, Total fuel = 21000 kg

③ Inner tanks 1, 2, 3 and 4 up to up to 18200 kg per tank, Total fuel = 81800 kg

④ Inner tanks 2 and 3 up to 25700 kg per tank, center tank up to 17000 kg and trim tank up to 2400 kg, Total fuel = 116200 kg

⑤ Center tank up to 40000 kg and trim tank up to 5900 kg, Total fuel = 142700 kg

⑥ A340-500: rear center tank up to 14956 kg, Total fuel = 157656 kg

⑦ Inner tanks 1, 2, 3 and 4 (full), outer tanks (full), center tank (full), trim tank (full) and for A340-500: rear center tank (full)

This sequence leads to the following refueling vectors:
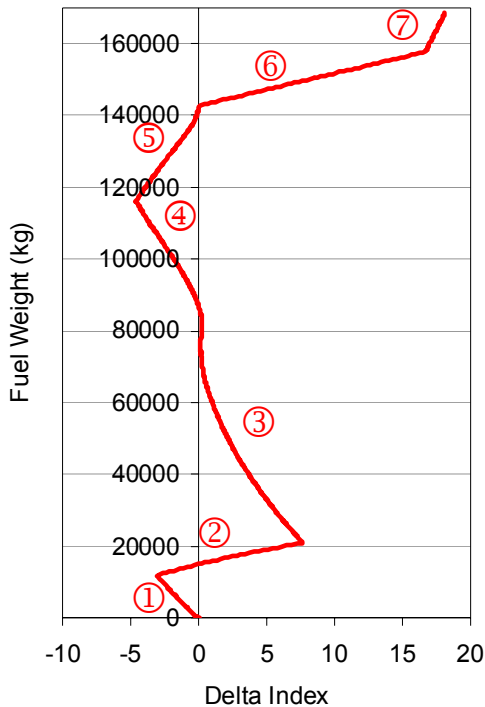
A340-500
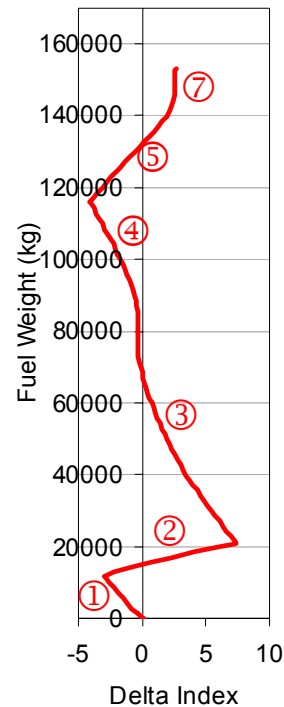
A340-600

The following graphs give an example of the fuel vector impact on the certified CG envelope.
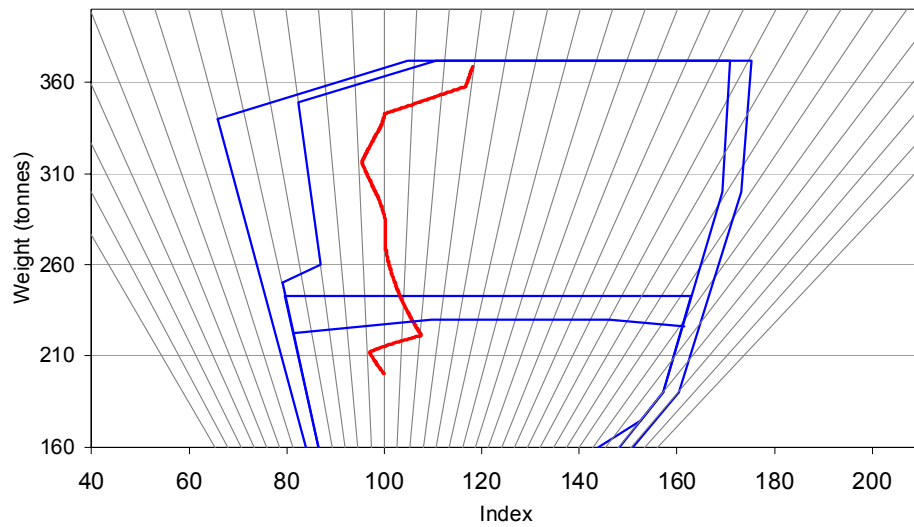
A340-500
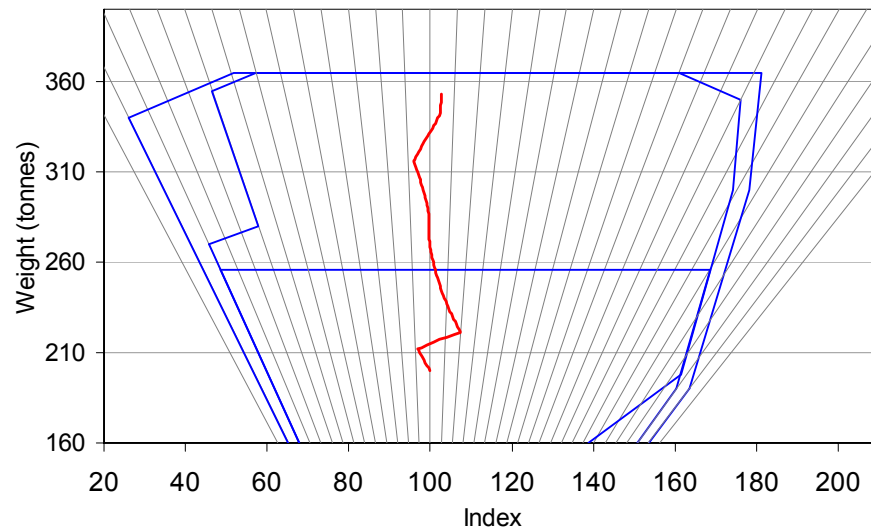
A340-600

3.4. In-flight CG travel

3.4.1. Fuel burn CG travel

This paragraph deals with in-flight CG travel due to depletion with no consideration of CG control, which is detailed in the next paragraph.

As described previously, engines are only fed from the inner tanks and so, all the fuel from the other tanks have to be transferred to the inner in order to be burnt.

Besides, the fuel burn sequence for long-range family aircraft and the associated fuel transfers are in accordance with the basic structural constraints (wing root stress).

As for refueling data, the following depletion sequence is applicable to FCMS 9.0 standard :

a) A330-200/-300 and A340-200/-300

- 1/ ACT (if applicable) fuel transferred to the center tank
- 2/ Center tank (if applicable) fuel transferred to the inner tanks
- 3/ Inner tanks down to a given level (ie 4000 or 5000 kg in each inner tank depending on the aircraft)
- 4/ Trim tank fuel transferred to the inner tanks
- 5/ Inner tanks is emptied down to a second given level (ie 3500 or 4000 kg in each inner tank)
- 6/ Outer tanks fuel transferred in the inner tanks
- 7/ Inner tanks (until empty)

b) A340-500/A340-600

- 1/ Center tank fuel transferred to all inner tanks until center tank fuel quantity reaches 17000 kg
- 2/ Center tank fuel transferred to inner tanks 1 and 4, to maintain full quantity, until all inner tanks are balanced (approximately 18000 kg per inner tank)
- 3/ Rear center tank (if applicable) fuel transferred to the center tank when the center tank quantity reaches 1000 kg
- 4/ Center tank fuel transferred to all inner tanks, cycling the inner tanks quantities between 17200 and 18200 kg, until the center tank is empty
- 5/ Inner tanks down to 4000 kg per inner
- 6/ Trim tank fuel transferred to the inner tanks
- 7/ Inner tanks is emptied down to 2000 kg per inner
- 8/ Outer tanks fuel transferred in the inner tanks
- 9/ Inner tanks (until empty)

All the transfers mentioned here are managed automatically by the fuel system.

The fuel burn sequence is a reference vector, which is not strictly followed in flight as the CG position is modified by the CG control system.

SYSTEMS

3.4.2. CG control system

The position of the aircraft CG during the flight has an impact on the fuel consumption. Indeed, an aft CG position reduces the drag and then implies fuel savings. That is the reason why a CG control system has been introduced on long-range family aircraft.

a) CG target

In flight, the FCMC controls the position of the center of gravity. It calculates the CG position and compares it to a target value, which depends on the aircraft weight. According to this calculated CG position compared to the target, the FCMC determines the fuel quantity that needs to be transferred aft or forward.

The graph below is published in FCOM 1.28.10 and provides with the target CG expressed in %MAC as a function of the aircraft weight:

AFT CG Target - A340-300

The FCMC determines the fuel quantities to be transferred to maintain the aircraft CG in a control band limited by the CG target position and CG target position – 0.5%.

Considering a typical CG envelope layout, the control band can be presented as follows:

Getting to Grips with Aircraft Weight and Balance
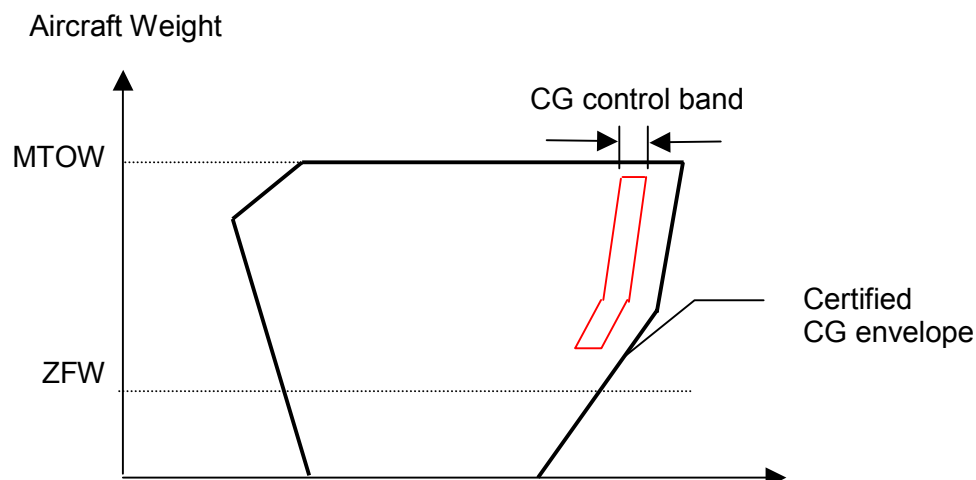
b) CG control

The following profile describes the CG control system behavior throughout the flight:
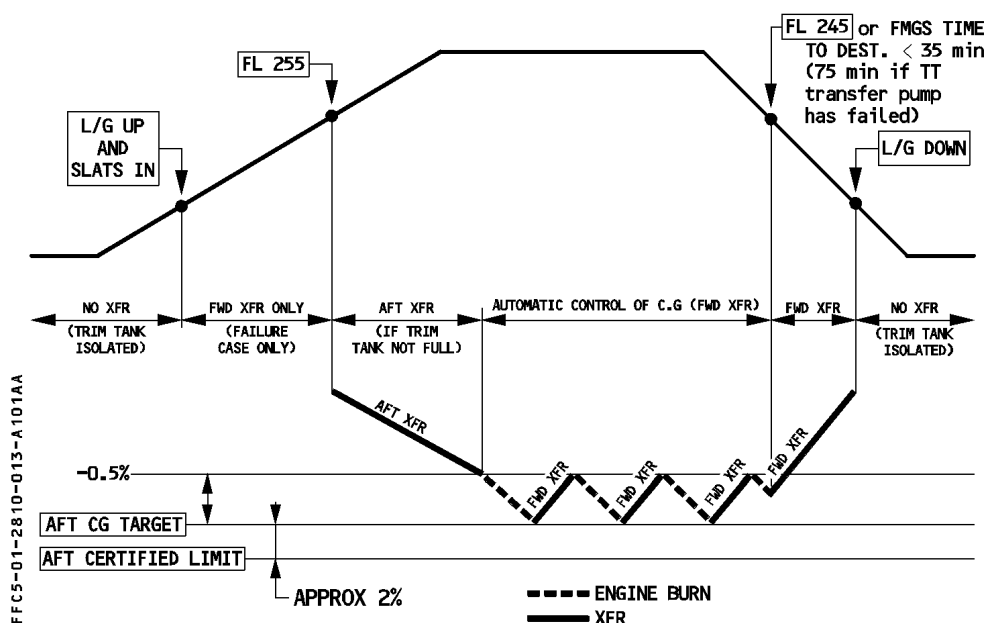
The CG control function is active once the aircraft has reached FL 255. It is deactivated when the aircraft flies below FL 245 or when time-to-destination from the FMGS is less than a given value, which depends on the aircraft type and on whether a trim tank pump is fitted and operative.

CG control starts with an aft transfer to the trim tank when all the following conditions are met:
- The landing gear is up and the slats are retracted
- The trim tank is not full
- The aircraft CG is not on the target
- Each inner tank quantity is above 6250kg (6000 kg for A340-500/-600)
- The Flight Level is above FL 255

Normally only one aft transfer is generated during the flight. However, it can happen that an additional aft transfer occurs when both the CG position is 2% forward the target value and the trim tank reaches a low level.

An aft transfer ends if one of these conditions is fulfilled:
- The computed CG reaches Target CG - 0.5%
- The trim tank is full
- The inner tank quantity reaches 6250kg (4000 kg for A340-500/-600)
- The crew requests a manual fuel transfer (forward trim transfer or transfer from the center or outer tanks to the inner tanks).
- Jettison is selected

Then, during the normal fuel burn, center tank and inner tanks depletion brings the CG further aft. Automatic forward transfers from the trim tank (and also from the RCT on A340-500) keep the CG position within the CG control band. These transfers occur in each of the following circumstances:

- The Calculated CG position reaches the target CG. The transfer stops when the calculated CG reaches CG Target -0.5%
- The fuel quantity in one of the inner tanks decreases down to 4000 kg (or 5000 kg depending on the aircraft). The transfer stops when the level reaches 5000 kg (or respectively 6000 kg).
- The FMGS sends a time-to-destination signal or the aircraft is in descent below FL245. In this case, the fuel transfer is continuous and stops only if the inner tanks are overflowing.

These transfers take into account potential tank imbalance that can be encountered during the flight. In case the inners are unbalanced by more than 500 kg, either forward transfer is directed to the lightest tank or aft transfer is stopped on the lightest tank.

c) CG target possible shifts during flight

During the flight all the fuel transfers are based on the CG position determined by the FCMC, these positions are linked to the ZFW and ZFCG values input by the pilot before flight in the MCDU.
An independent CG determination is made by the FMGC. If the CG position computed by the FMGC is too far aft, the target CG position in the FCMC is automatically shifted forward (by 1.5% or 2%). If the resulting corrections are not enough to avoid the CG position to excess the FE limit, an aft CG warning is triggered that requires a manual forward transfer.

In order to protect the aft CG limitation, the target also moves forward by 1.5% in case of FQI data degradation or if ZFCG/ZFW have not been entered or need to be reinitialized.

d) Example of CG control operation

Automatic fuel transfers that actually happen during the flight depend on the initial amount of fuel in the tanks and on the aircraft Zero Fuel CG position.

The following table presents the different cases that can be encountered according to the initial conditions (CG position and fuel quantity):

(Metric tonnes)	─── Refuel vector ─── Depletion vector ☐ CG control band	
	Control band reached	**Control band not reached**
A340-300 max full ~ 116.7 t		
A340-300 wings full ~ 75.3 t		
A340 wings half full ~ 60 t		

4. THE WIDE-BODY FAMILY (A300-600/A310)

4.1. Tanks and capacities
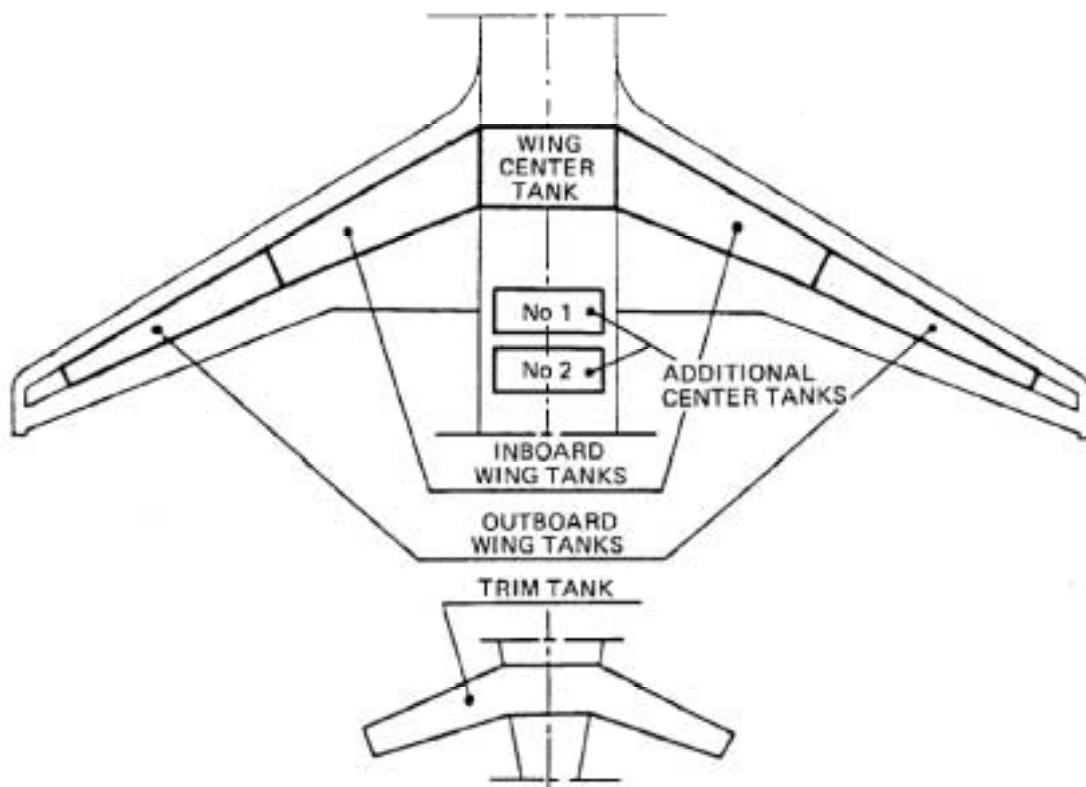
Note : One or 2 ACTs can be installed on A300-600 and A310-300. Please refer to the Weight and Balance Manual for applicable information.

Fuel Capacity (Usable fuel) – density: 0.782kg/L

A300-600 A300-600R		Outer Tanks (x2)	Inner Tanks (x2)	Center Tank	Total A300-600	Trim Tank	Total A300-600R	ACT	Total A300-600 1 ACT	Total A300-600 2 ACTs
Volume	Liters	4630	17570	17600	**62000**	6150	**68150**	7000	**69000**	**76000**
	US Gal	1223	4642	4650	**16380**	1625	**18005**	1849	**18230**	**20079**
Weight	Kg	3621	13740	13763	**48483**	4809	**53292**	5474	**53957**	**59431**
	Lb	7982	30290	30342	**106886**	10602	**117488**	12068	**118954**	**131022**

Fuel Capacity (Usable fuel) – density: 0.785kg/L

A310-200 A310-300		Outer Tanks (x2)	Inner Tanks (x2)	Center Tank	Total A310-200	Trim Tank	Total A310-300	ACT	Total A310-300 1 ACT	Total A310-300 2 ACTs
Volume	Liters	3700	13950	19640	**54940**	6150	**61090**	7200	**68290**	**75490**
	US Gal	978	3686	5189	**14515**	1625	**16140**	1902	**18042**	**19944**
Weight	Kg	2905	10951	15417	**43128**	4828	**47956**	5652	**53602**	**59260**
	Lb	6403	24143	33988	**95080**	10644	**105724**	12460	**118184**	**130644**

4.2. Fuel Systems

4.2.1. Engine feed and fuel transfers

Each of the five main fuel tanks (inner, outer and center tank) is equipped with two fuel pumps. Engines are fed:

- From the center tank when the aircraft is on ground and in flight when slats are retracted. The pumps supply both engines simultaneously.
- From inner tanks at takeoff, with slats extended and when the center tank is empty.
- From the outer tanks when the inner and center tanks are empty. The pumps in the outer tanks are kept on throughout the flight.

When the aircraft is equipped with ACT(s), the fuel is transferred in the center tank by pressurization. ACT fuel transfer pump is used on ground and in case of the pressurization system failure. This transfer is inhibited during trim forward transfer to the center tank.

The tail trim tank (when applicable) is fitted with two transfer pumps for aft transfers generated by the CG control system.

4.2.2. Control and indication

The FQI (Fuel Quantity Indicating) computer provides the crew with fuel quantity information by processing data from:

- A fuel specific gravity sensor (Cadensicon)
- An attitude sensor which provides with aircraft pitch attitude and bank angle
- A compensator probe in each tank for the fuel dielectric characteristics

The resulting fuel quantity is displayed on the ECAM fuel page, on the fuel quantity indicator on the overhead panel and on the external fuel panel.
The FQI uses this information to monitor the refueling by closing the refuel valves when the preset quantities are reached.

The Fuel Autofeed System controls the inner tanks and center tank pumps according to the normal fuel feed sequence. The Autofeed system is activated when at least one pump pushbutton is switched in NORMAL position for each inner tank and for the center tank. The outer tank pumps are not managed by the Autofeed system. They run continuously during the flight.

Contrary to the long-range family, the center of gravity control system is independent of the fuel feed and the refueling system. The CGCC (Center of Gravity Control Computer) controls the transfers from and to the trim tank.

4.3. CG Travel during refueling

Tanks are refueled in the following order:

**Refueling vector
A300-600R**

**Refueling vector
A310-300 with 2ACTs**

① Outer tanks

② Inner tanks

③ Center tank

④ A300-600 and
A310-300:
ACT 1 (if applicable)

⑤ A300-600R and
A310-300 :
Trim tank

⑥ A300-600 and
A310-300:
ACT 2 (if applicable)
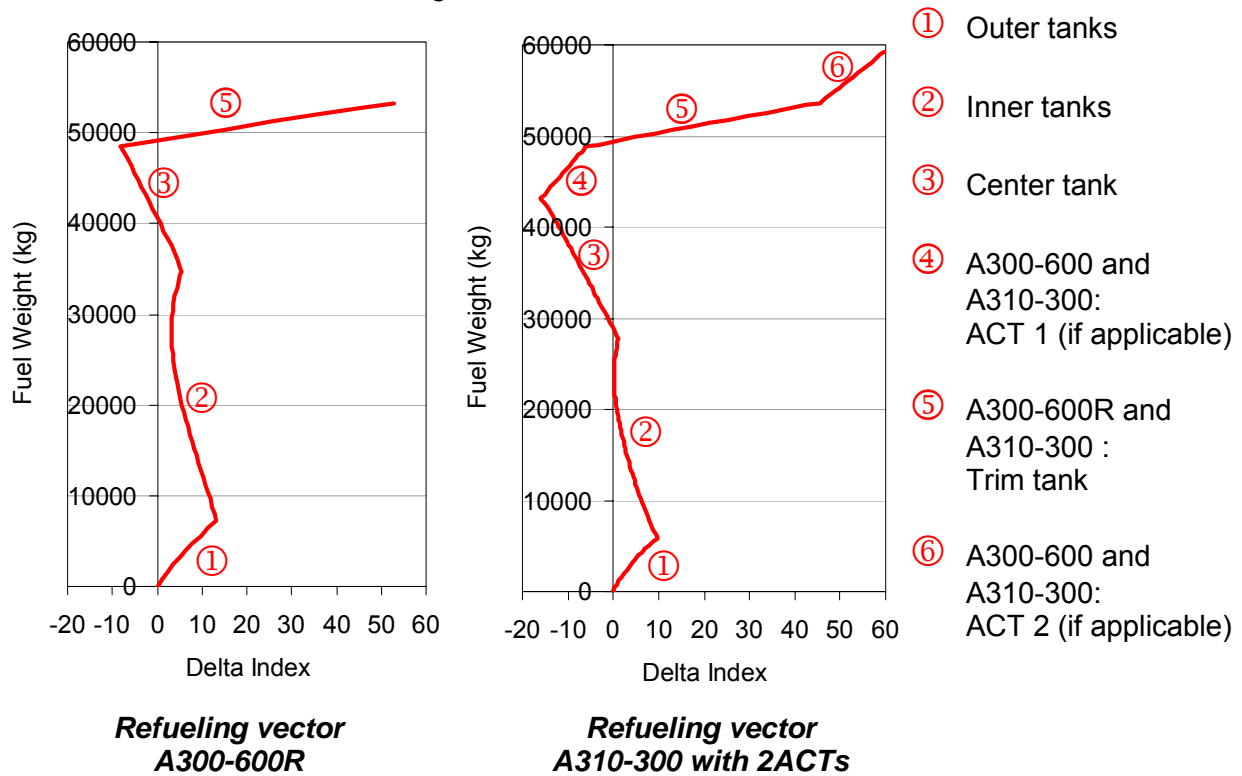
The graphs below give an example of the fuel vector impact on the certified CG envelope:

A300-600 (no ACT)

A310-300 (1 ACT)
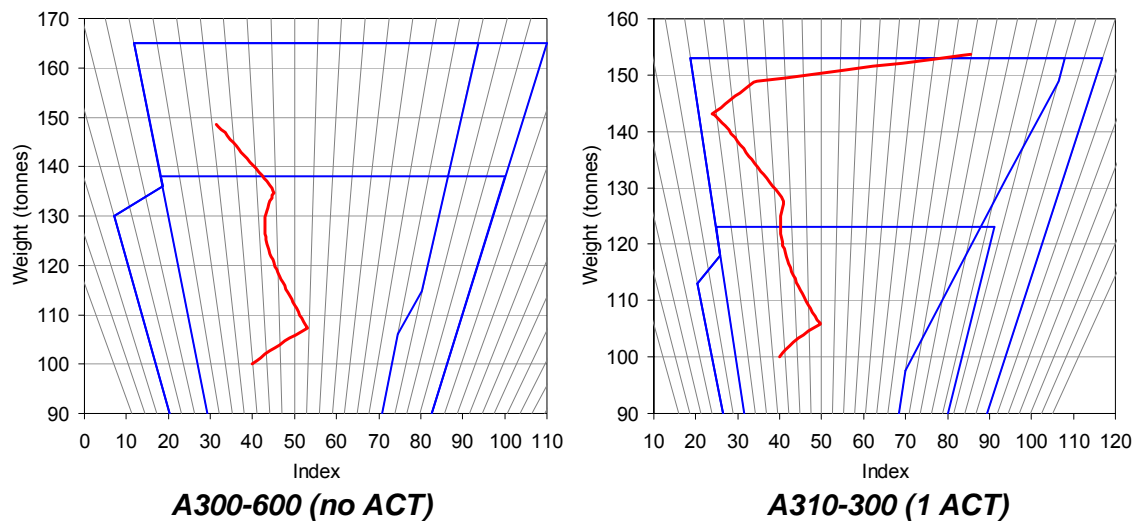
4.4. In-flight CG travel

The normal fuel burn with no consideration of the CG control system is as follows:
- 1/ ACT 2 then ACT 1 (when applicable) fuel transferred in the center tank
- 2/ Center tank
- 3/ Inner tanks
- 4/ Trim tank fuel transferred progressively in the center tank until the trim tank is empty
- 5/ Center tank
- 6/ Outer tanks

As explained previously, the Autofeed system controls the fuel feed sequence.

Automatic fuel transfer from ACT to the center tank occurs when center tank high level has been dry for ten minutes. It stops when the center tank high level is rewetted.

Once the inner tanks are empty, the CGCC generates a forward fuel transfer from the trim tank to the center tank.

The normal depletion vector is a reference that is not actually fulfilled as the CG position is impacted by the CG control system.

4.5. CG control system

Only A300-600R and A310-300 are equipped with a trim tank and an associated CG control system. Center of Gravity control and monitoring is achieved by the CGCC (Center of Gravity Control Computer). The CGCC has three main functions:
- To compute the aircraft CG and gross weight based on the ZFCG and ZFW (entered by the crew in the CDU), the fuel quantity in each tank and the aircraft pitch angle.
- To monitor the CG and maintain a CG target
- To order fuel transfers in order to maintain the CG target.

As for long-range aircraft, the CG target is defined as a function of the aircraft weight. It also depends on the flight level. The following graph is published in FCOM.

CG target A310-300
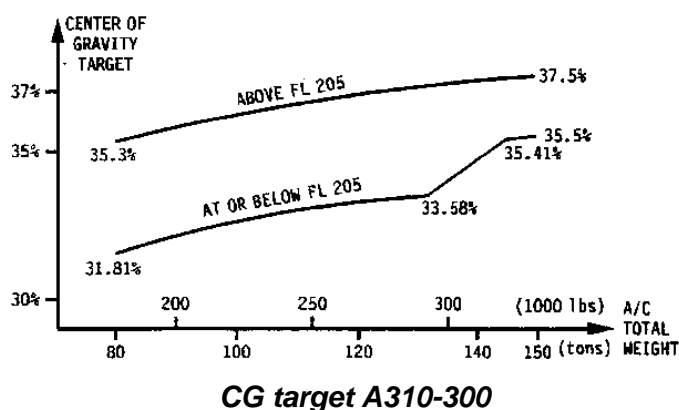
During takeoff and landing, the trim tank is isolated. The trim tank isolation valve opens at takeoff when the slats are retracted and closes at landing when the gear is down.

CG control is activated above FL 205. In climb below FL 205, forward transfers can be initiated if the aircraft reaches its aft CG target. However, no aft transfer is permitted. Above FL205, the CGCC initiates fuel transfers in order to maintain the CG within 0.5% forward of the CG target. As for the long-range family, this starts with an aft fuel transfer (normally only one per flight) and continues with forward fuel transfers to compensate for the fuel burn.

If the inner tanks are empty, the CGCC transfers fuel from trim tank into the center tank in order to maintain fuel quantity in the center tank (500 to 1000 kg). This is done without any regards to the CG target.

The fuel used in aft transfers comes from the center tank or from the inner tanks if the center tank is empty. Forward transfers bring fuel from the trim tank to the center tank. No fuel can be transferred from the trim tank to the inner tanks.

In descent below FL 200, the CGCC orders a fast forward fuel transfer from the trim tank to the center tank. This stops when one of the following conditions is met:
- the trim tank is empty
- the center tank is full
- the CG has reached the forward CG limit.

In order to protect the aft CG limit, an independent CG monitoring is performed by the FWC (Flight Warning Computer) based on THS position data. In case the CG is found too far aft, an ECAM warning is triggered and the CG target is shifted forward. The CG target is also moved forward in case of a manual forward transfer (for more than 10 seconds) and when FQI data accuracy is degraded.

C. LESS PAPER IN THE COCKPIT WEIGHT AND BALANCE SYSTEM

1. GENERALITIES

The Less Paper in the Cockpit – Weight & Balance module is an interface designed for the pilot for use in the cockpit to compute the different weights and center of gravity (CG) positions of the aircraft and to check them against their operational limitations. The interface runs on a laptop equipped with Windows operating system.

The Less paper cockpit package is a more comprehensive package comprising of document consultation (FCOM and/or MEL) and of performance computation (Takeoff, Landing, Weight & Balance, Flight). Each module may be present or not depending on the operator's choice.

The user interface of the Less Paper in the Cockpit – Weight & Balance module (termed as LPCWBU in the following) uses the data exclusively defined by the administrator.
Indeed, the LPCWB package is delivered as an empty shell and the administrator has to feed the LPCWB environment with the fleet's weight and balance data (aircraft main characteristics, fuel tanks data…) as well as the operational data (influence of passengers and cargo loading on the CG - operational envelopes). The administrator defines also the general layout and operations of the user interface as this latter is very flexible and can be adapted to the airline's type of operations. To complete these tasks, the administrator uses the dedicated functions of the administrator interface namely LPCA and in addition can optionally use comprehensive data files produced the LTS software.

With the LPCWBU interface, pilots define the configuration of the flight, load the aircraft with passengers, cargo and fuel and distribute the payload in the cabin and in the holds. Various checks are performed throughout the data entry process and at the end, pilot gets results graphically and numerically.

2. USER INTERFACE – GENERAL PRESENTATION
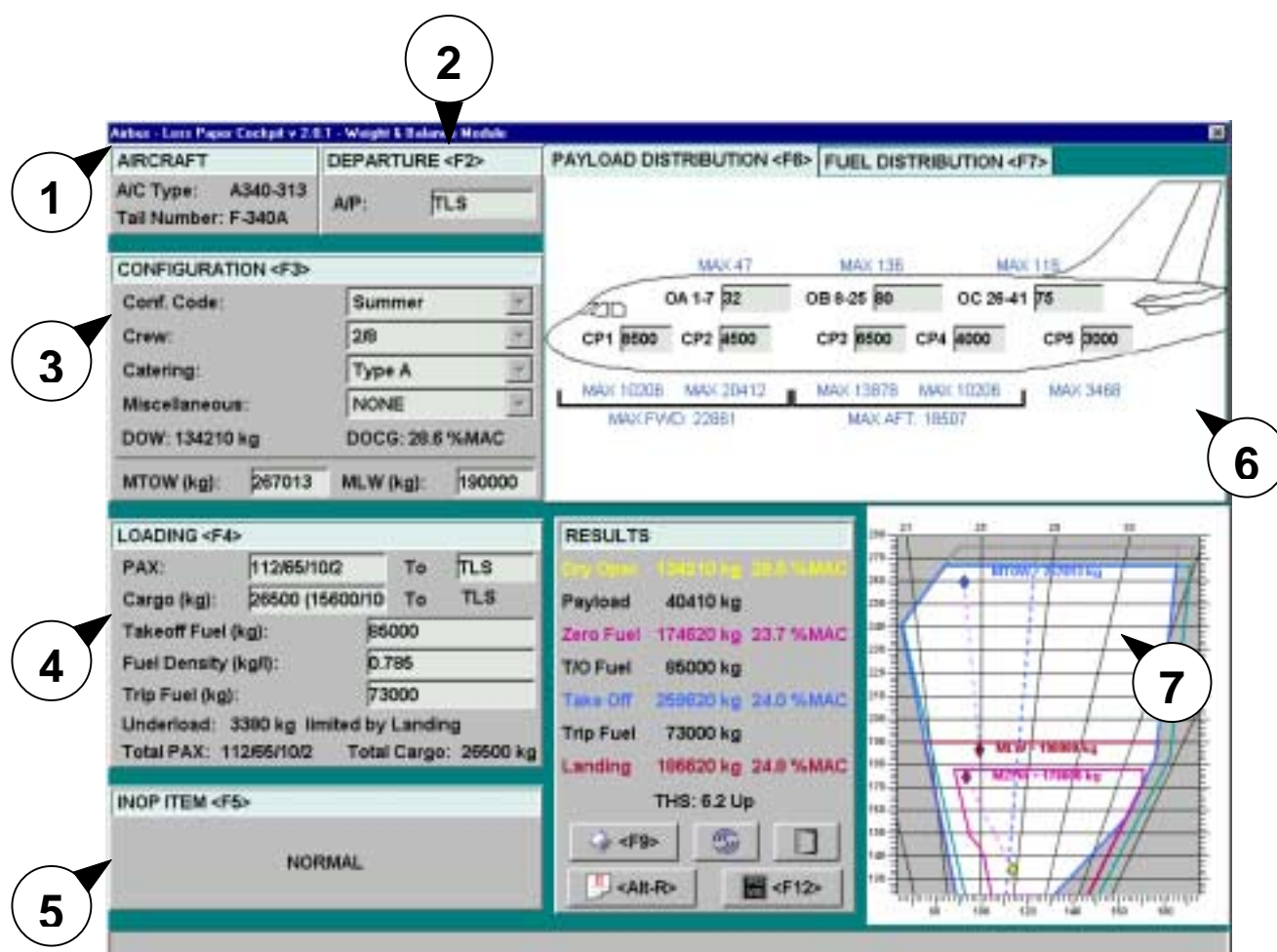
The interface is composed of the following frames:

Aircraft frame: Displays information regarding aircraft selection made on welcome page (given for information only).

- − 1 and 2 Departure frame (Shortcut <F2>): Allows selecting the departure airport.
- − 3 Configuration frame (Shortcut <F3>): Allows defining the aircraft configuration before loading payload and fuel.
- − 4 Loading frame (Shortcut <F4>): Enables to load the aircraft. This frame fulfils all the tasks of a conventional load sheet.
- − 5 Inop Item (Shortcut <F5>) This function is not available at this version.
- − 6 Payload distribution (Shortcut <F6>) and Fuel distribution (Shortcut <F7>): Enables to visualize or define passenger, cargo and fuel distribution
- − 7 Results frame: Presentation of results (numerically and graphically).

WEIGHT AND BALANCE ENGINEERING

GENERALITIES INTRODUCTION

The purpose of this section is to present the impact of the aircraft CG position on aircraft performance and the certified limits design process. First it is necessary to define precisely what is the Center of Gravity, the way to express it in relation to the Reference Chord (RC) and to detail the forces applied on the aircraft.

A. GENERALITIES

1. DEFINITIONS

1.1. Center of Gravity (CG)

The Center of Gravity or CG is the point where the aircraft's weight is applied. The position of the CG has to stay within certain limits to ensure aircraft maneuverability and stability and also the aircraft structure integrity.

1.2. Mean Aerodynamic Chord (MAC)

All the limitations and the definitions related to weight and balance aspects use what is called the Mean Aerodynamic Chord (MAC) or the reference chord (RC). For example, the position of the center of gravity (CG) is usually expressed in terms of percentage of MAC. The safe limits for the CG are also expressed in terms of percentage of MAC (the symbol used is %MAC)

The MAC is a reference line used in the design of the wing; its position relative to the wing and the fuselage is accurately known. The position and dimensions of this reference line are mentioned in the Weight and Balance Manual (WBM Chapter 1.00.05 page2).
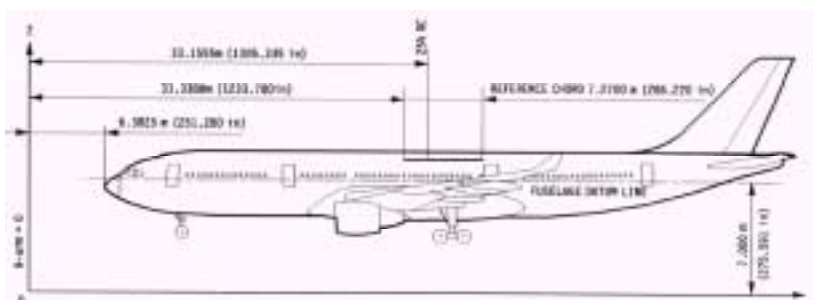
- Example of the A330-200 -

The important points to notice are:
- the position and dimension of the MAC
- the position of the point located at 25% of the MAC's length. This point is the reference when it comes to measuring moments.

Conversion from %MAC to H-arm

$$\% MAC = \left(\frac{H\!-\!arm_{CG} - H\!-\!arm_{Leading\ Edge\ of\ MAC}}{Length\ of\ MAC} \right) \times 100$$

In the above case, the formula would be: $\% MAC = \dfrac{H\!-\!arm_{CG} - 31.3380}{0.072700}$.

$$H\!-\!arm_{CG} = H\!-\!arm_{Leading\ Edge\ of\ MAC} + \frac{Length\ of\ MAC \times \% MAC}{100}$$

In the above case, the formula would be: $H\!-\!arm_{CG} = 31.3380 + \dfrac{7.27 \times MAC}{100}$.

In order to facilitate the operator's work, conversion tables from H-arm to %RC and conversion tables from %RC to H-arm are available in the Weight and Balance Manual in chapter 1.00.06.

2. FORCES APPLIED ON FLYING AIRCRAFT

a) Diagram of forces

Let us first consider main forces applied on the aircraft.
- The **weight**, applied on the aircraft CG.
- The **lift**, applied on the center of pressure (CP).
- The **thrust**, due to the engines power.
- The **drag**.
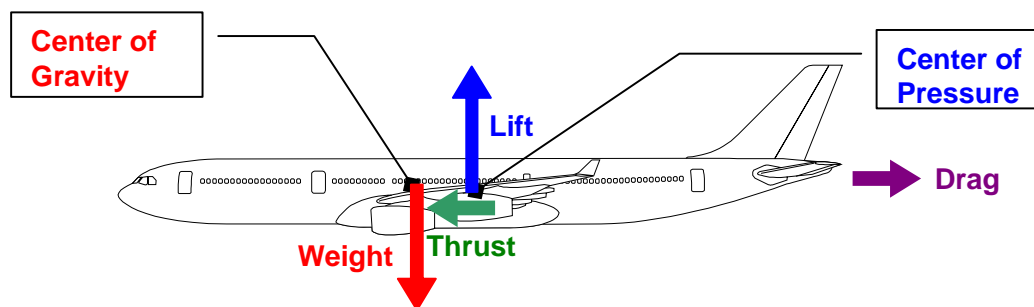
b) Influence of the THS (Trimmable Horizontal Stabilizer)

As **lift** and **weight** are not applied on the same point, a **pitch-down moment** is generated during the flight.
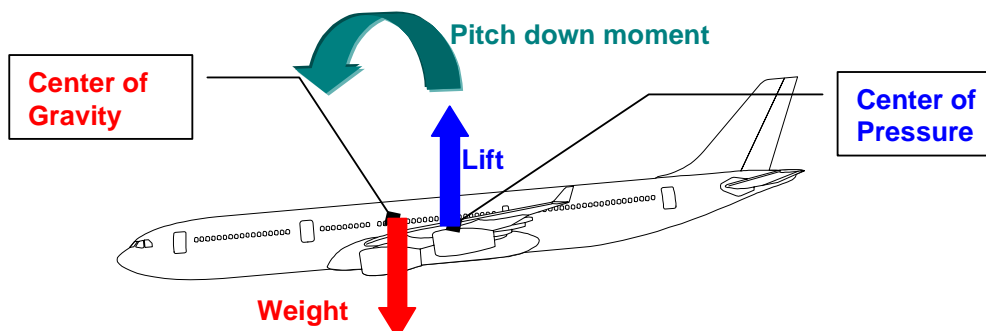
In order to keep the airplane level, a **downward force** is created by the Trimmable Horizontal Stabilizer (THS) which has to be trimmed accordingly. This additional force creates both lift degradation and important pitch-up moment that counters the pitch-down moment.

The pitch up moment is due to important balance arm between the aircraft CG position and the THS where the additional force is applied.
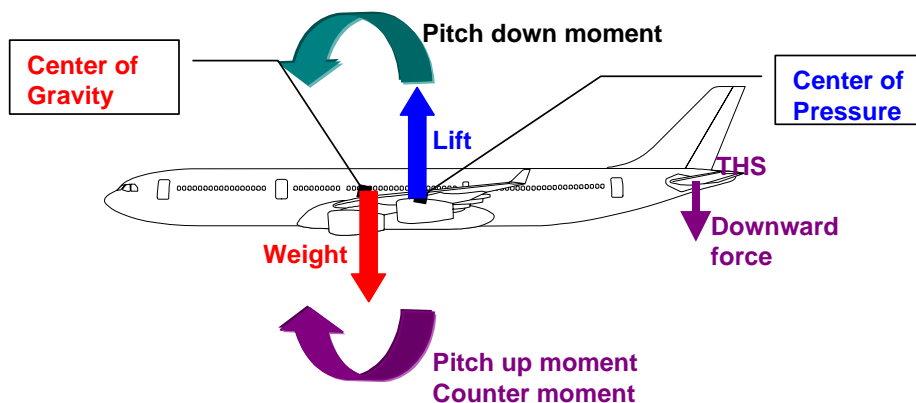
Note : for aircraft stability reasons the CP is always located behind the CG.

3. INFLUENCE OF THE CG POSITION ON PERFORMANCE

The impact of CG position on performance varies depending on the flight phase. All influences are linked to the impact of the CG position on the stall speed.

3.1. Impact on the stall speed

The stall speed (Vs) is speed at which the aircraft will stall. At that speed the upward force (mainly lift) is equal to the downward force (mainly weight + THS counter force) applied on the aircraft.

The lift is directly related to the aircraft speed: **the faster the aircraft flies the greater the lift**.

CG forward
⇒High pitch down moment
⇒Need for high THS counter moment
⇒lift = weight + THS counter force
⇒Stall speed is high

CG aft
⇒Small pitch down moment
⇒Need for small THS counter moment
⇒lift = weight + THS counter force
⇒Stall speed is smaller than for forward CG
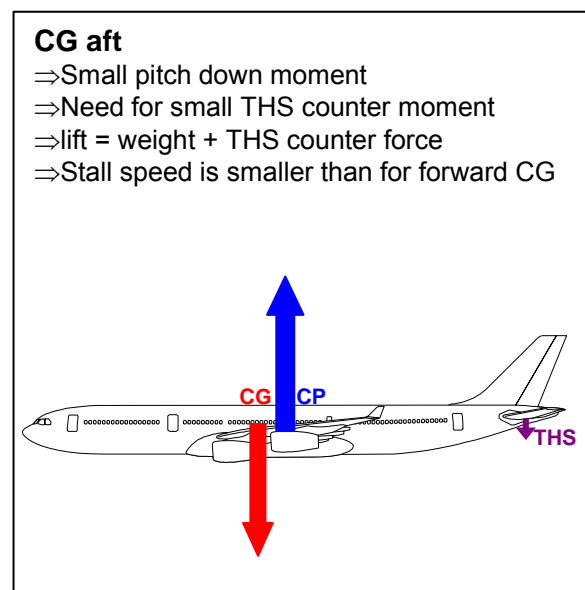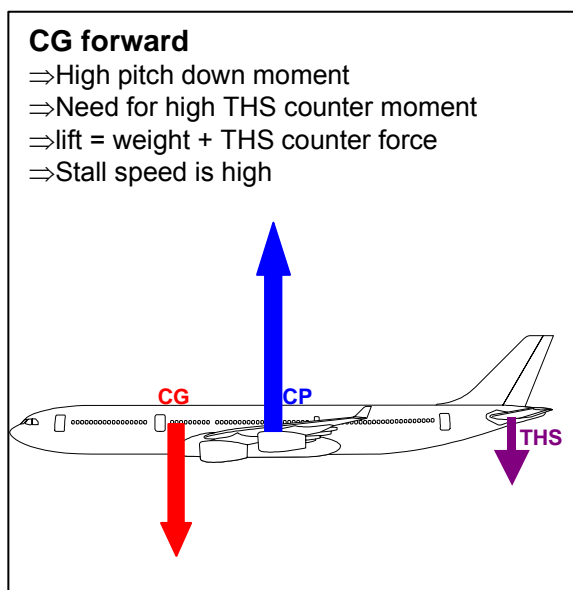
The more forward the CG position, the greater the stall speed (Vs) value.

A. GENERALITIES

![AIRBUS logo]

- **Example : A340 (High Gross Weight A340-313 with CFM65-5C4 engines) at take off CONF 1+F, Gear up**

The following graph gives the stall speed value for different aircraft weights, and for two different CG positions (Most forward CG and CG at 26%MAC).

Stall Speed at Take Off (Conf 1+F, Gear UP)
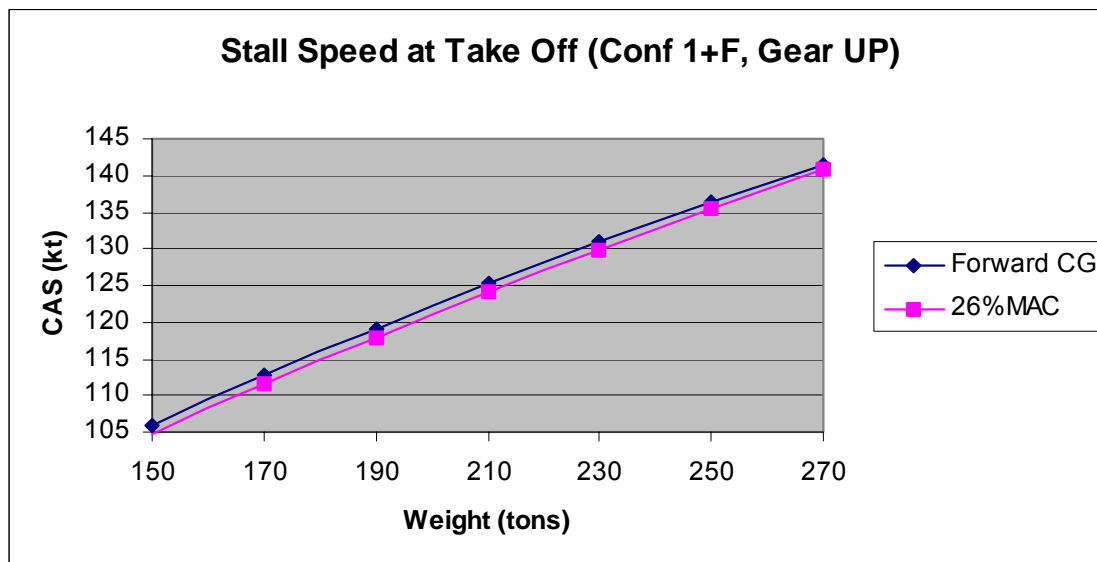
This graph confirms the stall speed corresponding to a forward CG position is higher than the stall speed for a CG at 26%MAC. The difference can reach 1.5 kts.

Note :
For conventional aircraft (A300, A300-600 and A310), the reference stall speed, Vs_{min}, is based on a load factor inferior to 1g. This gives a stall speed that is lower than the stall speed at 1g. All operating speeds are expressed as functions of this speed.
For Fly by Wire aircraft (A319, A320, A321, A330 and A340), the airworthiness authorities have reconsidered the definition of stall speed: the stall speed is based on a load factor equal to 1g. It is called Vs_{1g}. Fly by Wire aircraft have a low-speed protection feature (alpha limit) that the flight crew cannot override.
Airworthiness authorities have agreed that a factor of 0.94 represents the relationship between Vs_{1g} and Vs_{min} : $Vs_{min} = 0.94\ Vs_{1g.}$

3.2. Impact on takeoff performance

3.2.1. Optimized takeoff distance or takeoff weight

The aircraft operating speeds are referenced to the stalling speed.
At takeoff: $V_2 \geq 1.2Vs \;\; (1.13Vs_{1g})$

Now, the V_2 value directly impacts the takeoff distance (or the takeoff weight).

$$Vs \searrow \Longrightarrow V_2 \searrow \Longrightarrow \mathit{TOD} \searrow$$

So for a given TOD: the lower the stall speed (Vs) value, the greater the takeoff weight (TOW).

The further aft the CG, the smaller the TOD (the greater the TOW).

- **Influence on TOD**

A340 CONF 3, AC OFF, AI OFF, OAT 15°C, Zp 0ft
TOW = 250 000 kg

	Forward CG	CG at 26%MAC
TOD (m)	3241.5	3164.8

$$\boxed{\Delta TOD = 76.7m = 2.42\%}$$

✏This example shows that, for a given TOW, the aircraft will need a longer runway if its CG is forward.

3.2.2. Takeoff roll

An aft CG position gives the aircraft a nose-up attitude that helps the rotation. On the contrary, a forward CG position leads to a nose-heavy situation and a difficult rotation.
Taking into account no other limitation (gear strength, VMU…),

The further aft the CG, the better the takeoff roll performances.

3.2.3. Takeoff climb

An aft CG position gives the aircraft a nose-up attitude that helps the aircraft climb. On the contrary, a forward CG position leads to a nose-heavy situation and a difficult climb.
Taking into account no other limitation (gear strength, VMU…),

The further aft the CG, the better the takeoff climb performances.

- **Influence on Climb Gradient**

A340 CONF 3, AC OFF, AI OFF, OAT 15°C, Zp 0ft
TOW = 250 000 kg

	Forward CG	CG at 26%MAC
2nd segment gradient	5.569%	5.689%

✏The aircraft climb is facilitated with an aft CG position.

• Influence on TOW

A340 CONF 3, AC OFF, AI OFF, OAT 15°C, Zp 0ft
The difference in 2nd segment gradient value may not seem significant.
So instead of calculating the difference in gradient for the same take-off weight, it is interesting to determine the maximum take off weight for a given climb performance.
A second segment climb gradient of 5% is imposed (i.e. obstacle in take-off path).

	Forward CG	CG at 26%MAC
TOW (kg)	256215.2	257581.3

$$\Delta TOW = 1366.1 kg$$

✎For a given second segment climb gradient, the allowed TOW is increased when the CG is aft.

3.2.4. Basic and alternate CG positions

From the 3 previous paragraphs it can be concluded that :

The best takeoff performances correspond to an aft CG position.

Now, when determining the aircraft takeoff performance (TOW, TOD), the calculation is always performed at the most forward-certified CG position. Therefore, for aircraft having a naturally aft CG position (tail heavy aircraft), everyday operations might be penalized using this very forward value.

The A320 and the A340 usually have a DOW CG of around 30%MAC and their most forward certified CG limit is around 17%MAC.
These *"tail-heavy"* aircraft usually have an aft takeoff CG position. This means that their everyday performance is better than the certified performance for the most forward CG position.
So a second CG position forward limit has been certified for these two aircraft.
  − at 25%MAC for the A320
  − at 26%MAC for the A340.
All takeoff performances in the certified Airplane Flight Manual are given for both these CG positions.

However, to take into account the errors in the determination of the CG position, a margin has to be applied on the calculated takeoff CG.
I.e., for an A320, in order to be able to use the performance calculated for a 25% CG, the calculated takeoff CG must be of at least 27%.

a) A320

A320 Basic CG limits	A320 Alternate CG limit
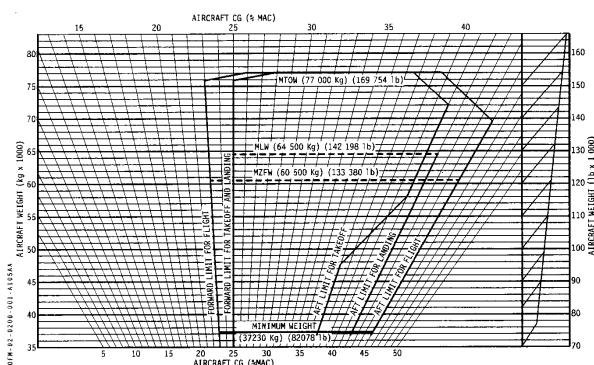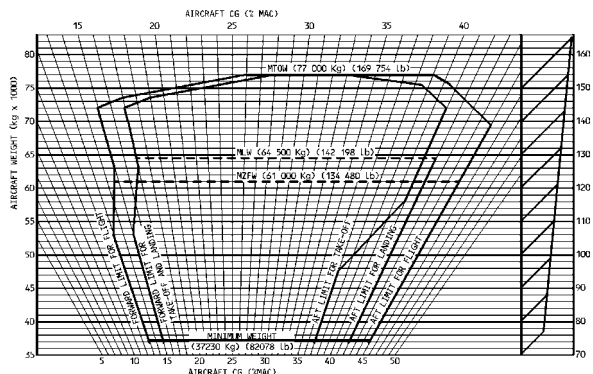
Therefore, for the A320, the basic certified CG is the aft CG (25%RC) and the alternate CG is the forward CG.

Takeoff charts and performances published in the FCOM are usually established for the basic CG position (25%)

CONF1+F	KUNMING - KUNMING/WUJIA	ZPPP 21

```
ELEVATION= 6217.0(FT)          CODES  LIMITATIONS          A320-232/AA/V2527-A5
T.O.R.A. = 3400.0(M )   1-STRUCTURE    5-TYRE SPEED        JARA   MC69   21-Feb-00
A.S.D.A. = 3460.1(M )   2-2ND-SEGMENT  6-BRAKE ENERGY
T.O.D.A. = 3600.0(M )   3-RUNWAY       7-RWY 2 ENGINES
SLOPE    = -0.10( %)    4-OBSTACLE     8-FINAL T.O.          QNH=1013.25  (MB)

 EOSID : 15deg banked climbing left turn commence      AIR COND. OFF   CG25%
 d at 500ft AAL to establish outbound on the KMG       ANTI-ICING OFF
```

TREF = 27 DC		WIND (KT)		WITHOUT REVERSE	
TMAX = 42 DC		MTOW (KG) CODES			
		MEAN V1 - VR - V2 (IAS.KT)		DRY RUNWAY	
O A T DC	-10	-5	0	10	20
-18.0	73344 2-4	74821 2-4	76222 2-4	77058 2-4	77771 2-4
	141 151 151	147 156 156	153 160 160	157 164 164	162 167 167
-3.0	71914 4-4	73633 2-4	75107 2-4	76018 2-4	76849 2-4

- Takeoff chart for an A320-232 -

If the CG position is forward to the 27% RC point, and if the operator does not have the take-off charts for a forward position, performance corrections have to be applied. These are given in the FCOM 2.02.10.

However, should an A320 be operated with an alternate CG position, it is preferable to establish the takeoff charts for that CG position, as the corrections given in the FCOM are conservative.

⊕A319/320/321	TAKEOFF	2.02.10	P 3
FLIGHT CREW OPERATING MANUAL	GENERAL (TEMPERATURE ENTRY)	SEQ 001	REV 22

Note : If the RTOW chart is based on the CG being at 25 %, the crew can find the takeoff performance at a more forward CG by decreasing the takeoff weight by 1000 kg (2200 lb) and increasing V1, VR and V2 by 1 knot.

b) A340

A340 Basic and Alternate CG
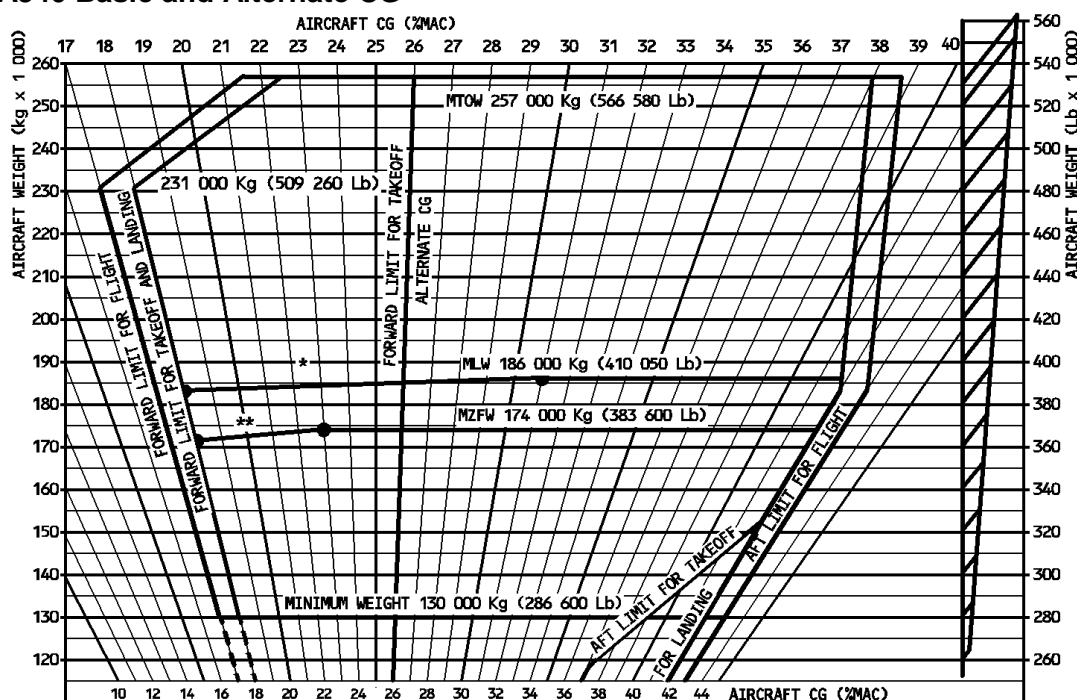
For the A340, the basic CG is the most forward CG and the alternate CG is the aft CG (26%).

Take off charts and performances published in the FCOM are established for the basic CG position.

No corrections are given in the FCOM because the alternate CG performances are better than the basic CG performances. Therefore, an operator that wishes to benefit from the advantages of the alternate CG must establish the appropriate takeoff charts.

Influence on TOW
Note : The following figures come from the PEP for Windows Take Off and Landing application. It takes into account all the limiting factors for take-off (runway length, climb…).

The following graphs show $\Delta TOW(\%)$ as a function of the TORA length.

$$\Delta TOW(\%) = \left(\frac{TOW_{AlternateCG} - TOW_{BasicCG}}{TOW_{BasicCG}} \right) \times 100 \quad \text{represents the difference in term of TOW when}$$

using the alternate CG for performance calculation instead of the basic CG.
Calculations have been performed for a range of TORA and for different airfield altitude.

A340-313 CONF 1+F
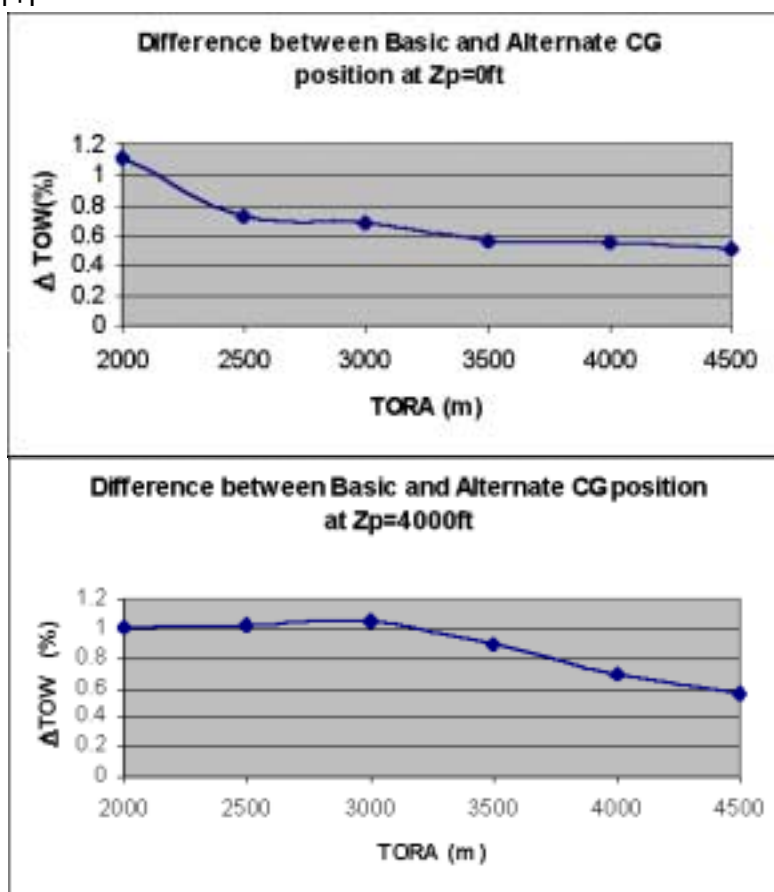
We can notice that the difference in take off weights is all the more important with short runways and an elevated terrain. For example:

OAT	20°C
Pressure Altitude (Zp)	0ft
Runway length	3000m

CG position	Basic	Alternate
Takeoff Weight (kg)	266013.9	264207.8

$$\Delta TOW = 1806.1 kg$$

- **Conclusion**

Therefore, by using the performances calculated for the alternate CG (A340) or for the basic CG (A320), the operator can increase the aircraft takeoff weight, thus the payload or the range of the aircraft.
On the other hand, the envelope is narrower, thus leading to more constraints on the loading aspect.

3.3. Impact on in-flight performance

Let's revert to the impact of the CG position on the forces applied on the aircraft and to the consequence it has on aircraft performance.

Reminder: In order to keep the airplane level, the Trimmable Horizontal Stabilizer (THS) creates a downward force. This additional force creates a pitch-up moment that counters the pitch-down moment due to the aircraft weight but also a drag increase which magnitude depends on the aircraft CG position.

a) AFT CG POSITION
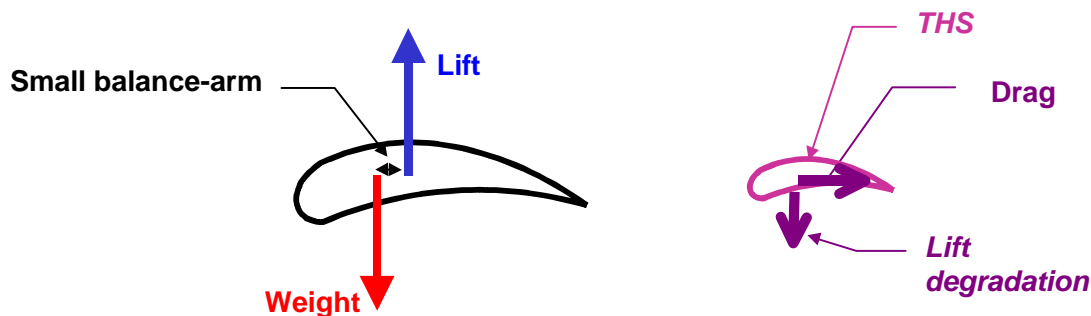
b) FWD CG POSITION
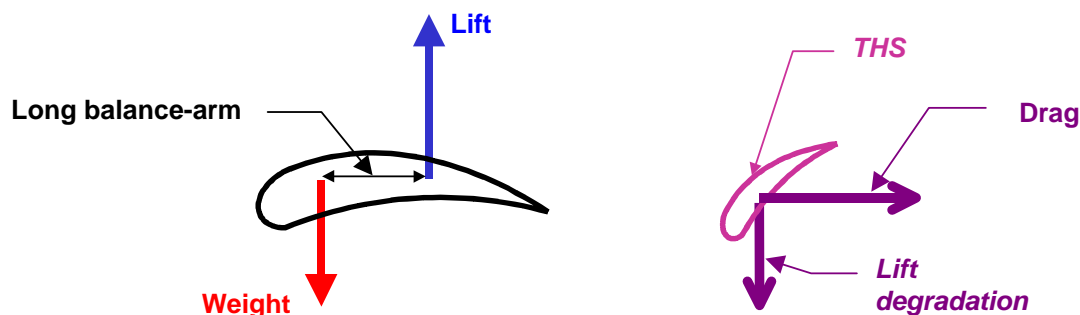
The further forward the CG, the greater the counter moment necessary to keep the flight level. This is due to the increasing balance arm between lift and weight.
In the case of a forward CG position, the THS is set to an aircraft nose-up position that creates important lift degradation therefore creating important drag. This drag will lead to an **increase in fuel consumption**.

The further aft the CG, the lower the fuel consumption.

c) <u>Influence on fuel consumption</u>

This part refers to the Airbus "Getting to Grips with Fuel Economy" Brochure.

During cruise, on all the wide-body Airbus aircraft, the FCMC (Fuel Control and Management Computer) on the A330 and the A340 or the CGCC (Center of Gravity Control Computer) on the A300-600 and the A310 controls the CG position by transferring fuel in the trim tank. The aircraft therefore flies with an aft CG, thus giving better in-flight performance. However, a failure can prevent the fuel transfer and CG position control.

The following graphs show the influence of the CG position on the aircraft specific range depending on the aircraft weight.
The data are expressed in Specific Range (SR) variations at cruise mach with a center of gravity of 20% and 35%. The SR with a CG position at 27 % is taken as a reference. For the other aircraft, the curves all have a similar shape as these ones:

For the A300-600, A310, A330 and A340 types, the further aft the CG, the more significant the fuel savings. Furthermore, when flying above FL350, at a high weight, the decrease or increase in fuel consumption according to the reference is significant.
Thus, loading is very important especially for high weights and for aircraft which have no automatic center of gravity management: we notice that, for high weights and FL above 350, the specific range variation can reach 2%.

Contrary to the other aircraft, specific range variations with respect to the CG position are random for the whole A320 family. This is due to a complex interaction of several aerodynamic effects. Whatever the influence of the CG position on specific range, it is negligible
The single aisle aircraft are not equipped with in-flight fuel transfer systems, they are not fitted with a trim tank.

A. GENERALITIES

d) Example

On a 1000 NM stage length, the increases in fuel consumption when the center of gravity position is 20% with regards to the fuel consumption when the center of gravity position is 35% are summed up in the following table for an aircraft with a high weight and at a high flight level.
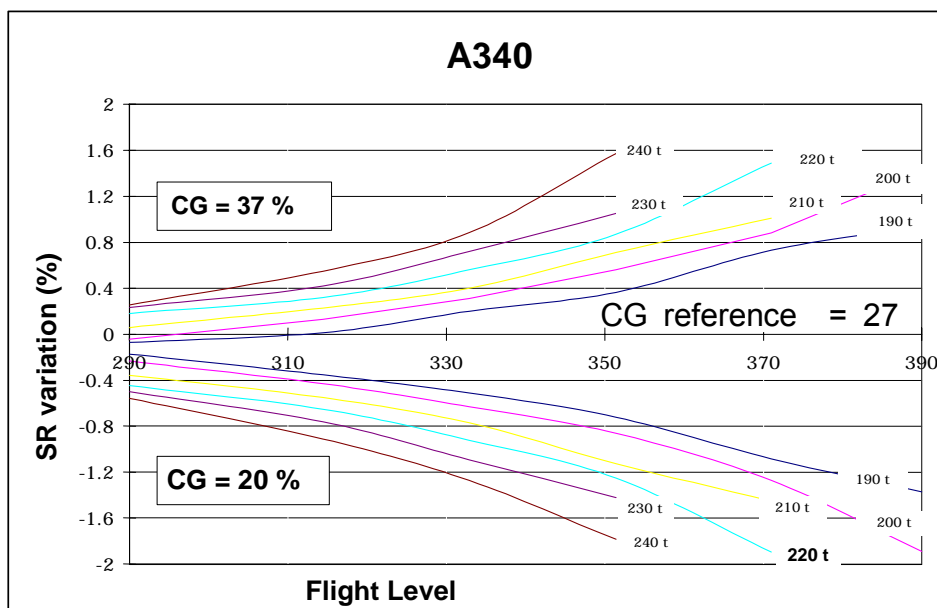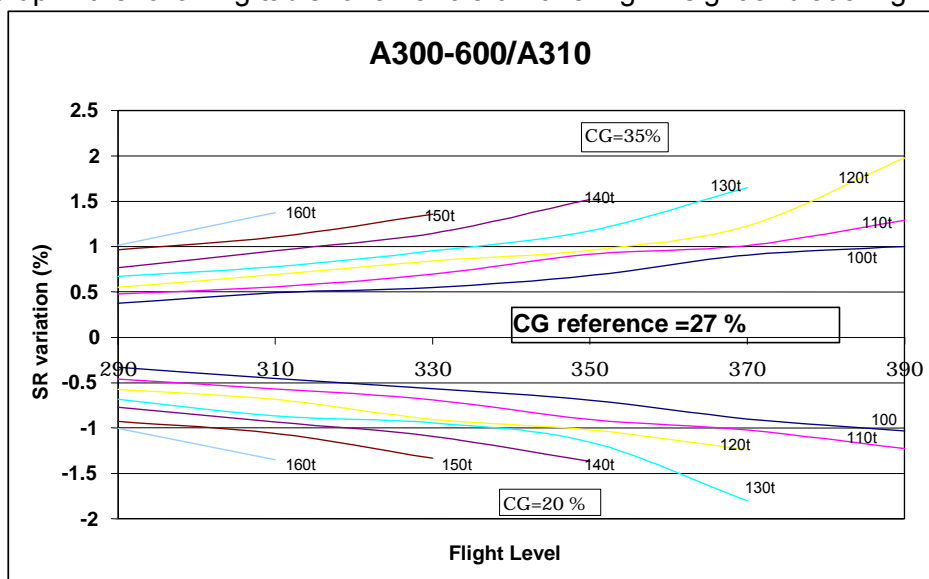
A300-600/A310

A340

Aircraft types	Fuel increment (Kg)/1000Nm between a 20% CG and a 35% CG
A319/A320/A321	Negligible
A330	220
A340	380
A310	250
A300-600	230

3.4. Impact on landing performance

3.4.1. Landing distance or landing weight

The aircraft operating speeds are referenced to the stalling speed.
At landing: $V_{App} \geq 1.3Vs \;\; (1.23Vs_{1g})$

Now, the V_{app} value directly impacts the landing distance (or the landing weight).

Vs ↘ ⇨ **V$_{app}$** ↘ ⇨ **LD** ↘

So for a given Landing Distance: the lower the stall speed (Vs) value, the greater landing weight (LW).

Reminder:

Forward CG position $\Rightarrow$ High stall speed
Aft CG position $\Rightarrow$ Low stall speed.

The further aft the CG, the smaller the LD (the greater the LW).

3.4.2. Basic and alternate CG positions

As for takeoff performances, when determining the aircraft landing performance (LW, LD), the calculation is always performed at the most forward-certified CG position. Therefore, for aircraft having a naturally aft CG position (tail heavy aircraft), everyday operations might be penalized using this very forward value.

Only the A320 has two different certified CG. For the other aircraft, the position of the CG is of no influence on landing performances as long as it stays within the certified limits.
The important performance as far as landing is concerned is the landing distance. As noted in the FCOM of the A320, a correction has to be made in the case of an alternate CG.

⊛ *A319/320/321*	LANDING PERFORMANCE	2.03.10	P 5
FLIGHT CREW OPERATING MANUAL	LANDING	SEQ 122	REV 21

REQUIRED LANDING DISTANCE

MANUAL LANDING

REQUIRED LANDING DISTANCE (FEET)								
WEIGHT (1000 LB)	100	110	120	130	140	150	160	170
CONF 3	3680	3940	4280	4680	5140	5660	6220	6810
CONF FULL	3470	3700	3990	4340	4730	5170	5660	6180

Corrections on landing distances
Wind : per 10 kt tailwind add 14 %
R no correction for headwind due to wind correction on approach
R speed.
Airport elevation : per 1000 ft above sea level add 4 %.
Forward CG : add 2 %.

3.5. Summary

$$\% MAC = \left(\frac{H\text{-}arm_{CG} - H\text{-}arm_{Leading\ Edge\ of\ MAC}}{Length\ of\ MAC} \right) \times 100$$

$$H\text{-}arm_{CG} = H\text{-}arm_{Leading\ Edge\ of\ MAC} + \frac{Length\ of\ MAC \times \% MAC}{100}$$

Stall speed
The further aft the CG, the smaller the stall speed (Vs) value.

Take off

The further aft the CG,
   the smaller the TOD (the greater the TOW).
   the better the take off roll performance.
   the better the take off climb performance.

3.6. Conclusion

The best take-off performances will correspond to an aft CG position.

In-Flight
The further aft the CG, the lower the fuel consumption.

Landing
The further aft the CG, the smaller the LD (the greater the LW).

The further aft the CG, the better the aircraft performance.

4. CERTIFIED LIMITS DESIGN PROCESS

The previous chapter has dealt with the influence of the position of the aircraft center of gravity on performance. The conclusion was that in general the further aft the CG, the better the aircraft performances.

However, the CG has to stay within certain certified limits. These limits are defined in the Limitations volume of the Flight Manual (Chapter 2.02.00) and are also in the Weight and Balance Manual (Chapter 1.10, Limitations)
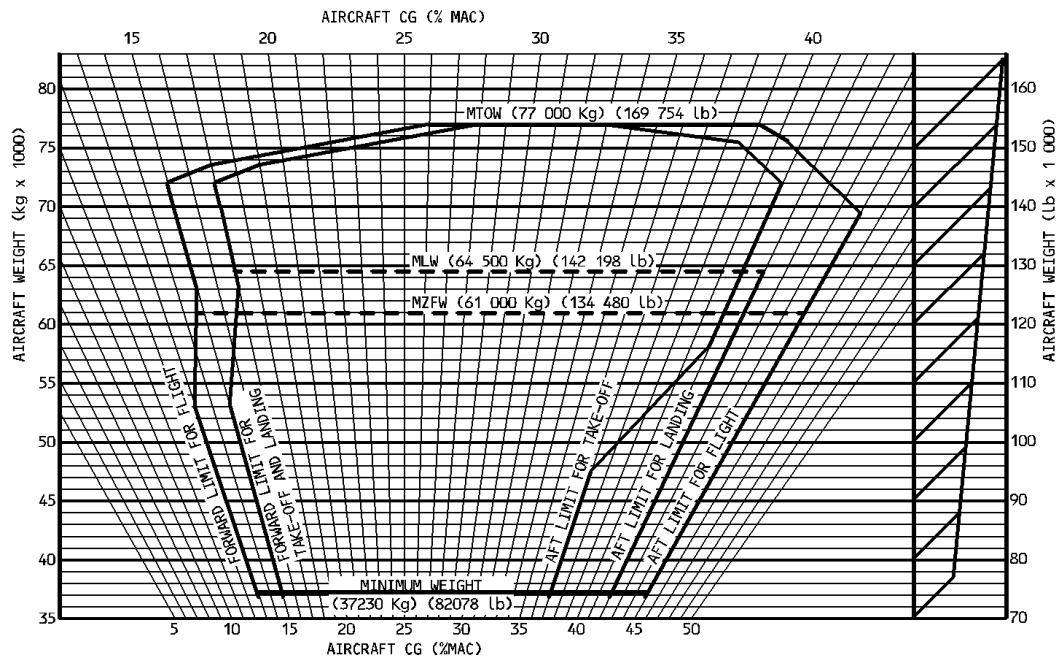
- **Example : A320-212**

The purpose of this chapter is to explain briefly how these limits are defined and why these limits vary according to the flight phase (take off, landing or in-flight)

These limits are mainly due to:

- − structural limitations
- − handling qualities
- − a compromise between performances and aircraft loading

4.1. Certification requirements

Certain rules have to be respected when designing a CG envelope. The following is an extract from the JAR 25.

- **J.A.R 25.27: Center of gravity limits**

    The extreme forward and the extreme aft center of gravity limitations must be established for each practicably separable operating condition.
    No such limits may lie beyond:

    - *(a) The extremes selected by the applicant;*
    - *(b) The extremes within which the structure is proven; or*
    - *(c) The extremes within which compliance with each applicable flight requirement is shown.*

- **J.A.R 25.143 : General**

    (a) The airplane must be safely controllable and maneuverable during

    - *(1) Take-off;*
    - *(2) Climb;*
    - *(3) Level flight;*
    - *(4) Descent;*
    - *(5) Landing.*

    (b) It must be possible to make a smooth transition from one flight condition to any other flight conditions without exceptional piloting skill, alertness, or strength, and without danger of exceeding the airplane limit-load factor under any probable operating conditions including:

    - *(1) The sudden failure of the critical engine.*
    - *(2) Configuration changes, including deployment or retraction of deceleration devices.*

In the following chapter all limitations are detailed by flight phase.
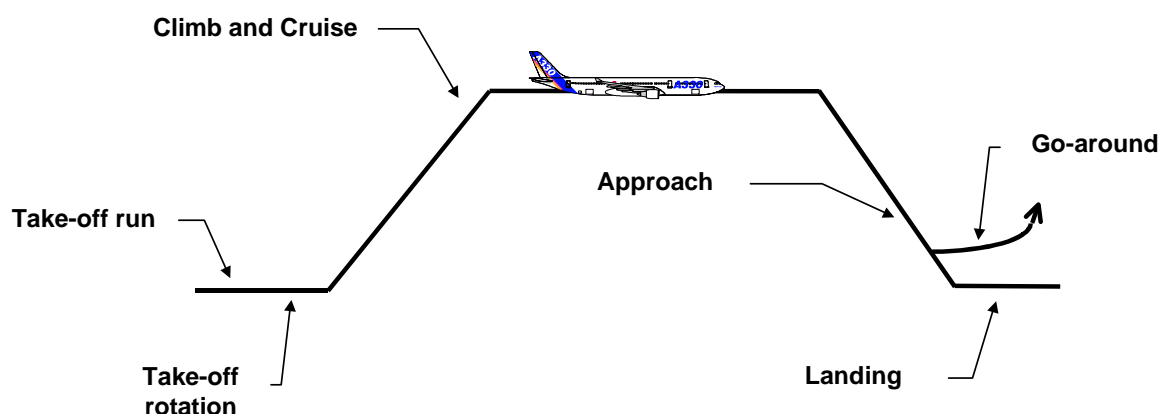
4.2. Take-off Limitations

4.2.1. Structural limitation

a) Main gear Strength:

☞ The further aft the CG is, the heavier the weight over the main gear
☞ The strength of the main gear limits the aft position of the CG for high TOW.

Main gear strength : AFT limit (take off)

b) Nose gear Strength:

☞ The more the CG is forward, the more the weight over the nose gear
☞ The strength of the nose gear limits the forward position of the CG for high TOW.

Nose gear strength : FWD limit (take off)

c) Wing strength:

The structural limits of the wing will have an effect on the CG limits at high weights.

4.2.2. Taxi and Take-off run

a) Nose Gear adherence:

During taxi and at the beginning of the take-off run, when the speed of the aircraft is not sufficient for the rudder to be effective, the only possible means of controlling the aircraft on the ground is the nose gear steering. In order to be effective, the nose gear wheel must have enough adherence.

To have an appropriate adherence, enough weight must be applied on the nose gear.
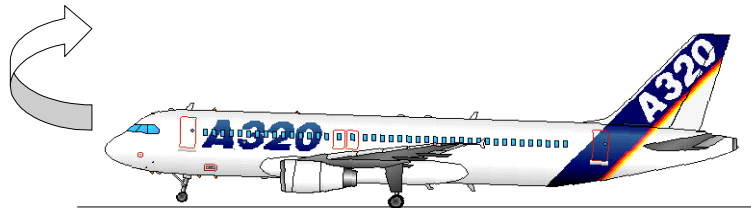
This adherence is further reduced during the take-off run when full power is applied on the engines, thus creating a pitch up moment. (This pitch up moment is due to the engines being located beneath the CG of the aircraft)

The further aft the CG, the lesser the adherence.

Nose gear adherence : AFT limit (take off)

b) Take-off Rotation

A forward CG means that the aircraft has a "heavy" nose. This leads to a difficult rotation. The CG position can be moved forward until it reaches the point where rotation becomes impossible.

An aft CG means that the aircraft's nose is relatively "light". This facilitates the rotation. However, an aft CG limit has to be established in order to prevent a tail-strike during the rotation.

Note: A forward CG implies an A/C nose-up trim setting, while an aft CG implies an A/C nose-down trim setting. If the correct trim setting is made prior to take-off, the pilot will always have the same feel during rotation no matter the CG position.

However, flight-testing is performed with a forward CG position and an A/C nose-down trim setting (conversely with an aft CG position and an A/C nose-up trim setting) in order to cover the critical condition.

Impossible rotation : FWD limit (take off) **Tail strike : AFT limit (take off)**

4.3. Aircraft stability and maneuverability Limitations

During all flight phases the aircraft must remain stable and maneuverable.
The aircraft CG position has an influence on the aircraft static longitudinal stability in steady flight and during maneuvers.

4.3.1. Static stability

Definition: The static stability of an object depends on its **tendency** to return to its initial position after being slightly moved.

Stable **Unstable** **Neutral**
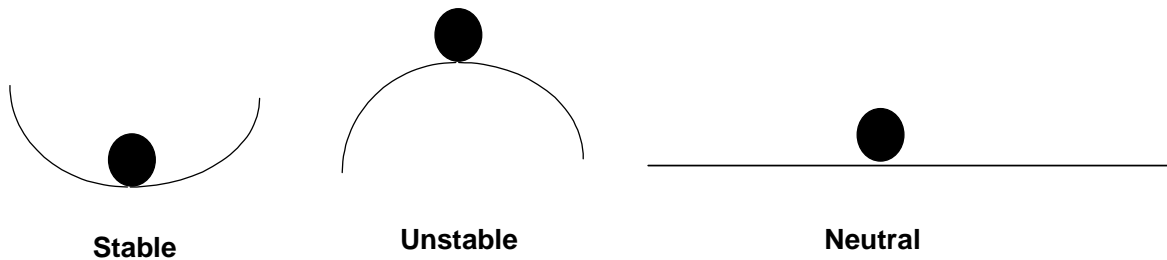
a) Longitudinal stability during steady flight

- **Aerodynamic center**

The increase (or decrease) in lift due to an increase (or decrease) in incidence (α) always applies on a fixed point of the wing. This point is called the ***aerodynamic center***.

- **Static stability**

When the aircraft is submitted to a gust, it is equivalent to an increase in incidence or to the creation of a pitch up moment.
A lift increase is created at the aerodynamic center.

If the CG is located **forward** of the aerodynamic center, the increase in lift creates a pitch down moment which reduces the incidence and brings the aircraft back to its initial conditions.

Pitch up moment due to the gust **Pitch down moment due to the lift increase**

CG X

Gust

Aerodynamic center

↳ **The aircraft is stable**

WEIGHT AND BALANCE ENGINEERING

A. GENERALITIES

If the CG is located **aft** to the aerodynamic center, the increase in lift creates a pitch up moment which adds to the initial pitch up moment due to the gust. This brings the aircraft further away from its initial conditions.
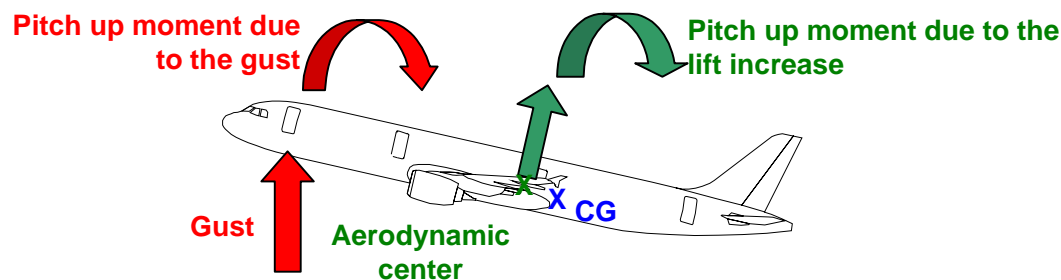
➥ The aircraft is unstable. The CG must not be behind the aerodynamic center.

Note :
If the center of gravity is located on the aerodynamic center, the lift and the weight have the same application point and there is no moment created the aircraft is neutral
Hence the other name for the aerodynamic center: the Neutral Point.

Neutral Point : AFT limit (all phases)

---

b) Maneuverability and elevator efficiency

Considering the previous paragraph, the more forward the CG, the more stable the aircraft.
However, in the case of a very forward CG position, a significant elevator deflection will be necessary to give the aircraft a pitch up attitude.
The CG position can be moved forward until it reaches the point where the aircraft is very stable but cannot be maneuvered because the elevator has reached its maximum deflection.

In order to be able to fly the aircraft, a compromise has to be reached between stability and maneuverability. The CG is shifted aft until an appropriate maneuverability is found.

Note : It is important to notice that the effects of the reduced maneuverability due to a forward CG are emphasized at low speeds when the elevators have a reduced efficiency.
The elevator efficiency limit is to be considered for all flight phases and it gives more constraining limit for take-off, approach, and landing than for flight phases.

Elevator maximum deflection + Maneuverability margin : FWD limit (all phases)

---

c) Longitudinal stability during maneuvers

During flight the aircraft must remain stable during steady flight but also during different maneuvers.

- **Maneuver point**

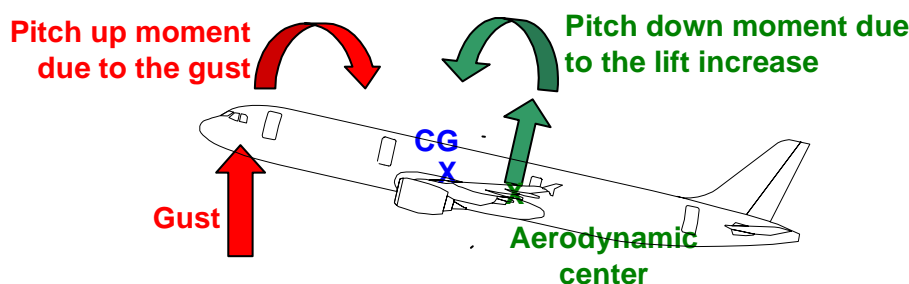The increase (or decrease) in lift due to an increase (or decrease) in load factor (n) applies on a fixed point of the wing. This point is called the *maneuver point*. This point varies with the type of maneuver (turn, pull-out) and with the aircraft's weight.

It is located behind the aerodynamic center (neutral point).
If the CG is located on the maneuver point, the elevator efficiency is infinite.
Experience has shown that for stability reasons the CG must be located ahead of the point and at a considerable distance.

In order to have an acceptable margin in regards to the maneuver point, a reference point is established for which the maneuverability of the aircraft is reasonable : Point at 1° per g. This point is considered as an aft limit.

- **Point at 1° per g**

Example of a turn.
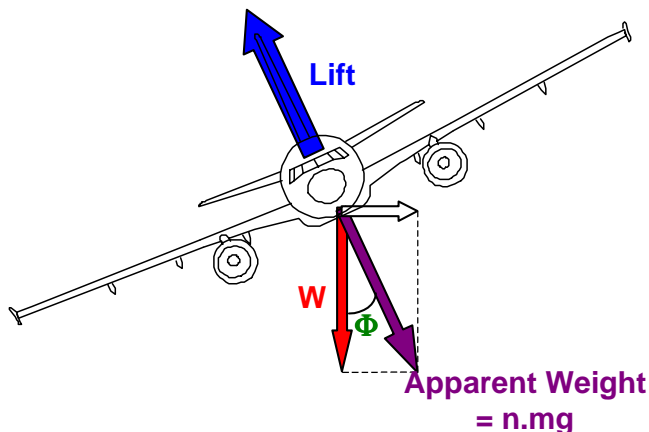
R = Turn radius
W = Weight = mg
Φ = Aircraft bank angle
n = Load factor

The load factor during a turn is: $\cos \Phi = \dfrac{1}{n}$

From the previous formula, it appears that the higher the bank angle the higher the load factor. In order to compensate for this higher load factor, the pilot must pull the stick, thus increasing elevator deflection.

A. GENERALITIES

![AIRBUS]

For commercial aircraft the law that gives the elevator deflection (δ) necessary to compensate a given load factor (n) can be represented as follows :
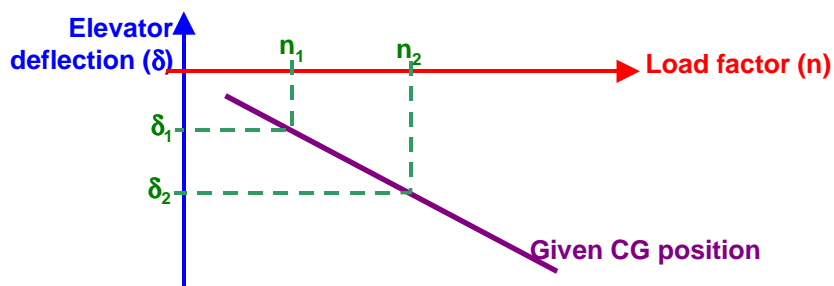
This law depends on the type of maneuver, aircraft speed, weight and CG position.

Drawing this graph for fixed conditions except CG position, gives the following:
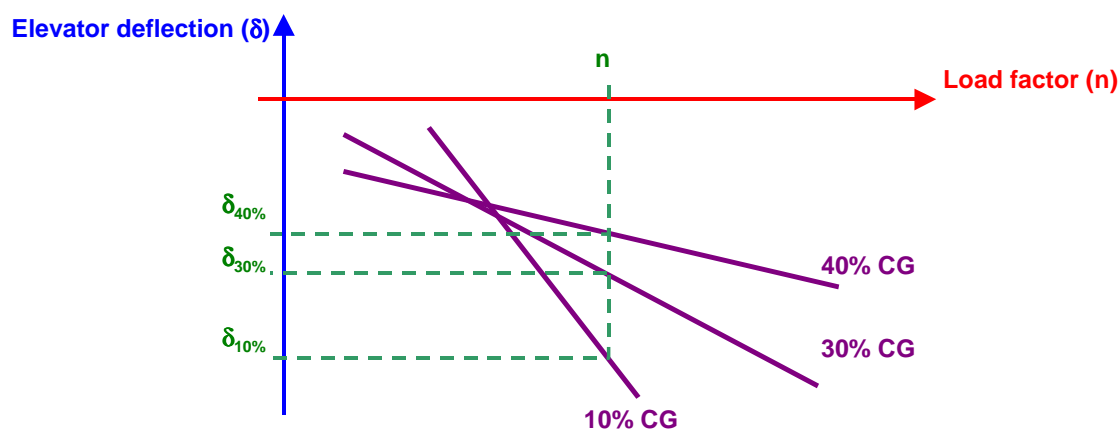
The further forward the CG position, the greater the necessary elevator deflection to compensate on given load factor.

There is a CG position for which 1 degree of elevator deflection compensates a 1 g load factor (for which 1 degree of elevator deflection creates a 1g load factor). This is the 1° per g CG.
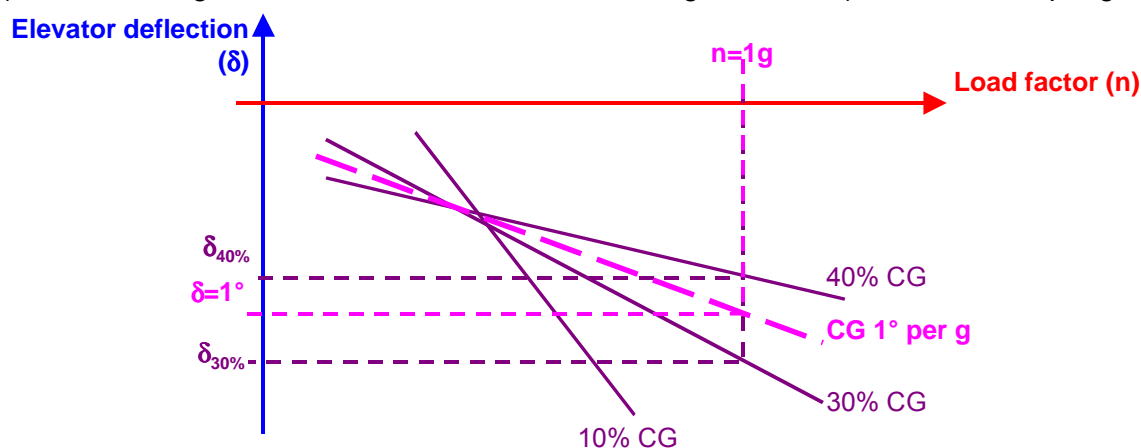
The experience has shown that the CG has to be ahead of the 1°/g CG.
The position of the 1°/g point depends on the aircraft's speed.

1° per g point : AFT limit (all phases)

d) Maximum elevator deflection and extreme load factor

Civil aircraft are certified according to the JAR/FAR 25 regulations. These regulations require for maximum acceptable load factor with no structural damage of 2.5g.
In order to keep full maneuverability capacity, the maximum elevator deflection must not prevent the pilot from reaching the maximum load factor (pull-out cases for example). This will therefore establish a forward CG limit as shown in the following figure:
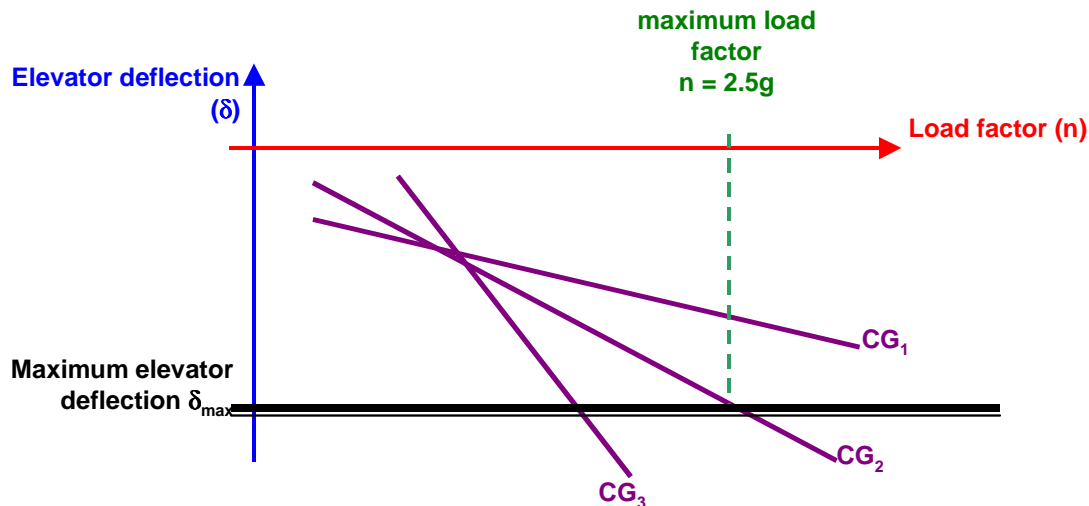
CG_3 : if aircraft CG is located on CG_3 load factor 2.5g cannot be reached whatever the elevator deflection is.
CG_1 : if aircraft CG is located on CG_1 load factor 2.5g can be reached for an elevator deflection lower than δ_{max}.
CG_2 : if aircraft CG is located on CG_2 load factor 2.5g is reached for elevator deflection δ_{max}.

Aircraft CG cannot be located forward of CG_2.

Maximum elevator deflection (max load factor) : FWD limit (all phases)

4.4. Final Approach Limitations

4.4.1. THS stall

a) Standard approach

During approach, the flaps and slats are extended. This configuration gives the aircraft a pitch-down attitude. This pitch-down moment is countered by an aircraft nose-up THS setting.
A forward CG position increases the pitch-down moment and is also countered by an aircraft nose-up THS setting.
The combination of the two effects can lead to an important aircraft nose-up THS setting which can eventually lead to a THS stall.

b) Approach + push-over

When during approach the pilot excessively reduces the speed, in order not to stall and regain a proper approach speed, he will push the stick ("push-over").
In case of a forward CG position countered by an aircraft nose-up THS setting, this procedure may lead to the THS stall because of the aircraft attitude change.

> **THS stall limit : FWD limit (flight and landing)**
> **(and take off for final approach in case of emergency landing)**

4.4.2. Go Around

Setting the engines at full throttle creates a significant pitch-up moment which must be compensated by the elevator.
The more aft the CG, the higher the pitch- up moment.

The CG position can be moved aft until it reaches the point where the pitch-up moment cannot be compensated anymore by the elevator deflection.

> **Go around : AFT limit (flight and landing)**
> **(and take off for final approach in case of emergency landing)**

4.4.3. Alpha Floor Protection

Alpha floor protection configuration: high angle of attack, low speed and TOGA power.
Low speed implies low elevator efficiency.
TOGA implies high pitch-up moment.
The more the CG is aft, the higher the pitch-up moment.
The CG position can be moved aft until it reaches the point where the pitch-up moment cannot be compensated anymore by the elevator deflection.

That will limit the aft position of the CG more than the go around limitation.

> **Alpha floor protection : AFT limit (flight and landing)**
> **(and take off for final approach in case of emergency landing)**

AIRBUS

4.5. Landing Limitations

4.5.1. Structural limitations

Landing structural limitations are similar to take off ones, they are usually less limiting as the aircraft is less heavy then at take off.

Main gear strength : AFT limit (landing) **Nose gear strength : FWD limit (landing)**

4.5.2. Maneuverability and elevator efficiency

This limitation concerns all flight phases (ref. B.1.2.3.2) but it is important just before landing, at low speed, when the elevator must enable the pilot to flare out.

Thus, elevator maximum deflection and aircraft maneuverability limit the CG position forward.

Elevator maximum deflection + Maneuverability margin : FWD limit (landing)

4.6. Limitation summary

TAKE OFF	
FWD	**AFT**
Nose gear strength (high weights) **Impossible rotation** **Elevator maximum deflection +** **maneuverability margin** **Maximum elevator deflection (max** **load factor)**	**Main gear strength (high weights)** **Nose gear adherence** **Tail strike** **Neutral Point** **1° per g point**

IN FLIGHT	
FWD	**AFT**
Elevator maximum deflection + **maneuverability margin** **Maximum elevator deflection (max** **load factor)**	**Neutral Point** **1° per g point** **THS stall limit** **Go around** **Alpha floor protection**

LANDING	
FWD	**AFT**
Nose gear strength **Elevator maximum deflection +** **maneuverability margin** **Maximum elevator deflection (max** **load factor)**	**Main gear strength** **Neutral Point** **1° per g point** **THS stall limit** **Go around** **Alpha floor protection**

4.7. Certified limits definition

4.7.1. Take off limits

a) Forward limit

The design of the forward limit takes into account the following:

- Nose gear strength
- Take-off rotation
- Maneuverability (efficiency of the elevator when aircraft in-flight)
- Flaps/slats extension (final approach in case of emergency landing).

Those limitations are classified as <u>handling quality and structural limitations</u>

As seen previously (in "Influence of CG Position on Performance"), the FWD CG limit is the reference CG for aircraft performance, as it corresponds to the worst CG position, as far as performances are concerned.

> ↳**From the performance point of view the forward limit of the envelope must stay as aft as possible.**

On the other hand, in order to facilitate the loading of the aircraft, the envelope must be as wide as possible (both aft and forward). If the envelope is too narrow, the operators will have to be very careful on where they locate the freight in the holds and on how they sit their passengers in the cabin.

> ↳ **From the loading point of view the forward limit must not be too aft.**

The retained limit is a compromise between loading and performance. In most of the cases, the handling qualities are ahead of the retained limit.

In other words, the envelope could be widened without any impact on handling quality and aircraft safety.

However, the handling quality of some "nose heavy" aircraft are already rather limiting. It would penalize the loading to set a more aft limit and in this case, the forward limit corresponds to the handling qualities limitations.

Structural limit :
Nose gear strength

Handling quality limits

Compromise Performance/Loading

Limit shift due to the compromise between performance and loading

For some aircraft and for high TOW the compromise Performance/Loading tends to favour performance more than for low TOW.
In aircraft operations the TOCG positions in this area are hardly reached because of loading procedures and fuel vector shape.
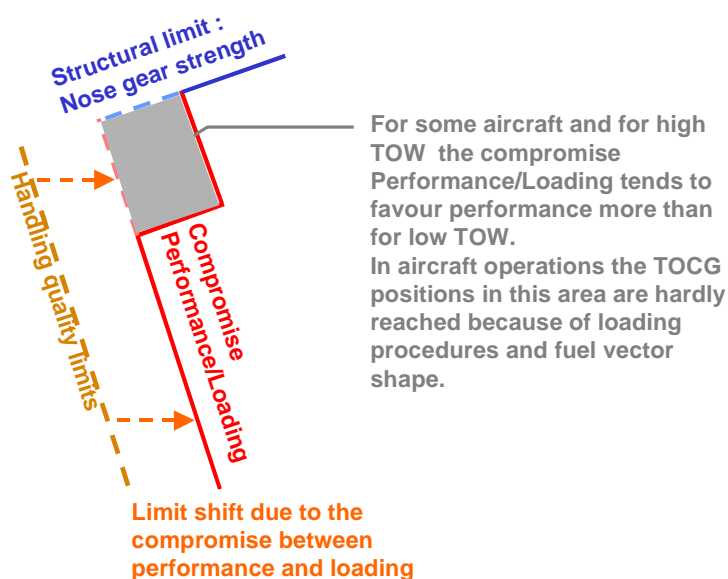
b) Aft limit

The design of the aft limit takes into account the following:
- Main gear strength
- Nose gear adherence
- Take-off rotation (Tail strike)
- Stability in steady flight and during maneuvers
- Go-around and Alpha Floor (final approach in case of emergency landing).

Those limitations are classified as handling quality and structural limitations

> ✎**From the performance point of view the aft limit of the envelope must stay as aft as possible.**
> ✎ **From the loading point of view the aft limit must be as aft as possible.**

For aft CG limits, there is no need for a compromise between loading operations and performance.
Only the structural limitations and the handling quality will be taken into account when establishing the aft limit of the CG envelope.

Structural limit :
Main gear strength

Handling quality :
Low speed configuration
(Alpha floor or Go around)

Handling quality :
Nose gear adherence
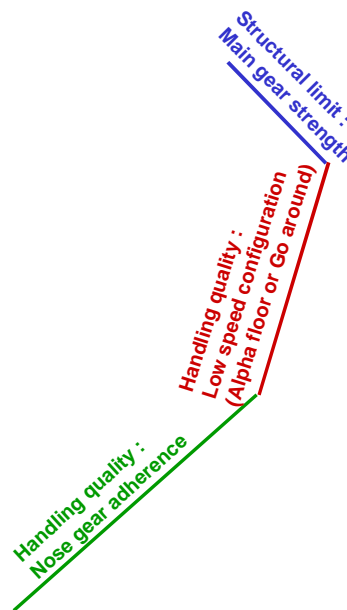
4.7.2. Landing limits

The limitations that apply for take-off also apply for landing.
Nevertheless at landing the aircraft weight is lower than at take off so some limitations are not as restrictive as for take off.
In addition the nose wheel adherence does not generate a limitation.

a) Forward limit

The forward landing envelope is superimposed on the take off one.

b) Aft limit

The aft landing envelope could usually be set aft of the take off one (less restrictive) . Depending on the aircraft type and on the fuel vector shape it might be useful or not to extend the landing aft limit, so the aft landing envelope is :
   −   either superimposed of the take off one, (fig1)
   −   or set aft of the take off one (fig 2).

Fig1   **Fig2**

4.7.3. In flight limits

a) Forward limit

The design of the forward limit takes into account the following:
- Fuel consumption
- Efficiency of the elevator
- THS stall

b) Aft limit

The design of the aft limit takes into account the following:
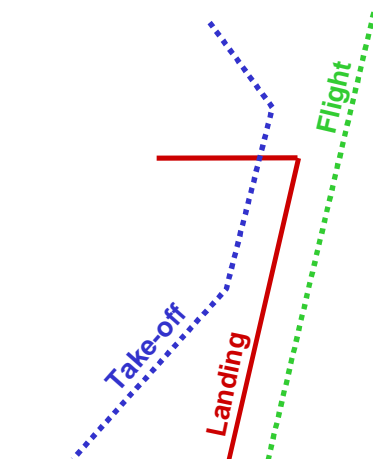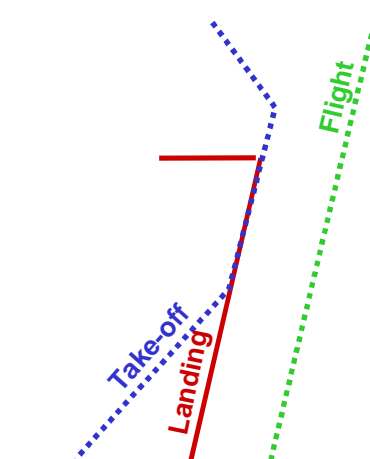- Point at 1° per g.
- Stability in steady flight and during maneuvers
- Go-around and Alpha Floor

Those limitations are classified as handling quality and structural limitations

> ✎From the performance point of view the forward and aft limit of the envelope must stay as aft as possible to reduce fuel consumption.
> ✎ From the loading point of view the operational limit must be as wide as possible.

Usually the in-flight phase is less limiting than the take-off one as limiting factors such as high weights; low speeds and TOGA are specific to take-off phase.
During cruise (flight phase), the passenger movements modify the aircraft CG, so during this phase to check the aircraft CG against the in flight envelope those slight CG position modifications must be taken into account.

Consequently, the in-flight envelope is chosen with respect to the take-off one.
- Opening this envelope as much as possible is useless as the CG is constrained by the T/O phase.
- Choosing the in-flight envelope of the same size as the take-off one is too restrictive. Indeed, because of the passenger movements during cruise the in flight envelope becomes more limiting than the take off one.

That is why the in-flight envelope is usually deduced from the take-off one and wider from roughly 1 or 2%.

Note : the nose gear adherence limitation is not taken into account for the determination of the aft limit.

4.8. SUMMARY : CG ENVELOPES

4.8.1. TAKE-OFF
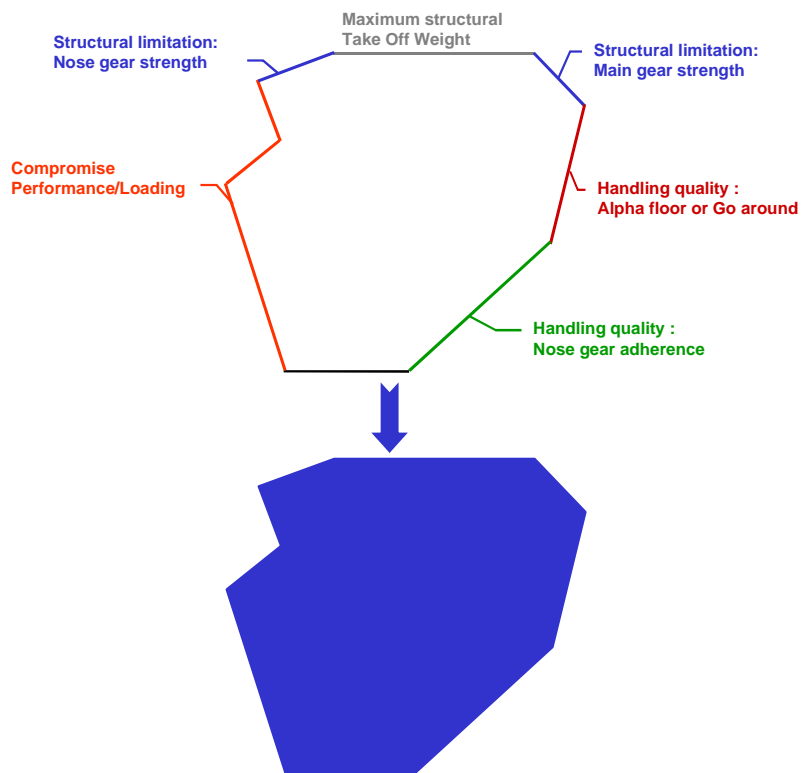
4.8.2. LANDING

4.8.3. IN FLIGHT

Maximum structural Take
Off Weight

Structural limitation:
Main gear strength

Structural limitation:
Nose gear strength

Handling quality :
Alpha floor or Go around

Compromise
Performance/Loading

Handling quality :
Nose gear adherence
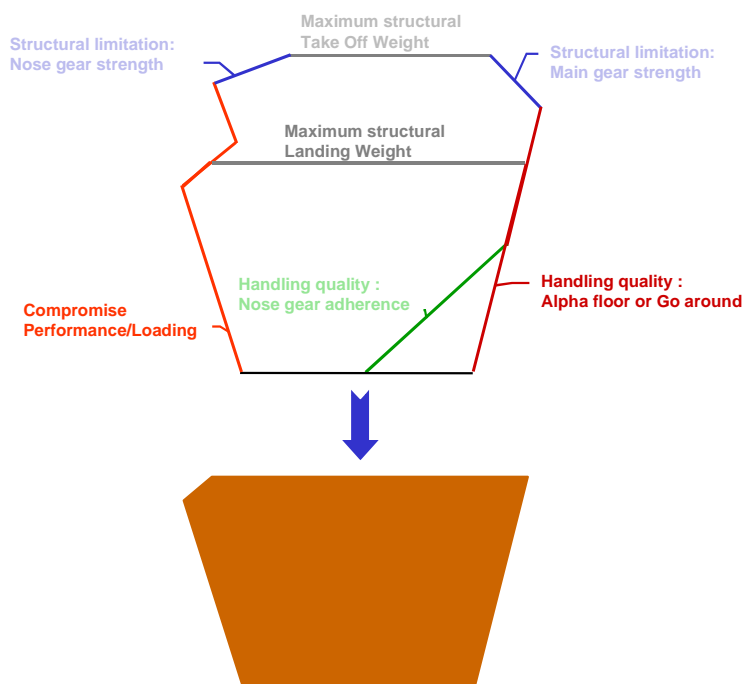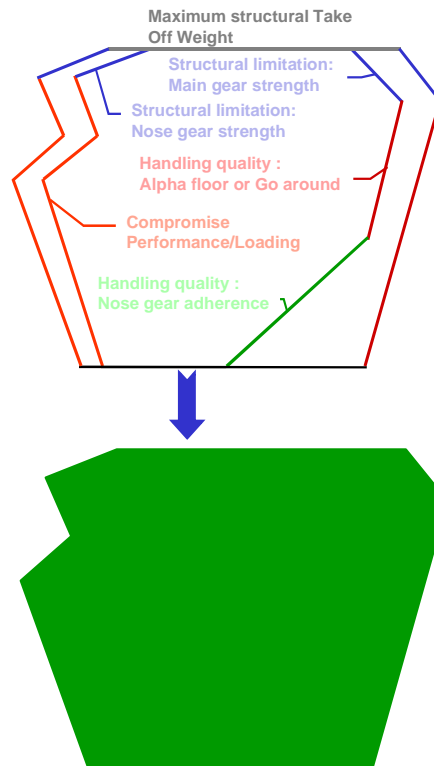
4.8.4. AIRCRAFT CERTIFIED ENVELOPE
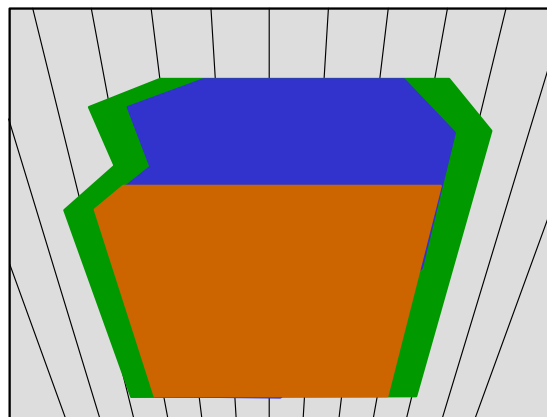
WEIGHT AND BALANCE MANUAL INTRODUCTION

The Weight and Balance Manual is the reference as far as weight, balance and loading are concerned. It is the document released by the manufacturer and given to the operator with the aircraft that contains all necessary information to determine loading instructions or to produce the Load and Trim Sheet.

The purpose of this chapter is to present the information included in the WBM.
This document is divided into three sections :

- 0.00 Arrangement of introduction pages, which contains all the pages describing the manual (Table of contents, List of figures …),
- 1. Weight and balance control, which describes generic weight and balance data for the concerned aircraft,
- 2. Aircraft weighing reports, which gives the results of the aircraft weighing (Operating Empty Weight and corresponding CG position).

WEIGHT AND BALANCE ENGINEERING

B. WEIGHT AND BALANCE MANUAL

1. SECTION 1 : WEIGHT AND BALANCE CONTROL

This section is divided into ten parts.

1.1. 1.00: GENERAL

This part of the WBM presents first generic information such as a **list of abbreviations, different weight definitions** and **conversion factors**.

Then it provides drawings and a description of the general characteristics of the aircraft.

- **ex A330-200: page 1.00.05, main aircraft dimensions**
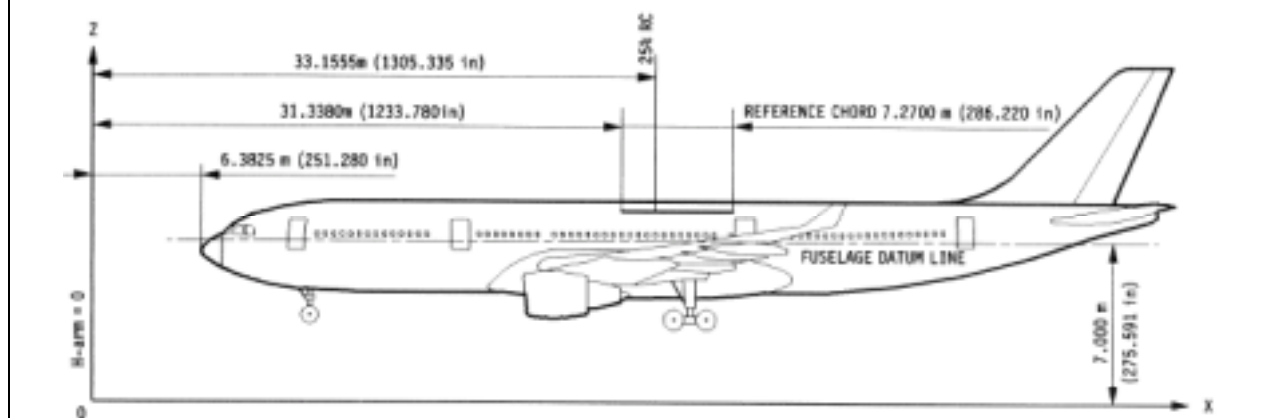
Two other pieces of information can be found in section 1.00 :

– An important graph on page 1.00.09: **the stabilizer trim wheel setting**. This graph enables to determine the correct trim setting according to the aircraft CG prior to take-off.

09. Stabilizer trim wheel setting

Stabilizer trim wheel setting at take-off may be derived from the figure below for all weights and all configurations.

– The **effect of moving components** (1.00.10) is used to determine the influence of the landing gear retraction and/or flaps/slats extension on the aircraft CG position (see B3.1 Principle of Error calculation).

- **ex : A330-200**

  C. Landing gear retraction

  Nose landing gear   =   – 1 018 kgm
  Main landing gear   =   – 5 659 kgm

  NOTE : *The aircraft is weighed with slats, flaps and thrust reverser retracted.*

1.2. 1.10: LIMITATIONS

This chapter deals with the different weight and balance limitations applied to the aircraft.

The first ones are **certified limits**, i.e. the maximum weights (1.10.01) and the certified CG limits (charts and diagrams 1.10.02). These certified CG limits are the starting point for the determination of the operational flight envelope.

- **ex : A330-200**

Other limitations are linked to payload carriage:
  – the permissible limits for **shear loads and bending moments** due to payload (1.10.03) and
  – the maximum weights that can be transported or loaded on cabin floor or on cargo compartment floor (1.10.04 **floor loading limits**).

- **ex : A330-200**

  > **D. Rear (bulk) cargo hold (compartment 5) floor**
  >
  > **(01) Structure**
  >
  > The floor structure is capable of supporting, via the floor panels in the flat and sloping floor areas, a maximum distributed load of 732 kg / sqm (150 lb / ft²), provided the requirements of paragraphs 1.10.07 and 1.60.05 are met.
  >
  > **(02) Panels**
  >
  > Each floor panel is capable to withstand a local load of 272 kg (600 lb) acting on an area of at least 0.093 m² (1 ft²), and a walking load of 91 kg (200 lb) acting on an area of at least 645 mm² (1 in²).
  > The local loads must be separated from each other in such a way that the floor structure load limitations as stated above are not exceeded, as well as the maximum compartment loads, refer to paragraph 1.10.07.

  – the paragraphs 1.10.05 to 1.10.07 deal with **cargo compartment loading** and give rules and recommendations for weight limitation, location, tying down of each load type (number of containers, maximum weight, load factors, …) and additional limitations in case of latch failure(s).

- **ex : A330-200**

  > **60.4 × 61.5 inches half size container and pallet latching in forward cargo hold, continued**

LATCH TYPE	FRAME POSITION OF LATCH	ULD CONCERNED POSITION	LATCH FAILURE	ULD WEIGHT REDUCED TO (kg)	(lb)	REMARK
▮	20/21 RH	11R	1 unit	0	(1)	
	20/21 LH	11L	1 unit	No Reduction		
			2 or more units	0	(1)	
◍	26/29 31/32 37.1	12R/L and 13R/L 13R/L and 21R/L 22R/L and 23R/L	1 unit	0	(1)	

Last paragraphs deal with aircraft stability during weighing and loading:
- 1.10.08 : **maximum jacking loads**
- 1.10.09 : **aircraft stability on jacks**
- 1.10.10 : **aircraft stability on wheels**

1.3. 1.20: FUEL

This chapter of the WBM describes the influence on the aircraft CG position of the use of the fuel systems (refueling and fuel burn).

The first part (1.20.01) describes briefly the aircraft fuel system : the arrangement of the tanks and the collector positions, fuel circulation within the different tanks during refueling and defueling.

The last part of the introduction is the following :

- **A310, A320 family, A330/340 family**

  ### C. Fuel volume, density and weight

  All fuel quantities in this manual are given in liters.

  All fuel weights are based on a fuel density of 0.785 kg per liter unless otherwise stated.

  NOTE : *Variations in actual fuel density due to specific gravity and temperature may result in large weight variations relative to those given in this manual.*

- **A300, A300-600**

  C. Fuel volume, density and weight

  All fuel quantities in this manual are in liters, and all fuel weights are based on a fuel density of 0.782 kg per liter unless otherwise specified.

It is important to note the value of the density used in the WBM, because *variations in actual fuel density due to specific gravity and temperature may result in large weight variations relative to those given in the manual.*

The second part (1.20.02) of the chapter details the aircraft **refueling of tanks** sequence :

- **ex : A330-200**

  ### 02. Refueling of tanks

  Refueling is accomplished through two couplings, mounted side by side under the leading edge of the right hand wings.

  The filling of tanks during automatic refueling is performed simultaneously. Refueling is controlled in stages to ensure that a fuel distribution as close as possible to that required is acheived, and that the following order of priority is maintained :

  A. Inner tanks are fueled to 3 000 kg per side.

  B. Outer tanks are fueled to high-level shut-off.

  C. Inner tanks are fueled to 15 385 kg per side.

  D. Trim tank is fueled to 2 400 kg.

  E. Inner tanks are fueled to high-level shut-off.

  F. Trim tank and center tank are fueled simultaneously, to high-level shut-off.

Using this sequence it is possible to determine for each fuel quantity on board the aircraft, how much fuel each tank contains.
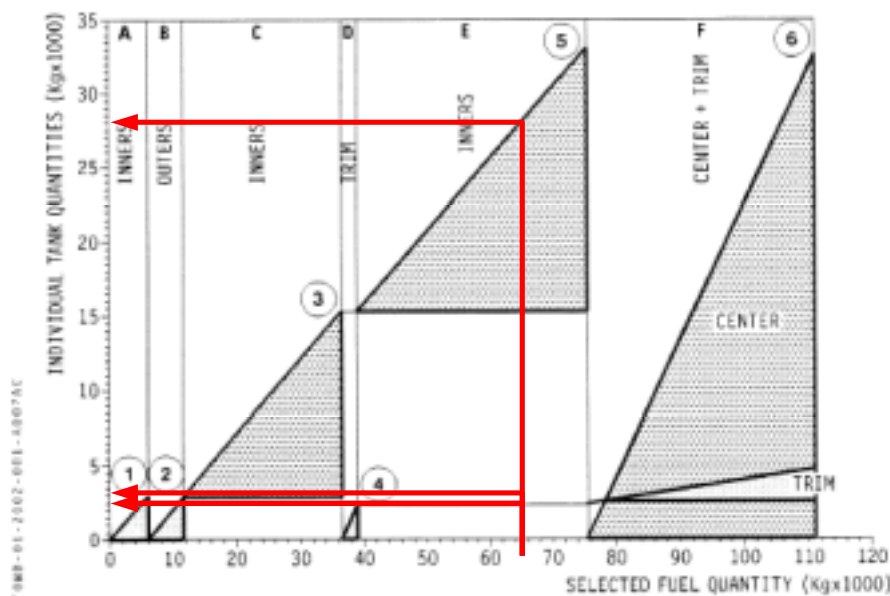
- **ex : A330-200**

Selected Fuel quantity 65 000 kg
       25 650 kg per inner tank
       outer full : 2 865 kg per outer tank (density : 0.785 kg/l)
       0 kg in center tank
       2 400 kg in trim tank

Points ①, ③ and ④ are fixed points in kg irrespective of fuel density.

Points ②, ⑤ and ⑥ are variables depending of fuel density.

Refueling is automatically stopped by the Fuel Control and Monitoring System (F.C.M.S) when the selected quantity of fuel has been delivered.

The H-Arm of the fuel as a function of the quantity, after the refueling sequence, is shown in figure 1-20-02A.

As noted below the graph in this example :
– Points ①, ③ and ④ are fixed in weight (kg or lb) irrespective of fuel density.
– Points ②, ⑤ and ⑥ are variable depending of fuel density.
This explains why for one selected fuel quantity there might be more or less fuel in a given tank depending on the fuel density value.

This is particularly appreciable for A330/340, A310 and A300-600R aircraft that is to say aircraft with fuel tank in the horizontal stabilizer.

In addition to the above graph, a second graph presents the variations of the CG position of the fuel loaded on aircraft and a table gives all the coordinates of this graph.

Note : the table and the corresponding graph are designed for the WBM standard fuel density (0.785 kg/l or 0.782 kg/l), whenever this table needs to be done for another density all break points (cf example points ②, ⑤ and ⑥) that depend on fuel density have to be recalculated with the corresponding fuel quantities.

The third part of the chapter details the **usable fuel** (1.20.03) quantities and the corresponding H-arm values for each tank. This paragraph data is independent of the fuel density value.

- **ex : A330-200**

OUTER TANK (PER SIDE)

Quantity (l)	H-arm (m)	Y-arm (m)
200	37.386	18.020
400	37.494	18.144
600	37.556	18.229
800	37.610	18.313
1 000	37.655	18.390
1 200	37.705	18.480
1 400	37.742	18.547
1 600	37.806	18.669
1 800	37.856	18.767
2 000	37.926	18.898
2 200	37.986	19.014
2 400	38.062	19.158
2 600	38.135	19.295
2 800	38.212	19.439
3 000	38.295	19.592
3 200	38.378	19.745
3 400	38.463	19.902
3 600	38.555	20.069
3 650	38.579	20.111

Note 1: For inner and outer tanks the quantity is given per side.
Note 2: In addition to the tables graphs showing the Fuel CG H-arm and Y-arm are provided.

Last paragraphs deal with:
- 1.20.04 : **Unusable fuel**
- 1.20.05 : **Unpumpable fuel**
- 1.20.06 : **Defueling procedure prior to weighing**

1.4. 1.30: FLUIDS

This section contains information on the fluids on board the aircraft:

- Engine fluids
- APU oil
- Hydraulic systems fluids
- Potable water
- Toilet fluids

The WBM gives information on the weight and the H-arm of the fluids.

- **ex : A330-200**

  A. **Engine Oil**

LOCATION	QUANTITY		WEIGHT		H-ARM	
	(l)	(US gal)	(kg)	(lb)	(m)	(in)
Engine 1	35	9.25	35	77.16	27.953	1100.51
Engine 2	35	9.25	35	77.16	27.953	1100.51

1.5. 1.40: PERSONNEL

This section contains weight and balance information for the **flight crew, the cabin crew and the passengers.**
For each category the H-arm of each person is given. The CG of each person is considered to be in the middle of the seat.

The drawing of the cabin layout is on page 3 of section 1.40.03.
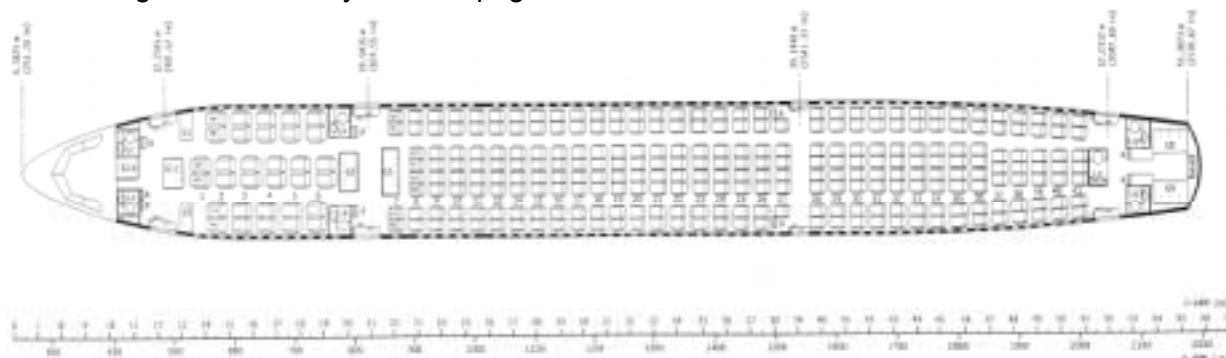
In section 1.40.04 the position of all passenger seat rows is given.

Row N°	WINDOW SEATS (lines A,C,H,K)				CENTER SEATS (lines D,E,F,G)		
	H-ARM		NUMBER PAX		H-ARM		NUMBER PAX
	(m)	(in)	LH	RH	(m)	(in)	
1	–	–	–	–	13.885	546.65	2
2	14.520	571.65	2	2	14.901	586.65	2
3	15.536	611.65	2	2	15.917	626.65	2
4	16.552	651.65	2	2	16.933	666.65	2
5	17.568	691.65	2	2	17.949	706.65	2

Last section **in-flight movements** (1.40.05) describes the method to determine the influence of in flight movement on the aircraft CG position.

1.6. 1.50: INTERIOR ARRANGEMENT

This section on the WBM contains information on the different **stowage capacities** in the aircraft: the flight compartment stowage, cabin overhead stowage compartment, galleys with their contents (trolleys, boilers…), toilets and the cabin stowage compartments.

In short, it describes all locations where some weight can be added in the upper deck area. For each location, the CG position of the weight is given as well as the maximum weight allowed.

Note: for some stowage areas the maximum load value includes the stowage device weight (galleys, cabin stowage compartments,…).

1.7. 1.60: CARGO

This section of the WBM deals with **cargo loading**.

After a brief description of the cargo area division in holds, the first section (1.60.02) details the **cargo hold doors opening sizes and stations**.

Then each cargo hold is fully described (1.60.03 forward hold, 1.60:04 aft hold, 1.60.05 bulk hold) :

– Description of each loading device that can be loaded in the hold with its dimensions and position,
– Tie down points identification and positions of the nets for bulk loading,
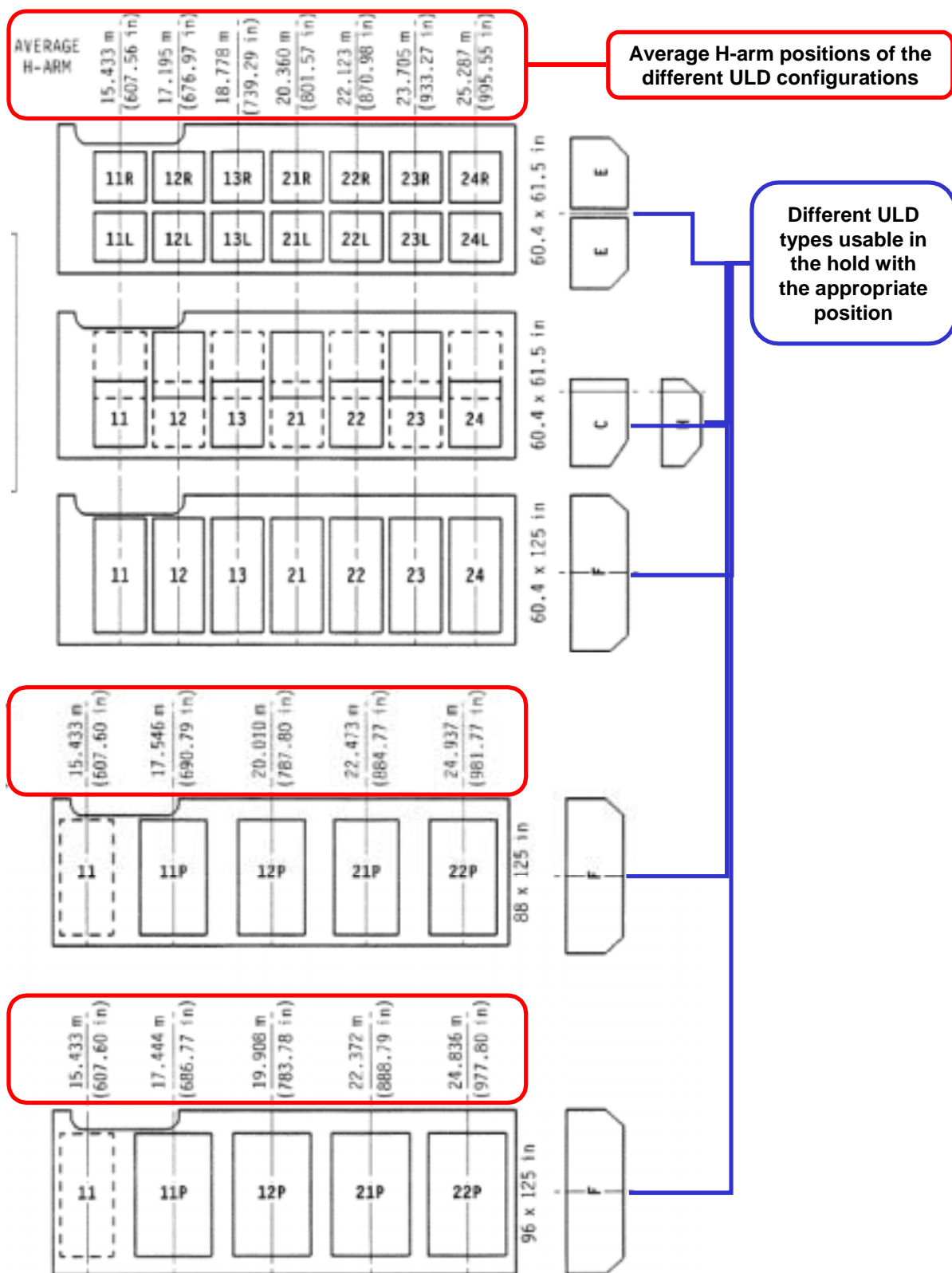– Limitations concerning package dimensions.

Note : all information on cargo weight limitation is provided in chapter 1.10 LIMITATIONS.

The last sections deal with methods and recommendations for cargo loading :

– Tie down method (method used to determine the number of tie down points to be used for each cargo weight),
– Gantry pallet transportation,
– Split engine transportation,
– Live animals transport,
– Container transport,
– Pallet transport.

Note : the above mentioned paragraph can be present or not depending on the cargo option of the aircraft.

- **Ex : A330-200**

Average H-arm positions of the different ULD configurations

Different ULD types usable in the hold with the appropriate position

1.8. 1.80: ACTIONS ON GROUND

This section contains information on jacking points, weighing on jacks or on wheels, and CG calculations.

It first describes the **Weighing point locations** (1.80.02) and then gives all formulae necessary to the calculation of the weight and CG of an aircraft **weighed on wheels** (1.80.04) and **weighed on jacks** (1.80.05).

Section 1.80.06 gives the **Equipment/component removal list**: information on weight and H-arm of equipment normally removable from the aircraft for maintenance purposes. These equipment are parts of the wing (slats, flaps…), part of the engine pylon and nacelle, doors,…

1.9. 1.90: Examples

01. General

This section contains :

– an example of operational empty weight and CG buildup,

– the vectors of cargo, passengers and fuel,

– a typical loading diagram.

Note 1 : the examples presented in this section are valid only for the balance scale presented in 1.00.05.

Note 2 : the Typical loading diagram (1.90.04) is drawn on the aircraft certified limits diagram. It should be drawn on the operational limits diagram to take into account the aircraft CG movements due to CG determination errors and moving part transfer during flight.

2. SECTION 2 : WEIGHT REPORT

This chapter contains the **documents supplied with the aircraft at delivery:**

- 2.10 : **Delivery weighing report** which contains data to establish aircraft Operational Empty Weight (OEW) and Manufacturer Empty Weight (MEW) and corresponding CG positions.
- 2.20 : **Weighing check list** which describes each item position and unit weight. In case the item is not present during aircraft weighing it should be mentioned in this section.
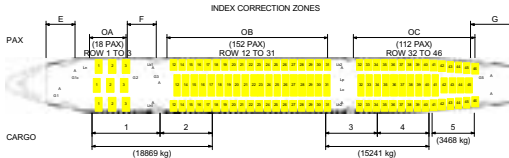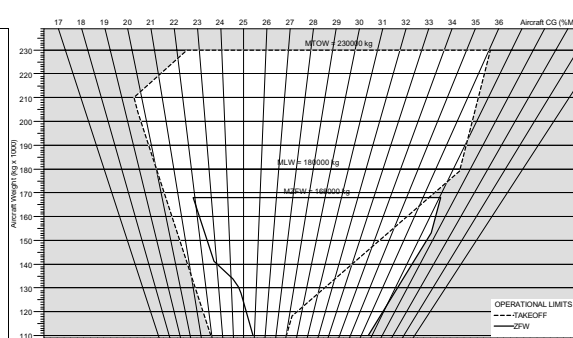
07. OEW and MEW established from weighing

A. Operating Empty Weight (OEW)

ITEM DESCRIPTION	WEIGHT (kg)	H-ARM (m)	MOMENT (kgm)
Basic corrected weight (paragraph 06)			
Operator's items missing (detailed in the weighing check list)			
OEW — H-arm = % RC = (H-arm − 31.338)/0.0727			

BALANCE CHART DESIGN INTRODUCTION

The purpose of this section is to detail the whole process that leads to the production of a balance chart and of the corresponding AHM560. It first describes the calculation tools that are used (moment and index), then the calculation of the influence on aircraft CG of any item loading and finally the method to determine the aircraft operational limits.

C. BALANCE CHART DESIGN

1. MOMENT AND INDEX DEFINITIONS

The purpose of the balance chart is to give an "easy way" to determine the influence on aircraft CG position of the loading of any item (passenger, cargo load, fuel, …).
This "easy way" consists in introducing the notions of aircraft moment and item moment and consequently in defining the index.

1.1. Moment

a) 1 Item moment :

Moment = Weight $\times$ Distance from item CG position to Reference axis

W = item weight

H-arm = item CG position
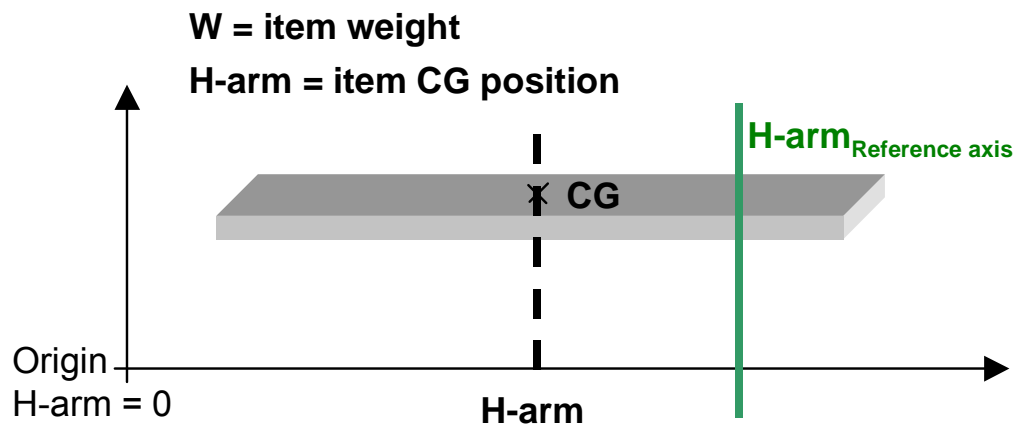
$$\text{Moment} = \text{Weight} \times \left(\text{H} - \text{arm}_{\text{Item}} - \text{H} - \text{arm}_{\text{Reference axis}} \right)$$

Note : in the whole process the moment notion has been simplified, normally a moment is determined by a Force multiplied by a distance. In this case the Force is simplified to the Mass of aircraft.
Note : As common vocabulary uses Weight term instead of Mass, the wording is kept throughout the document.

b) (Item1 +Item2) moment

$$\text{Moment}_{(\text{Item}_1+\text{Item}_2)} = \text{Moment}_{\text{Item}_1} + \text{Moment}_{\text{Item}_2}$$

C. BALANCE CHART DESIGN

c) HOW TO DETERMINE THE CG position of the set (Item+Additional item) ?

Item
weight = W
CG position = h-arm$_{Item}$

Additional item
weight = w
CG position = h-arm$_{Additional item}$

Item + Additional item
Final Weight = W + w'
Final CG position = h-arm$_{Item + Additional item}$
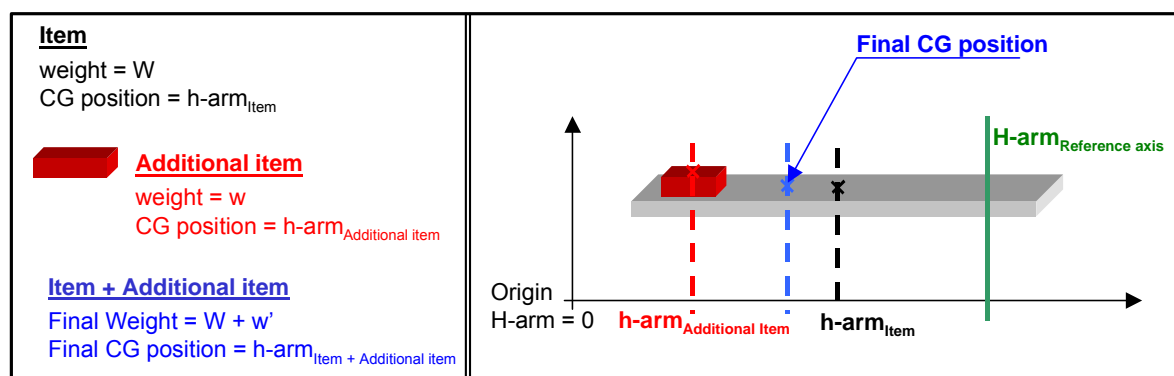
Moment$_{item}$ = W x (H-arm$_{Item}$ - H-arm$_{Reference axis}$)
Moment$_{additional item}$ = w' x (h-arm$_{Additional item}$ - H-arm$_{Reference axis}$)
Moment$_{item+additional item}$ = (W+w') x (H-arm$_{Item+Additional item}$ - H-arm$_{Reference axis}$)

$$\textbf{Moment}_{\textbf{Item+Additional Item}} = \textbf{Moment}_{\textbf{Item}} + \textbf{Moment}_{\textbf{Additional Item}}$$

(W + w') x (H-arm$_{Item+Additional item}$ - H-arm$_{Reference axis}$) = W x (H-arm$_{Item}$ - H-arm$_{Reference axis}$) + w' x (h-arm$_{Additional item}$ - H-arm$_{Reference axis}$)

$$\text{H-arm}_{Item + Additional\ item} = \frac{W \times \text{H-arm}_{Item} + w' \times H - \text{arm}_{Additional\ Item}}{W + w'}$$

d) ZFCG and TOCG determination

So to determine the aircraft Zero Fuel and TakeOff CG positions we can use the following :

$$ZFCG = \frac{\text{Moment}_{empty\ aircraft} + \text{Moment}_{on\ board\ passenger} + \text{Moment}_{loaded\ cargo}}{\text{WEIGHT}_{Zero\ Fuel}}$$

$$\textbf{TOCG} = \frac{\textbf{Moment}_{empty\ aircraft} + \textbf{Moment}_{on\ board\ passenger} + \textbf{Moment}_{loaded\ cargo} + \textbf{Moment}_{fuel\ on\ board}}{\textbf{WEIGHT}_{Takeoff}}$$

To calculate each moment individually, a common reference axis has to be fixed. For all Airbus current aircraft the reference has been set for standard balance chart design at **25% of Mean Aerodynamic Chord** as it is approximately in the middle of the certified envelopes of Airbus aircraft.
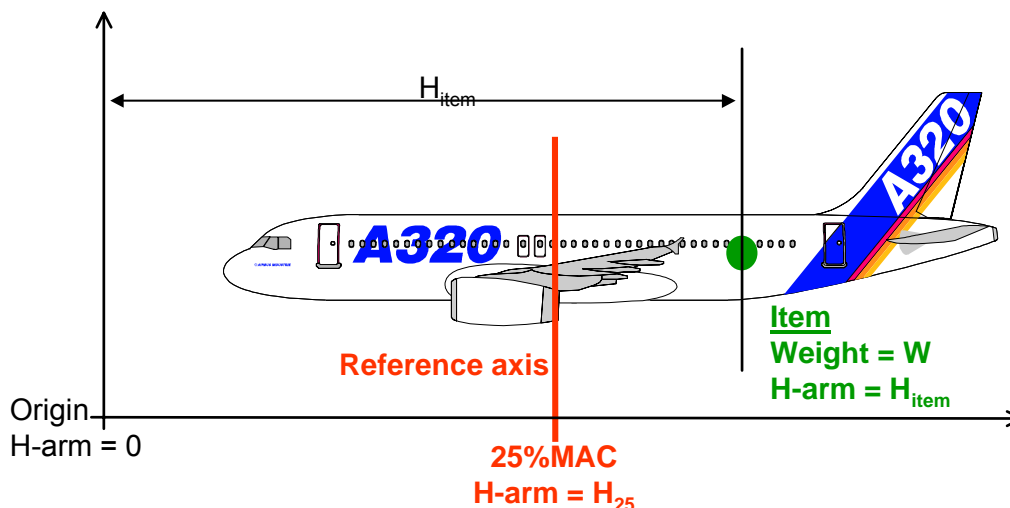
$$\text{Moment}_{item} = W \times (H - arm_{item} - H_{25})$$

Note : If an item is loaded forward to the reference the resulting moment will be a negative value (<0).
If an item is loaded forward to the reference the resulting moment will be a positive value (>0).

Note 2 : For the A380 as the certified limits will be more aft than for the other Airbus fleet aircraft the reference will be set at 35% of Mean Aerodynamic Chord.

Nevertheless, the figures obtained when calculating each moment individually are very large and consequently not easy to manipulate. In order to reduce the figures of moments to a more workable magnitude, we use the Index.

1.2. Index

a) Definition

The index is a means to both reduce figures manipulated by the user, and represent the weight and the location of each item.

$$\boldsymbol{Index}_{item} = \boldsymbol{I}_{item} = \frac{\boldsymbol{Moment}_{item}}{\boldsymbol{C}} + \boldsymbol{K} = \frac{\boldsymbol{W} \times (\boldsymbol{H} - \boldsymbol{arm}_{item} - \boldsymbol{H})}{\boldsymbol{C}} + \boldsymbol{K}$$

It is a value with no unit. In the following chapter it may appear as IU : Index Unit.
Two constants appear in this formula:
C: constant that allows having more workable figures. It has the same units as the moment (kg.m or lb.in).
K: constant that is set so that the final ZF and TO index value is never negative.

The value of these constants depends on the aircraft type and on the airline policy. But usually, Airbus applies the following constants to its aircraft:

		A300B2 / A300B4	A300-600 / A310	A318	A319 / A320 / A321	A330 / A340	A340-500 / A340-600
C	(kg.m)	2 000	1 000	500	1 000	2 500	5000
	(lb.in)	200 000	100 000	40 000	100 000	200 000	500 000
K		50	40	50	50	100	100

Note : two different index formulae can be used depending on the unit of item H-arm : length (m or in) or %MAC.

$$Index = \frac{Weight \times (H - arm_{Item} - H_{25})}{C} + K = Weight \times (\%MAC_{item} - 25) \times C' + K$$

$$with : C' = \frac{Length\ of\ RC}{100 \times C}$$

b) ΔIndex : Index variation for any additional item loaded

For any item loaded on board the aircraft, the index variation due to this specific loading can be determine

$$\Delta Index_{Additional\ Item} = \frac{Moment_{Additional\ Item}}{C}$$

c) ZF Index and TO Index determination

So to determine the aircraft Zero Fuel and TakeOff index we can use the following :

$$ZF\ Index = Index_{empty\ aircraft} + \Delta Index_{on\ board\ passenger} + \Delta Index_{loaded\ cargo}$$

$$TO\ Index = Index_{empty\ aircraft} + \Delta Index_{on\ board\ passenger} + \Delta Index_{loaded\ cargo} + \Delta Index_{fuel\ on\ board}$$

Then it is possible to determine the moment corresponding to the resulting index and then the corresponding CG position.

In the following paragraph, the method to determine the ΔIndex for any item loaded on the aircraft is detailed (passengers, cargo, fuel, additional catering…).

2. INDEX VARIATION CALCULATION (ΔINDEX)

The index variation calculation is used to fill in the AHM560 document and to design the Balance Chart.

2.1. ΔIndex for one item

$$\Delta Index_{item} = \frac{Moment_{item}}{C} = \frac{Weight_{item} \times (H-arm_{item} - H_{25})}{C}$$

ΔIndex is calculated for any person or item that can be loaded on board the aircraft.
In the AHM560, ΔIndex figures are usually given for 1 kg (or 1 lb) of weight.
$Weight_{item} = 1$ and $H-arm_{item}$ is read in the Weight and Balance Manual.

2.2. ΔIndex for additional crew member

WBM 1.40 Personnel chapter gives information on the position of all the flight and cabin crew seats.

- **Ex : A330-200 additional Flight crew member**

02. **Flight crew members**

The flight compartment arrangement is shown in figure 1-40-02.

The flight compartment accommodates four occupants :
– Two pilots (Captain and first officer),
– Third occupant : located at the rear of the pedestal,
– Fourth occupant : located at the rear of the compartment on RH side.

The take-off and landing H-arm positions for the flight crew members are shown on the table below.

NUMBER SEAT	FLIGHT CREW	H-ARM (m)	H-ARM (in)
1	Captain	8.872	349.29
1	First officer	8.872	349.29
1	Third occupant	9.800	385.83
1	Fourth occupant	9.850	387.80

$H_{25} = 33.1555$ m, $C = 2500$ kg.m, $K = 100$

$$\Delta Index(1kg)_{Flight\ Crew\ Third\ occupant} = \frac{1\times(9.8 - H_{25})}{C} = \frac{(9.8 - 33.1555)}{2500} = -0.00934\ IU/kg$$

So for one additional person in the cockpit (85 kg) : $\Delta Index(85kg) = -0.794\ IU$

Note 1: the calculation principle is the same for cabin crew members.
Note 2: in the AHM560, for cockpit crew members information is displayed as shown below.

5. **COCKPIT**

5.1 **Number of seats and average station**

Maximum number of cockpit seats	Length of arm from reference station	Index influence per 1 kg
	meters	
4	-23.807	-0.00952

Remarks:

The ΔIndex value is given for the average H-arm of the 4 cockpit positions.

$$H-arm_{Cockpit\ average} = \frac{H-arm_{Captain} + H-arm_{First\ Officer} + H-arm_{Third\ occupant} + H-arm_{Fourth\ occupant}}{4}$$

$$\Delta Index(1kg)_{Cockpit\ average} = \frac{(H-arm_{Cockpit\ average} - H_{25})}{C}$$

2.3. ΔIndex for additional weight on the upper deck

WBM 1.50 Interior Arrangement chapter describes the different stowage capacities in the flight and cabin compartments, the galleys and the toilets. This section gives information on the H-arm of each item: flight compartment stowage, overhead stowage compartments, cabin stowage compartments, galleys, toilet.

- **Ex : A330-200 galleys capacities and positions**

04. Galleys

The galley locations are shown in figure 1-40-03 (Cabin arrangement).

The table below gives the H-arm for each galley and the maximum permissible load.

LOCATION	REF N°	H-ARM		MAX LOAD	
		(m)	(in)	(kg)	(lb)
Forward cabin	G1b	10.714	421.81	510	1 124
Forward cabin	G1c	12.545	493.90	850	1 874
Forward cabin	G2	19.973	786.34	1 060	2 337
Mid cabin	G3	21.756	856.54	1 270	2 800
Aft cabin	G8	54.064	2 128.50	1 100	2 425
Aft cabin	G9	54.064	2 128.50	1 260	2 778

NOTE : *Max load is the maximum permissible load on the aircraft structure, it therefore includes the weight of the galley and its contents. It also includes the structural weights of integrated stowages. Max. load of galleys G8 and G9 also includes the weight of one each cabin attendant seat with cabin crew member.*

$$H_{25} = 33.1555\ m, \quad C = 2500\ kg.m, \quad K = 100$$

$$\Delta Index(1kg)_{G1b} = \frac{1 \times (10.714 - H_{25})}{C} = \frac{(10.714 - 33.1555)}{2500} = -0.00898\ IU/kg$$

Note : Each item H-arm represents the load CG position, it is usually located at the item barycentre.

2.4. ΔIndex for passenger boarding

WBM 1.40 Personnel chapter gives information on the H-arm of each passenger seat row CG position.
For each window seat row and each center seat row, the ΔIndex is calculated.

- **Ex : A330-200 seat row positions**

Row N°	WINDOW SEATS (lines A,C,H,K)				CENTER SEATS (lines D,E,F,G)		
	H-ARM		NUMBER PAX		H-ARM		NUMBER PAX
	(m)	(in)	LH	RH	(m)	(in)	
1	–	–	–	–	13.885	546.65	2
2	14.520	571.65	2	2	14.901	586.65	2
3	15.536	611.65	2	2	15.917	626.65	2
4	16.552	651.65	2	2	16.933	666.65	2
5	17.568	691.65	2	2	17.949	706.65	2
6	18.584	731.65	2	2	18.965	746.65	2

Note : passenger seat CG is usually located in the middle of the seat.

$H_{25} = 33.1555$ m, $C = 2500$ kg.m, $K = 100$

$$\Delta Index(1kg)_{Center\ seat\ row\ 1} = \frac{1 \times (13.885 - H_{25})}{C} = \frac{(13.885 - 33.1555)}{2500} = -0.00771\ IU/kg$$

$$\Delta Index(1kg)_{Window\ seat\ row\ 2\ LH} = \Delta Index(1kg)_{Window\ seat\ row\ 2\ RH}$$

$$= \frac{1 \times (14.520 - H_{25})}{C} = \frac{(14.520 - 33.1555)}{2500} = -0.00745\ IU/kg$$

These ΔIndex values per kg are presented in the AHM560, nevertheless on the manual balance chart it is not possible to take into account the ΔIndex of each individual row.

So the aircraft cabin is divided into several sections (usually 2 to 4 parts) and a generic influence is determined for each cabin.

- **Ex : A330-200 Cabin OA influence**
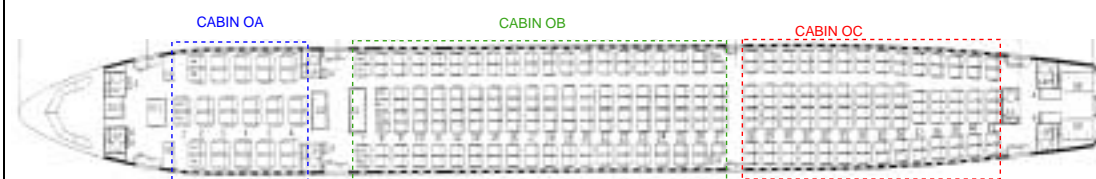
First step is to determine each cabin weighted average H-arm.

$$H-arm_{OA} = \frac{(H-arm_{C1} \times 2 + H-arm_{C2} \times 2 + \ldots + H-arm_{C6} \times 2) + (H-arm_{W1} \times 4 + \ldots + H-arm_{W6} \times 4)}{32}$$

$$= 16.5\ m$$

$$\Delta Index(1kg)_{Cabin\ OA} = \frac{1 \times (16.5 - H_{25})}{C} = \frac{(16.5 - 33.1555)}{2500} = -0.00666\ IU/kg$$

2.5. ΔIndex for cargo loading

WBM 1.60 Cargo chapter gives information on the H-arm of cargo CG position for each cargo type (container, pallets or bulk).
For each cargo type on each cargo position the ΔIndex is calculated.

- **Ex : A330-200 AFT cargo compartment positions**
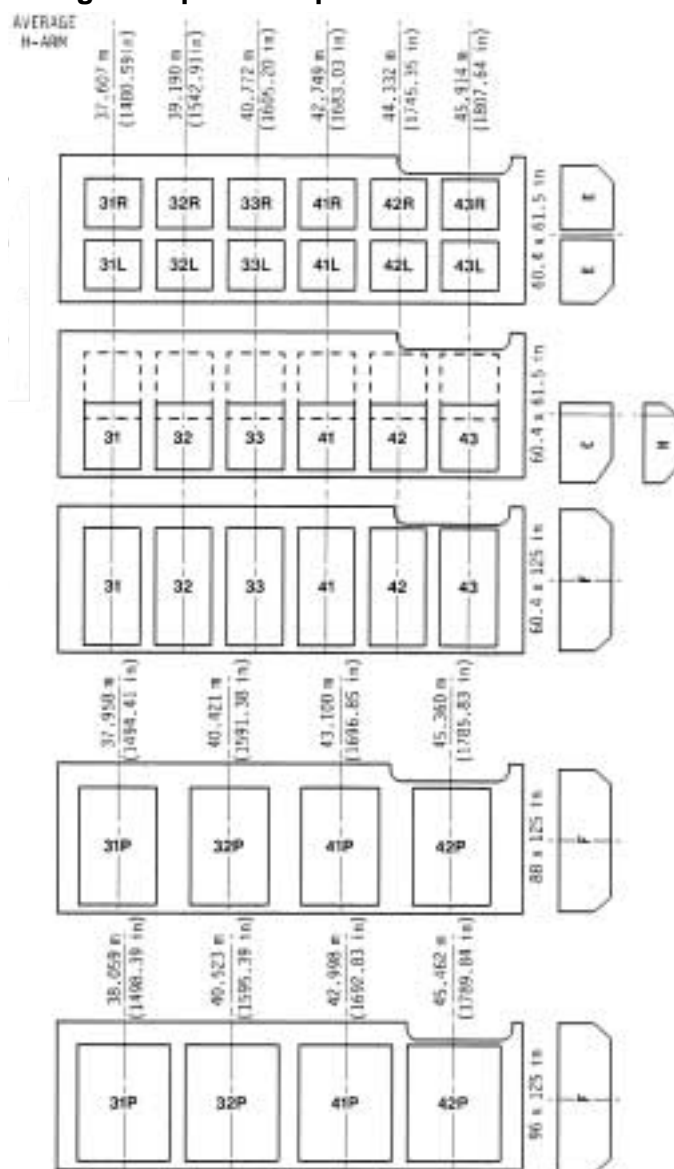
Position 31
Containers : H-arm$_{average}$=37.607 m

$$\Delta\text{Index(1kg)}_{31} = \Delta\text{Index(1kg)}_{31R} = \Delta\text{Index(1kg)}_{31L}$$

$$= \frac{1\times(37.607 - H_{25})}{C} = \frac{(37.607 - 33.1555)}{2500} = +0.00178 \text{ IU}/\text{kg}$$

Pallets 88" : H- arm$_{average}$=37.958 m

$$\Delta\text{Index(1kg)}_{31P\,Pallet\,88"} = \frac{1\times(37.958 - H_{25})}{C} = \frac{(37.958 - 33.1555)}{2500} = +0.00192 \text{ IU}/\text{kg}$$

Pallets 96" : H-arm$_{average}$=38.095 m

$$\Delta Index(1kg)_{31P\ Pallet\ 96"} = \frac{1 \times (38.095 - H_{25})}{C} = \frac{(38.095 - 33.1555)}{2500} = +0.00198\ IU/kg$$

Note : Each item H-arm represents the load CG position, it is usually located at the ULD barycentre for non bulk cargo and at the cargo position surface barycentre for bulk cargo.

These ΔIndex values per kg are presented in the AHM560, nevertheless on the manual balance chart it is not possible to take into account the ΔIndex of each individual cargo position and each individual cargo type.

So the cargo loaded is divided into cargo holds and a generic influence is determined for each hold.

- **Ex : A330-200 AFT cargo holds**
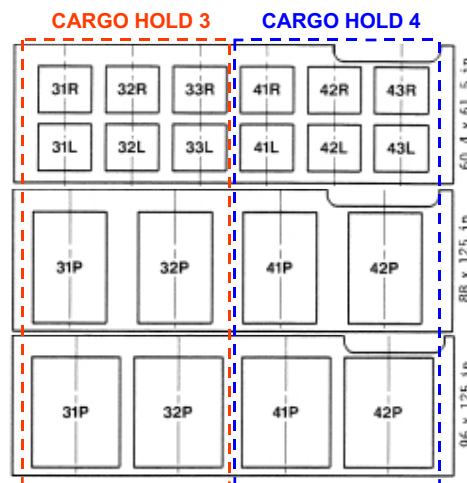
First step is to determine each cargo hold weighted average H-arm.
Containers : Max weight = 2x1587 kg = 3174 kg
Pallets 88" : Max weight = 4626 kg
Pallets 96" : Max weight = 5103 kg

$$H_{Cargo3} = \frac{(H_{31} + H_{32} + H_{33}) \times 3174 + (H_{31P\ 88"} + H_{32P\ 88"}) \times 4626 + (H_{31P\ 96"} + H_{32P\ 96"}) \times 5103}{3 \times 3174 + 2 \times 4626 + 2 \times 5103}$$

$$= 39.225\ m$$

$$\Delta Index(1kg)_{Cargo3} = \frac{1 \times (39.225 - H_{25})}{C} = \frac{(39.225 - 33.1555)}{2500} = +0.00243\ IU/kg$$

2.6. ΔIndex for fuel loading

Weight & Balance Manual section 1.20 ("Fuel") provides with information on the aircraft fuel tanks, the H-arm of the fuel in each individual fuel tank for each fuel quantity and describes the automatic refueling sequence.

From this data it is possible to determine for each total fuel quantity, on the first hand the fuel quantity that will be in each tank after the refueling sequence is completed and on the second hand the corresponding total fuel CG position. Last, for each total fuel quantity the ΔIndex is calculated.

a) Determination of the fuel distribution per tank after the refueling process

First it is necessary to know the fuel quantity in each tank depending on the total selected fuel on board. Thanks to the automatic refueling system, the fuel dispatch among the several tanks of the aircraft is automatic and leads always to the same fuel distribution in each tank for a given total fuel quantity and a given fuel density.

- **Ex : WBM A330-200 refueling sequence**

In WBM section 1.20.02 page 1, a graph (established at the standard fuel density of 0.785 kg/l) and a written procedure (irrespective of fuel density) summarize the refueling sequence: from a given total fuel quantity (in kg), the fuel quantity that will be dispatched by the automatic refueling system in each individual tank can be deduced.

For instance the automatic refueling procedure on A330-200 aircraft (equipped FCMS standard 7.0) is:
- inner tanks refueled up to 3000kg per side (to fill in the collector cells)
- outer tanks refueled to full
- inner tanks refueled up to total fuel equals 36500 kg
- trim tank refueled up to 2400 kg
- inner tank refueled to full
- trim tank and center tanks are simultaneously refueled up to full.

        Getting to Grips with Aircraft Weight and Balance
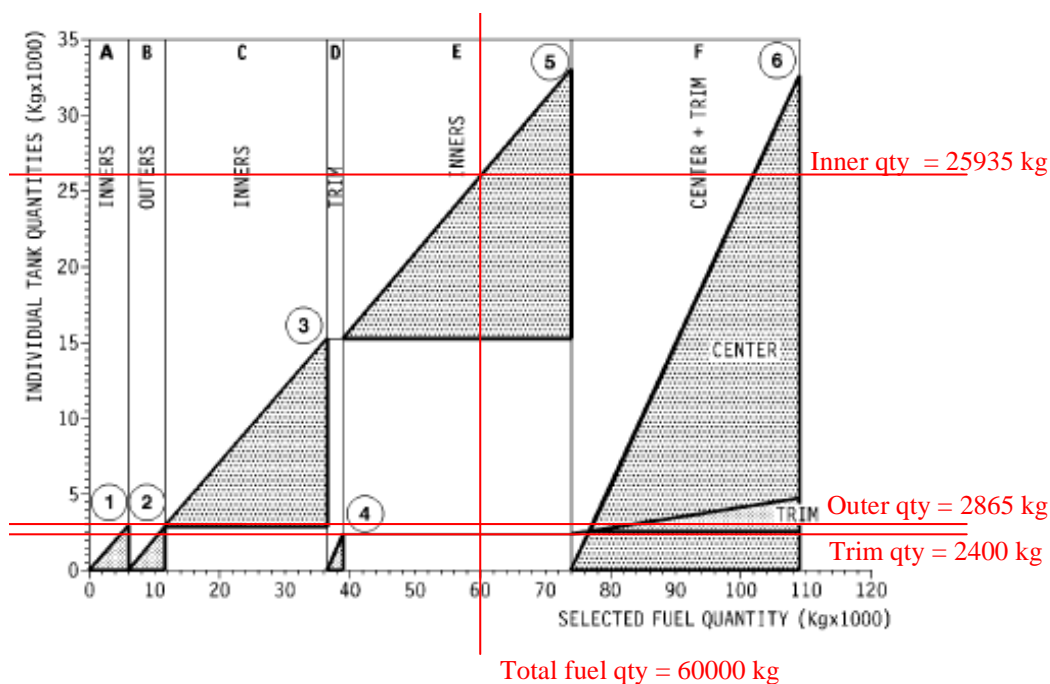
In the above example, FOB = 60000 kg. It leads to the following fuel tank distribution (when the fuel density is equal to 0.785 kg/l):

Inner (one side) : 25935 kg

Outer (one side) : 2865 kg corresponding to full outer (3650 liters) at the standard fuel density 0.785 kg/l

Trim : 2400 kg

As the automatic refueling sequence contains break points defined in volume (outer tanks are fueled to high level shut-off for instance), the corresponding fuel quantity in weight will depend on the fuel density. On the above example, if the density were 0.76 kg/l, then the outer weight would have been 2774 kg and so the inner weight would have been 26026 kg:

$$\text{Inner\_weight} = \frac{60000 - (2774 \times 2 + 2400)}{2} = 26026 \text{ kg} \quad \text{per side}$$

Consequently, the fuel weight distribution per tank depends on the fuel density.

b) Determination of the fuel CG position per tank after the refueling process

Once the fuel weight distribution per individual tank is known, the fuel CG per tank can be deduced thanks to individual fuel tank table published in WBM section 1.20.03. To do so, we need to convert the fuel weight in each tank in term of volume per tank. In fact, the fuel CG position per tank depends on the fuel volume in it.

As a general fact, because to the fuel tanks shape the fuel CG in the tank depends on the actual fuel quantity in it. .That is why WBM individual fuel tank tables give the H-arm of the tank as a function of the fuel volume.

- **Ex : WBM A330-200 Table of Fuel H-ARM Outer tanks**

Corresponding to 2865 kg at fuel density = 0.785 kg/l

Outer fuel CG position is obtained

Back to the previous example, the outer fuel quantity (one side) was 2865 kg, i.e. 3650 l at 0.785 kg/l. The corresponding H-arm is therefore 38.579 m for both outer tanks (same quantity in both tanks).
Using corresponding tables for inner and trim tanks, we can deduce:
Inner: 25935 kg centered at 31.287 m
Trim: 2400 kg centered at 59.096 m.

Thanks to these individual fuel tank tables, we can now determine the total fuel CG position equal to the weighted average of the individual tank CG positions.
Total fuel = 60000 kg
Outer (one side) = 2865 kg centered at 38.579 m
Inner (one side) = 25935 kg centered at 31.287 m
Trim = 2400 kg centered at 59.096 m

The total fuel CG position is:

$$TotalFuelCG = \frac{2 \times 2865 \times 38.579 + 2 \times 25935 \times 31.287 + 2400 \times 59.096}{60000} = 33.096 \text{ m}$$

WEIGHT AND BALANCE ENGINEERING

c) Determination of the fuel vector after the refueling process

The above process needs to be repeated for total fuel quantities from zero to full.
In the Weight and Balance Manual the result is displayed in a graph with fuel quantity in liter on vertical axis and H-ARM in meter on horizontal axis : the fuel vector.

It is important to note that this fuel vector depends on the fuel density. In fact, weight break points of the automatic refueling sequence lead to different volumes according to the fuel density and so, the shape of the fuel vector is impacted.

In the WBM, the automatic refueling fuel vector is represented only at the standard fuel density: 0.785 kg/l. To obtain fuel vector at another fuel density, the whole above process has to be repeated for different values of automatic refueling sequence break points.

- **Ex : WBM A330-200 Automatic Refueling Fuel Vector at standard fuel density 0.785 kg/l**

76433 liters
(corresponding to 60000 kg at standard fuel density)

33.093 meters
(corresponding to 60000 kg fuel CG position)
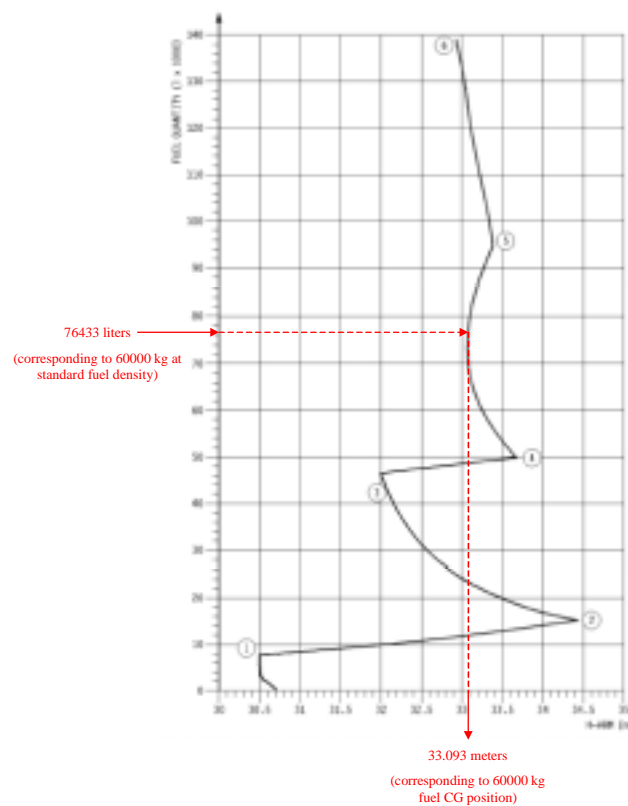
Thanks to the fuel vector and for a given fuel density (here, 0.785 kg/l), for any fuel quantity, the corresponding fuel CG position can be easily found. As per previous example, for 60000 kg FOB (equivalent to 76433 liter at fuel density 0.785 kg/l) the corresponding fuel CG position is 33.093m (as computed above).

AIRBUS

d) Determination of the fuel vector expressed in ΔIndex after the refueling process

Now, for Balance Chart production purpose, we need to have this fuel vector expressed in ΔIndex as a function of the fuel weight. This is realized converting the volume values into weight values and converting H-arm values into ΔIndex.

$$\Delta Index_{fuel\ Weight} = \frac{W_{Fuel} \times (H - arm_{fuel} - H_{Ref})}{C},$$

A new fuel vector is obtained giving for any fuel weight the impact in term of ΔIndex. As for the WBM fuel vector (expressed in H-arm as a function of the fuel volume), this new fuel vector depends also on the fuel density.

The below graph presents two fuel vectors for two different fuel densities: the standard one 0.785kg/l and a higher one 0.83 kg/l.

The differences between the two fuel vectors are due to the definition of the break points of the automatic refueling sequence. Then, these differences are more important at break points where the involved tank(s) has (have) either a great capacity or a great lever arm compared to the lever arm reference.

• **Ex : A330-200 Automatic Refueling Fuel Vector**

Fuel Vectors :
0.76 kg/l
0.785 kg/l
0.83 kg/l
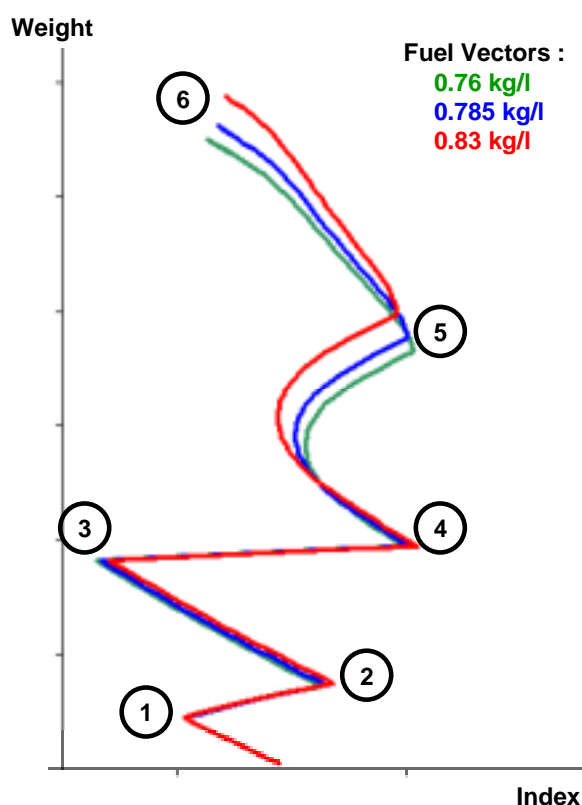
From the above graph, it can be noted that the fuel density variation has a double effect on the fuel vector:
1. A vertical distortion (weight distortion) increasing with the fuel quantity and affecting points defined in volume (2, 5 and 6)
2. A horizontal distortion (index distortion) increasing with the tank H-arm compared to H_{Ref} and affecting point defined in weight (1, 3 and 4).

---

3. OPERATIONAL LIMITS DETERMINATION

3.1. Calculation principle

The determination of the aircraft CG position using a paper or computerised trim sheet is affected by inaccuracy on the influence of item loading on the final aircraft CG position. Furthermore the aircraft CG position changes during flight because of different items moving (landing gear,…)

Before flight the aircraft CG position must be checked against the three certified envelopes. Due to the CG position uncertainties some margins must be determined between the certified envelopes and the ones used on the trim sheet : the operational limits.

CERTIFIED LIMITS	*Operational margin* →	OPERATIONAL LIMITS

On the balance chart the 3 operational limits – Takeoff, Landing and In-flight – are not represented because even if the Takeoff CG position check against its corresponding limit can be done after a manual or computerized computation, the determination of the Landing CG and furthermore the In-flight CG positions on a paper document is much more difficult, it is impossible to check these CG positions against their corresponding CG limits.
So on balance charts two operational limits are represented :
- Operational Takeoff limit
- Operational Zero Fuel limit

The Zero Fuel limit is determined to ensure that during the whole flight and at landing the aircraft CG remains within the limits.

3.2. Margins determination method

3.2.1. Method

To determine the aircraft ZFW, TOW and CG position during flight one needs to know :
- aircraft CG position and weight before loading any item
- weight and position of each item loaded on the aircraft (cargo, pax, fuel, any additional item)
- possible CG movements due to moving items during flight.

An inaccuracy on the final CG value can be introduced because of a lack of precision either on item weight, or on its location and/or CG position.
The total possible inaccuracy made on CG estimation will result of a combination of all the individual errors :
- due to initial conditions (aircraft DOW and DOCG)
- due to cargo loading
- due to passenger boarding
- due to fuel loading.

In addition to these inaccuracy sources, the method used to determine the aircraft CG may also add an inaccuracy source if it needs index rounding or index interpolation.

C. BALANCE CHART DESIGN

The aircraft ZFW, TOW and CG position computation is based on initial aircraft configuration corresponding to DOW and DOCG. Due to some item movements during the flight the aircraft configuration may change, this CG movement needs to be taken into account in the operational limits determination.

Operational margins are the sum of the total possible inaccuracy and the possible aircraft CG movements due to :

- landing gear movements
- flaps/slats movements
- water movements
- movements in the cabin.

Operational Limits
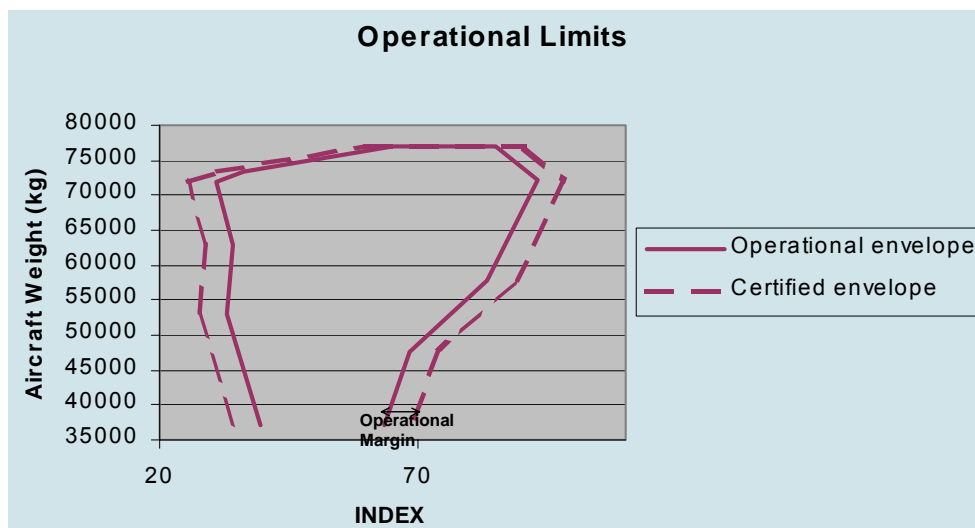
The following paragraphs detail each error and CG movement evaluation.

The method is to determine the influence that each lack of precision or each CG movement will have on the aircraft final CG position. This influence can be quantified as the difference between the trimming document final index and the index that would result of a calculation with no accuracy.

Instead of using the index value the following method uses the moment and evaluate difference between the aircraft moment determined using the trimming document (assumed) and the real one.

Operational margins = (Real Aircraft Moment) – (Assumed Aircraft Moment)

Note : inaccuracies and movements can shift the aircraft CG forward or aft. If the CG shifts forward the CG H-arm decreases and so the resulting moment also decreases. The inaccuracy shifting the CG forward reduces the aircraft total moment so this inaccuracy or movement results in a negative moment.

CG moves FWD	*moment < 0*
CG moves AFT	*moment > 0*

3.2.2. Resulting moments determination

After evaluating the individual moments corresponding to each lack of precision and/or to each movement it is necessary to determine their total effect in term of moment.
This total effect definition depends on the type of situation.

Lets consider the total effect (E) is made of several individual effects E_1, E_2...E_n.

e.g. The resulting cargo loading effect is the made of the effects due to the different cargo compartments.

> When the individual effects are **SYSTEMATIC** *(if they occur surely at each flight)* then they will **CUMULATE** and the total effect is,
> $$E = E_1 + E_2 + ... + E_n$$
> it is also said they are **NON RANDOM** or **DEPENDENT**,

> When the individual effects are **NON SYSTEMATIC** *(if they may occur or not at each flight)* then they can **COMPENSATE** and the total effect is,
> $$E = \sqrt{E^2_1 + E^2_2 + ... + E^2_n}$$
> it is also said they are **RANDOM** or **INDEPENDENT**,

When effects are non-systematic, they can compensate each other and the resulting error is always less important with independent effects than with systematic effects.

Note : Sometimes, the two types of effects may be mixed. This occurs for the final calculation per flight phase.

3.3. Inaccuracy on initial data (DOW and DOCG)

3.3.1. Dry Operating Weight (DOW) definition :

a) DOW and DOCG definition policy

At delivery each aircraft is weighed to determine its Manufacturer's Empty Weight (MEW) and the Corresponding CG position. Using these values the operator can determine the aircraft Dry Operating Weight (DOW) and the corresponding CG position of each aircraft.

When defining the DOW and DOCG to be used in the loading and trimming documents the operator has two choices:
1. considering each aircraft as independent so for each aircraft an individual set of values (DOW and DOCG) is set
2. considering a group of aircraft as being part of one fleet so one single set of values (DOW_{fleet} and $DOCG_{fleet}$) is defined and used in the loading and trimming documents. As per aviation regulations a fleet of aircraft can be defined provided that, for each aircraft of the fleet, $DOW_{aircraft}$ and $DOCG_{aircraft}$ meet the allowed deviations to the fleet values :

> A DOW maximum deviation of $\pm$ 0.5% of the aircraft Maximum Landing Weight
> A CG position maximum deviation of $\pm$ 0.5% of the Reference Chord length

Note : in other words : an aircraft can be part of a fleet as long as
$$DOW_{fleet} - 0.5\%MLW \leq DOW_{aircraft} \leq DOW_{fleet} + 0.5\%MLW$$
$$DOCG_{fleet} - 0.5\%Length\ of\ RC \leq DOCG_{aircraft} \leq DOCG_{fleet} + 0.5\%Length\ of\ RC$$

Then during the aircraft life, between two weighings, its weight and CG position can be modified following maintenance tasks or cabin interior modifications, paintings. In that case the DOW and DOCG values used to enter the loading and trimming documents should be amended.
As per aviation regulations the $DOW_{document}$ and $DOCG_{document}$ values amendment is mandatory as soon as

$$DOW_{document} - 0.5\%MLW \leq DOW_{aircraft} \leq DOW_{document} + 0.5\%MLW$$
$$DOCG_{document} - 0.5\%Length\ of\ RC \leq DOCG_{aircraft} \leq DOCG_{document} + 0.5\%Length\ of\ RC$$

b) Inaccuracy on initial data

In conclusion to the above statements, the DOW and DOCG assumed used in the loading and trimming documents is the aircraft one with a tolerable inaccuracy of $\pm0.5\%MLW$ for the weight and $\pm0.5\%$ of the Reference Chord length for the CG position.

- **Ex: A320 in the following configuration:**
    MLW = 64 500 kg,
    DOW = 39 400 kg
    RC = 4.1935 m

The weight allowance is ±0.5 % of 64 500 kg = ±322.5 kg
The CG position allowance is ±0.5 % of 4.1935m = ±0.0210 m
Then the aircraft weight and CG position can vary within the following values:
$$DOW_{document} - 322\ kg \leq DOW \leq DOW_{document} + 322\ kg$$
$$DOCG_{document} - 0.021\ m \leq CG \leq DOCG_{document} + 0.021\ m$$

3.3.2. Effect on the final aircraft CG position

The inaccuracy on the aircraft initial CG position will generate an inaccuracy on the final CG position (ZFCG or TOCG) which can be determined in term of moment (E_{DOCG})

E_{DOCG} = Real Aircraft Moment – Assumed Aircraft Moment
E_{DOCG} = DOW_{real} x (H-arm$_{real}$ – H_{25}) – $DOW_{assumed}$ x (H-arm$_{assumed}$ – H_{25})

In the following we consider that $DOW_{real} \approx DOW_{assumed}$ so
E_{DOCG} = $DOW_{assumed}$ x (H-arm$_{real}$ – H_{25}) – $DOW_{assumed}$ x (H-arm$_{assumed}$ – H_{25})
E_{DOCG} = $DOW_{assumed}$ x (H-arm$_{real}$ – H-arm$_{assumed}$)
As per regulation (H-arm$_{real}$ – H-arm$_{assumed}$) cannot exceed ±0.5% of the Reference Chord length.

$$E_{DOCG} = DOW_{assumed} \times \frac{\pm 0.5 \times Length_{Reference\ Chord}}{100}$$

Note : the effect value depends on the $DOW_{assumed}$ so each time the DOW has to be changed the effect needs to be recalculated and so the total effect on the aircraft CG determine shall be modified also. In order to avoid continuous balance documentation modification, the operator can take a weight value of ($DOW_{assumed}$ + margin) including the possible weight modifications.

$$E_{DOCG} = (DOW_{assumed} + m\arg in) \times \frac{\pm 0.5 \times Length_{Reference\ Chord}}{100}$$

- **Ex: A320 in the following configuration:**
  MLW = 64 500 kg,
  DOW = 39 400 kg
  RC = 4.1935 m

$$E_{DOCG} = (39400 + 4000) \times \frac{0.5 \times 4.1935}{100} = \pm 910 m.kg$$

3.4. Inaccuracy on items loading on board the aircraft (passengers, cargo, fuel)

Any item loaded onboard the aircraft has a given weight and location. Nevertheless, this weight and/or CG position might not be known with enough precision. So there is an inaccuracy in the determination of the delta index due to the item loading which is due to an inaccuracy on either the item weight or on the item location.

In the following paragraphs the method to determine the effect of each inaccuracy is developed.

Note : Effects are supposed to be independent : location is supposed to be accurately known to calculate the effect of the error in weight, and the weight is supposed to be accurately known to determine the effect of the error on location.

- **Inaccuracy on the item location**

The inaccuracy on the item position generates an inaccuracy on the final aircraft CG position that can be determined in terms of moment ($E_{item\ location}$).

Note : the item weight is considered to be accurately known.

$E_{item\ location}$ = Real Aircraft Moment – Assumed Aircraft Moment
$E_{item\ location}$ = (Aircraft Moment + Real Item Moment) – (Aircraft Moment + Assumed Item Moment)
$E_{item\ location}$ = Real Item Moment – Assumed Item Moment
$E_{item\ location}$ = W_{item} x (H-arm$_{item\ real}$ – H-arm$_{ref}$) – W_{item} x (H-arm$_{item\ assumed}$ – H-arm$_{ref}$)

$$\boxed{E_{item\ location} = W_{item} \text{ x } (\text{H-arm}_{item\ real} - \text{H-arm}_{item\ assumed})}$$

- **Inaccuracy on the item weight**

Each item weight is known with a certain inaccuracy (ΔW_{Item}) so for each item :
$W_{item\ real} = W_{item\ assumed} \pm \Delta W_{Item}$

The inaccuracy on the item weight generates an inaccuracy on the final aircraft weight and CG position that can be determined in term of moment ($E_{item\ weight}$).
The inaccuracy value depends on the relation between the position of the ΔW_{Item} and the assumed position of the aircraft final CG

- If the ΔW_{Item} is forward of the assumed aircraft final CG then a positive weight inaccuracy $+\Delta W_{Item}$ will move the CG forward, a negative weight inaccuracy $-\Delta W_{Item}$ will move the CG aft
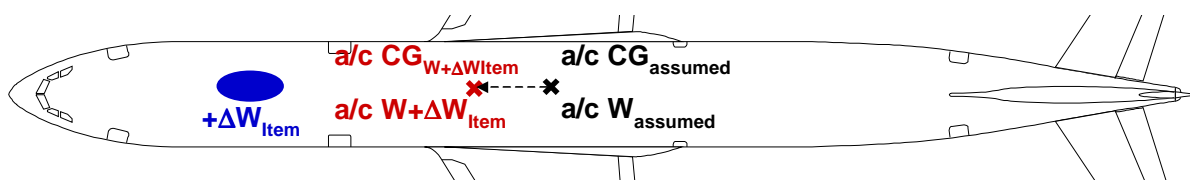
– If the ΔW_{Item} is aft of the assumed aircraft final CG then a positive weight inaccuracy $+\Delta W_{Item}$ will move the CG aft, a negative weight inaccuracy $-\Delta W_{Item}$ will move the CG forward
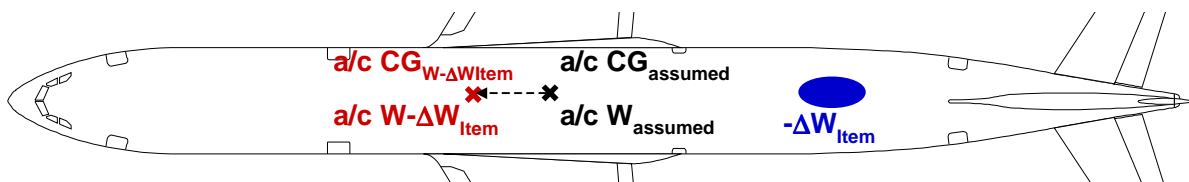
Note : the item position is considered to be accurately known.

The ΔW_{Item} impact is critical when the aircraft assumed CG is close to the limits, because the weight inaccuracy may lead to a real CG out of the limits.

- **Eg : impact of ΔW_{Item} if ΔW_{Item} is located in front of CG$_{assumed}$.**

Positive weight inaccuracy : $+\Delta W_{Item}$
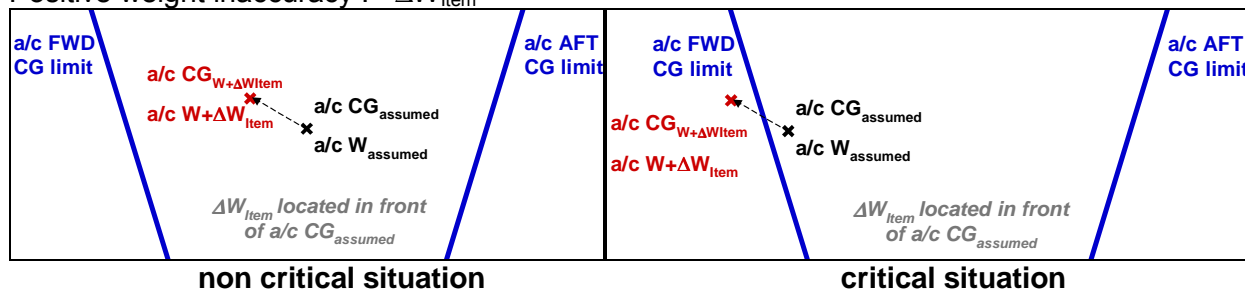
Negative weight inaccuracy : $-\Delta W_{Item}$
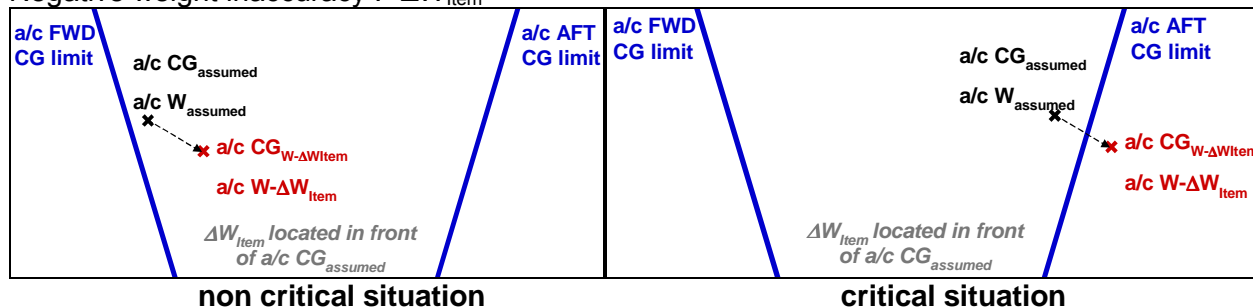
C. BALANCE CHART DESIGN

The impact in term of moment ($E_{item\ weight}$) of this inaccuracy is determined by the difference between the aircraft real moment at aircraft weight : $W_{item\ assumed} \pm \Delta W_{Item}$ and the aircraft moment if the aircraft CG remains in the limit at aircraft weight : $W_{item\ assumed} \pm \Delta W_{Item}$.
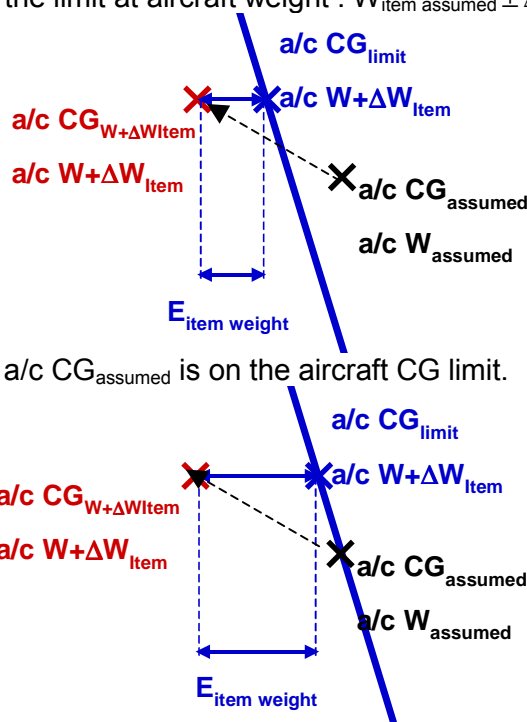
$E_{item\ weight}$ is maximum when a/c $CG_{assumed}$ is on the aircraft CG limit.

So $E_{item\ weight}$ is determined by the difference between the moment of the aircraft $\pm \Delta W_{Item}$ on board and the moment of the aircraft at ($W_{aircraft\ assumed} \pm \Delta W_{Item}$) in case $\pm \Delta W_{Item}$ has no impact on the aircraft CG, in other words in the case when with the inaccuracy in weight the aircraft CG remains at the same position, on the limit.

$E_{item\ weight}$ = (Moment$_{aircraft\ assumed}$ + Moment$_{\Delta Witem}$) – Moment$_{aircraft\ on\ the\ limit}$

$E_{item\ weight}$ = [$W_{aircraft}$ x (H-arm$_{aircraft}$ - H-arm$_{Ref}$) $\pm \Delta W_{Item}$ x (H-arm$_{\Delta Witem}$ - H-arm$_{Ref}$)]

       - (W $\pm \Delta W_{Item}$) x (H-arm$_{aircraft}$ – H-arm$_{Ref}$)

$E_{item\ weight}$ = $\pm \Delta W_{Item}$ x (H-arm$_{\Delta Witem}$ - H-arm$_{aircraft}$)

With H-arm$_{aircraft}$ = H-arm$_{limit}$

$$\boxed{E_{item\ weight} = \pm \Delta W_{Item} \text{ x } (H\text{-arm}_{\Delta Witem} - H\text{-arm}_{limit})}$$

Determining the $E_{item\ weight}$ value consists of checking the different possible H-arm$_{limit}$ to determine the more limiting $E_{item\ weight}$.

3.4.1. Inaccuracy on cargo loading on board the aircraft

a) Inaccuracy on the cargo location

For cargo loading, two sources of inaccuracies have to be considered.

- On the one hand, on the balance chart the cargo influence is taken into account as a delta index per cargo compartment (CARGO 1, CARGO2…), this delta index is based on an average H-arm for the corresponding compartment. Now the real loading may have an average H-arm different from the average one. This difference will generate an inaccuracy on the aircraft CG determination. This inaccuracy is named **cargo distribution inaccuracy**.
- On the other hand, when determining the average cargo compartment H-arm, each cargo position CG is known with a certain inaccuracy, this inaccuracy will generate an inaccuracy on the aircraft CG determination. This inaccuracy is named **cargo CG tolerance inaccuracy**.

- **Cargo distribution inaccuracy:**

$E_{item\ location} = W_{item} \times (H\text{-arm}_{item\ real} - H\text{-arm}_{item\ assumed})$

For this inaccuracy determination the different loading scenarios have to be studied. For each of them, $E_{item\ location}$ is determined with $H\text{-arm}_{item\ assumed}$ being $H\text{-arm}_{CargoX}$ and $H\text{-arm}_{item\ real}$ being the H-arm of the studied configuration.

The process for checking the different configuration is the following :

- Determine the cargo compartment average H-arm : refer to paragraph *2.5 ΔIndex for cargo loading.*
- Study each configuration separately (containers, pallets 88", pallets96" and/or Bulk)
- For each configuration the forward inaccuracy is determined when all the positions in front of the average H-arm are full and all the positions aft of the average H-arm are empty.
- For each configuration the aft inaccuracy is determined when all the positions aft of the average H-arm are full and all the positions in front of the average H-arm are empty.
- Determine the configuration generating the highest inaccuracy.

This inaccuracy needs to be determined for each cargo compartment that is represented on the balance chart. Then the total inaccuracy is determined considering each cargo compartment inaccuracy independent from the other ones.

$$E_{cargo\ distibution\ fwd} = -\sqrt{E^2_{cargo1\ fwd} + E^2_{cargo2\ fwd} + E^2_{cargo3\ fwd} + E^2_{cargo4\ fwd} + E^2_{cargo5\ fwd}}$$

$$E_{cargo\ distibution\ aft} = +\sqrt{E^2_{cargo1\ aft} + E^2_{cargo2\ aft} + E^2_{cargo3\ aft} + E^2_{cargo4\ aft} + E^2_{cargo5\ aft}}$$

Note : when an EDP system is used to compute the aircraft CG position and weight, then the cargo delta index may be determined for each individual cargo position, in this case the cargo distribution inaccuracy is nil.

- **Example Cargo 1 inaccuracy for configuration with 5 ULDs :**

Forward inaccuracy
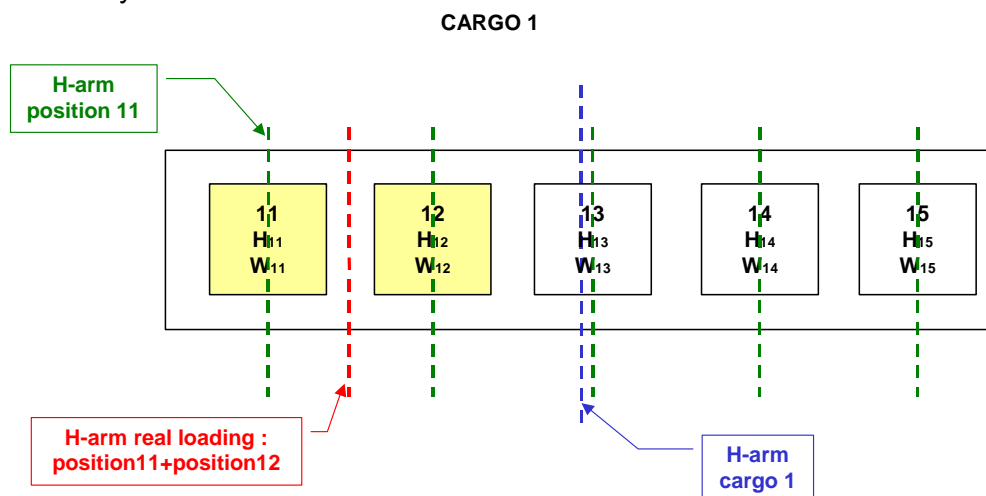
CARGO 1

$E_{item\ location} = W_{item} \times (H\text{-arm}_{item\ real} - H\text{-arm}_{item\ assumed})$

$E_{Cargo1\ distribution\ fwd} = W_{position11+position12} \times (H\text{-arm}_{position11+position12} - H\text{-arm}_{cargo1})$

According to *2.5 ΔIndex for cargo loading*

$$- H-arm_{cargo1} = \frac{W_{11} \times H_{11} + W_{12} \times H_{12} + W_{13} \times H_{13} + W_{14} \times H_{14} + W_{15} \times H_{15}}{W_{11} + W_{12} + W_{13} + W_{14} + W_{15}}$$

$$- H-arm_{Position11+position12} = \frac{W_{11} \times H_{11} + W_{12} \times H_{12}}{W_{11} + W_{12}}$$

and $W_{position11+position12} = W_{position11} + W_{position12}$

Aft inaccuracy
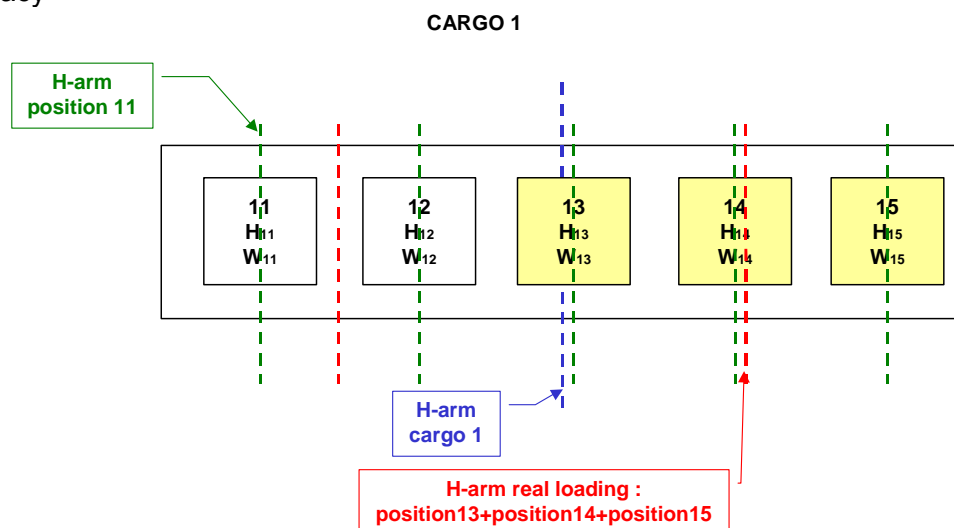
CARGO 1

$E_{item\ location} = W_{item} \times (H\text{-arm}_{item\ real} - H\text{-arm}_{item\ assumed})$

$E_{Cargo1\ distribution\ aft} = W_{position13+position14+position15} \times (H\text{-arm}_{position13+position14+position15} - H\text{-arm}_{cargo1})$

According to *2.5 ΔIndex for cargo loading*

$$- H-arm_{cargo1} = \frac{W_{11} \times H_{11} + W_{12} \times H_{12} + W_{13} \times H_{13} + W_{14} \times H_{14} + W_{15} \times H_{15}}{W_{11} + W_{12} + W_{13} + W_{14} + W_{15}}$$

$$- H-arm_{Position13+position14+position15} = \frac{W_{13} \times H_{13} + W_{14} \times H_{14} + W_{15} \times H_{15}}{W_{13} + W_{14} + W_{15}}$$

and $W_{position13+position14+position15} = W_{position13} + W_{position14} + W_{position15}$

- **Ex: A320 bulk loading in the compartment 1.**

Determination of the average H-arm of the compartment 1:

Position (Bulk)	Maximum allowable Weight (kg)	H-arm (m)	MOMENT (kg.m) (W x H)
11	1045	10.744	11227.5
12	1225	12.433	15230.4
13	1132	13.971	15815.2
$\sum =$	3402		42273.1
H-arm$_{cargo1}$ = 12.426 m			

FORWARD INACCURACY:

Position 11 is the only position in front of the average H-arm.

$E_{Cargo1\ distribution\ fwd} = W_{11} \times (H_{11} - H_{cargo1})$

$E_{Cargo1\ distribution\ fwd} = 1045 \times (10.744 - 12.426) = -1757.7$ kg.m

AFT INACCURACY:

Position 12 and 13 are aft of the average H-arm.

$E_{Cargo1\ distribution\ aft} = W_{12+13} \times (H_{12+13} - H_{cargo1})$

$W_{12+13} = W_{12} + W_{13} = 1225 + 1132 = 2357$ kg

$H_{12+13} = \dfrac{H_{12} \times W_{12} + H_{13} \times W_{13}}{W_{12} + W_{13}} = \dfrac{12.433 \times 1045 + 13.971 \times 1132}{1045 + 1132} = 14.260\,m$

$E_{Cargo1\ distribution\ aft} = 2357 \times (14.260 - 12.426) = +4322.7$ kg.m

- **Ex: A330-200 containerized loading in the compartment 1.**

The compartment 1 of the A330-300 has 3 individual positions (11, 12, 13). It can be loaded with:
Either 6 containers LD3 (AKE) or 3 containers LD1 (AKC) or 3containers LD6 (ALF)
Or   3 pallets 60.4 x 125 in (PKx) or 2 pallets 88 x 125 in (PAx) or 2 pallets 96 x 125 in (PMx)
Containers (LD3, LD1 and LD6) and pallets PKx have the same lever arm. So, we will just use one of those ULDs, one allowing the highest loaded weight, in this example LD6.

The following table gives the H-arm for each ULD position on the compartment 1.

		H-arm (m)		
		Container (LD6)	Pallet 88"	Pallet 96"
POSITION	11 or 11P	15.432	15.738	15.885
	12 or 12P	17.218	18.450	18.348
	13	18.801	-	-
Maximum allowable weight (kg) per ULD		3174	4626	5103

The average center of gravity position of this compartment is 17.128 meters H_{cargo1} = 17.128 m.
FORWARD INACCURACY:
   LD6 configuration
      Position 11 is the only position in front of the average H-arm.
      $E_{Cargo1\ distribution\ fwd} = W_{11} \times (H_{11} - H_{cargo1})$
      $E_{Cargo1\ distribution\ fwd} = 3174 \times (15.432 - 17.128) = -5383$ kg.m
   Pallet 88" configuration
      Position 11P is the only position in front of the average H-arm.
      $E_{Cargo1\ distribution\ fwd} = 4626 \times (15.738 - 17.128) = -6222$ kg.m
   Pallet 96" configuration
      Position 11P is the only position in front of the average H-arm.
      $E_{Cargo1\ distribution\ fwd} = 5103 \times (15.885 - 17.128) = -6343$ kg.m
The highest inaccuracy is obtained for Pallet 96" configuration, this value is retained as $E_{Cargo1\ distribution\ fwd} = -6343$ kg.m

AFT INACCURACY:
   LD6 configuration
      Position 12 and 13 are aft of the average H-arm.
      $E_{Cargo1\ distribution\ aft} = W_{12+13} \times (H_{12+13} - H_{cargo1})$
      $W_{12+13} = W_{12} + W_{13} = 2 \times 3174 = 6348$ kg
      $H_{12+13} = \dfrac{H_{12} \times W_{12} + H_{13} \times W_{13}}{W_{12} + W_{13}} = \dfrac{17.218 \times 3174 + 18.801 \times 3174}{3174 + 3174} = 18\,\text{m}$
      $E_{Cargo1\ distribution\ aft} = 6348 \times (18.0095 - 17.128) = +5595$ kg.m
   Pallet 88" configuration
      Position 12P is the only position in front of the average H-arm.
      $E_{Cargo1\ distribution\ aft} = 4626 \times (18.450 - 17.128) = +6115$ kg.m
   Pallet 96" configuration
      Position 12P is the only position in front of the average H-arm.
      $E_{Cargo1\ distribution\ aft} = 5103 \times (18.348 - 17.128) = +6225$ kg.m
The highest inaccuracy is obtained for Pallet 96" configuration, this value is retained as $E_{Cargo1\ distribution\ aft} = +6225$ kg.m

Note: In this particular case (A330) the scenario with the highest inaccuracy corresponds to the heaviest pallets configuration, nevertheless it is not always the case and all scenarios need to be checked for each individual computation.

- **Cargo CG tolerance inaccuracy:**

$E_{item\ location} = W_{item}$ x $(H\text{-arm}_{item\ real} - H\text{-arm}_{item\ assumed})$

For this inaccuracy determination the different loading scenarios have to be studied. For each of them, $E_{item\ location}$ is determined with $(H\text{-arm}_{item\ real} - H\text{-arm}_{item\ assumed})$ being the allowed tolerance when loading a cargo position.

$E_{item\ CG\ tolerance} = W_{item}$ x tolerance

This tolerance is described in the WBM for ULD loaded aircraft in section 1.10.
For each ULD baseplate the CG is never right on the baseplate geometric center.
The longitudinal allowance is equal to $\pm 10\%$ of the depth of the baseplate.

Center of gravity limits of containers and pallets

The design capacities of the support fittings and structure have been established with the center of gravity of the container and pallet load within the envelopes defined below.

(01) Half size containers IATA contour C, E, G (NAS 3610-2K units)

Maximum center of gravity height is 34 inches (0.86 meter) IATA contour C, E and 25 inches (0.64 meter) IATA contour G, from the bottom of the unit load device. The maximum allowable cargo center of gravity deviation from the unit load device geometric center is + 6.04 inches (0.153 meter) in the longitudinal direction. Maximum allowable cargo center of gravity deviations in the lateral direction are defined in the illustrations below.
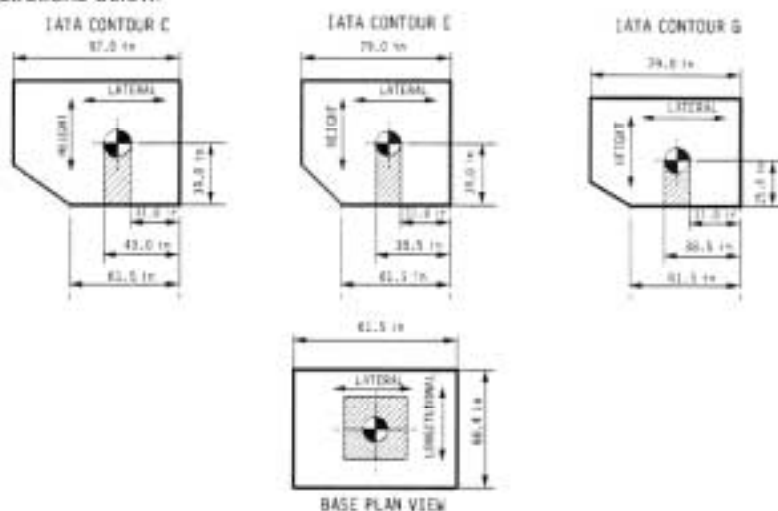
For, bulk loaded aircraft the same principle is considered.
The longitudinal allowance is equal to $\pm 10\%$ of the depth of the bulk position.

The process for checking the different configuration is the following :

- Study each configuration separately (containers, pallets 88", pallets96" and/or Bulk)
- For each configuration determine the total inaccuracy considering that the inaccuracy for each ULD/bulk position is independent from the other ones. E = $\sqrt{E^2_1 + E^2_2 + ... + E^2_n}$
- Determine the configuration generating the highest inaccuracy.

- **Ex: A330-200 containerized loading in the compartment 1.**

The compartment 1 of the A330-300 has 3 individual positions (11, 12, 13). It can be loaded with:
Either 6 containers LD3 (AKE) or 3 containers LD1 (AKC) or 3 containers LD6 (ALF)
Or   3 pallets 60.4 x 125 in (PKx) or 2 pallets 88 x 125 in (PAx) or 2 pallets 96 x 125 in (PMx)

The longitudinal allowance for each type of ULD is :

Container (LD3, LD1, LD6)	$\pm$ 0.153 m ($\pm$ 6.04 in)
Pallet 88" (PAx: 88 x 125 in)	$\pm$ 0.2235 m ($\pm$ 8.8 in)
Pallet 96" (PMx: 96 x 125 in)	$\pm$ 0.244 m ($\pm$ 9.6 in)

The maximum allowable weight (kg) per ULD is

Container (LD3, LD1)	1587 kg
Container (LD6)	3174 kg
Pallet 88" (PAx: 88 x 125 in)	4626 kg
Pallet 96" (PMx: 96 x 125 in)	5103 kg

LD3 configuration
    6 LD3 can be loaded
    $E_{\text{item CG tolerance}} = W_{\text{item}}$ x tolerance
    $E_{\text{LD3 CG tolerance}} = 1587$ x $\pm$ 0.153 = $\pm$ 242.8 kg.m

$$E_{\text{LD3 configuration CG tolerance}} = \pm \sqrt{E^2_{\text{LD3 CG tolerance}} \times 6} = \pm 242.8 \times \sqrt{6} = \pm 594.8 \text{ kg.m}$$

LD1 configuration
    3 LD1 can be loaded
    $E_{\text{item CG tolerance}} = W_{\text{item}}$ x tolerance
    $E_{\text{LD1 CG tolerance}} = 1587$ x $\pm$ 0.153 = $\pm$ 242.8 kg.m

$$E_{\text{LD1 configuration CG tolerance}} = \pm \sqrt{E^2_{\text{LD1 CG tolerance}} \times 3} = \pm 242.8 \times \sqrt{3} = \pm 420.5 \text{ kg.m}$$

LD6 configuration
    3 LD6 can be loaded
    $E_{\text{item CG tolerance}} = W_{\text{item}}$ x tolerance
    $E_{\text{LD6 CG tolerance}} = 3174$ x $\pm$ 0.153 = $\pm$ 485.6 kg.m

$$E_{\text{LD6 configuration CG tolerance}} = \pm \sqrt{E^2_{\text{LD6 CG tolerance}} \times 3} = \pm 485.6 \times \sqrt{3} = \pm 841.1 \text{ kg.m}$$

Pallet 88" configuration
    2 pallets can be loaded
    $E_{\text{item CG tolerance}} = W_{\text{item}}$ x tolerance
    $E_{\text{Pallet 88" CG tolerance}} = 4626$ x $\pm$ 0.2235 = $\pm$ 1033.9 kg.m

$$E_{\text{Pallet 88" configuration CG tolerance}} = \pm \sqrt{E^2_{\text{Pallet88" CG tolerance}} \times 2} = \pm 1033.9 \times \sqrt{2} = \pm 1462.1 \text{ kg.m}$$

Pallet 96" configuration
    2 pallets can be loaded
    $E_{\text{item CG tolerance}} = W_{\text{item}}$ x tolerance
    $E_{\text{Pallet 96" CG tolerance}} = 5103$ x $\pm$ 0.244 = $\pm$ 1245.2 kg.m

$$E_{\text{Pallet96" configuration CG tolerance}} = \pm \sqrt{E^2_{\text{Pallet 96" CG tolerance}} \times 2} = \pm 1245.1 \times \sqrt{2} = \pm 1760.9 \text{ kg.m}$$

The highest inaccuracy is obtained for Pallet 96" configuration, this value is retained as $E_{\text{Cargo1 CG tolerance}}$ = $\pm$ 1760.9 kg.m

---

Note: In this particular case (A330) the scenario with the highest inaccuracy corresponds to the heaviest pallets configuration, nevertheless it is not always the case and all scenarios need to be check for each individual computation.

b) Inaccuracy on the cargo weight

Cargo weight is supposed to be known without inaccuracy : for freight loading airlines usually weight the pallets and container after they are prepared, then for baggage the total weight of baggage per flight is accurately known as each individual piece of luggage is weighed.
So $E_{cargo\ weight}$ is usually supposed to be nil.

Note : in case the cargo weight cannot be accurately known it may be needed to introduce a cargo weight inaccuracy, this inaccuracy may be due to the fact that the ULD weight is estimated and not weighed or to the fact that the baggage weight per cargo position is estimated, usually using an average weight per baggage piece.
In the case a cargo weight inaccuracy is to be determined the method to be applied is similar to the one described in the next chapter for passenger weight inaccuracy.

3.4.2. Inaccuracy on passenger loading on board the aircraft

a) Inaccuracy on the passengers' location

On the balance chart the passenger influence is taken into account as a delta index per passenger cabin section (CABIN OA, CABIN OB, …), this delta index is based on an average H-arm for the corresponding cabin section. Now the real loading may result in an H-arm different from the average one. This difference will generate an inaccuracy on the aircraft CG determination. This inaccuracy is named **passenger distribution inaccuracy**.

- **Passenger distribution inaccuracy:**

$E_{item\ location} = W_{item} \times (H\text{-}arm_{item\ real} - H\text{-}arm_{item\ assumed})$

$E_{item\ location}$ is determined with $H\text{-}arm_{item\ assumed}$ being $H\text{-}arm_{CabinOX}$ and $H\text{-}arm_{item\ real}$ being the H-arm of the real passengers seating configuration.

The process for checking the different configuration is the following :
  - Determine the cabin section average H-arm : refer to paragraph *2.4 ΔIndex for passenger boarding.*
  - Determine the passenger seating configuration which generates a significant inaccuracy.

The maximum inaccuracy would be determined when all seats in front of the average H-arm are full and all seats aft of the average H-arm are empty. But this boarding configuration is not a realistic one and the inaccuracy is in this case very high. So a realistic boarding scenario needs to be determined.
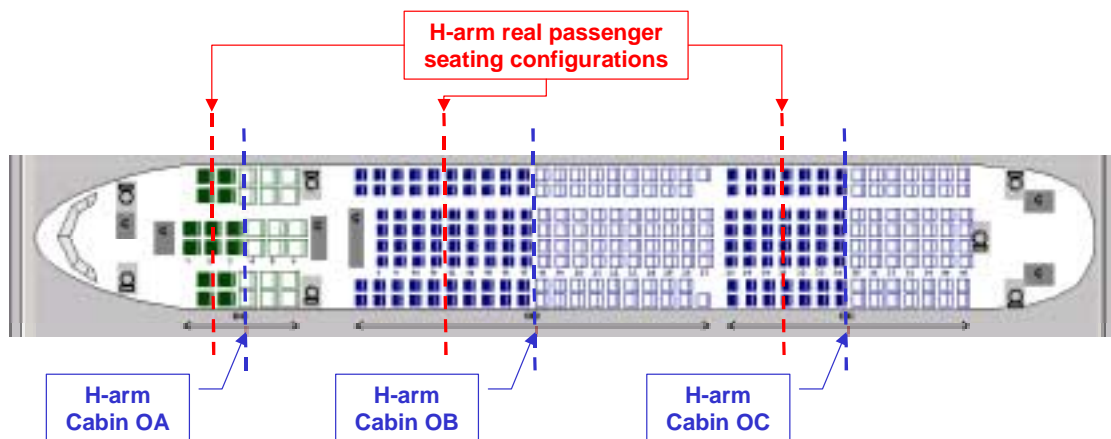
The following boarding scenario is taken into account :
- − Passengers board first on (or ask first for) window seats.
- − Passengers board then on aisle seats
- − Finally passengers board on middle seats.

Following this scenario the forward inaccuracy is determined when
- − Either all the window seats in front of the average H-arm are full and all the window seats aft of the average H-arm are empty.
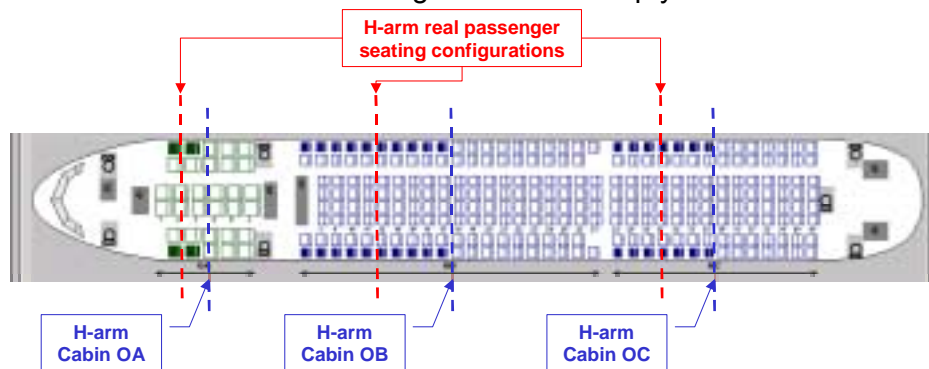
- − Or all window seats are full and all the aisle seats in front of the average H-arm are full and all the aisle seats aft of the average H-arm are empty.
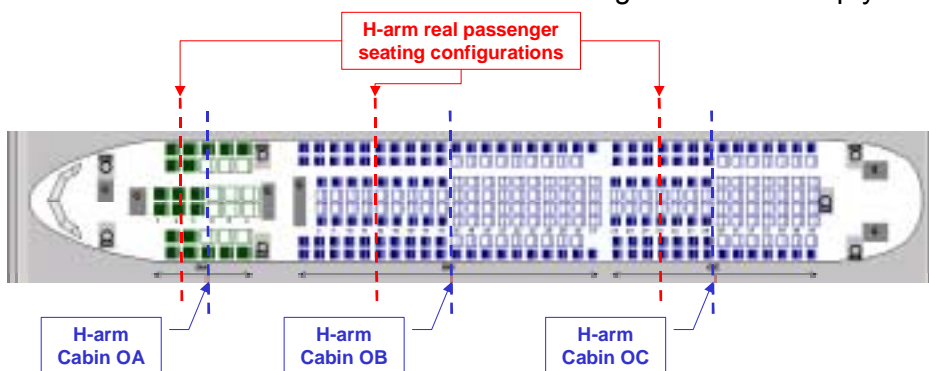
- − Or all window and aisle seats are full and all the center seats in front of the average H-arm are full and all the center seats aft of the average H-arm are empty.
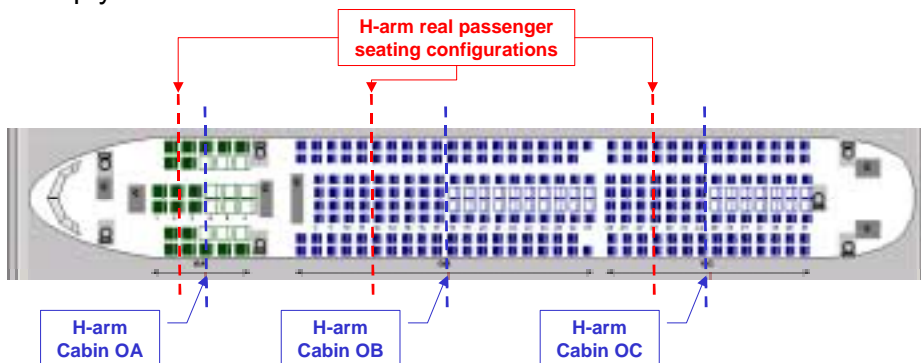
The aft inaccuracy is computed following the same passenger seating configuration but with passengers first seated in the rear part of the cabin section.

Note : on the majority of cabin layouts the second option generates the highest significant inaccuracy.

The passenger distribution inaccuracy is determined for each cabin section that is represented on the balance chart. Then the total inaccuracy is determined considering each cabin section inaccuracy independent from the other ones.

$$E_{passenger\ distribution\ fwd} = -\sqrt{E^2_{Cabin\ OA\ fwd} + E^2_{Cabin\ OB\ fwd} + E^2_{Cabin\ OC\ fwd} + \ldots}$$

$$E_{passenger\ distribution\ aft} = +\sqrt{E^2_{Cabin\ OA\ aft} + E^2_{Cabin\ OB\ aft} + E^2_{Cabin\ OC\ aft} + \ldots}$$

Note : when an EDP system is used to compute the aircraft CG position and weight, then the passenger delta index may be determined for each individual passenger seat row, in this case the passenger distribution inaccuracy is nil.

Note : when applying the realistic boarding scenario, it is considered that all the passenger seats are available. In some case airlines may decide that some seats must remain unoccupied, for example if one emergency exit is inoperative. In these specific cases passenger boarding may generate a higher inaccuracy than the one taken into account in the operational margin determination. It is worth taking in account additional margins for those specific cases. These margins are computed for each specific cabin layout and unoccupied seats configurations.

- **Ex : A320 forward inaccuracy with the following cabin layout**

	ROW	H.ARM (m)	LHPAX	RHPAX			ROW	H.ARM (m)	LHPAX	RHPAX
OA	01	9.475	2	2			15	20.416	3	3
	02	10.440	2	2			16	21.204	3	3
	03	11.405	2	2			17	21.991	3	3
OB	04	12.390	3	3			18	22.779	3	3
	05	13.177	3	3			19	23.566	3	3
	06	13.965	3	3			20	24.353	3	3
	07	14.752	3	3	**OC**		21	25.141	3	3
	08	15.540	3	3			22	25.928	3	3
	09	16.327	3	3			23	26.716	3	3
	10	17.191	3	3			24	27.503	3	3
	11	18.054	3	3			25	28.290	3	3
	12	18.842	3	3			26	29.078	3	3
	14	19.629	3	3			27	29.865	3	3
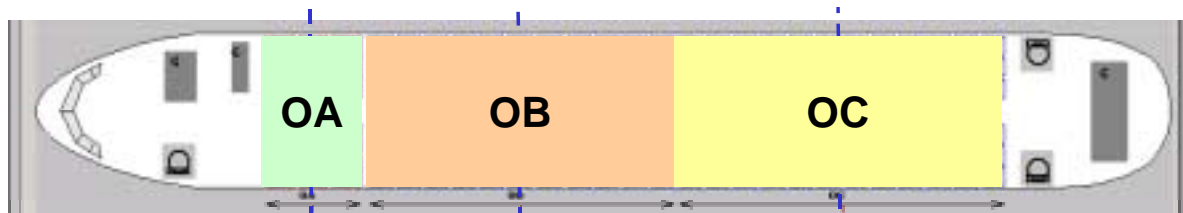
Referring to *2.4 ΔIndex for passenger boarding* determine.

H_{OA}=10.44 m
H_{OB}=16.39 m
H_{OC}=25.53 m

FORWARD INACCURACY
Considering the following loading scenario

WEIGHT AND BALANCE ENGINEERING
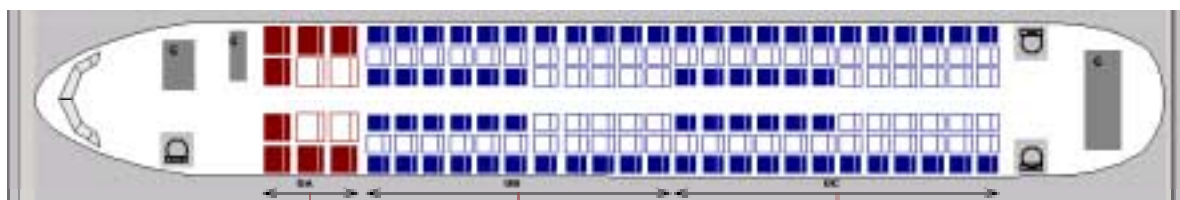
Inaccuracy for cabin OA

$E_{\text{cabin OA distribution fwd}} = W_{\text{pax in cabin OA fwd}} \times (H\text{-arm}_{\text{pax in cabin OA fwd}} - H\text{-arm}_{\text{OA}})$

$W_{\text{pax in cabin OA fwd}} = 8 \times$ Pax average weight $= 8 \times 84 = 672$ kg

$H\text{-arm}_{\text{pax in cabin OA fwd}} = \dfrac{H_{\text{row1}} \times 4 \times \text{Pax average weight} + H_{\text{row2}} \times 2 \times \text{Pax average weight} + H_{\text{row3}} \times 2 \times \text{Pax average weight}}{8 \times \text{Pax average weight}}$

$H\text{-arm}_{\text{pax in cabin OA fwd}} = \dfrac{9.475 \times 4 \times 84 + 10.44 \times 2 \times 84 + 11.405 \times 2 \times 84}{8 \times 84} = 10.2$ m

$E_{\text{cabin OA distribution fwd}} = 672 \times (10.2 - 10.44) = -161.28$ kg.m

Inaccuracy for cabin OB

$E_{\text{cabin OB distribution fwd}} = W_{\text{pax in cabin OB fwd}} \times (H\text{-arm}_{\text{pax in cabin OB fwd}} - H\text{-arm}_{\text{OB}})$

$W_{\text{pax in cabin OB fwd}} = 34 \times$ Pax average weight $= 34 \times 84 = 2856$ kg

$H\text{-arm}_{\text{pax in cabin OB fwd}} = 15.37$ m

$E_{\text{cabin OB distribution fwd}} = 2856 \times (15.37 - 16.39) = -2913.12$ kg.m

Inaccuracy for cabin OC

$E_{\text{cabin OC distribution fwd}} = W_{\text{pax in cabin OC fwd}} \times (H\text{-arm}_{\text{pax in cabin OC fwd}} - H\text{-arm}_{\text{OC}})$

$W_{\text{pax in cabin OC fwd}} = 36 \times$ Pax average weight $= 36 \times 84 = 3024$ kg

$H\text{-arm}_{\text{pax in cabin OC fwd}} = 24.35$ m

$E_{\text{cabin OC distribution fwd}} = 3024 \times (24.35 - 25.53) = -3568.32$ kg.m

Total inaccuracy for all the cabins

$E_{\text{passenger distibution fwd}} = -\sqrt{161.23^2 + 2931.12^2 + 3568.32^2} = -4620.64$ kg.m

b) Inaccuracy on the passengers' weight

On the balance chart the passenger influence is taken into account as a delta index per passenger cabin section (CABIN OA, CABIN OB, …), this delta index is based on an average passenger weight for the corresponding cabin section. Now the real loading may have a total weight different from the one determined using average weight. This difference will generate an inaccuracy on the aircraft CG determination. This inaccuracy is named **passenger weight inaccuracy**.

- **Passenger weight inaccuracy**

The real passenger weight is $W_{pax\ real} = W_{pax\ average} \pm \Delta W_{pax}$

$W_{pax\ average}$ and ΔW_{pax} are determined in relation with the statistical survey used to determine the passenger weight.
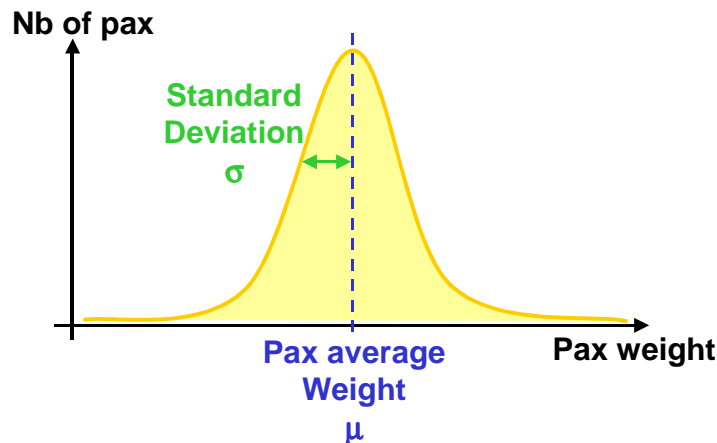
$W_{pax\ average} = \mu$ and $\Delta W_{pax} = 3\sigma$, the 3σ value is chosen to ensure that $W_{pax\ average}$ covers 99,73 % of the population.

For each cabin section used on the balance chart we have

$W_{pax\ real\ OX} = W_{pax\ average\ OX} \pm \Delta W_{pax\ OX}$

$W_{pax\ real\ OX} = W_{pax\ average} \times (\text{number of pax in OX}) \pm \Delta W_{pax\ OX}$

$\Delta W_{pax\ OX}$ is determined considering that each individual passenger weight inaccuracy is independent from the weight inaccuracy of the other passengers.

$$\Delta W_{n\ pax} = \sqrt{\Delta W_{pax1}^2 + \Delta W_{pax2}^2 + ... + \Delta W_{paxn}^2}$$

The inaccuracy is the same for each individual passenger and equals 3σ.

$$\Delta W_{npax} = \sqrt{n \times (3\sigma)^2} = 3\sigma\sqrt{n}$$

- **Impact of pax weight inaccuracy on aircraft CG determination**

$E_{passenger\ weight} = \pm \Delta W_{passenger} \times (\text{H-arm}_{\Delta Wpassenger} - \text{H-arm}_{limit})$

The passenger weight inaccuracy is determined for each cabin section that is represented on the balance chart.

$E_{cabinXX\ weight} = \pm \Delta W_{passengers\ in\ cabin\ XX} \times (\text{H-arm}_{cabin\ XX} - \text{H-arm}_{limit})$

The inaccuracy in weight is maximum when the cabin section is full of passengers so

$$\Delta W_{passengers\ in\ cabin\ XX} = 3\sigma\sqrt{\text{maximum number of passengers in section XX}}$$

Then the total inaccuracy is determined considering each cabin section inaccuracy independent from the other ones.

$$E_{passenger\ weight\ fwd} = -\sqrt{E^2_{Cabin\ OA\ fwd} + E^2_{Cabin\ OB\ fwd} + E^2_{Cabin\ OC\ fwd} + ...}$$

$$E_{passenger\ weight\ aft} = +\sqrt{E^2_{Cabin\ OA\ aft} + E^2_{Cabin\ OB\ aft} + E^2_{Cabin\ OC\ aft} + ...}$$

- **Ex : A320 forward inaccuracy with the above example cabin layout**

Referring to *2.4 ∆Index for passenger boarding* determine.

H_{OA}=10.44 m for 12 passengers
H_{OB}=16.39 m for 66 passengers
H_{OC}=25.53 m for 72 passengers

Passenger average weight = 84 kg and corresponding standard deviation = 15 kg.
The forward limit CG of the A320 is between 15% (18.43 m) and 17% (18.51 m) for aircraft weight between minimum weight and 73 500 kg.

Cabin OA :

$E_{cabinOA\ weight}$ = $\pm \Delta W_{passengers\ in\ cabin\ OA}$ x (H-arm$_{cabin\ OA}$ - H-arm$_{limit}$)

H_{OA}=10.44 m is forward for the limit so a positive $\Delta W_{passengers\ in\ cabin\ OA}$ may cause the CG move out of the limit. The more conservative $E_{cabinOA\ weight}$ is obtained for H-arm$_{limit}$ = 18.51 m

$$E_{cabinOA\ weight} = 3 \times 15\sqrt{12} \times (10.44 - 18.51) = -1258 kg.m$$

Cabin OB :

$E_{cabinOB\ weight}$ = $\pm \Delta W_{passengers\ in\ cabin\ OB}$ x (H-arm$_{cabin\ OB}$ - H-arm$_{limit}$)

H_{OB}=16.39 m is forward for the limit so a positive $\Delta W_{passengers\ in\ cabin\ OB}$ may cause the CG move out of the limit. The more conservative $E_{cabinOB\ weight}$ is obtained for H-arm$_{limit}$ = 18.51 m

$$E_{cabinOC\ weight} = 3 \times 15\sqrt{66} \times (16.39 - 18.51) = -755 kg.m$$

Cabin OC :

$E_{cabinOC\ weight}$ = $\pm \Delta W_{passengers\ in\ cabin\ OC}$ x (H-arm$_{cabin\ OC}$ - H-arm$_{limit}$)

H_{OC}=25.53 m is aft for the limit so a negative $\Delta W_{passengers\ in\ cabin\ OC}$ may cause the CG move out of the limit. The more conservative $E_{cabinOC\ weight}$ is obtained for H-arm$_{limit}$ = 18.43 m

$$E_{cabinOA\ weight} = -3 \times 15\sqrt{72} \times (25.53 - 18.43) = -2711 kg.m$$

Total inaccuracy for all the cabins

$$E_{passenge\ weight\ fwd} = -\sqrt{1258^2 + 755^2 + 2711^2} = -3082 kg.m$$

3.4.3. Inaccuracy on fuel loading on board the aircraft

a) Inaccuracy on the fuel location

On the balance chart the fuel influence is taken into account as a delta index per total fuel quantity, this delta index is based on a fuel H-arm for the corresponding fuel weight. Now the fuel H-arm depends on the fuel volume contained in each tank and this volume is linked to the fuel weight through the fuel density. So an inaccuracy on fuel density will generate an inaccuracy on the fuel H-arm and consequently on the aircraft CG determination.

In addition the Zero Fuel limit design is based on the theoretical fuel vector at a chosen density (usually 0.785 kg/l). This Zero Fuel limit is used to ensure that flight CG all along the flight and landing CG before landing are within their own operational limits. As a standard density value is used for the Zero Fuel limit determination it is necessary to take into account the possible differences on actual aircraft CG due to density impact.

This inaccuracy is named **fuel density inaccuracy**.

Note : Fuel density is also called fuel specific gravity, in this document the word density will be used.

- **Fuel density inaccuracy**
  1. *Inaccuracy on the fuel Δindex determination.*

Fuel index table can be available for one single fuel density (usually for single aisle aircraft) or for a discrete range of fuel densities (for aircraft equipped with a trim tank).

On single aisle aircraft (A318/A319/A320/A321, A319 corporate jet excluded), total fuel quantity is around 20 tons, consequently the fuel density variation does not lead to huge fuel quantity variation, furthermore the fuel tanks position is close to the Reference Chord. That is why fuel index table is established at a single reference density (usually 0.785 kg/l). As the fuel density can be assumed to vary between 0.76 kg/l and 0.83 kg/l, the maximum forward and aft Δindex between the reference fuel index table and the fuel index values determined at extreme fuel densities must be included into the fuel allowance.

- **Ex : A320-200**

AIRBUS
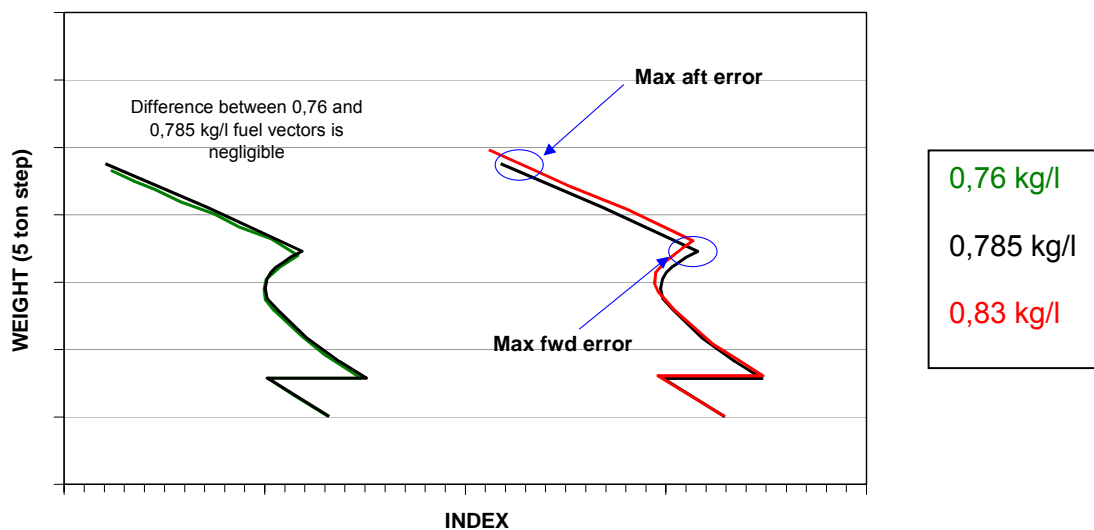
On long range aircraft (A330/A340), wide-body aircraft (A300/A310) and single aisle aircraft equipped with ACTs the total fuel quantity reaches higher values and the fuel tanks may far from the Reference Chord (specially Trim Tank and ACTs). Consequently, a fuel density variation can imply a significant Δindex variation for a given weight value. That is why, fuel index tables are usually established for a discrete range of fuel densities. Actual density of the day can be an intermediate density and an interpolation will be required to get the fuel Δindex. To cover interpolation potential error, half of the maximum forward and aft index variation between two consecutive fuel densities has to be included into the fuel allowance.

- **Ex : A330-200**

WEIGHT (kg)	DENSITY (kg/l)														
	0,760	0,765	0,770	0,775	0,780	0,785	0,790	0,795	0,800	0,805	0,810	0,815	0,820	0,825	0,830
000	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2
4000	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4
6000	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6
8000	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8
10000	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8	–8
12000	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4
14000	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1
16000	+1	+1	+1	+2	+2	+2	+2	+2	+2	+2	+2	+2	+3	+3	+3
18000	–1	–1	–1	+0	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1	+1
20000	–3	–3	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–1	–1	–1
22000	–5	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–3	–3	–3	–3
24000	–6	–6	–6	–6	–6	–6	–6	–6	–6	–6	–5	–5	–5	–5	–5
26000	–8	–8	–8	–8	–8	–8	–8	–8	–7	–7	–7	–7	–7	–7	–7
...	....	....	...	....	....	....	....	....	....	...	...	...	...	...	...
87000	+2	+2	+2	+2	+2	+2	+3	+3	+3	+3	+3	+3	+3	+4	+3
89000	+1	+1	+1	+1	+1	+2	+2	+2	+2	+2	+2	+2	+2	+3	+3
91000	+0	+0	+0	+0	+1	+1	+1	+1	+1	+1	+1	+1	+1	+2	+2
93000	–1	–1	–1	+0	+0	+0	+0	+0	+0	+0	+0	+0	+0	+1	+1
95000	–2	–2	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	–1	+0	+0
97000	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–2	–1	–1	+0	–1
99000	–3	–3	–3	–3	–3	–3	–3	–3	–3	–3	–3	–2	–2	–1	–2
101000	–4	–4	–4	–4	–4	–4	–4	–4	–4	–4	–3	–3	–3	–2	–3
103000	–6	–6	–5	–5	–5	–5	–5	–5	–5	–4	–4	–4	–4	–3	–4
105000	–8	–7	–7	–6	–6	–6	–6	–6	–6	–5	–5	–5	–5	–4	–5
107000			–9	–8	–8	–7	–7	–7	–7	–6	–6	–6	–6	–5	–6
109000						–9	–9	–8	–8	–8	–8	–7	–7	–6	–7
111000									–10	–9	–9	–9	–8	–7	–8
113000												–10	–10	–8	–9
115000														–10	–11
FULL	–9	–9	–9	–9	–9	–9	–9	–9	–9	–10	–10	–10	–10	–10	–10

> Maximum fwd and aft index difference between two consecutives fuel densities: 1 i.u
> Consequently, to cover interpolation, a 0.5 i.u fwd and aft margin will be included into the fuel allowance.

2. Inaccuracy on the Zero fuel limit design

The Zero Fuel limit design process (see related chapter "Zero fuel limit determination") uses a reference fuel vector that is leaned on operational flight and landing operational limits.

As actual fuel vector may be different from the reference one (due to a different fuel density), flight and landing operational allowances have to include an additional margin covering the zero fuel limit design.

To do so, maximum forward and aft index variation at critical points (because they are the points used in the zero fuel limit design) between the reference fuel vector and the extreme fuel vectors have to be included into the fuel allowance.

b) Inaccuracy on the fuel weight

On the balance chart the fuel influence is taken into account as a delta index per total fuel quantity which is the sum of the delta indexes per individual tanks. For each tank the fuel quantity is known with a certain accuracy. This inaccuracy is linked to the Fuel Quantity Indicator (FQI) system inaccuracy whatever the flight phase an inaccuracy needs to be taken into account.

This difference between estimated and real fuel weight per tank will generate an inaccuracy on the aircraft CG determination. This inaccuracy is named **fuel weight inaccuracy**.

- **Fuel weight inaccuracy**

The real fuel weight is $W_{fuel\ real} = W_{fuel\ estimated} \pm \Delta W_{fuel}$
For each tank, the inaccuracy is $\pm 1\%$ of the tank capacity, plus $\pm 1\%$ of the actual fuel quantity in the tank.
$\Delta W_{fuel\ tank\ n} = \pm 1\%\ Total\_weight_{tank\ n} \pm 1\%\ Actual\_weight_{tank\ n}$

Note : if one tank is empty the $\Delta W_{fuel\ tank}$ is considered nil.
Note : These figures are conservative ones (refer to Aircraft Maintenance Manual section 28-42-00).

Each tank quantity is independent from the other tanks' one.

Such a weight deviation per tank has an impact on the actual fuel vector shape, some points of the vector being shifted forward or aft.
Some points are more critical than others: those points corresponding to a fuel quantity for which $\pm \Delta W_{fuel}$ may cause the aircraft CG be shifted out of the certified limits.
There are called **critical points**.

Critical points are defined phase per phase, one being critical for the forward certified limit and another for the aft certified limit.
They are determined leaning the fuel vector on the aircraft certified limits, indeed throughout the whole fuel vector the aircraft CG must remain in the limits.

- **Ex: A330-200 aircraft with FCMC stage 9.0**

Takeoff phase
     - Forward critical point:

The forward critical point for the takeoff phase is defined as the contact point between fuel vector and forward takeoff certified limit corresponding to the highest fuel quantity, the whole fuel vector between the critical point and fuel = 0 kg remaining inside flight and landing limits.
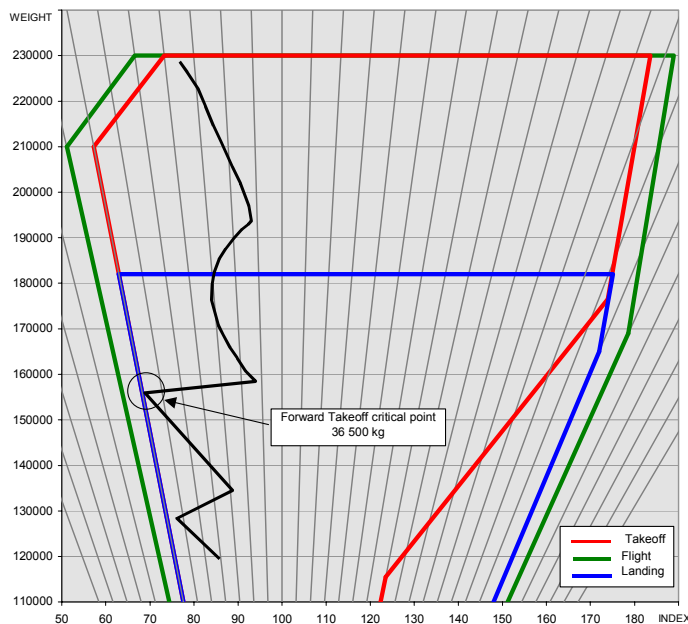
     - Aft critical point:
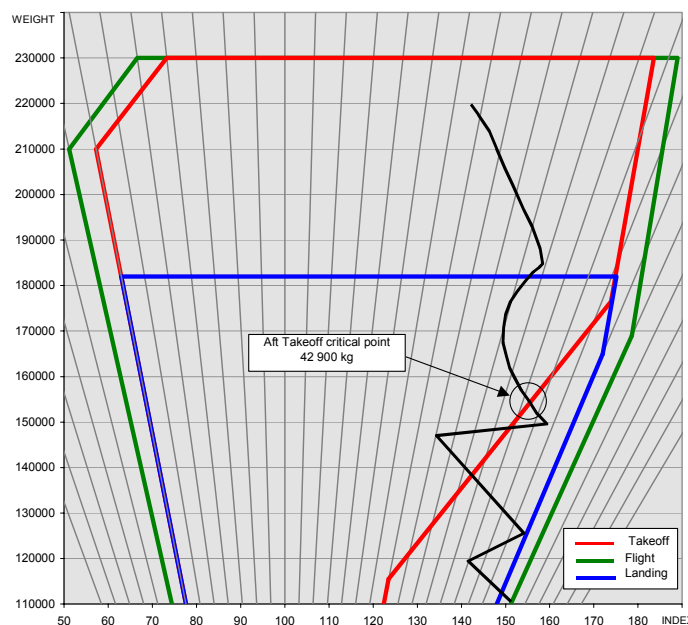
The aft critical point for the takeoff phase is defined as the forward one but with respect to the aft takeoff envelope.

In flight phase
        - Forward critical point:
The forward critical point for the flight phase is defined as the contact point between fuel vector and forward flight certified limit, the whole fuel vector between the critical point and fuel = 0 kg being inside the flight certified limit. The fuel vector can be during flight outside the landing certified limit because of in-flight movements (pax and cabin attendants movements) that slightly modify aircraft CG compared to static situations (takeoff and landing).
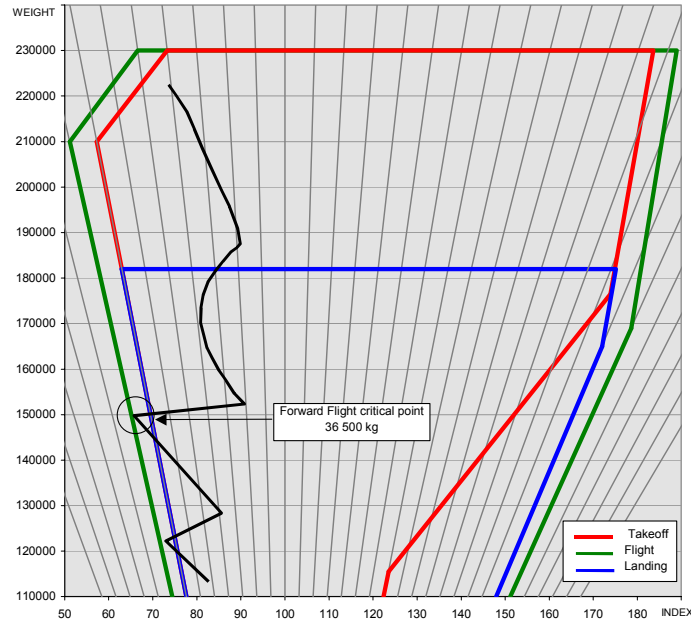
        - Aft critical point:
The aft critical point for the flight phase is defined as the forward one but with respect to the aft flight limits.

WEIGHT AND BALANCE ENGINEERING
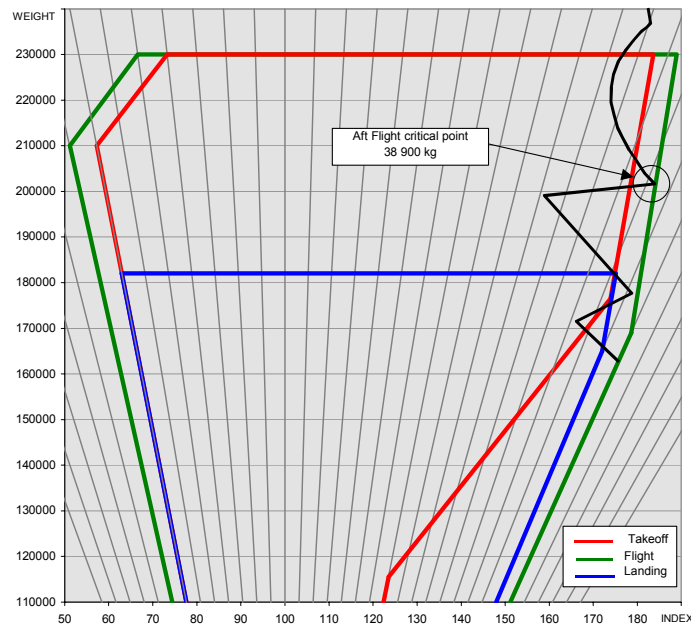
Landing phase
    - Forward critical point:
The forward critical point for the landing phase is defined as the contact point between <u>landing</u> fuel vector and forward landing certified limit, the whole landing fuel vector between the critical point and fuel = 0 kg remaining inside the landing limit and the associated flight fuel vector remaining inside the flight envelope.
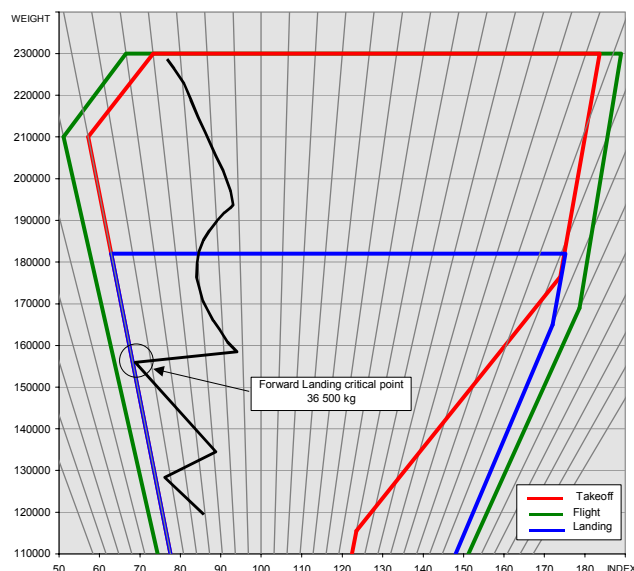
    - Aft critical point:
The aft critical point for the landing phase is defined as the forward one but with respect to the aft landing envelope.
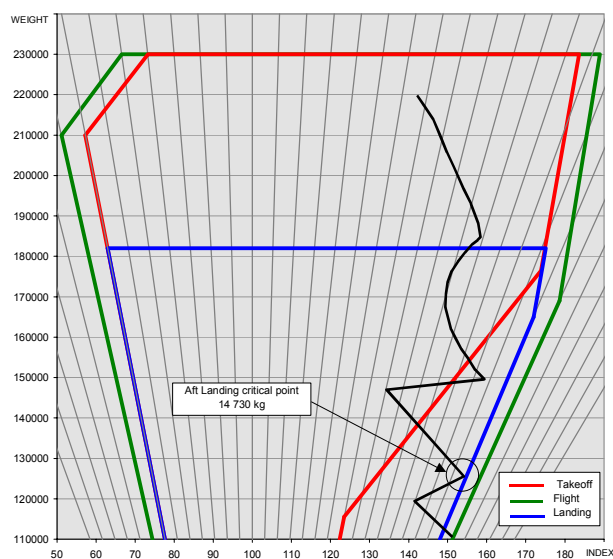
Fuel Weight inaccuracy (E$_{fuel weight}$) is determined for the fuel quantity corresponding to the critical point. And it is calculated for each individual tank.

$$E_{fuel\ weight} = \pm \Delta W_{fuel} \times (H\text{-arm}_{\Delta Wfuel} - H\text{-arm}_{limit})$$

Then the total inaccuracy is determined considering each fuel tank weight inaccuracy independent from the other ones.

$$E_{fuel\ weight\ fwd} = -\sqrt{E^2_{Inner\ tanks\ fwd} + E^2_{Outer\ tanks\ fwd} + E^2_{Center\ tank\ fwd} + \ldots}$$

$$E_{fuel\ weight\ aft} = +\sqrt{E^2_{Inner\ tank\ aft} + E^2_{Outer\ tank\ aft} + E^2_{Center\ tank\ aft} + \ldots}$$

c) Total fuel inaccuracy

The final fuel allowance includes the three above mentioned inaccuracies:
- Fuel weight inaccuracy linked to FQI inaccuracy (all flight phases)
- Inaccuracy on the fuel Δindex determination. (takeoff phase)
- Inaccuracy on the Zero fuel limit design (flight and landing phase only in case of non takeoff protected Zero Fuel limit and on all three phases in case of takeoff protected Zero Fuel limit)

Then the total inaccuracy is determined considering each inaccuracy independent from the other ones.

3.5. Inaccuracy due to CG computation method

The balance chart used to determine the aircraft CG position can be :
- graphical
- tabulated
- computerized
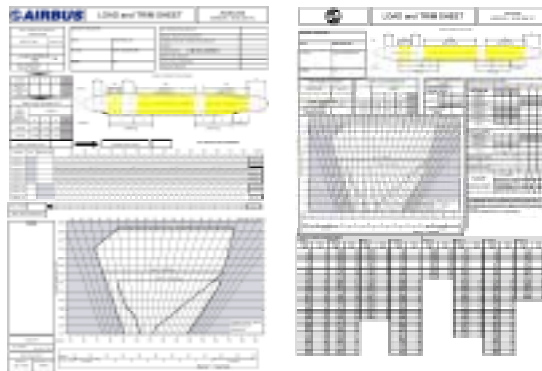
In each case the computation is based on
- a sum of weights = DOW + Payload Weight +Fuel Weight
- a sum of index = DOI + Payload ΔIndex +Fuel ΔIndex

Each weight of the sum is rounded to the closest unit value.
Each index and Δindex of the sum may be rounded to :
- the closest index unit in the case of paper systems (graphical or tabulated)
- the closest decimal (tenth or hundredth) in the case of computerized systems.

The weight sum is then considered to be precise and no inaccuracy is taken into account.
Depending of the rounding system of the index and on the method to determine the index value for each weight value, an index inaccuracy has to be taken into account.

Note1 : the computerized systems rounded to the tenth or hundredth, are considered usually to be precise enough not to take into account any inaccuracy.
Note2 : some computerized systems may be based directly on each item H-arm value and not on the item Δindex, in this case the computation is usually much more precise (without pre-computation) and no inaccuracy is considered.

The index inaccuracy is first determined analyzing the balance chart as a number of index units. The value of the inaccuracy in term of moment depends on the index formula chosen.

3.5.1. Tabulated balance chart inaccuracy

On the tabulated balance chart the Δindex value for each item loaded is read in an index table. There are two methods to define index tables :

- Tables with constant step in index
- Tables with constant step in weight.

a) Tables with constant step in index

Those tables are usually used for passengers and cargo Δindex for fuel Δindex tables with constant step in weight are used.

CARGO n	
Weight (kg)	Δindex
203	+1
611	+2
1018	+3
1426	+4
1833	+5

CARGO n			
Weight (kg)			Δindex
0	-	203	+0
204	-	611	+1
612	-	1018	+2
1019	-	1426	+3
1427	-	1833	+4

CARGO n	
Weight (kg)	Δindex
0	
	+0
204	
	+1
612	
	+2
1019	
	+3
1427	
	+4

Building this type of table consists of determining the transition weights for which there is a step between one index value and the other.
In the above example :

- For weight between 0 and 203 kg the Δindex value varies between 0 and 0.49…
- For weight between 204 and 611 kg the Δindex value varies between 0.5 and 1.49…
- …

Note : The same examples apply for passenger Δindex table except that the weight is replaced by the number of passengers.

In those tables the user selects the Δindex corresponding to the weight or passenger number range he is considering.
For each weight range the Δindex range is 1 index value.
So selecting the rounded figure the user generates an maximum inaccuracy of ±0.5 index unit in each table.

The inaccuracy due to one table is independent from the inaccuracies due to the other tables so :

$$E_{\text{cargo index tables}} = \pm\sqrt{E^2_{\text{cargo1 index table}} + E^2_{\text{cargo2 index table}} + E^2_{\text{cargo3 index table}} + E^2_{\text{cargo4 index table}} + E^2_{\text{cargo5 index table}}}$$

$$E_{\text{passenger index tables}} = \pm\sqrt{E^2_{\text{cabin OA index table}} + E^2_{\text{cabin OB index table}} + E^2_{\text{cabin OC index table}} + \ldots}$$

b) Tables with constant step in index

Those tables are usually used for fuel Δindex or for all Δindex tables in the balance chart.

WEIGHT (kg)	DENSITY (kg/l) 0.785
3000	+2
4000	+1
5000	+0
6000	−2
7000	−4
8000	−7

In those tables the user selects the Δindex corresponding to the weight or passenger number he is considering. For a weight value not presented in the table different solutions are available :

- interpolation allowed : the user finds the Δindex by interpolating between the 2 closest Δindex values. Ex: for weight of 6500 kg the Δindex is –3.
  In this case the maximum inaccuracy value is reached for the maximum range of Δindex between two weights and the inaccuracy value equals half the Δindex range. Ex: in the above table the maximum Δindex range is between 7000 kg and 8000 kg and corresponds to a maximum inaccuracy in index of ±1.5 index units.
- interpolation is not recommended by the operator procedure, the user always retains the value corresponding to the lowest (highest) weight. Ex: for weight of 6500 kg the Δindex is –2 (–4).
  In this case the maximum inaccuracy value is reached for the maximum range of Δindex between two weights and the inaccuracy value equals the Δindex range. Ex: in the above table the maximum Δindex range is between 7000 kg and 8000 kg and corresponds to a maximum inaccuracy in index of ±3 index units.

The inaccuracy due to one table is independent from the inaccuracies due to the other tables so :

$$E_{\text{cargo index tables}} = \pm\sqrt{E^2_{\text{cargo1 index table}} + E^2_{\text{cargo2 index table}} + E^2_{\text{cargo3 index table}} + E^2_{\text{cargo4 index table}} + E^2_{\text{cargo5 index table}}}$$

$$E_{\text{passenger index tables}} = \pm\sqrt{E^2_{\text{cabin OA index table}} + E^2_{\text{cabin OB index table}} + E^2_{\text{cabin OC index table}} + \ldots}$$

3.5.2. Graphical balance chart inaccuracy

On the graphical balance chart the Δindex value for each item loaded is read on a diagram.
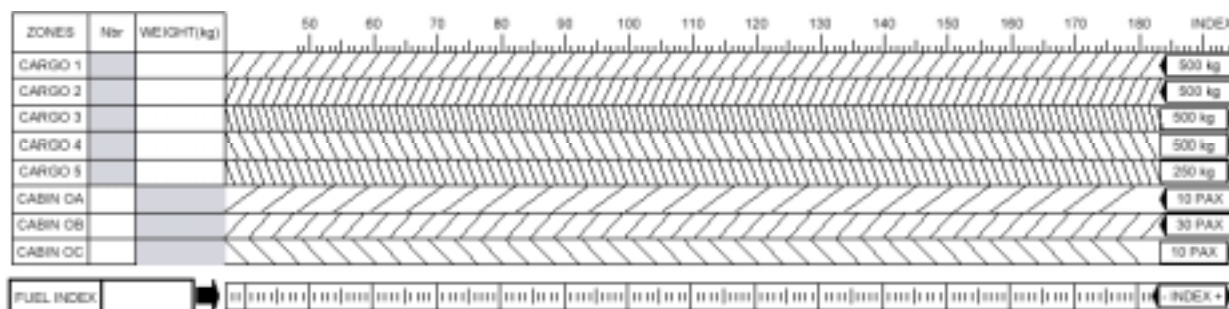
On this diagram the Δindex is drawn manually on each line for each item loaded.
The manual drawing generates an inaccuracy due to the drawing precision as illustrated below :
the blue line being the ideal drawing and the red line a manual drawing.
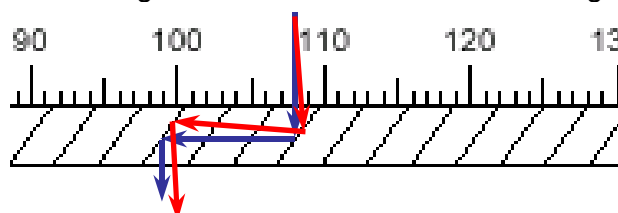
The inaccuracy due to this manual input is highly dependant on the index scale readability on the balance chart and the index scale is linked to the choice of index formula C constant.
AIRBUS standard constants are determined in order to have a major step in index length drawn on the chart between 1 and 1.5 cm, each major step is divided into 10 minor steps so one minor step length is between 1 and 1.5 mm. Then the cargo weight steps and passenger number steps on the diagram are determined so that between two oblique lines on the scale there is no more than 5mm to ensure sufficient accuracy when interpolating.

Following these design rules it is assumed that on each scale the maximum inaccuracy is of 0.5 index unit.
The inaccuracy due to one scale is independent from the inaccuracies due to the other scales so :

$$E_{\text{cargo index tables}} = \pm\sqrt{E^2_{\text{cargo1 index table}} + E^2_{\text{cargo2 index table}} + E^2_{\text{cargo3 index table}} + E^2_{\text{cargo4 index table}} + E^2_{\text{cargo5 index table}}}$$

$$E_{\text{passenger index tables}} = \pm\sqrt{E^2_{\text{cabin OA index table}} + E^2_{\text{cabin OB index table}} + E^2_{\text{cabin OC index table}} + \ldots}$$

3.5.3. example on A330 graphical balance chart
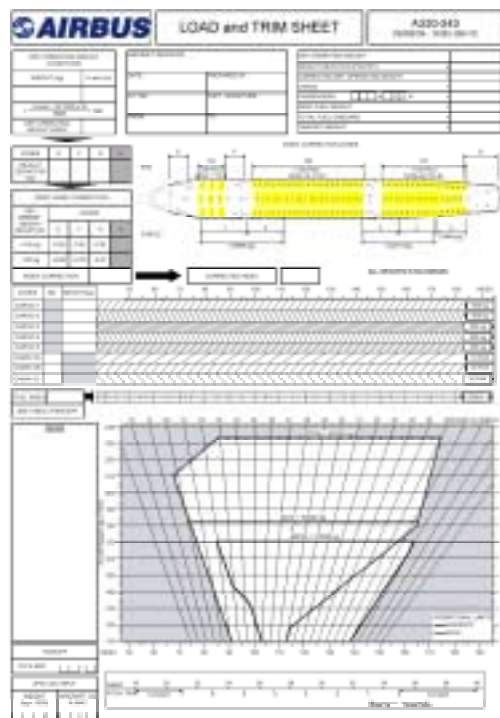
On this balance chart the final CG is determined

- entering the Dry Operating Index in the initial scale.
- determining Δindex for each cargo compartment (5 scales)
- determining Δindex for each cabin section (3 scales)
- determining the fuel Δindex in the fuel index table (inaccuracy depends on the weight step in the table, and on the procedure interpolation/no interpolation) in this example inaccuracy = 2 index units.
- entering the fuel index in the fuel scale

Each inaccuracy scale is independent from the other ones.

$$E_{CG\ determination\ method} = \pm\sqrt{E^2_{inital\ scale} + 5 \times E^2_{Cargo\ scale} + 3 \times E^2_{Cabin\ section\ scale} + E^2_{fuel\ table} + E^2_{fuel\ scale}}$$

$$E_{CG\ determination\ method} = \pm\sqrt{0.5^2 + 5 \times 0.5^2 + 3 \times 0.5^2 + 2^2 + 0.5^2} = \pm\sqrt{10 \times 0.5^2 + 2^2}$$

$$E_{CG\ determination\ method} = \pm 2.55 \text{ index unit}$$

$$\Delta Index = \frac{Moment}{C} = \frac{Moment}{2500}$$

$$E_{CG\ determination}\ method = \pm 2.55 \text{ index units} = \pm\ 2.55 \times 2500 = \pm\ 6374 \text{ kg.m.}$$

3.6. Item movements during flight impacting the aircraft CG position

Aircraft CG positions computed on the balance chart are based on DOW and DOCG values.

DOW and DOCG values are published for the following configuration :
- Flaps/slats in clean position
- Landing Gear extended
- Reversers in retracted position
- Water in potable water tanks.

This configuration corresponds to the aircraft configuration used at aircraft weighing.

Note : the above mentioned configuration at DOW is the most common one, some operators may use a different configuration. In this case the below presented method has to be adapted.

Note : on all the aircraft the movement of the reversers is considered negligible in term of CG movements so they are no more considered below.

The computed aircraft CG positions during the flight are computed for a given configuration in the cabin, passengers and crew seated in Takeoff/Landing configuration and trolleys locked in the galleys. During the flight, passengers and crew members move together with the trolleys, these movements generate a shift of the aircraft CG position.

These differences in aircraft configuration have to be taken into account when checking the CG position against the relevant certified CG limits, introducing an additional moment in the operational margin.

$E_{aircraft\ CG\ movement}$ = Real Aircraft Moment – Balance Chart Aircraft Moment

$E_{aircraft\ CG\ movement}$ = Moment due to item movement

Item being : Flaps/Slats, Landing Gear, Revesers, Water, Passenger, Crew…

3.6.1. Flaps/Slats and Landing gear movements
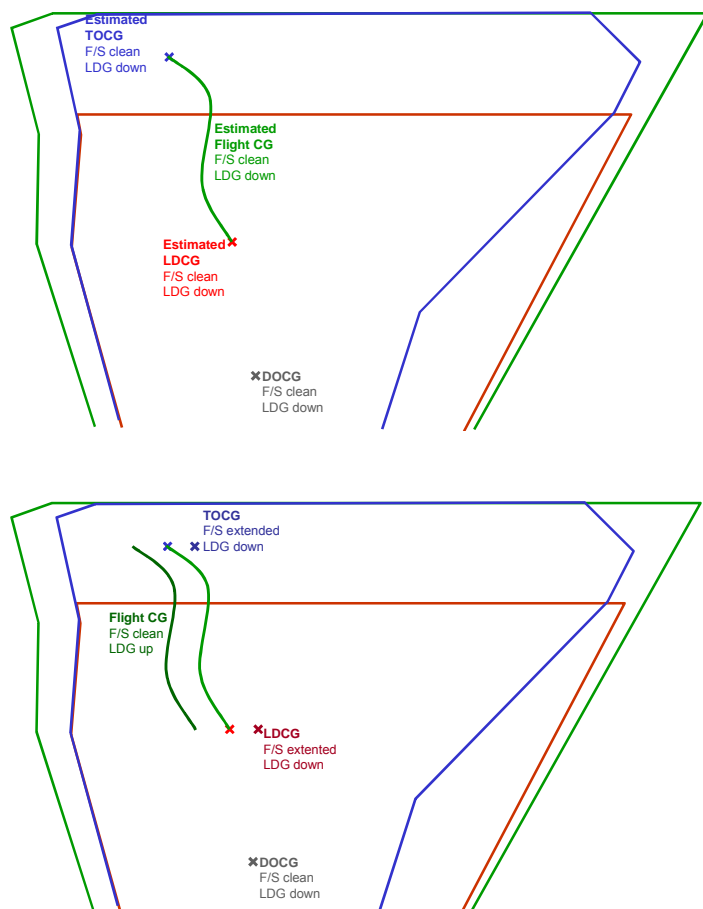
DOW and DOCG values are published for the following configuration :
- Flaps/slats in clean position
- Landing Gear extended

So on the balance chart all the aircraft CG values correspond to this configuration.

In reality Takeoff configuration is Flaps/slats extended, Landing configuration is Flaps/slats extended and Flight configuration is landing gear retracted.

$E_{aircraft\ CG\ movement}$ = Moment due to Flaps/Slats or Landing Gears movement

The moments generated by Flaps/Slats and Landing Gears movement are published in the WBM in section 1.00.

Flaps extension moves the aircraft CG aft, Slats extension moves it forward, the total resulting moment for takeoff and landing possible configuration moves it aft so the real takeoff and landing CG will always be aft of the estimated value.

So for aft certified CG operational margins determination the maximum aft movement has to be taken into account to prevent the aircraft CG being out of the limits.

For the forward certified CG operational margins determination, there is no risk of being out of the limits as the operational configurations will always lead to a more aft CG than the estimated one. Nevertheless it is possible to take benefit of this situation by taking into account this CG movement is reducing the forward operational margin.

Landing gears retraction moves the aircraft CG forward so the real in flight CG will always be forward of the estimated value.

So for forward certified CG operational margins determination the maximum forward movement has to be taken into account to prevent the aircraft CG being out of the limits.

For the aft certified CG operational margins determination, there is no risk of being out of the limits as the operational configurations will always lead to a more forward CG than the estimated one. Nevertheless it is possible to take benefit of this situation by taking into account this CG movement is reducing the aft operational margin.

- **ex : A330-200**

  10. Effect of moving components on the aircraft CG

  Balance effects caused by operation of slats, flaps, thrust reverser and landing gear are given below.

  A. Slats and flaps extension

COCKPIT INDICATION (°)		MOMENTS (kgm)		
SLATS INBOARD/OUTBOARD	FLAPS	SLATS	FLAPS	TOTAL
14/16	0	− 498	0	− 498
14/16	8	− 498	+ 823	+ 325
17.7/20	14	− 638	+ 966	+ 328
19.6/23	22	− 719	+ 1 087	+ 368
19.6/23	32	− 719	+ 1 195	+ 476

  B. Thrust reverser extension

  Thrust reverser = Negligible

  C. Landing gear retraction

  Nose landing gear = − 1 018 kgm
  Main landing gear = − 5 659 kgm

  NOTE : *The aircraft is weighed with slats, flaps and thrust reverser retracted.*

Flaps and Slats movements :
  Takeoff configuration : the possible configurations are CONF 1+F, CONF 2, CONF 3.
    Impact on forward operational limit : $E_{\text{aircraft CG movement}}$ = 0 kg.m or $E_{\text{CONF 1+F}}$
    Impact on aft operational limit : $E_{\text{aircraft CG movement}}$ = $E_{\text{CONF 3}}$ = + 368 kg.m
  Landing configuration : the possible configurations are CONF 3, CONF FULL.
    Impact on forward operational limit : $E_{\text{aircraft CG movement}}$ = 0 kg.m or $E_{\text{CONF 3}}$
    Impact on aft operational limit : $E_{\text{aircraft CG movement}}$ = $E_{\text{CONF FULL}}$ = + 476 kg.m

Landing Gears movements :
  Flight configuration : Nose and Main landing gears retracted
    Impact on forward operational limit : $E_{\text{aircraft CG movement}}$ = $E_{\text{Main}} + E_{\text{Nose}}$ = - 6677 kg.m
    Impact on aft operational limit : $E_{\text{aircraft CG movement}}$ = 0 kg.m or $E_{\text{Main gear}} + E_{\text{Nose gear}}$

3.6.2. Water movement from potable to waste tank

Estimated TOCG
Water in Potable water tanks

Estimated Flight CG
Water in Potable water tanks

Estimated LDCG
Water in Potable water tanks

✕ **DOCG**
Water in Potable water tanks

Flight CG
Water moving between potable tanks and waste tanks

LDCG
Water in waste tanks

✕ **DOCG**
Water in Potable water tanks
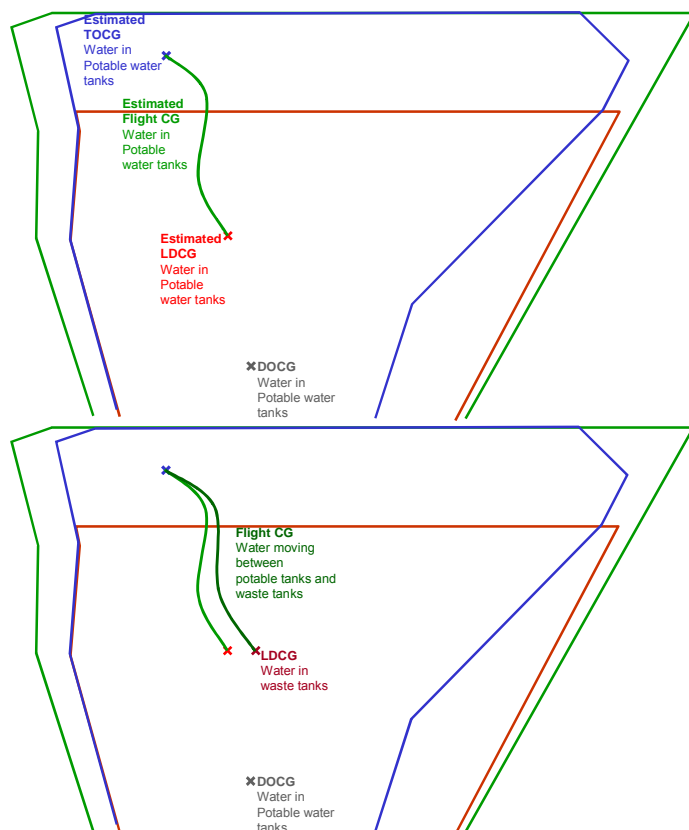
DOW and DOCG values are published for the following configuration :

- Water is located in the potable water tanks.

So on the balance chart all the aircraft CG values correspond to this configuration.

In reality at landing part of the water is located in the waste tanks and part of the water has been ejected out of the aircraft.

$E_{aircraft\ CG\ movement}$ = Moment due to item movement = Moment due to water movement from potable tanks to waste tanks + Moment due to water ejection.

$E_{aircraft\ CG\ movement}$ = $W_{Water\ in\ waste\ tank}$ x (H-arm$_{final\ position}$ − H-arm$_{initial\ location}$) + $W_{Water\ ejected}$ x (H-arm$_{final\ position}$ − H-arm$_{initial\ location}$).

$E_{aircraft\ CG\ movement}$ = $W_{Water\ in\ waste\ tank}$ (H-arm$_{waste\ tank}$ − H-arm$_{potable\ water\ tank}$) - $W_{Water\ ejected}$ x H-arm$_{potable\ water\ tank}$.

Position of the different tanks in the aircraft are published in WBM 1.30

- **ex : A330-200**

04. Potable water

ITEM	CAPACITY		WEIGHT		H-ARM	
	(l)	(US gal)	(kg)	(lb)	(m)	(in)
Tank N° 1	350	92.47	350	771.61	39.167	1 542.00
Tank N° 2	350	92.47	350	771.61	51.694	2 035.20

05. Waste tanks

ITEM	CAPACITY		WEIGHT		H-ARM	
	(l)	(US gal)	(kg)	(lb)	(m)	(in)
Tank N° 1	350	92.47	350	771.61	51.587	2 030.98
Tank N° 2	350	92.47	350	771.61	52.369	2 061.77

Takeoff configuration 700 kg of water in the potable water tanks.
Landing configuration :
- 1/3 of the water ejected out of the aircraft,
- 2/3 of the water in the waste tank.

$E_{aircraft\ CG\ movement}$ = $W_{Water\ in\ waste\ tank}$ (H-arm$_{waste\ tank}$ − H-arm$_{potable\ water\ tank}$) - $W_{Water\ ejected}$ x H-arm$_{potable\ water\ tank}$.

$$E_{aircraft\ CG\ movement} = \frac{2}{3} \times 700 \times \left(\frac{52.587 + 52.369}{2} - \frac{39.167 + 51.691}{2} \right) - \frac{1}{3} \times 700 \times \left(\frac{39.167 + 51.691}{2} \right)$$

$E_{aircraft\ CG\ movement}$ = 3289.53 – 10600.1 = - 7310.57 kg.m

---

3.6.3. In flight passenger and crew movements
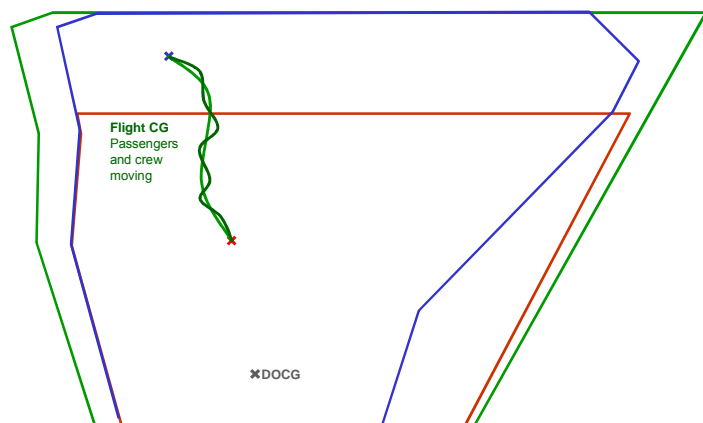
On the balance chart all the aircraft CG values are based on the passenger and crew position at takeoff.
We consider that at landing the configuration is identical to the takeoff one.
During the flight passengers and crew are moving throughout the cabin.

$E_{aircraft\ CG\ movement\ item}$ = Moment due to item movement
$E_{aircraft\ CG\ movement\ item}$ = W_{item} x (H-arm$_{Item\ final\ position}$ – H-arm$_{Item\ initial\ location}$)

The estimation of the possible inflight movements depends on the airline operations, on the cabin layout, on the flight type…
The objective is to determine realistic impact on the aircraft CG during the flight by considering the different periods of the flight when there are movements in the cabin :

- Meal servicing,
- Passengers moving to the lavatories
- Crew moving to the crew rest areas
- Duty free sells
- …

Some of these movements may happen simultaneously, some will move the aircraft CG forward, some will move it aft.

A standard movement scenario is used in Airbus standard method :

- All movements are defined based on initial position of the item or person at takeoff.
- Galleys, lavatories and crew are assigned per passenger class, and movements are performed within each class section.
- All movement in one direction (forward/aft) happen simultaneously.
- There is one passenger per lavatory, when 2 lavatories are available for the same passenger section then 2 passengers from the middle of the section move toward them at the same time.
- There is one cabin crew and one trolley per aisle for meal servicing.
- When underfloor crew rest or crew rest area is defined in the cabin, then additional movements towards the rest area are taken into account. Crew members form the whole cabin are moving.
- Additional movement may be added : cabin crew to the cockpit, cockpit crew to cabin area.

This scenario enables to establish for each item or person moving $E_{aircraft\ CG\ movement\ item}$ = W_{item} x (H-arm$_{Item\ final\ position}$ – H-arm$_{Item\ initial\ location}$), then as all movement in one direction (forward/aft) happen simultaneously, the total $E_{aircraft\ CG\ movement}$ is the sum of each individual $E_{aircraft\ CG\ movement\ item}$.

- **ex : A330-200 movements forward**

2 B class pax from row 4 to La and Lb

2 Eco class pax from row 21 to Lc and Ld

2 trolleys from G5/G6 to pax row 18

1 cabin crew from forward position to cockpit

2 cabin crew from aft positions to pax row 18
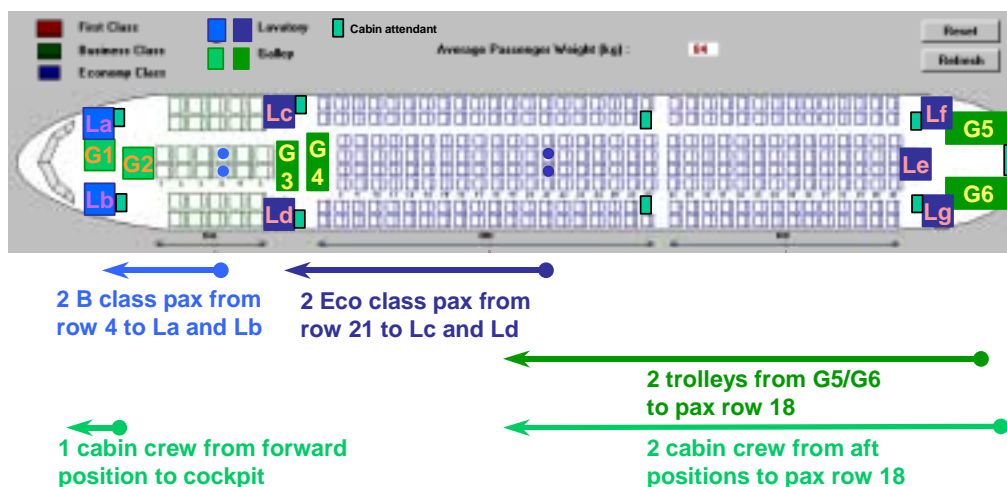
Forward movements are split into 3 movements for each movement $E_{aircraft\ CG\ movement\ item}$ = W_{item} x $(H\text{-arm}_{Item\ final\ position} - H\text{-arm}_{Item\ initial\ location})$ needs to be determined.

W_{item} depends on the operator assumptions, passenger or crew member weights are defined without hand luggage. Eg : for average pax weight = 84 kg, the pax weight considered for the movement is (average pax weight – hand baggage weight) = 84-9 = 75 kg.

$H\text{-arm}_{Item\ final\ position}$ and $H\text{-arm}_{Item\ initial\ location}$ are published in the weight and balance manual in the 1.40 and 1.50 sections.

1. passenger movements :

    2 business class passengers to business class lavatories

$$E_{aircraft\ CG\ movement\ 2\ pax\ from\ row\ 4\ to\ La/Lb} = W_{2\ pax} \times (H\text{-arm}_{La/Lb} - H\text{-arm}_{Row4})$$

Row Nº	WINDOW SEATS (lines A,C,H,K)				CENTER SEATS (lines D,E,F,G)		
	H-ARM		NUMBER PAX		H-ARM		NUMBER PAX
	(m)	(in)	LH	RH	(m)	(in)	
1	–	–	–	–	13.885	546.65	2
2	14.520	571.65	2	2	14.901	586.65	2
3	15.536	611.65	2	2	15.917	626.65	2
4	16.552	651.65	2	2	16.933	666.65	2
5	17.568	691.65	2	2	17.949	706.65	2

05. Toilets

The aircraft is equipped with toilets as shown in figure 1–40–03 (Cabin Arrangement).

The table below shows the average H-arm for each toilet.

CABIN LOCATION	REF	H-ARM	
		(m)	(in)
Forward	La	10.750	423.20
Forward	Lb	10.800	425.20
Forward	Lc	19.627	772.72
Forward	Ld	19.627	772.72

$$E_{aircraft\ CG\ movement\ 2\ pax\ from\ row\ 4\ to\ La/Lb} = 2x\ 75 \times (10.755 - 16.933) = -926.7\ kg.m$$

2 economy class passengers to economy class lavatories

$E_{\text{aircraft CG movement 2 pax from row 21 to Lc/Ld}} = W_{2\ pax} \times (H\text{-arm}_{Lc/Ld} - H\text{-arm}_{Row21})$

Row N°	WINDOW SEATS (lines A,C,H,K)				CENTER SEATS (lines D,E,F,G)		
	H-ARM		NUMBER PAX		H-ARM		NUMBER PAX
	(m)	(in)	LH	RH	(m)	(in)	
16	28.910	1138.19	2	2	29.043	1143.43	4
17	29.774	1172.20	2	2	29.906	1177.40	4
18	30.638	1206.22	2	2	30.770	1211.42	4
19	31.502	1240.24	2	2	31.634	1245.43	4
20	32.365	1274.21	2	2	32.497	1279.41	4
21	33.229	1308.23	2	2	33.360	1313.39	4
22	34.093	1342.20	2	2	34.224	1347.40	4

$E_{\text{aircraft CG movement 2 pax from row 21 to Lc/Ld}} = 2 \times 75 \times (19.627 - 33.360) = -2059.95 \text{ kg.m}$

2. Trolley movements

2 trolleys from G5/G6 to passenger row 18

$E_{\text{aircraft CG movement 2 trolleys from G5/G6 to row 18}} = W_{2\ trolleys} \times (H\text{-arm}_{Row\ 18} - H\text{-arm}_{G5/G6})$

04. Galleys

The galley locations are shown in figure 1-40-03 (Cabin arrangement).

The table below gives the H-arm for each galley and the maximum permissible load.

LOCATION	REF N°	H-ARM		MAX LOAD	
		(m)	(in)	(kg)	(lb)
Forward cabin	G1b	10.714	421.81	510	1 124
Forward cabin	G1c	12.545	493.90	850	1 874
Forward cabin	G2	19.973	786.34	1 060	2 337
Mid cabin	G3	21.756	856.54	1 270	2 800
Aft cabin	G8	54.064	2 128.50	1 100	2 425
Aft cabin	G9	54.064	2 128.50	1 260	2 778

$E_{\text{aircraft CG movement 2 trolleys from G5/G6 to row 18}} = 2 \times 80 \times (30.77 - 54.064) = -3727.04 \text{ kg.m}$

3. Crew members movements

2 cabin crew from aft positions to passenger row 18

$E_{\text{aircraft CG movement 2 cabin crew from aft position to row18}} = W_{2\ cabin\ crew} \times (H\text{-arm}_{Row18} - H\text{-arm}_{aft})$

$E_{\text{aircraft CG movement 2 cabin crew from aft position to row18}} = 2 \times 70 \times (30.77 - 55.21) = -3421.6 \text{ kg.m}$

1 cabin crew from forward position to cockpit

$E_{\text{aircraft CG movement 1 cabin crew from fwd position to cockpit}} = W_{1\ cabin\ crew} \times (H\text{-arm}_{cockpit} - H\text{-arm}_{fwd})$

$E_{\text{aircraft CG movement 1 cabin crew from fwd position to cockpit}} = 70 \times (8.872 - 11.575) = -189.21 \text{ kg.m}$

Total forward movements :

$E_{\text{aircraft FWD CG movement}} = E_{\text{aircraft CG movement 2 pax from row 4 to La/Lb}}$

$+ E_{\text{aircraft CG movement 2 pax from row 21 to Lc/Ld}}$

$+ E_{\text{aircraft CG movement 2 trolleys from G5/G6 to row 18}}$

$+ E_{\text{aircraft CG movement 2 cabin crew from aft position to row18}}$

$+ E_{\text{aircraft CG movement 1 cabin crew from fwd position to cockpit}}$

$E_{\text{aircraft FWD CG movement}} = -(926.7 + 2059.95 + 3727.04 + 3421.6 + 189.21) = -10320.5 \text{ kg.m}$

3.7. Total operational margins determination

The total operational margins per flight phase are determined summing each individual margin, some of them being considered as systematic, the other ones as non systematic.

OPERATIONAL MARGIN			Systematic / Non systematic	Aircraft CG affected		
				TO	LD	IF
Inaccuracy on initial data (DOW and DOCG)			Non Syst	X	X	X
Inaccuracy on items loading on board the aircraft (passengers, cargo, fuel)						
	Passenger loading	Inaccuracy on the passengers' location	Non Syst	X	X	X
		Inaccuracy on the passengers' weight	Non Syst	X	X	X
	Cargo loading	Inaccuracy on the cargo location	Non Syst	X	X	X
		Inaccuracy on the cargo weight	Non Syst	X	X	X
	Fuel loading	Inaccuracy on the fuel location	Non Syst	X	X	X
		Inaccuracy on the fuel weight	Non Syst	X	X	X
Inaccuracy due to CG computation method						
	Manual balance chart		Non Syst	X	X	X
	Computerized balance chart					
Item movements during flight impacting the aircraft CG position						
	Flaps/Slats movements		Syst	X	X	
	Landing gear movements		Syst			X
	Water movement from potable to waste tank		Syst		X	
	In flight passenger and crew movements		Syst			X

$$\text{FWD margin}_{\text{flight phase1}} = -\sqrt{\text{FWDmargin}_{\text{NON Systematic 1}}^2 + ... + \text{FWDmargin}_{\text{NON Systematic n}}^2} + \text{FWDmargin}_{\text{Systematic 1}} + ... + \text{FWDmargin}_{\text{Systematic n}}$$

$$\text{AFT margin}_{\text{flight phase1}} = +\sqrt{\text{AFTmargin}_{\text{NON Systematic 1}}^2 + ... + \text{AFTmargin}_{\text{NON Systematic n}}^2} + \text{AFTmargin}_{\text{Systematic 1}} + ... + \text{AFTmargin}_{\text{Systematic n}}$$

3.8. Takeoff, Landing, In-Flight operational limits determination

When total operational margins per flight phase are determined they are applied to each corresponding certified limit to obtain the operational limits per flight phase.
Certified limits are published in the WBM 1.10 tables presenting A/c Certified Weight = W and A/c Certified CG limit (%RC) = CG.

Certified limits $_{Flight\ phase}$			
Weight W	CG (%RC) $CG_{certified}$	CG (H-arm) $H\text{-arm}_{certified}$	Aircraft Moment on certified limit
W	CG	$LEMAC \times \dfrac{MAC \times CG}{100}$	$W \times LEMAC \times \dfrac{MAC \times CG}{100}$

Total operational margin $_{Flight\ phase}$ = E

Operational limits $_{Flight\ phase}$			
Weight W	Aircraft Moment on operational limit	CG (H-arm) $H\text{-arm}_{operational}$	CG (%RC) $CG_{operational}$
W	W x $H\text{-arm}_{certified}$ - E	$\dfrac{W \times H\text{-}arm_{certified} - E}{W}$	$\left(\dfrac{W \times H-arm_{certified} - E}{W} - LEMAC\right) \times \dfrac{100}{MAC}$

- **ex : A320-200 Takeoff forward operational limits determination**

Weight W kg	Certified limit			Operational margin kg.m	Operational limit		
	$CG_{certified}$ %RC	$H\text{-arm}_{certified}$ m	Moment kg.m		Moment kg.m	$H\text{-arm}_{operational}$ m	$CG_{operational}$ %RC
37320	15	18.431	686 168		691 465	18.573	18.393
53000	15	18.431	976 818		982 114	18.530	17.383
63000	17	18.514	1 166 406	- 5 296.33	1 171 703	18.598	19.005
72000	17	18.514	1 333 036		1 338 333	18.588	18.754
73500	18.9	18.594	1 366 664		1 371 961	18.666	20.618
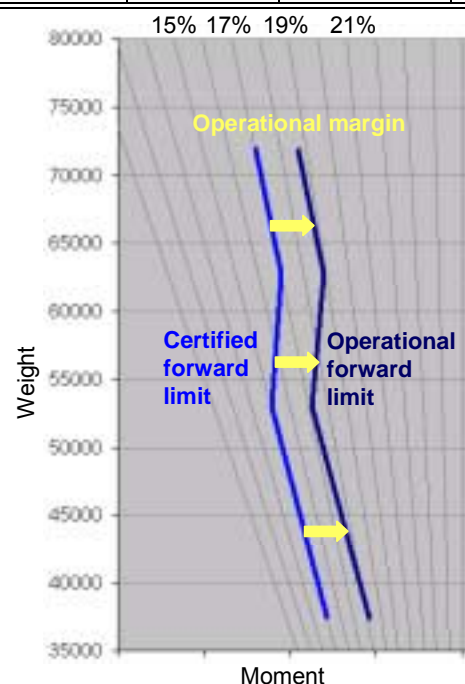
$H\text{-arm}_{Certified} = (CG_{Certified} \times 0.041935) + 17.8015$
$Moment_{Certified} = H\text{-arm}_{Certified} \times Weight$
$Moment_{0perational} = Moment_{Certified} - (- 5\ 296.33)$
$H\text{-arm}_{operational} = Moment_{0perational} / Weight$
$CG_{operational} = (H\ arm_{operational} - 17.8015) / 0.041935$

The complete computation leads to the determination of each individual operational limit.
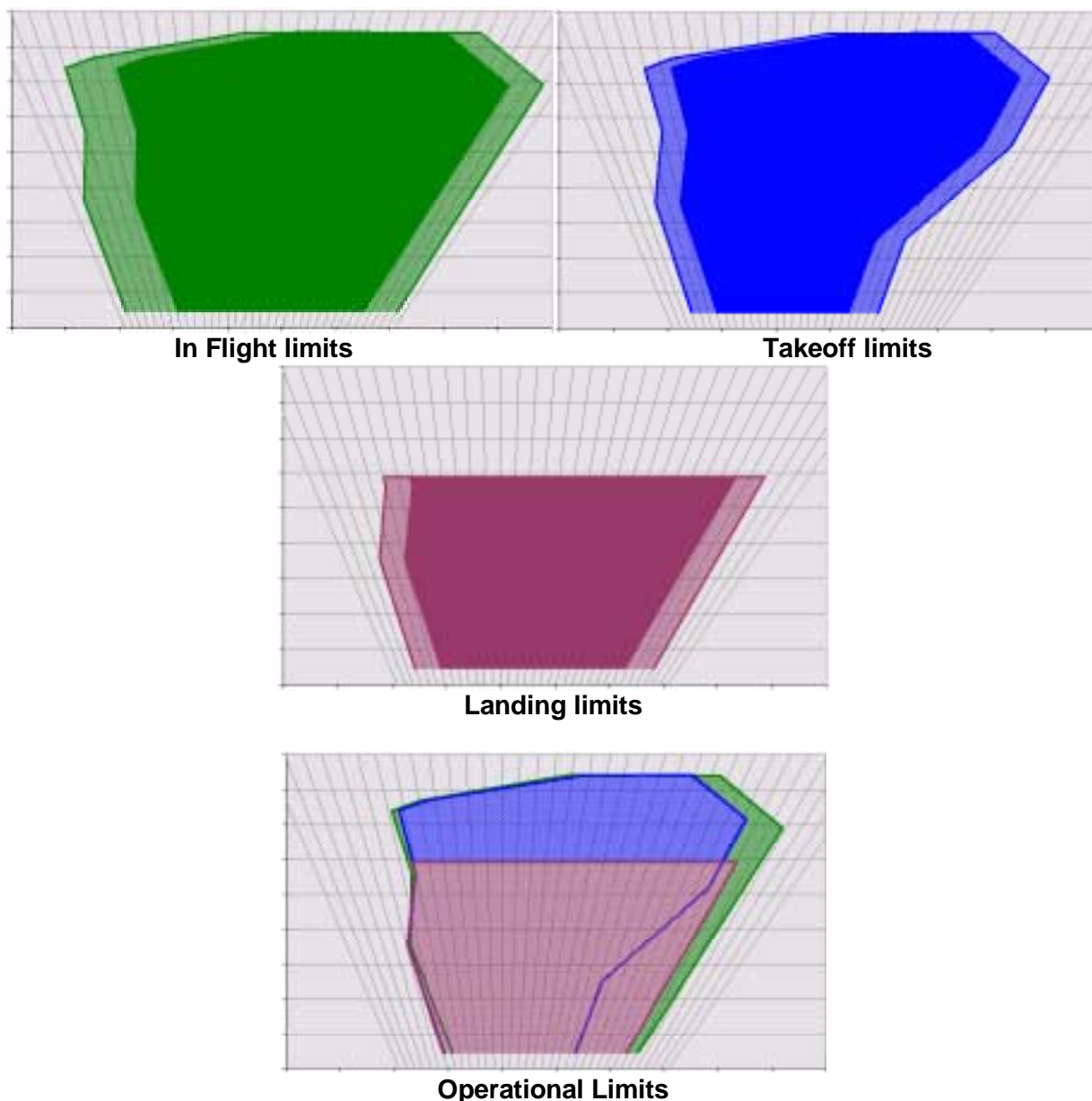
In Flight limits

Takeoff limits

Landing limits

Operational Limits

On the balance chart the 3 operational limits – Takeoff, Landing and In-flight – are not represented because if the Takeoff CG position check against its corresponding limit can be done after a manual or computerized computation, the determination of the Landing CG and furthermore the In-flight CG positions on a paper document is much more difficult, it is hardly possible to check these CG positions against their corresponding CG limits.

So only a Takeoff limit is drawn on the Load and Trim Sheet, this takeoff limit is the more limiting one of the three operational limits, depending on the values of each operational margins.

Note often on A320 documents the forward In Flight limit is more limiting than the Takeoff one. And this specially for low aircraft weights. So the forward operational limit published on the balance chart or in the AHM560 is made of part of the In Flight limit and part of the Takeoff limit.

3.9. Zero Fuel limit determination

3.9.1. Definition of the Zero Fuel Limit

On the balance chart it is necessary to check the Takeoff CG position against the Takeoff operational limit, this ensures that the aircraft CG position is within the certified takeoff limit. Nevertheless this check is not sufficient to ensure that the aircraft CG remains within the in flight and landing limits during the whole flight.

This second check cannot be made easily by checking the landing CG position and the different flight CG positions because of the difficulty to estimate these values.

To perform this check an additional limit has been introduced : the Zero Fuel Limit.

> **The Zero Fuel limit is determined to ensure that during the whole flight and at landing the aircraft CG remains within the limits.**

3.9.2. Zero Fuel limit computation method

Two different methods are used to determine the Zero Fuel limit, depending on procedure applied on the balance chart.

a) Zero fuel limit takeoff protected :

- **IF** Zero fuel CG is within the Zero fuel limit
- And **IF** takeoff weight and landing weight are compliant with the operational takeoff and landing maximum weights.

THEN Takeoff, Landing and In Flight CG are within the allowed limits using the whole flight.

With this type of limit, assuming that the takeoff and landing weight limitations are checked on the AHM516 (Load Message) the only check to be performed on the balance chart is to ensure that the Zero Fuel CG position is within the Zero Fuel limit.

b) Zero fuel limit not takeoff protected :

- **IF** Zero fuel CG is within the Zero fuel limit
- **IF** Takeoff CG is within the Takeoff operational limit
- And **IF** takeoff weight and landing weight are compliant with the operational takeoff and landing maximum weights.

THEN Takeoff, Landing and In Flight CG are within the allowed limits using the whole flight.

With this type of limit, assuming that the takeoff and landing weight limitations are checked on the AHM516 (Load Message) the check to be performed on the balance chart is to ensure that the Zero Fuel and Takeoff CG position are within the Zero Fuel and Takeoff operational limits.

c) Computation method :

For each type of Zero Fuel limit the calculation principle is the same, it consists in :
- Determining the possible aircraft CG position at Takeoff, Landing and Flight provided the Zero Fuel CG position is known, by analyzing the fuel vectors applicable to each flight phase. (refer to Fuel System Chapter).
- Using the fuel vectors, determining all the allowed Zero Fuel CG positions so that all possible takeoff (for takeoff protected limit), landing and in flight CGs remains within their operational limits from no fuel to maximum fuel quantity.

3.9.3. Zero Fuel limit computation example : A320
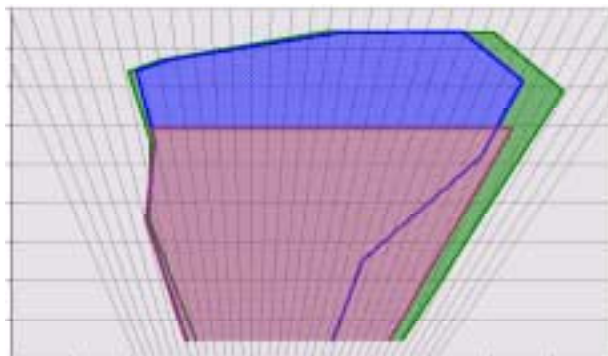
The computation is based on the operational limits previously determined and on the possible CG positions at takeoff, landing and in flight for a given Zero Fuel CG position, these positions are given by the different fuel vectors.

For A320 family aircraft the takeoff, in flight and landing fuel vectors are identical.

a) Zero fuel limit takeoff protected :
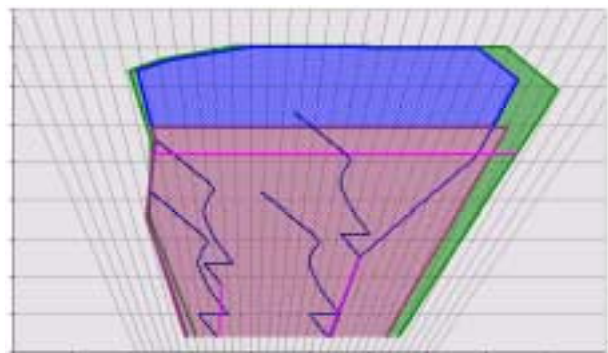
Each flight phase fuel vector is leaned against the corresponding operational limit. In the case of A320 aircraft the fuel vector is leaned against the more inside operational limit.

This operation is repeated for Zero Fuel weights between minimum aircraft weight and Maximum Certified Zero Fuel Weight.
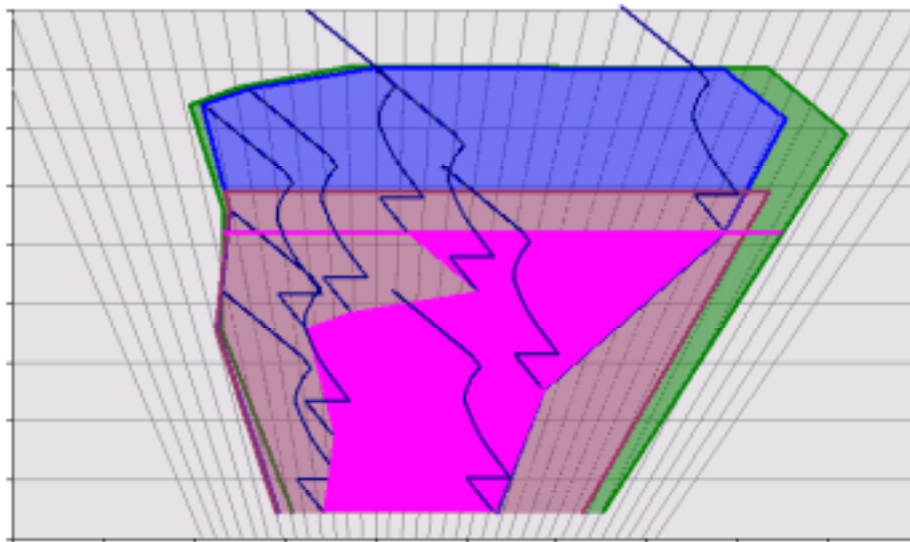
For this example the final result is the pink area above.

Note : This area is determined for all fuel quantities between 0 to maximum fuel quantity. But if the fuel quantity is lower than maximum fuel quantity the resulting Zero Fuel limit would be larger than the one above. So some operators using the takeoff protected Zero Fuel limit may chose to have several limits presented depending on the takeoff fuel quantity.

b) Zero fuel limit not takeoff protected :
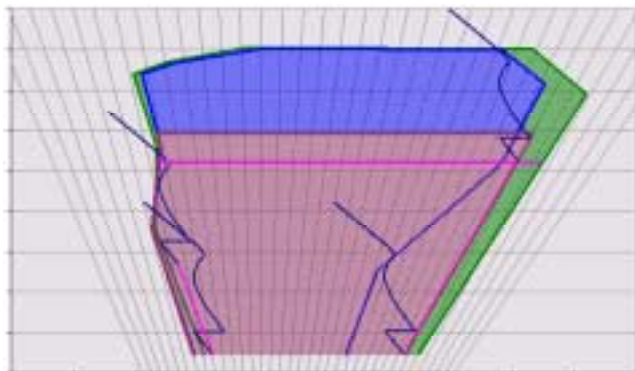
Landing and flight phase fuel vector are leaned against the corresponding operational limit. In the case of A320 aircraft the fuel vector is leaned against the more inside operational limit between landing and flight.

The takeoff limit is not used as the takeoff CG position is supposed to be checked within the operator procedure.

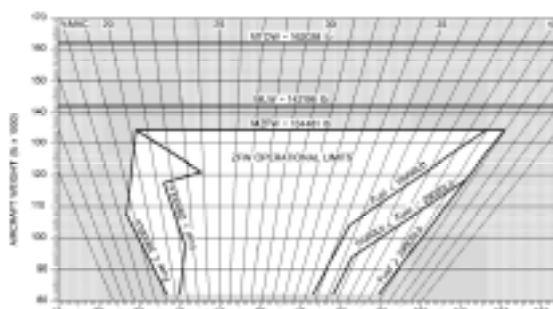On the forward limit, the final part of the vector, which corresponds to the center tank refueling or consumption, is not taken into account (it goes out of the operational limits on the graph). This optimization is made to enlarge as much as possible the Zero Fuel limit. It is possible because the takeoff CG position is checked and because the fuel burn in the center tank shifts the aircraft CG aft. So it ensures that if the takeoff CG is within of the takeoff operational limit then the other CG positions will remain in the limits also during the whole flight.

This operation is repeated for Zero Fuel weights between minimum aircraft weight and Maximum Certified Zero Fuel Weight
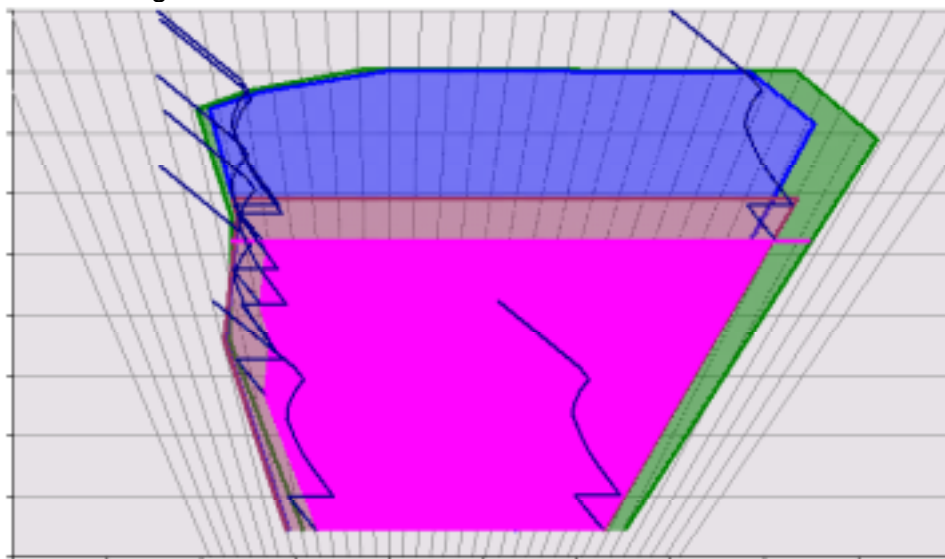
For this example the final result is the pink area above.

Note : In this case the Zero Fuel limit is optimized and there is no need to have different limits for different fuel quantities.

4. BALANCE CHART DRAWING PRINCIPLE

A balance chart is made of several parts – the Δindex scales or tables and the operational limits graph. The aim of this chapter is to explain the way to draw the different parts.

AIRBUS | LOAD and TRIM SHEET | A330-243
VERSION : 18 BC-264 YC

DRY OPERATING WEIGHT CONDITIONS

WEIGHT (kg)	H-arm (m)

$$I = \frac{(H\text{-arm} - 33.1555) \times W}{5000} + 100$$
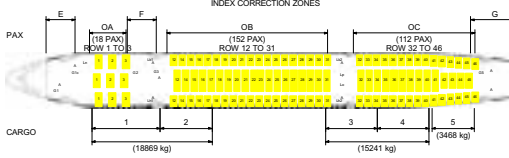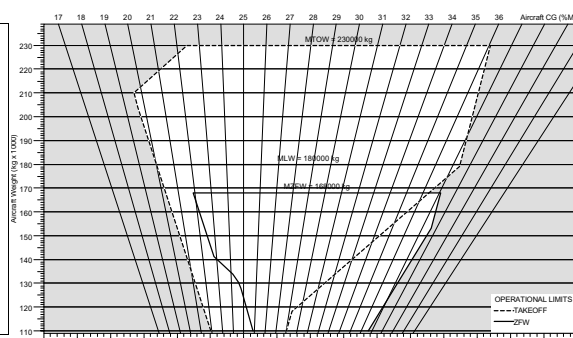
DRY OPERATING WEIGHT INDEX

AIRCRAFT REGISTER :
DATE : / PREPARED BY :
FLT Nbr : / CAPT. SIGNATURE :
FROM : / TO :

DRY OPERATING WEIGHT	
WEIGHT DEVIATION (PANTRY)	±
CORRECTED DRY OPERATING WEIGHT	=
CARGO	+
PASSENGERS [ ] x [B] 4 =	+
ZERO FUEL WEIGHT	=
TOTAL FUEL ONBOARD	+
TAKEOFF WEIGHT	=

INDEX CORRECTION ZONES

ZONES	E	F	G	H
WEIGHT DEVIATION (kg)				

PAX
OA (18 PAX) ROW 1 TO 8
OB (152 PAX) ROW 12 TO 31
OC (112 PAX) ROW 32 TO 46

CARGO
1 2 (18869 kg)
3 4 5 (15241 kg) (3468 kg)

BASIC INDEX CORRECTION

DRY OPERAT. WEIGHT DEVIATION	ZONES			
	E	F	G	H
+300 kg	-1.30	-0.82	+1.22	
-300 kg	+1.30	+0.82	-1.22	

INDEX CORRECTION → CORRECTED INDEX

ALL WEIGHTS IN KILOGRAMS

ZONES	Nbr	WEIGHT(kg)
CARGO 1			500 kg
CARGO 2			500 kg
CARGO 3			500 kg
CARGO 4			500 kg
CARGO 5			250 kg
CABIN OA			10 PAX
CABIN OB			40 PAX
CABIN OC			15 PAX

INDEX scale: 70 80 90 100 110 120 130 140 INDEX

FUEL INDEX → (INDEX +)
SEE TABLE OVERLEAF

NOTES

Aircraft CG (%MAC): 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36

Aircraft Weight (kg x 1000): 230 220 210 200 190 180 170 160 150 140 130 120 110

MTOW = 230000 kg
MLW = 180000 kg
MZFW = 168000 kg

OPERATIONAL LIMITS
- - - TAKEOFF
—— ZFW

INDEX 70 80 90 100 110 120 130 140

TAKEOFF
CG % MAC

ZFW CDU INPUT

WEIGHT (kg x 1000)	AIRCRAFT CG % MAC

%MAC: 18 20 22 24 26 28 30 32 34 36 38 40
PITCH TRIM: Constant 7 6 5 4 3 2 1 0 Constant
Nose Up Nose Down

4.1. Δindex scales or tables for loaded items

4.1.1. Graphical balance chart

On the graphical balance chart the Δindex value for each item loaded – passenger or cargo – is read on a diagram.
One scale per cargo compartment and one scale per passenger cabin section are represented.
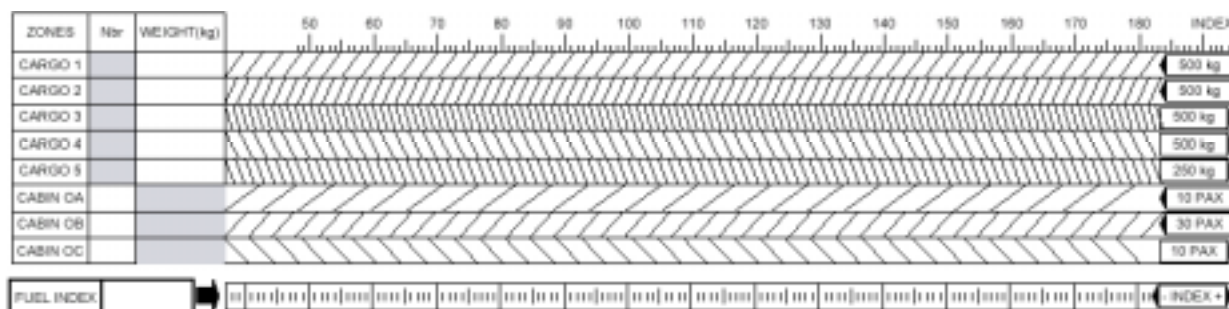

The scales are made of oblique lines, with distance between 2 lines representing the Δindex corresponding to the individual cargo weight or passenger number, usually presented on the right end of each scale.
The oblique lines have been introduced in order to ease the manual drawing on the document. Indeed the first possibility is to have vertical lines but is it difficult to determine the end point of the drawing.
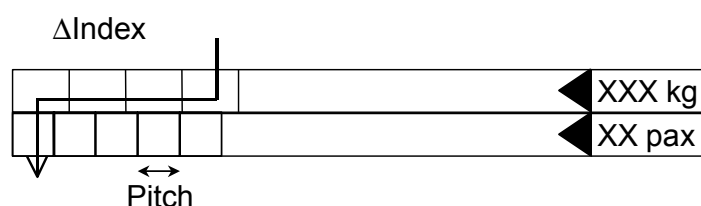
Whereas with oblique line the horizontal and vertical lines can be more easily drawn.
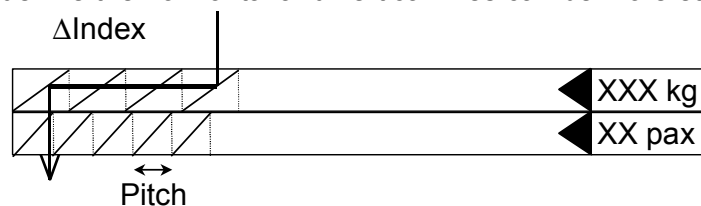
To draw the pitch between two line use the Δindex(1 kg) value.

$$\Delta \text{Index}_{item}(1kg) = \frac{(H - arm_{item} - H_{Ref})}{C}$$ and determine the Δindex(XXX kg) or Δindex(XX PAX)

needed on the balance chart.

Note 1 : the horizontal distance between the oblique line top and bottom points represents exactly Δindex(XXX kg) or Δindex(XX PAX) on the index scale.

Note 2 : the oblique line orientation : from top right to bottom left in case of forward CG movement, and from top left to bottom right in case of aft CG movement when loading the item must be strictly applied, because of the habits taken when manually using a balance chart. A change in the orientation may lead to misusing of the document.

Note 3 : the fuel loading Δindex used to be drawn on similar scales for some specific aircraft, nevertheless today due to the complexity of the refuel vectors and the high impact of fuel density on the fuel vector, this graphical method is no more used for Airbus aircraft.

4.1.2. Tabulated balance chart

a) Tables with constant step in index

Those tables are usually used for passengers and cargo Δindex for fuel Δindex tables with constant step in weight are used.

CARGO n	
Weight (kg)	Δindex
203	+1
611	+2
1018	+3
1426	+4
1833	+5

CARGO n		
Weight (kg)		Δindex
0 - 203		+0
204 - 611		+1
612 - 1018		+2
1019 - 1426		+3
1427 - 1833		+4

CARGO n	
Weight (kg)	Δindex
0	+0
204	
	+1
612	
	+2
1019	
	+3
1427	
	+4

Building this type of table consists of determining the transition weights for which there is a step between one index value and the other.
In the above example :

- For weight between 0 and 203 kg the Δindex value varies between 0 and 0.49…
- For weight between 204 and 611 kg the Δindex value varies between 0.5 and 1.49…
- …

b) Tables with constant step in weight

Those tables are usually used for fuel Δindex or for all Δindex tables in the balance chart.

WEIGHT (kg)	DENSITY (kg/l) 0.785
3000	+2
4000	+1
5000	+0
6000	–2
7000	–4
8000	–7

Building this type of table consists of determining the Δindex(XXX kg) and rounding it to the closest unit or closest tenth, depending on the airline procedure.

4.2. Operational limits diagram

The operational limits are represented on a diagram
   - on X-axis the aircraft index values
   - on Y-axis the aircraft weight values

Then iso-CG lines are represented to enable the user to determine finally the aircraft CG position value in %RC.

It is based on the index formula expressed in %RC.

$$Index = \frac{Weight \times (\%RC - Ref\%)}{C} \times MAC + K$$

With:
   C and K constants depending on the aircraft type
   MAC = Mean Aerodynamic Chord of the aircraft.

- **For CG = Ref% then**

$$Index = \frac{Weight \times (Ref\% - Ref\%)}{C} \times MAC + K$$

Index = K, whatever the weight value.

Therefore the Ref% the iso-CG line is a straight line associated to index = K.
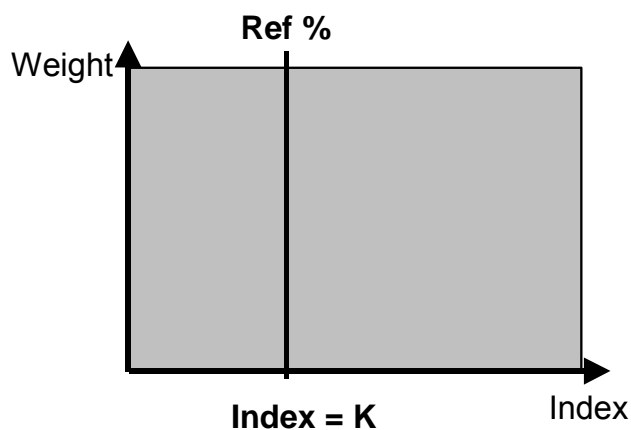
- **For other CG values then:**

The index values corresponding to two weights W_1 and W_2 are linked by the iso-CG line.

$$\text{Index}_1 = \frac{W_1 \ (CG_a - Ref\%)}{C} \times MAC + K \quad \text{and} \quad \text{Index}_2 = \frac{W_2 \ (CG_a - Ref\%)}{C} \times MAC + K$$
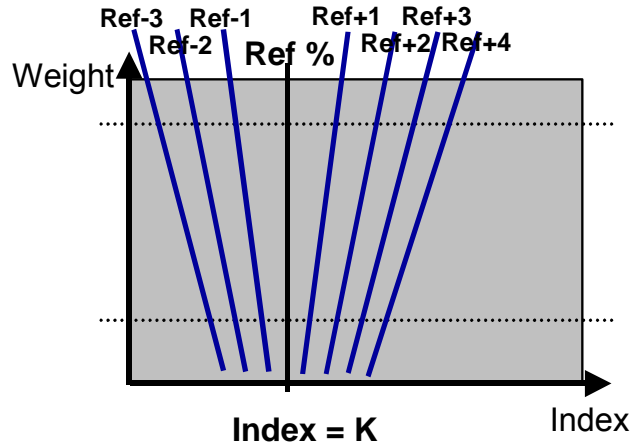
When the diagram is prepared the operational limits can be drawn on it :

- "takeoff" operational limit (the limit resulting from the operational margins computation and the selection of the more limiting part between takeoff, landing and in flight operational limits)
- zero fuel operational limit.

5. THE AHM560

The AHM560 is a standardized IATA document containing weight and trimming data necessary for both the aircraft CG position and the operational limits calculations. The computerized balance chart systems (EDP systems) are based on the data provided in the AHM560.

Part of this document contains the results from the balance chart design process, other information is linked to operators' needs in term of EDP system computation and EDP system output.

A specific AHM560 should be used by airlines for each type of aircraft they have, information given in the AHM560 can be applied to several aircraft registrations, provided those aircraft have the same Weight & Balance characteristics (same weight variants, same certified limits, same cabin layout, etc.).

5.1. Generalities

The AHM560 is divided into four main parts:
- PART A: COMMUNICATION ADDRESSES
- PART B: GENERAL INFORMATION
- PART C: AIRCRAFT DATA
- PART D: LOAD PLANNING DATA

Each part is divided into several Sheets, that correspond to different types of data. The aircraft type, the airline code and the part and sheet number of each page are written in the header as follows:

5.2. PART A: COMMUNICATION ADDRESSES

This part provides with the handling agents' and the carrier' addresses. It also lists all the documents that need to be produced by the EDP system. The supplemental documents are for instance a Loadsheet, a Loading Instruction/Report, a NOTOC, a LDM, a CPM, …

5.3. PART B: GENERAL INFORMATION

Part B is a summary of weight data used by the airline : passenger weights (Male / Female / Children / Infants), crew weights and cabin baggage weights, as well as the list of items taken into account for the Dry Operating Weight (DOW) and Dry Operating Index (DOI) calculation.

3. DRY OPERATING WEIGHT AND DRY OPERATING INDEX SPECIFICATIONS (tick as appropriate)

Item	DOW incl.	DOW Excl.	DOI incl.	DOI Excl.	Remarks
Basic weight	✓		✓		
Crew					
Crew baggage					
Pantry					
Containers					
Pallets					

5.4. PART C: AIRCRAFT DATA

This part contains the aircraft detailed list for which the document is applicable with the aircraft definition in term of weights and index and all the trimming data.

5.4.1. C Sheet 1

C Sheet 1 contains the information the operator needs to be shown on the EDP system Loadsheet output and the way the operator has chosen to determine the passenger loading influence on aircraft CG position.

5.4.2. C Sheet 2

C Sheet 2 contains the aircraft list for which the document is applicable and their definition in term of Dry Operating Weight or Basic Weight.

2   AIRCRAFT REGISTRATIONS, WEIGHT AND INDEX DETAILS

DRY OPERATING WEIGHT   ☐   BASIC WEIGHT   ☐   (tick as appropriate)

For check purposes add list of valid weights and indices.

Standard Fleet Weight:_____   Standard Fleet Index:_____

Registration	Weight Adjustment	Index Adjustment	Registration	Weight Adjustment	Index Adjustment

5.4.3. C Sheet 3

C Sheet 3 is a reminder of the index formula used for index calculation, with the exact values of constants and aircraft data that enter in this formula.

At the bottom of this sheet, the stabilizer trim setting is given in function of the MAC value at takeoff.

3.4   **Stabilizer trim setting**

MAC range	STAB range		
		Up Up Down Down	linear variation between % and %

5.4.4. C Sheet 4

C Sheet 4 contains the fuel index tables, there may be only one fuel table for the standard fuel density used by the operator of several tables for a range of densities.

Note : for all aircraft equipped with a trim tank it is recommended to issue several tables for different densities.

5.4.5. C Sheet 5

C Sheet 5 gives the Δindex to be used to determine the influence of items or persons in the cockpit.

5.4.6. C Sheet 6

C Sheet 6 contains the aircraft list for which the document is applicable (same list as in *C Sheet 2*) and their definition in term of maximum weights.

Maximum weights for:

Aircraft Reg. or Subtype No.	Ramp/Taxi	Design take-off wet*	Design take-off dry	Zero fuel	Design landing

5.4.7. C Sheet 7

C Sheet 7 contains the operational limits to be used for CG checks in the EDP system.
- "takeoff" operational limit (the limit resulting from the operational margins computation and the selection of the more limiting part between takeoff, landing and in flight operational limits)
- zero fuel operational limit.

FORWARD			AFT		
Special condition if applicable			Special condition if applicable		
Specify applicability *	Weight	Index Value	Specify applicability *	Weight	Index Value
ZFW			ZFW		

5.4.8. C Sheet 8, 9, 10

C Sheet 8 details the cabin sections defined by the operator to determine the passenger loading influence per section.
C Sheet 9 gives the Δindex to be used to determine the influence of passenger loading per cabin section.
C Sheet 10 gives the Δindex to be used to determine the influence of passenger loading per seat row. It also enables to indicate the type of seat used in the cabin.

5.4.9. C Sheet 11, 12

C Sheet 11 and 12 gives the Δindex to be used to determine the influence of any cabin crew, any item in the galleys and any pantry.

5.4.10. C Sheet 13, 14

C Sheet 13 gives the Δindex to be used to determine the influence of cargo loading per cargo compartment.
C Sheet 14 gives the Δindex to be used to determine the influence of cargo loading per cargo position.

5.4.11. C Sheet 15

C Sheet 15 details the operator's procedure for ballast carriage.

5.5. PART D: LOAD PLANNING DATA

This part is composed of sheets to enter general miscellaneous information such as the ideal trim line data in *D Sheet 1*, details about ULD (containers and pallets) in *D Sheet 2*, and regulations about special loads transportation in *D Sheet 3*.

D. LOAD AND TRIM SHEET SOFTWARE

1. INTRODUCTION

The Load and Trim sheet software enables the Airbus operators to produce a load and trim sheet and its associated AHM560, AHM516 and AHM515 documents for any Airbus model: A319, A320, A321, A300, A310, A330 and A340 except for freighter and combi aircraft.

These loading and trimming documents are generated from the weight and balance characteristics of the aircraft supplied in a database, from the assumptions set by the user and from the cabin arrangement defined for the aircraft.

This software allows the Airbus operators to quickly produce and update these documents following any aircraft modification affecting the certified limits, the passenger distribution, the cargo distribution or the fuel management.

The LTS software enables also to produce specific data files that are used by the Weight&Balance module of the Less Paper Cockpit package.

2. OBJECTIVES

The main objectives of this software are the electronic distribution and update of the Weight&Balance data of Airbus aircraft and the calculation and creation of the loading and trimming documents.

This software allows:

− To improve access time to the information.
− To ensure technical data accuracy
− To propose a user-friendly interface to visualize and update the Weight & Balance data.
− To perform the error calculation required for the operational envelopes determination.
− To reduce the production time of the loading and trimming documents.
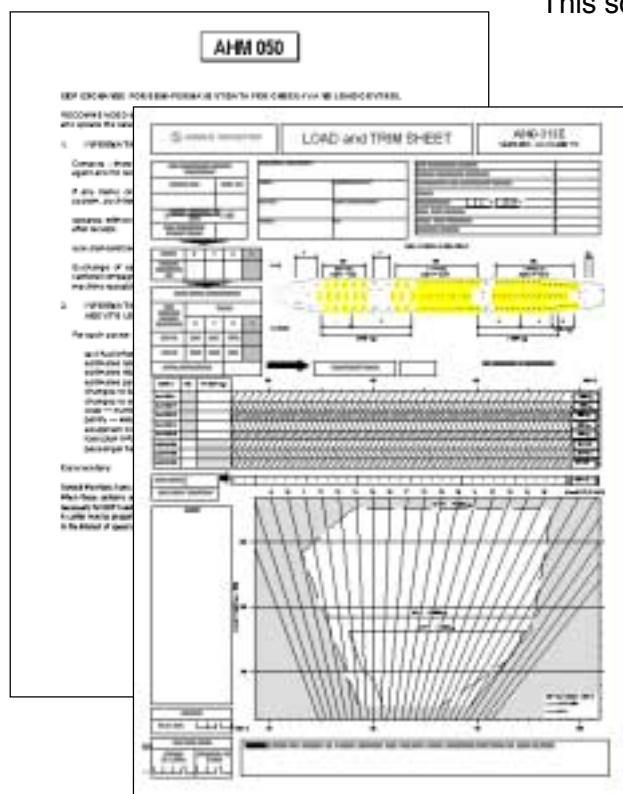
3. SOFTWARE DESCRIPTION

First of all, the LTS program uses a database containing a complete set of assumptions and data. The program structure relies on a relational database that stores the following pieces of information:

- The weight and balance data for all the MSN of the operator. These data will be updated and sent to the operator by Airbus at each aircraft modification affecting the loading and trimming.
- The Airbus default settings and the user's personal settings for various parameters such as the index formula, the passengers' average weights…
- The cabin layout data.

The loading and trimming documents are generated for any aircraft of the user's fleet. The selection of the relevant aircraft is performed at the interface initialization.
The interface of the LTS program allows the user to perform with several tasks described below.
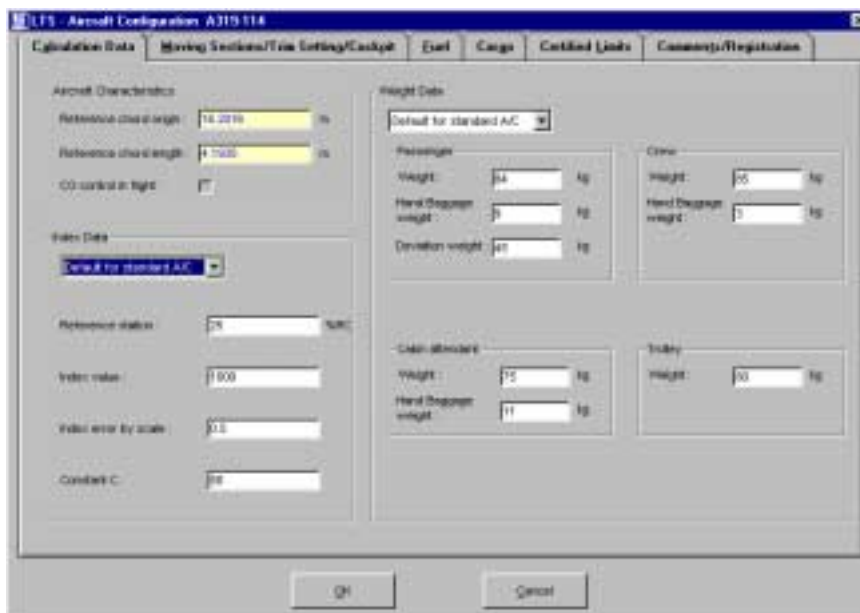
3.1. Unit system:

It is possible to select the unit system either metric or US system.

3.2. Aircraft modifications:

It is possible to consult the aircraft modifications validated for the aircraft chosen. The modifications enumerate the weight variant certified for the aircraft, the cargo configuration, the fuel system installed on the aircraft…

3.3. Aircraft configurations:

Through the Aircraft Configuration frame, the user can:
– Set the index formula.
– Define the average weights for the passengers, crew and trolley.
– Consult the tanks' characteristics and the fuel management curve.
– Consult and update the cargo holds' characteristics. The update function enables to take into account the modifications that can be carried out in the cargo holds: installation of a new cargo system, installation of an ACT (Auxiliary Center Tank) or an UCRC (Under Crew Rest Container)… For instance, for the A320 family, the program can select any of the available cargo options: Bulk, CLS (Cargo Loading System), CLS and Occasional Bulk…
– Consult and update the certified design weights and the certified design CG limits. The update function allows to select a new weight variant and/or a new certified CG envelope that has been approved in the Aircraft Flight Manual.

3.4. Cabin layout:
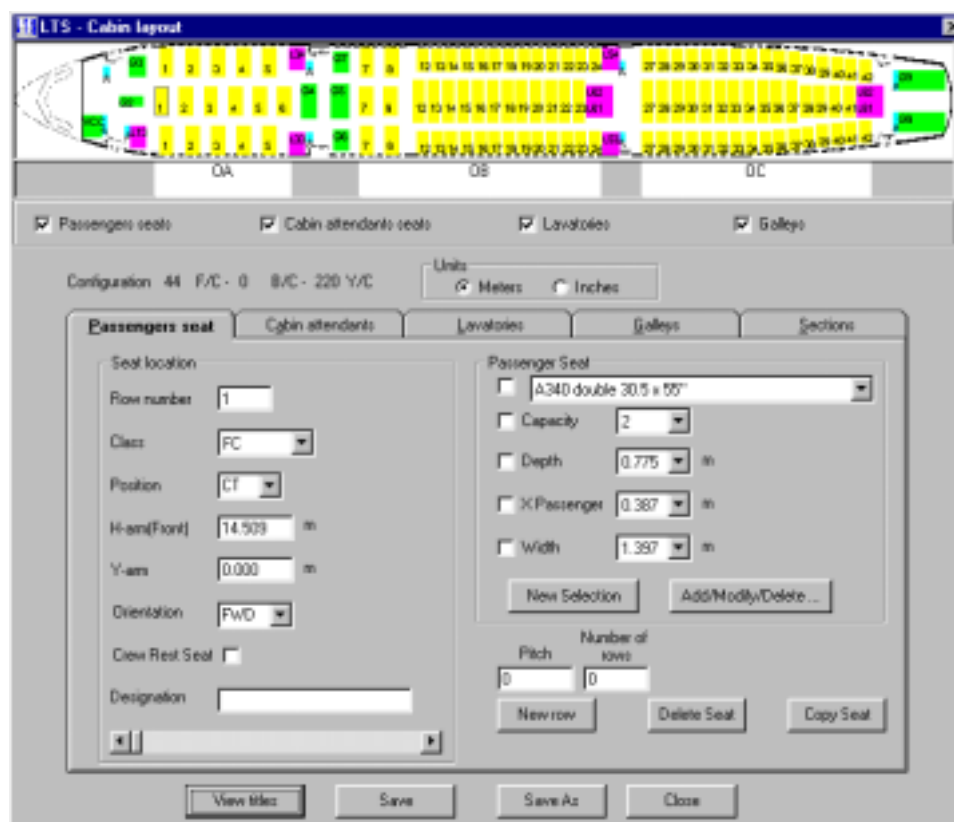
Through the cabin layout frame, the user can visualize or create a cabin layout thanks to a graphical interface. The cabin layout describes all the main deck's characteristics that affect the aircraft CG position: passenger seats, cabin attendant seats, lavatories, galleys and the aircraft section. Some specific functions allow to create quickly a new cabin layout: utilization of the pitch, copy of the seats when the left and the right side of the cabin are identical.

With those users entries and with the aircraft data, the LTS carries out the following tasks:
- Calculation of the influence of passengers, cargo and fuel loading on the aircraft weight and CG position.
- Calculation of the operational margins (to consider the different errors and assumptions made during a CG determination).
- Productions of the Load and Trim sheet and of the AHM 050 document.

Moreover, additional possibilities are also offered:
- Calculation and production of a Load and Trim sheet for training flights (non-commercial flights).
- Production of data files for the LPC Weight&Balance module (see paragraph "Less Paper in the Cockpit" in part D).
- Saving and storage of documents for history and follow-up.

3.5. Operational margins customization

The LTS software enables to customize certain assumptions used for the operational margins.

- DOW weight used for initial data inaccuracy determination
- Passenger weight standard deviation
- In flight cabin movements.

Some inaccuracy sources may be canceled such as

- Passenger distribution
- Cargo distribution
- Inaccuracy due to CG computation method

These inaccuracies may be canceled in case of CG determination using an EDP system.

WEIGHT AND BALANCE ENGINEERING

WEIGHT AND BALANCE ENGINEERING

LOADING OPERATIONS

LOADING GENERALITIES INTRODUCTION

During aircraft preparation before a flight the aircraft loading process is one of the key steps, which must follow some strict rules to ensure passenger, loads and aircraft safety and security.

The following chapter details the loading constraints and the necessary organization to fulfil them.

The first step before ensuring the aircraft loading is correct is to determine with the necessary accuracy the empty aircraft weight and corresponding CG position, then the determination of the average passenger weight is also important for the loaded aircraft weight determination.

Air transport is not more risky than other ways of transport. Indeed, air journey, with no vibration, shunting or bumping shocks, is probably the smoothest method of carrying cargo. Air transport has another advantage that can be very useful for cargo such as perishable goods or live animals: its rapidity. To ensure an adequate loading and a safe air transport, it is necessary to prepare the shipment. The shipment must be checked and pre-packed before loading.

Aircraft have a flexible structure. In addition to their natural contortion in flight, the quantity and distribution of load transported have an influence on the fuselage deformation. Therefore, Airbus has defined structural loading limitations that the operator must respect. These limitations are certified by airworthiness authorities. Detailed definitions of these limitations are proposed in this chapter.

A. LOADING GENERALITIES

1. LOAD CONTROL

1.1. Loading constraints

The main constraints an airline has to face for loading are the following:

- **Safety** must be insured during the whole flight whatever goods are transported.
- **Short time** for loading: airlines want to have the aircraft ground time as short as possible in order to respect schedules if an operational irregularity occurred and to make more profit increasing the aircraft utilization.
- The whole shipment must arrive **in good condition** at destination airport, particularly special goods such as dangerous goods, perishable cargo and live animals.
- Loading and unloading must be done **at the right place**: any mistake concerning the location of the shipment in the aircraft or, above all, its destination could engender extra expenses and be very detrimental to the image of the airline.

To meet the above objectives and in the interest of flight safety, airlines have to set up an organization for an efficient load control and ensure a high level of proficiency of all staff engaged in load control work. Recommendations are provided in IATA AHM part 590.

1.2. Load control organization and responsibilities

Load control is a procedure ensuring that:
- Aircraft center of gravity will remain within limits during the whole flight
- Aircraft weight limitations are not exceeded
- Aircraft is loaded in accordance with the airline's regulation
- Information on the loadsheet reflects the actual load on the aircraft

A few years ago, airlines used to issue manual loadsheets. Nowadays, EDP (Electronic Data Processing) systems are widely used, leading to different working organizations. Nevertheless, responsibilities inside the organization remain comparable.

1.2.1. Manual loadsheet

The load control organization shall be based, at every station, on three functions to ensure the compatibility of all figures on the loadsheet with the actual loading of the aircraft:

a) Function 1 : Load planner and loadsheet agent / Load controller / D1 …

The main task of this agent is to issue loading instructions (LIR) for people in charge of the loading, according to the information collected from the passenger and cargo departments, and then to prepare the loadsheet.

The responsibilities of the load planner are to:
- Collect all data relating to the load for a specific flight (Cargo, baggage, mail, transit load from incoming LDM/CPM)
- Plan load for total flight and ensure that hold capacities and different limitations are not exceeded and center of gravity remains within limits
- Plan special loads according to restrictions, maximum quantities, separation and segregation requirements
- Consider the effect of the center of gravity on fuel consumption
- Issue the Loading Instruction Report (LIR)

The loadsheet agent has to prepare the loadsheet. The main tasks are to:
- Collect the relevant Dry Operating Weight / Index of the aircraft
- Fill out the number of passengers according to booking information
- Transfer the Loading Information (LIR) into the loadsheet.
- Collect estimated fuel figures from the dispatch and fill out the loadsheet
- Enter the transit load data from incoming loadmessage (LDM)
- Ensure that the total traffic load does not exceed the allowed traffic load
- Ensure that the center of gravity will not exceed the operational limits

b) Function 2 : Loading supervisor / loading agent / C2 … (Ramp handling)

The loading supervisor carries out the aircraft loading or supervises the aircraft loading when it is subcontracted to a handling company. He must ensure that the loading is done in accordance with the LIR, and after completion, confirms the loading or advise the Load control Supervisor or loadsheet agent of any deviation from the initial loading instruction (Loading Report).

The loading supervisor is responsible for the following tasks. He has to:
- Obtain the Loading Information (LIR)
- Assemble the load and necessary equipment
- Off-load disembarking deadload and dispatch it as fast as possible
- Ensure ULD's are serviceable and secure
- Ensure ULD's are correctly tagged
- Ensure correct lashing and spreading
- Check that dangerous goods are correctly stowed
- Check that security lockers procedures are followed
- Confirm the loading or advise the Load controller / Loadsheet agent of any deviation from the Loading Instructions
- Sign the Loading Report (LIR)

c) Function 3 : Load control supervisor / Dispatcher / Red cap / D3 …

The Load control supervisor is the responsible agent for the check of the loadsheet against the final loading report, fueling order and actual number of passengers in the cabin. He has to organize as well the turnaround and is in contact with the crew.

The main responsibilities of the Load control supervisor are to:
- Inform all parties of the aircraft position and estimated time of arrival on ramp
- Check that the loading agent received the LIR and that relevant equipment is correctly planned and positioned
- Ensure availability of passenger handling equipment
- Ensure that passenger handling personnel is briefed
- Confirm passenger boarding time with the authorities
- Ensure liaison with crews, both cockpit and cabin
- Collect the Loading Report (LIR) from the loading supervisor, and check the loading is in accordance with the LIR
- Collect final fuel information from the fueling order
- Establish the final loadsheet:
    - Update number of passengers according to passenger boarding information at the gate
    - Enter exact deadload from the Loading Report (LIR)
    - Enter exact amount of fuel from the fueling order
    - Ensure that the total traffic load does not exceed the allowed traffic load
    - Ensure that the center of gravity will not exceed the operational limits
    - Enter last minute changes and inform the flight crew
    - Sign the loadsheet and give a copy to the crew (or send it by ACARS)
- Check that aircraft documents are on board (Loadsheet, Trim sheet, NOTOC)
- Release the aircraft
- Send the LDM/CPM to the next station (Loadmessage/Cargo Pallet message)
- Store documents in the station's flight file

These three functions must be performed by at least two agents to minimize the risk of mistake and ensure a high safety level. The same person can cumulate, as an example, function 1 and function 3.

1.2.2. EDP loadsheet

In case of EDP (Electronic Data Processing) loadsheet, the responsibility for correct loadsheet and trim data must be shared and clearly identified due to the various operational possibilities (decentralized input of data, decentralized loadsheet issuance, LMC…).

The above three functions still exist, but can be decentralized. As an example, Load planning and loadsheet can be prepared at the airline's base (function 1), whereas loading (function 2) and Load control supervision (function 3) is done at the station.

1.3. Load control qualification

The carrier is responsible for its shipment. In order to achieve an acceptable level of standardization and proficiency, minimum requirements shall be recognized in the training of carriers or handling companies' personnel involved in load control functions.

The carrier has the responsibility to:
- evaluate and approve the handling company's training program or subject the personnel involved to a single or periodical qualification tests
- Obtain a list of qualified personnel for a given aircraft type

2. AIRCRAFT WEIGHT

2.1. Regulation

The purpose of this chapter is to present what is required by the authorities concerning aircraft weighing. The following part will present how the weighing is performed. For more detailed information on aircraft weighing please report to JAR-OPS 1 Subpart J – Mass and Balance. (Paragraph 1.605 and appendix 1 to JAR-OPS 1.605) or/and to FAA Advisory circular 120-27A.

2.1.1. General information:

In order to elaborate a proper weight and balance document prior to a flight, the weight of the aircraft (as well as its center of gravity) has to be determined. This weight is first determined by the aircraft manufacturer and is found in the Weight and Balance Manual (Chapter 2.00: Weighing Report). It is the Operating Empty Weight in the Airbus weighing report, it may be named Basic Weight in some other weighing reports.
From this Operating Empty Weight/Basic Weight the operator can define the aircraft Dry Operating Weight for each aircraft flight.

During its operational life, the aircraft is going to be modified in different possible ways (new cabin arrangement, Service Bulletin implementation, new equipment…). These modifications are going to have an impact on the weight and the CG of the aircraft and therefore the aircraft as to be weighed on a regular basis.
Moreover, the mass and the CG of each aircraft shall be re-established either by weighing or calculation (if the operator is able to provide the necessary justification to prove the validity of the method of calculation chosen), whenever:

- the cumulative changes to the dry operating mass exceed ± 0·5% of the maximum landing mass
- or the cumulative change in CG position exceeds 0·5% of the mean aerodynamic chord.

2.1.2. Fleet mass and CG position:

The FAA and the JAA allow an operator that flies a fleet of the same type of aircraft (same model and configuration) to use an average dry operating weight and CG position for the whole fleet. However, individual aircraft weight and CG have to meet the following tolerances:

- The weighed or calculated weight of the aircraft varies by less than ±0.5% of the maximum structural landing weight from the established dry operating fleet mass.
- The CG position varies by less than ±0.5% of the mean aerodynamic chord from the fleet CG.

If an aircraft does meet these tolerances, it has to be omitted from the fleet.
However, in the case where an aircraft falls within the tolerance for the dry operating weight but is out of the CG range, it can still be operated with the fleet average mass but with an individual CG position.

- **Fleet values determination:**

The number of aircraft that have to be weighed varies with the number of aircraft in the operator's fleet. If 'n' is the number of aircraft in the fleet using fleet values, the operator must at least weigh, in the period between two fleet weight evaluations, a certain number of aircraft defined in the Table below:

Number of aircraft in the fleet	Minimum number of weighing
Less than 3	n
4 – 9	$\dfrac{n+3}{2}$
10 or more	$\dfrac{n+51}{10}$

The interval between two fleet mass evaluations must not exceed 48 months and the airplanes that have not been weighed for the longest time shall be weighed in priority.

2.1.3. Individual weights:

An aircraft that does not use fleet values must be weighed every 48 months.

2.2. Aircraft Weighing

The weighing of the aircraft can either be done on the aircraft's wheel or on jacks.

2.2.1. Defueling

The first action prior to aircraft weighing is the defueling of the aircraft. In order to do so, the aircraft's nose is lifted up to bring the aircraft to a zero degree pitch attitude. This is done with the help of the aircraft clinometer located in the refueling panel. Once this is done, defueling can be started. The information used is the information of the FQI. The defueling procedure prior to weighing can be found in the Weight and Balance Manual.
When the fuel quantity indicated is equal to zero, this means that all the pumpaple fuel has been removed from the aircraft. Extra fuel can be removed using the water drain. Once this is done the only fuel left on board the aircraft is the undrainable fuel (for quantities, refer to the W&B Manual).
Fire services have to be present during the operation and the aircraft must be earthed.

2.2.2. Inventory

During the defueling of the aircraft, a complete inventory of the equipment fitted on the aircraft is carried out. This inventory is executed with a pre established check list of the equipment that are supposed to be on board the aircraft for normal operations. This checklist will be useful when calculating the Operating Empty Weight and the associated CG. The missing equipment will be added in the weighing report.

2.2.3. Weighing

Weighing has to be performed in a closed hangar. Prior to the aircraft's positioning in the hangar, the scales have to be set to zero. Once the aircraft is in position, its pitch attitude has to be precisely measured.
The weighing can then be performed.

3. PASSENGER WEIGHT

3.1. General

In order to complete the Load and Trim Sheet, a standard weight for passengers had to be adopted. These values have been fixed by the authorities. In this paragraph, we will consider aircraft seating more than 30 passengers. (For more information, please refer to the appropriate regulation: JAR-OPS1.620 or FAR 121). It is important to notice that the same rules apply to passenger checked-in baggage.

The standard values used in the JAR-OPS for passenger weights are the following (**these weights include passenger and carry-on baggage**):

All flights except holiday charters	84 kg
Holiday charters	76 kg
Children	35 kg

However, if for some reason the operator considers that the standard weights do not apply to the routes he operates, he has the possibility of setting his own standard weights. According to the JAR-OPS1 Subpart J, the procedure is the following:

If an operator wishes to use standard mass values other than those contained in the table above, he must advise the Authority of his reasons and gain its approval in advance. He must also submit for approval a detailed weighing survey plan and apply the statistical analysis method given in Appendix 1 to JAR–OPS 1.620(g). After verification and approval by the Authority of the results of the weighing survey, the revised standard mass values are only applicable to that operator. The revised standard mass values can only be used in circumstances consistent with those under which the survey was conducted. Where revised standard masses exceed those in the above table, then such higher values must be used.
JAR-OPS 1.620(g)

3.2. Survey

The methods necessary to revise the standard weights are described in appendix 1 to JAR-OPS 1.620(g) with reference to the IEM to JAR-OPS 1.620(g) and IEM to Appendix 1 to JAR-OPS 1.620(g). The purpose of this paragraph is to give the reader a quick overview of the methods used.

In order to change the standard values, the operator must conduct a survey. This survey has to follow a certain number of rules.

The average mass of passengers and their hand baggage is determined by weighing random samples of passengers representative of the type of operation (frequency of flights on various routes, in/outbound flights, applicable season, seat capacity of the aircraft…)
All adult revised standard mass values must be based on a male/female ratio of 80/20 in respect of all flights except holiday charters which are 50/50. It is possible to use a different male/female ratio if it is representative of the activity (refer to regulation, in particular: IEM to Appendix 1 to JAR-OPS 1.620(g): Guidance on passenger weighing surveys)

3.2.1. Statistical Analysis

Passenger weight follows a Gaussian distribution that can be studied using statistical methods.
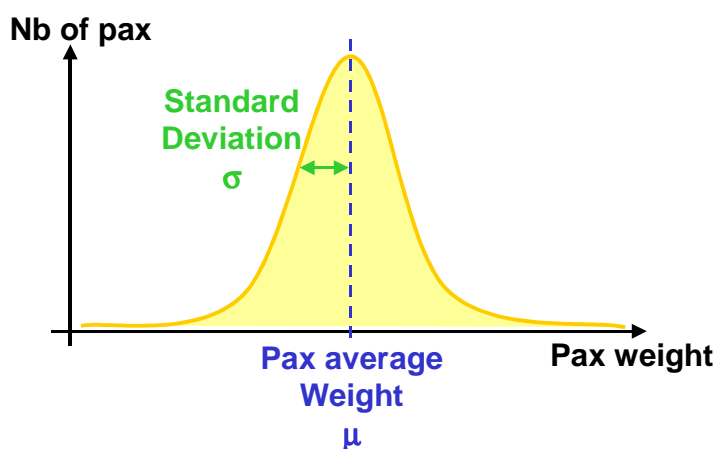
The number of passengers to weigh must be of at least the greatest of:
- − A number of passengers calculated from a pilot sample, using normal statistical procedures and based on a relative confidence range (accuracy) of 1% for all adult (in order to find this number of passenger, a previous survey is necessary)
- − 2000 passengers. (for aircraft of over 40 seats)

The precision of a sample estimate is calculated for 95% reliability or 'significance', i.e. there is a 95% probability that the true value falls within the specified confidence interval around the estimated value. This standard deviation value is also used for calculating the standard passenger mass.

As a consequence, for the parameters of mass distribution, i.e. mean and standard deviation, two cases have to be distinguished:
- − μ, σ: the true values of the average passenger mass and standard deviation, which are unknown and which are to be estimated by weighing passenger samples.
- − μ', σ': the 'a priori' estimates of the average passenger mass and the standard deviation, i.e. values resulting from an earlier survey, which are needed to determine the current sample size.

The sample size can then be calculated using the following formula:

$$n \geq \left[\frac{1.96 * \sigma' * 100}{e_r' * \mu'} \right]^2$$

where:

n   is the number of passengers to be weighed (sample size)

e_r' is the allowed relative confidence range (accuracy) for the estimate of μ by (see also equation in paragraph 3).

NOTE: The allowed relative confidence range specifies the accuracy to be achieved when estimating the true mean. For example, if it is proposed to estimate the true mean to within ± 1%, then e_r' will be 1 in the above formula.

1.96 is the value from the Gaussian distribution for 95% significance level of the resulting confidence interval.

- **Calculation of average mass and standard deviation.**

Arithmetic mean of sample: $\mu = \dfrac{\sum\limits_{j=1}^{n} x_j}{n}$

Where x_j are the mass values of individual passengers (sampling units).

Standard deviation: $\sigma = \sqrt{\dfrac{\sum\limits_{j=1}^{n}\left(x_j - \bar{x}\right)^2}{n-1}}$

3.2.2. Accuracy of the sample mean.

The accuracy (confidence range) which can be ascribed to the sample mean as an indicator of the true mean is a function of the standard deviation of the sample which has to be checked after the sample has been evaluated. This is done using the formula:

$$e_r = \frac{1.96 * \sigma * 100}{\sqrt{n} * \mu}$$

whereby e_r should not exceed 1%. The result of this calculation gives the relative accuracy of the estimate of µ at the 95% significance level. This means that with 95% probability, the true average mass µ lies within the interval:

$$\mu \pm \frac{1.96 * \sigma}{\sqrt{n}}$$

4. LOADING OPERATIONS

4.1. Preparation before loading

4.1.1. Generalities

Air transport is not more risky than other ways of transport. Indeed, air journey, with no vibration, shunting or bumping shocks, is probably the smoothest method of carrying cargo. Air transport has another advantage that can be very useful for cargo such as perishable goods or live animals: its rapidity.

To ensure an adequate loading and a safe air transport, it is necessary to prepare the shipment. The shipment must be checked and pre-packed before loading.

4.1.2. ULD / Bulk

Airbus aircraft have different configurations of compartments: they can be loaded either with bulk or with ULDs (Unit Load Devices). The different configurations for each aircraft are described in the "Cargo systems" part of this manual.

In bulk compartments, all the items are stacked without any order. Compartments equipped with the Cargo Loading System are filled with ULDs. These ULDs allow to group items into larger units, which is easier and faster to load.

ULDs can be either pallets or containers. Certified containers protect the aircraft systems and structure. They are expensive and delicate units because of the materials used to make it. Non certified containers are sometimes used to take several loads into large pre-packaged units. Both pallets and containers are locked in the aircraft using latches and end-stops.

Since ULDs must be pre-packed, most of the job is done before and after the flight. It allows decreasing the station time for each aircraft, which reduces the airline's expenses. ULDs are loaded into the aircraft thanks to specialized ground equipment.

4.1.3. Packing

Items should not be loaded in the aircraft if they are not properly packed. Specific packages are required for specific cargo such as live animals, dangerous goods, wet cargo, flowers, etc.

Collection sacks or nets are used to facilitate handling of small items. They are called "cover bags". Parcels that are in the same cover bag must be off-loaded at the same airport. The destination must be written on a label attached to the sack. Not all the items can be transported in collection sacks:

- Radioactive loads must not be put in collection sacks because of the minimum distances imposed between two radioactive loads
- Cargo and mail must not be in the same cover bag.

Each package is then packed itself into a ULD when the aircraft is equipped. For a safe cargo transport, general rules must be applied:

- When packages are loaded in a container, it is necessary to visualize the whole container load before packing (nature, form, weight and strength)
- Big or heavy items must be on the bottom, small, light or weak items on the top.
- Leave as few spaces as possible between two items
- The load must be evenly distributed in the ULD. Heavy items must not be concentrated on a small area in the center of the pallet and/or container because of the risk of dishing.
- Spreader boards could be used for high density items
- If the package moves in the ULD or if the load is very heavy, then the package should be tied down
- Packages loaded on open pallets should be stacked so that the whole load is stable (interlocking layers). The nets retain the load.

Once they are loaded, cargo pallets and containers are weighed. Their weight is then entered on the tag described hereafter.

4.1.4. Special loads

Dangerous and perishable goods, live animals, valuable cargo, human remains and urgent shipments are considered as special cargo, and special requirements apply to them. Here are some rules concerning special goods transportation.

- Not all the dangerous goods can be transported in passenger aircraft because of the obvious risk they engender for the safety of passengers. Some dangerous goods are even forbidden for transport by air. When they are allowed for transport by air, they must be wrapped with specific packages to minimize the risk of accident and/or incident.
- For **live animals**, two rules have a very big importance: they must not be exposed to extreme temperatures and they should be loaded in the aircraft as late as possible. Ventilation and heating systems are greatly recommended.
- To arrive at their destination in good condition, **perishable goods** require specific temperatures and relative humidity that depend on the good transported.
- The security of **valuable cargo** must be ensured during the whole journey.
- Handling and loading of **human remains** must be done with respect; coffins containing human remains must be loaded in a horizontal position, never in a vertical position. Moreover, human remains must be kept far away from other shipments such as food or some animals (dogs for example).
- Staff concerned by transportation of special loads must be aware of the requirements of such a cargo. Thanks to labels affixed to each package, especially to packages containing special goods, loading staff is able to identify the content of the package.

4.1.5. Incompatibilities

Some shipments are particularly restrictive to transport, like dangerous goods, live animals and perishable goods. Special requirements concerning transportation of such goods are developed in other parts of this manual (refer to "DANGEROUS GOODS TRANSPORTATION" and "LIVE ANIMALS & PERISHABLE GOODS TRANSPORTATION"). The following table from IATA AHM 645 sums up the incompatibilities between different shipment types:

Legend:

Symbol	Meaning
↔	Minimum separation distance as specified by IATA Regulations.
◀▶	Shall not be loaded in close proximity of one another.
◀▶¹	Must not be stowed in the same compartment, unless loaded in ULDs not adjacent to one another or in closed ULDs.
◀▶²	The ◀▶ segregation requirement applies only to laboratory animals and to animals which are natural enemies.

TABLE OF INCOMPATIBILITIES

Class or Division and Comp. Group	Cargo IMP Code	RCX	RGX	RXB	RXC	RXD	RXE	RXG	RXS	RNG/RFG/RPG	RCL	RFL	RSC/RFW	RCX/RCP	RPB/RS	RRY	RCM	ICE	FIL	HUM	EAT	HEG	AVI
1.3C	RCX*		◀▶	◀▶				◀▶		◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.3G	RGX*	◀▶		◀▶	◀▶	◀▶	◀▶			◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4B	RXB	◀▶	◀▶		◀▶	◀▶	◀▶	◀▶		◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4C	RXC		◀▶	◀▶				◀▶		◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4D	RXD		◀▶	◀▶				◀▶		◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4E	RXE		◀▶	◀▶				◀▶		◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4G	RXG	◀▶		◀▶	◀▶	◀▶	◀▶			◀▶	◀▶	◀▶	◀▶	◀▶			◀▶						
1.4S	RXS																◀▶						
2	RNG/RFG/RPG	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶															
2	RCL	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶														◀▶	◀▶
3	RFL	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶						◀▶									
4	RSC/RFW	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶						◀▶			◀▶						
5	RCP/RCX	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶					◀▶	◀▶			◀▶						
6	RPB/RS															◀▶							◀▶
7	RRY																		↔			↔	↔
8	RCM	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶					◀▶	◀▶								
9	ICE																					◀▶	◀▶
	FIL															↔							
	HUM																				◀▶		◀▶
	EAT													◀▶¹						◀▶			◀▶
	HEG									◀▶						↔	◀▶						
	AVI									◀▶				◀▶¹	↔		◀▶			◀▶	◀▶		◀▶²

* Codes RCX and RGX are assigned exclusively to those items identified in the current edition of the IATA Dangerous Goods Regulations as authorised on cargo aircraft. All other explosives in Division 1.3 are forbidden for air transportation.

Note: Animals that are natural enemies such as cats and dogs should not be loaded in sight, sound, smell or reach of each other.

Here are general rules that can be extracted from this document:
- Dangerous goods from classes 2, 3, 4, 5 and 8 shall not be loaded in close proximity of dangerous goods from class 1
- Dangerous goods from class 7 must be separated from animals, hatching eggs and unexposed films
- Live animals must be loaded in close proximity of neither foodstuffs nor human remains
- Live animals and hatching eggs must not be loaded in close proximity of dry ice
- Live animals should be separated from laboratory animals
- Animals that are natural enemies such as cats and dogs should not be loaded in sight, sound, smell or reach of each other
- Foodstuffs must not be loaded in close proximity of human remains….

4.1.6. Labelling, tagging

Each package or collection sack is labelled to indicate the destination and the category of load it contains. Specific labels are used for special loads; labels used to indicate the presence of dangerous goods, live animals or perishable cargo are provided in the corresponding sections.
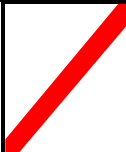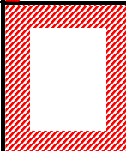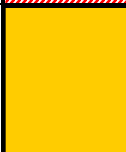
Here are some codes used to identify which category a load belongs to:

$$B \rightarrow \text{Baggage}$$
$$C \rightarrow \text{Cargo (including special loads)}$$
$$M \rightarrow \text{Mail}$$

Unit Load Devices (ULDs) must be tagged so that the loader is able to identify loads in the containers and/or pallets. The tag must be easily readable: it must be at eye level, on a fixed side of the container or on the net of the pallet. A tag must be completed, even for empty ULDs. Its shape and colors are standardized:

   Size: A5 (148 x 210 mm)
   Color: Black letters with:

BAGGAGE	A red slash on a white background[*]	
DANGEROUS GOODS	Red hatching surrounding the tag	
UNSERVICEABLE UNITS	Orange background	
OTHER LOAD	White background	

[*]Whenever an ULD contains baggage, the red line must appear on the tag.

ULD tag example

Some operators use an electronic system to read ULD tags. A bar code that contains all the previous information is then shown on the form.

4.2. Opening/Closing the doors

There are two different types of cargo doors: some open manually and others automatically (hydraulically, electrically). Ground staff operates cargo doors. No special training is required for manual doors, whereas only qualified staff is allowed to open hydraulic or electric doors. Airbus provides a detailed description of the doors and the way to operate them in the Weight & Balance Manual, so that ground staff can open and close them.

In presence of wind, special care must be taken before opening the doors or when the doors are already opened. The maximum wind speed allowed to have the door opened is given in the **Cargo Loading System Manual**.

In Airbus aircraft, the forward and aft cargo compartments doors open to the outside, whereas the bulk compartment door (compartment 5) opens to the inside. No equipment must obstruct the passage of the door.

Bulk Cargo door   **FWD or AFT Cargo door**
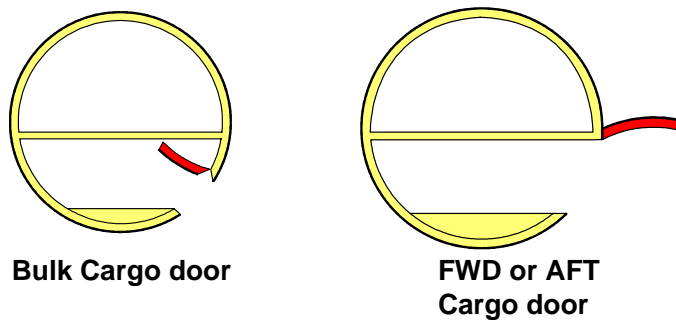
Before closing the bulk compartment door (compartment 5), it is necessary to ensure that the door protector nets are installed and secured.

After on-loading and off-loading, the loading supervisor must ensure that doors are closed and secured.

4.3. On loading

4.3.1. Bulk

This way of transporting loads is used in cargo holds not equipped with a Cargo Loading System (CLS). Most Airbus types have at least one bulk compartment at the rear, named compartment 5.

The bulk compartment is divided into sections thanks to nets. Before loading, it is necessary to ensure that the separation nets are properly secured. In case of failure, refer to the "Limitations" section of the Weight and Balance Manual of the aircraft to determine the weight restriction engendered by the failure.

Before loading bulk load, the loading agent has to check that there is no leaking or damaged package. This check is absolutely necessary when transporting live animals or wet cargo; every leaking or damaged package must not be loaded. Moreover, the loading agent has to ensure that the floor, the walls, and the bulkhead are in good conditions.

Several precautions must be taken for loading. Most of them are common with the loading of items into ULDs, but it may be useful to remind them:
- Heavy items at the bottom
- Use the maximum available volume
- The load must be evenly distributed in the net section
- Follow specific instructions shown on the labels and place the articles so that the labels are easily visible
- Respect weight limitations of the aircraft given in the Weight and Balance Manual. If one limit is exceeded, use spreader boards.
- If a package is likely to damage other packages (heavy item, pieces with sharp points or edges, etc.), then the package should be tied down.
- Use mechanical handling aids to handle heavy items

4.3.2. Cargo Loading System (CLS)

The Cargo Loading System is installed as basic in the aft and forward cargo compartments of all the Airbus aircraft except the A318, A319, A320 and A321 where it is optional.

Before being loaded in the aircraft, ULDs are filled as described above. They must be cleared of snow, ice and water.

The Cargo Loading System makes the loading easier for loading staff: once in the aircraft, ULDs can be either pushed into position or progressed by powered rollers. The positions where ULDs must be loaded are indicated in the Loading Instructions/Report form (refer to "Operational Loading Documents"). A few rules must be respected to load ULDs:
- Each ULD must go to the position indicated by the Loading Instructions prepared by the load planner
- All obstacles have to be removed (including floor locks and side restraints) to allow the ULD to go into its position, otherwise CLS latches and or ULDs could be damaged
- No staff must be in front of an ULD when it is pushed or driven into position
- All the stops, locks and restraints necessary to fix the ULD in position must be used.

Once all the ULDs are loaded into the aircraft, the responsible loading supervisor checks the loading. He checks that they have been loaded in compliance with the regulations and if so, he fills the Loading Report in and signs it (refer to "Operational Loading Documents").

4.3.3. Seats Occupied by Cargo (SOC)

Sometimes, when there is not enough space in the cargo holds or for some specific cargo items, small items of cargo, baggage or mail are loaded on seats in the passenger cabin provided that several constraints are respected:
- Weight limitations must not be exceeded
- Safety rules must be respected (not next to emergency exits, no emergency equipment obstructed, etc.)
- The package must not contain liquid, live animal or smelling cargo
- The package must be tied down and covered
- The seat should be protected from possible damage

4.4. Off loading

The items must be off-loaded in descending order of priority:

1) Baggage must always be off-loaded first, even before passengers disembark when it is possible, so that passengers are not delayed by waiting for their baggage. There is a priority between different sorts of baggage:

Code	Priority	Description
TB	1	Baggage for transfer to various connecting flights
HB	1	Group of baggage (ULD) that must be transshipped to the same connecting flight
HTB	1	Group of baggage (ULD) that must be transshipped to various connecting flights
FB	2	First class baggage and/or priority handled baggage
B	3	Baggage (no specification)

2) Cargo
3) Mail

In case of a multi-sector flight, at a transit station, the load planner has to prepare off-loading instructions (LIR[1]) from the incoming messages (CPM/LDM[1]). Loading agents must check cargo and mail against these instructions, and any irregularity or discrepancy with the document must be reported, at transit airport loading agents have to check all that must be off-loaded is off-loaded, and that transit shipment is at the right place.

An inspection of the shipment allows determining the presence of damaged or leaking packages. In case of leakage, the source must be identified and the compartment in which leaking goods were transported must be inspected for contamination.

[1] *Refer to "Operational loading documents" paragraph*

5. LOADING LIMITATIONS

5.1. Structural limitations and floor panel limitations

5.1.1. Introduction

Aircraft have a flexible structure. In addition to their natural contortion in flight, the repartition and the quantity of load transported have an influence on the fuselage deformation. Therefore, Airbus has defined structural loading limitations that the operator must respect. These limitations are certified by airworthiness authorities and can be found in the "Limitations" section of the Weight and Balance Manual. They follow IATA AHM 513 recommendations.

5.1.2. Structural limitations

a) Running (Linear) Load Limitation

- **Definition: The running load limitation is the maximum load acceptable on any given fuselage length of an aircraft floor.**

- **Unit: kg/m or lb/ft**

$$\text{Running Load} = \frac{\text{Weight of the piece}}{\text{Length of the piece in the flight direction}} = \frac{W}{L}$$

The length to take into account is the length of the contact points on the floor.

- **Example: Let's assume a Maximum Running Load of 2000 kg/m**

Example 1

Running load $= \frac{870}{1.2}$ = **725 kg/m < 2000 kg/m**

Max weight = 2000 x 1.2 = **2 400 kg > 870 kg**

Running load not exceeded

Example 2

Running load $= \frac{870}{0.4}$ = **2175 kg/m > 2000 kg/m**

Max weight = 2000 x 0.4 = **800 kg < 870 kg**

Running load exceeded
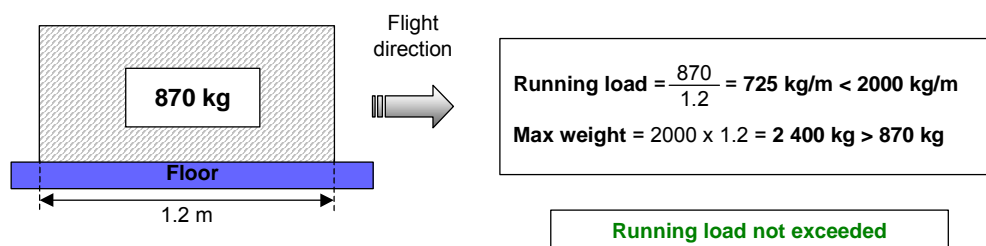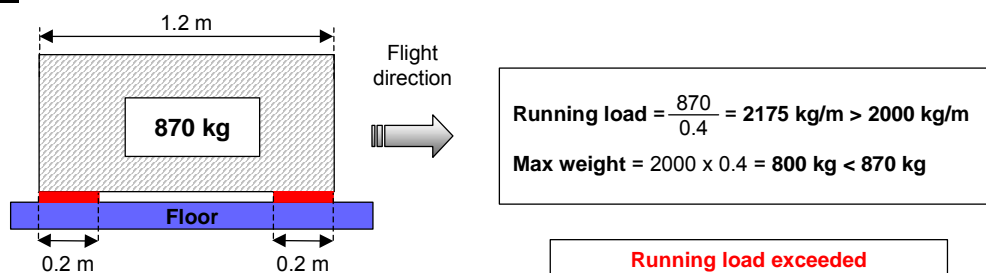
b) Area load limitation

- **Definition: The area load limitation is the maximum load acceptable on any surface unit of an aircraft floor. It prevents the load from exceeding the capability of the aircraft structure (floor beams, floor posts, floor panels and frames).**

*Note: The Area Load Limitation is called "**Uniformly distributed load**" limitation in the Airbus Weight and Balance manuals.*
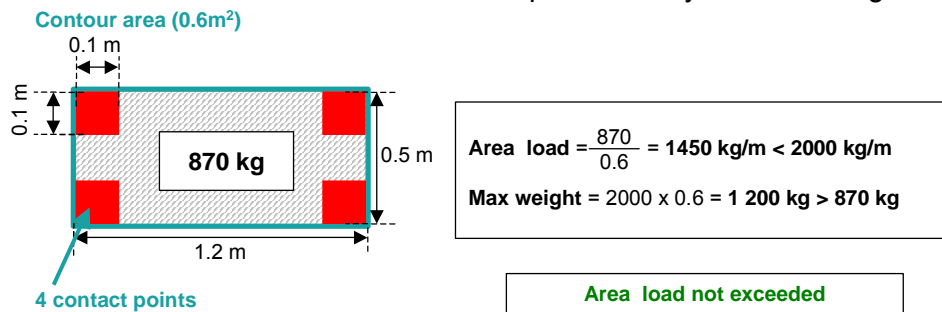
- **Unit: kg/m^2 or lb/ft^2**

$$\text{Area Load} = \frac{\text{Weight of the piece}}{\text{Contour Area}} = \frac{W}{S}$$

The contour area is the external contour of the contact points on the floor.

- **Example: Let's assume a Maximum Area Load of 2000 kg/m^2**

The following rectangular load is laying onto four pieces in direct contact with the floor. The surface used for the calculation of the area load is represented by the external green contour.

Contour area (0.6m^2)
0.1 m
0.1 m
870 kg
0.5 m
1.2 m
4 contact points

$$\text{Area load} = \frac{870}{0.6} = 1450 \text{ kg/m} < 2000 \text{ kg/m}$$

Max weight = 2000 x 0.6 = **1 200 kg > 870 kg**

Area load not exceeded

c) Compartment Load Limitation

- **Definition: The compartment load limitation is the maximum load acceptable in an entire compartment. This limitation applies to the whole load located in a given compartment.**

*Note: The Compartment Load Limitation is called "**Cumulative load**" limitation in the Airbus Weight and Balance manuals and it concerns the complete forward or aft hold or the aircraft.*
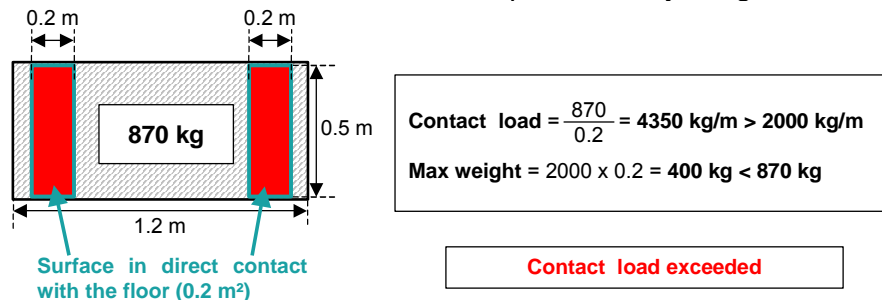
- **Unit: kg or lb**

d) Cumulative Load Limitation

- **Definition: The cumulative load limitation is the maximum weight that can be carried forward or aft of a given section. This limitation prevents the weight loaded in the forward and aft fuselage sections to exceed the capability of the frames and skin stringers.**

*Note: The Cumulative Load Limitation is called "**Fuselage Shear load**" limitation in the Airbus Weight and Balance manuals.*

- **Unit: kg or lb**

- **Example: Fuselage shear load forward of frame 40.**

Weight and balance manual extract
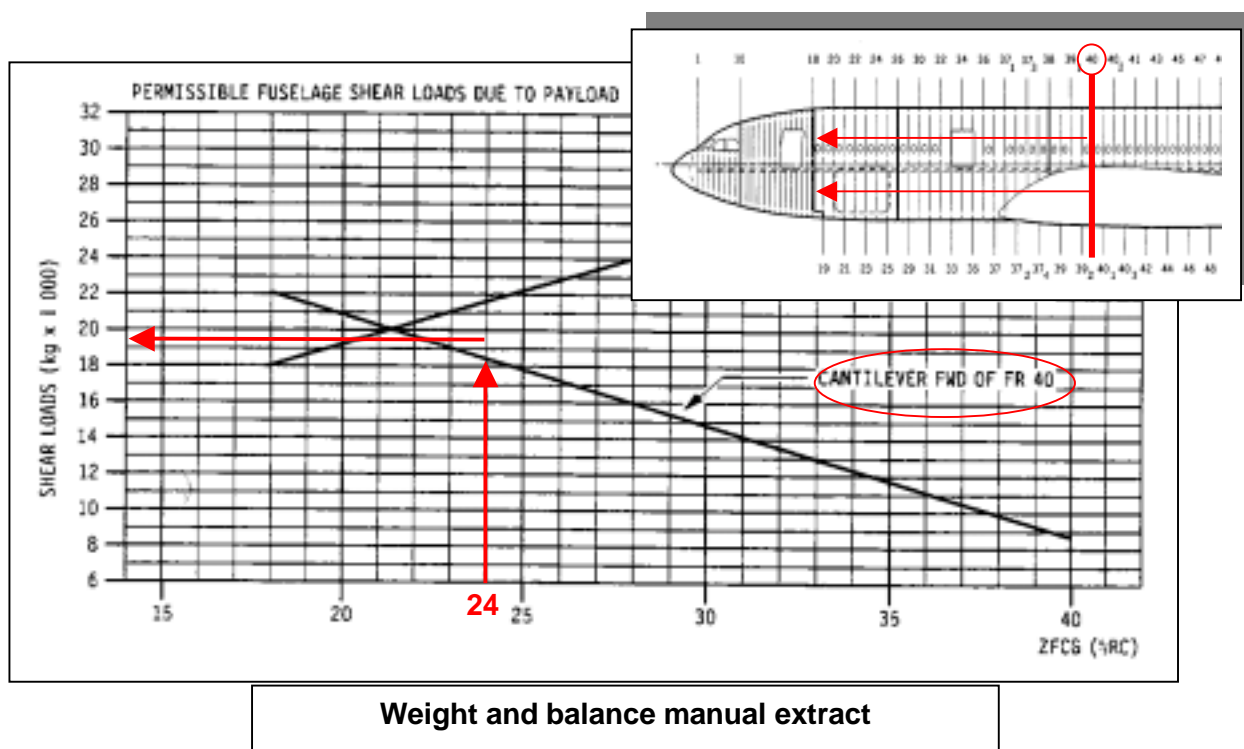
The total payload weight applied on the main deck <u>and</u> the lower deck forward of frame 40 must not exceed 18 tons when the ZFWCG is 24%.

5.1.3. Floor panel limitations

a) Contact load limitation

- **Definition: The contact load limitation is the maximum load acceptable in direct contact with the aircraft floor per surface unit. This limitation is used to prevent the load in direct contact with the floor from exceeding the capability of the horizontal floor panels (metal sheet, honey comb sandwich panels).**

*Note: The Contact Load Limitation is called "**Local load**" limitation in the Airbus Weight and Balance manuals.*

- **Unit: kg/m^2 or lb/ft^2**

$$\text{Contact Load} = \frac{\text{Weight of the piece}}{\text{Contact Area}} = \frac{W}{S}$$

The contact area is the surface in direct contact with the floor.

- **Example: Let's assume a Maximum Contact Load of 2000 kg/m^2**

The following rectangular load is laying onto two pieces in direct contact with the floor. The area used for the calculation of the contact load is represented by the green contours.

Contact load $= \dfrac{870}{0.2}$ = 4350 kg/m > 2000 kg/m

Max weight = 2000 x 0.2 = **400 kg < 870 kg**

Contact load exceeded

b) Point Load Limitation

- **Definition: The point load limitation represents the resistance to puncture by a heavy load bearing onto a very small surface of the floor panels.**

*Note: The Point Load Limitation is called "**Walking load**" in the Airbus Weight and Balance manuals.*
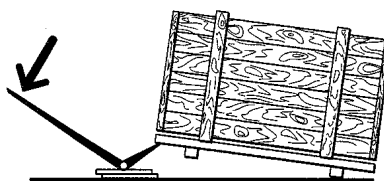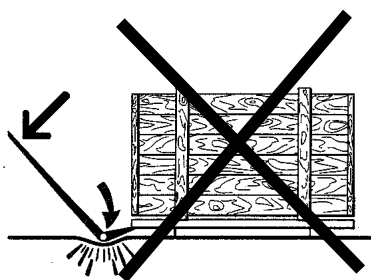
- **Unit: kg/cm^2 or lb/ft^2**

- **Examples: To avoid floor panel punctures, the following elementary handling precautions are recommended.**

− Never lay a heavy package on an edge or a corner:
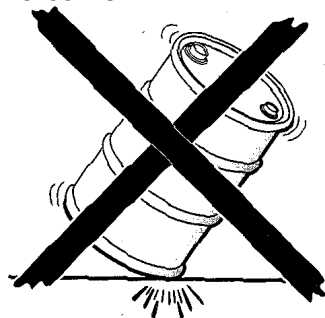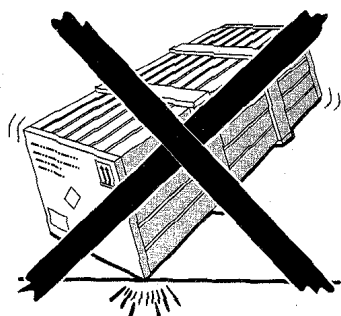
− When using a pinch bar, place a floor protector device beneath the pinch bar (plank, piece of wood):

5.1.4. Spreader floor

A spreader floor enables to transport loads whose weight exceeds one of the previous limitations (running load, area load or contact load). It allows increasing either the length of the piece or the area in direct contact with the floor.

Example :   Max running load = 500 kg/m
Max area Load = 1000 kg/m^2
Max contact load = 2000 kg/m^2
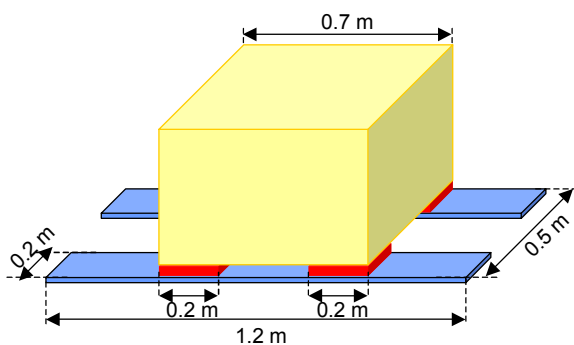
Without spreader floor

Running load = $\dfrac{500}{0.4}$ = 1250 kg/m

Area load = $\dfrac{500}{0.35}$ = 1429 kg/m^2

Contact load = $\dfrac{500}{0.16}$ = 3125 kg/m^2

With spreader floor

Running load = $\dfrac{500 + 20}{1.2}$ = 434 kg/m

Area load = $\dfrac{500 + 20}{0.6}$ = 867 kg/m^2

Contact load = $\dfrac{500 + 20}{0.48}$ = 1084 kg/m^2

Note: Spreader's weight = 20 kg

5.2. Stability on ground – Tipping

5.2.1. Introduction

During on-loading and off-loading operations, an aft center of gravity position may lead to a tail tipping of the aircraft. Therefore, specific precautions should be considered to avoid this kind of critical situation.

5.2.2. Precautions

a) <u>Load planning</u>

During load planning, the load planner must allocate a sufficient load ahead of the aircraft center of gravity, and pay a particular attention to the distribution of the transit load on multi-sector flights.

b) <u>Loading/Off-loading</u>

Loading operations should start in the forward compartment and then in the aft ones, while off-loading operations should start in the aft compartment and then the forward ones. The same sequence applies for the galleys, whereas passenger distribution must not be considered to secure ground stability.

To help the operator establishing its own recommendations for loading and off-loading, the tip up CG position (max aft CG position) is provided in the limitation section of the Weight & Balance Manual (refer to the graph "Aircraft stability on wheels"). Thus, the operator can simulate different critical scenarios and evaluate the risk of tipping of its aircraft in these configurations.

## c) Maximum wind for stability on wheels

Due to the large surface of the wings, the wind can affect the stability of the aircraft on ground by providing a lift force ahead of the center of gravity and as a consequence a rolling moment around the main landing gear group or the center gear if any.

The following graph, provided in the limitation chapter of the weight and balance manual, enables to determine the maximum allowable wind for a given aircraft weight and center of gravity position, as shown in the example. It can help the operator establishing its own recommendations for loading and off-loading rules in windy conditions.

10. Aircraft stability on wheels

CAUTION : THE STABILITY OF THE AIRCRAFT MUST BE ASSURED DURING EMBARKATION AND DISEMBARKATION OF PASSENGERS AND THE LOADING OR UNLOADING OF BAGGAGE AND CARGO.

The tip up CG position is considered to be 57 %RC H-arm = 24.459 m (962.95 in).
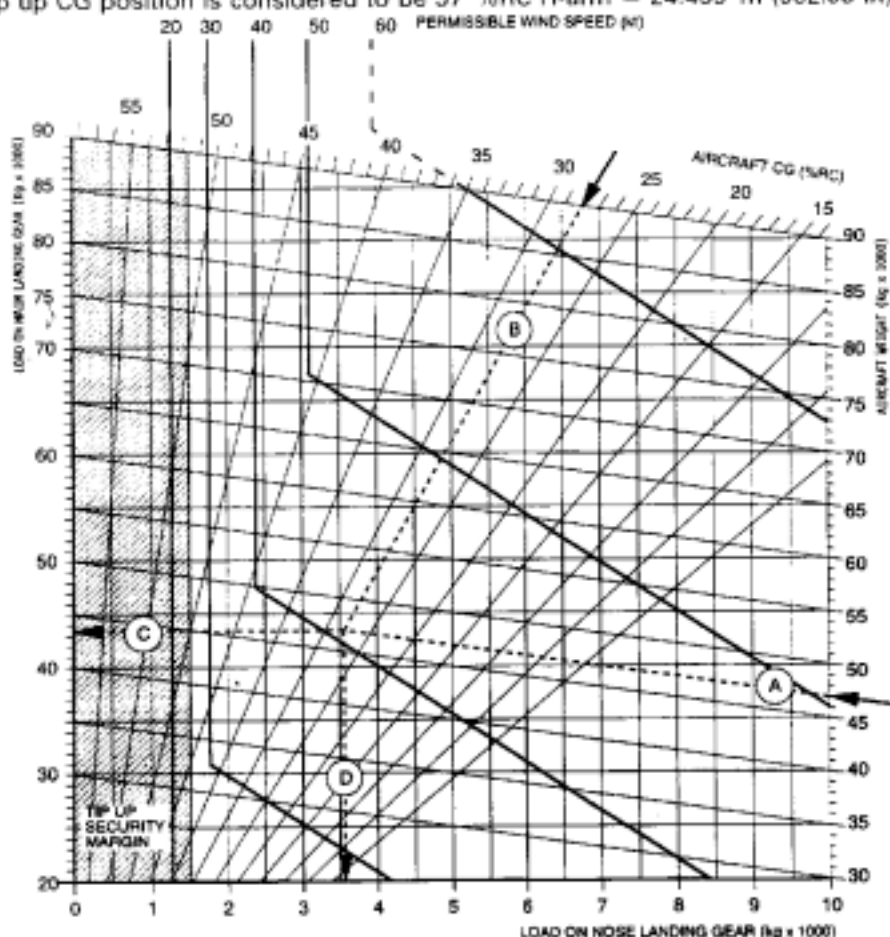
EXAMPLE : Assume aircraft with gross weight of 47 000 kg (A) and center of gravity at 28 % RC (B). The reaction at the main landing gear is 43 450 kg (21 725 kg per side) (C) and the reaction at the nose landing gear is 3 550 kg (D). If the aircraft must be lifted outside the wind speed must not be in excess of 42 km/h

6. SECURING OF LOADS

6.1. Introduction

As per IATA AHM 311, all individual items of load, which by their nature, shape or density may constitute a hazard, shall be restrained. Restraint can be achieved by filling volumetrically the compartment, the net section or the ULD, or by tie-down.

Note: In IATA Airport Handling Manual (AHM) Compartments, net sections and ULDs are considered to be **volumetrically full** *when they are filled up to three-quarters (75%) of their height.*
Note 2 : this value is indicated as 80% of the height in Airbus Weight and Balance Manuals.

Pieces weighing 150 kg or more, when loaded as bulk in compartments or net sections should always be tied down, except on single sector flights when the compartments or net section is volumetrically full.
Pieces weighing 150 kg or more, when packed in certified ULDs should be individually tied-down except when the unit is volumetrically full.

Note : the 150 kg figure is the value recommended in the AHM document, nevertheless each individual operator may define a lower value for Heavy Items definition.

6.2. Aircraft acceleration

6.2.1. Influence on cargo items

Anytime an aircraft accelerates, decelerates or turns, forces are generated on each cargo item. As a consequence, hazardous or heavy items must be tied-down in order to prevent them from moving, damaging the structure of the aircraft or crashing other cargo loads. The force generated by the movement of the aircraft depends on the aircraft acceleration and the weight of the piece.

6.2.2. Load factor

The load factor represents the "apparent weight", in a given direction, of an item submitted to an acceleration that can be caused by: a speed increase, a slow down, sideway movements or vertical drops.

M = mass of the item
W = weight of the item = $M.g$

a_X = item's acceleration in the X direction
F_X = Force in the X direction = $M.a$ = $n_X.M.a$

F_Z = Force in the X direction = $M.a$ = $M.g$

W_a = Apparent weight = $n.M.g$

n = Load factor
n_X = Load factor in the X direction
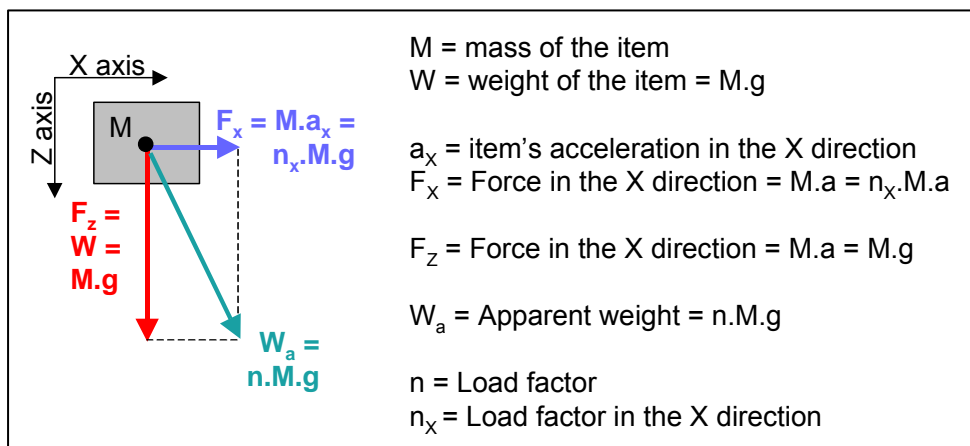
Therefore, if an item weighing 1000 kg is submitted to a load factor of 1.5 in a given direction, the apparent weight of this item is equivalent to the weight of an item with a mass of 1500 kg and no load factor applied.

The operator has to forecast the restraint of heavy items in each direction, taking into account the maximum admissible load factors published in the limitation chapter of the weight and balance manual of each aircraft type. Each restraint must resist to the maximum apparent weight in each direction.

D. Tie down methods

Methods of tie down are given in paragraph 1.60.06.

The load factors below must be used when establishing the ultimate load.

COMPARTMENT NUMBER	LOAD FACTOR				
	FWD	AFT	SIDE		UP
			LH	RH	
3 (Aft)	1.69	0.95	1.35	1.35	2.00
4 (Aft)	1.69	0.95	1.54	1.54	2.25

6.3. Tie-down computation

6.3.1. 3.1 Tie-down equipment

a) Breaking strength

The breaking strength for a lashing or a tie-down fitting represents the maximum load that the item shall withstand without failure. Only equipment for which the breaking strength is ascertained should be used.

b) Lashing equipment

Different types of equipment can be used for lashing: nets, cables, ropes or straps. Lashing equipment must indicate permanently the maximum breaking strength, except when the restraint equipment is part of a pallet or an aircraft compartment (pallet nets and divider nets).

c) tie-down fittings

Airbus cargo hold floors are equipped with tie-down points enabling quick fastening of small rings only (single stud fittings). Only the tie down points which are not required for net fastening may be used for restraint of packages.
The maximum breaking strength of a single stud fitting is 900 kg (2000 lb).
Heavy rings (double stud fittings), can not be used for direct tie-down on the cargo floor, but for tie-down on pallet's or container's rims.
The maximum breaking strength for a double stud fitting is 2270 kg (5000 lb).

6.3.2. General tie-down recommendations

− It is **prohibited** to tie-down a load with different lashing equipment (straps and ropes as an example).

− Single stud fittings and ropes can be used in case of absolute necessity, when no other equipment is available, for tie-down in bulk compartments or inside containers.

− Tie-down shall ensure restraint in the forward, aft, up, left and right directions. With a standard lashing, lateral tie-down is generally covered if tie-down in the forward, aft and up directions is adequately performed except for irregular shape loads and for high CG loads.

− A minimum distance between two tie-down points shall be respected (generally 30 cm between two single stud fittings and 50 cm between two double stud fittings).

− Each strap or rope shall make a maximum angle of 30 degrees with the direction of restraint (e.g. α_A, α_F, δ, β_A, β_F).

α_A = Floor angle
(Restraint in the AFT direction)

α_F = Floor angle
(Restraint in the FWD direction)

$\delta_{L/R}$ = Wall angle Left / Right
(Restraint in the UP direction)

$\beta_{A\ L/R}$ = Wall angle Left / Right
(Restraint in the AFT direction)

$\beta_{F\ L/R}$ = Wall angle Left / Right
(Restraint in the FWD direction)
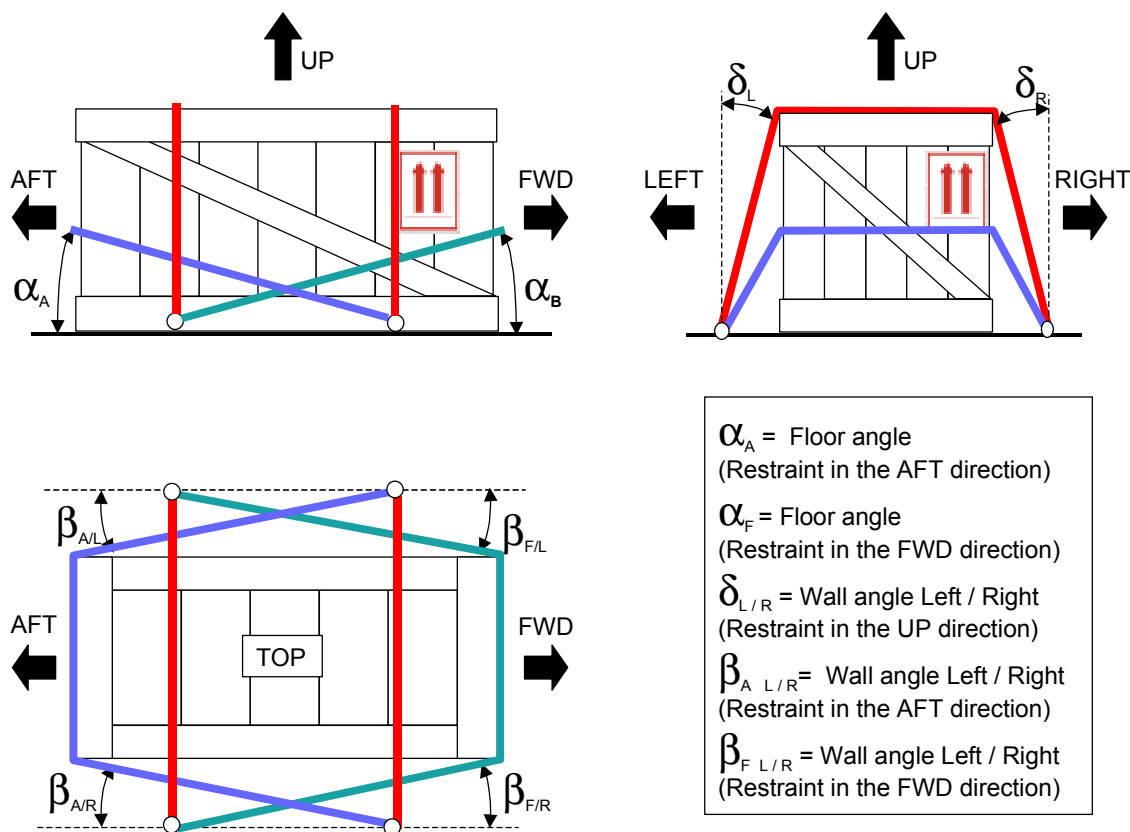
− It is prohibited to use two ropes or straps attached to the same tie-down point and restraining the load in the same direction.

6.3.3. Standard lashing

A standard lashing consists into four straps or ropes (2 Up, 1 Forward, 1 Aft), attached to 4 tie-down points (2 on each side of the piece in the flight direction). This basic pattern solves most of the lashing problems.

A security rope may be used to maintain straps in correct position and prevent them from slipping down.
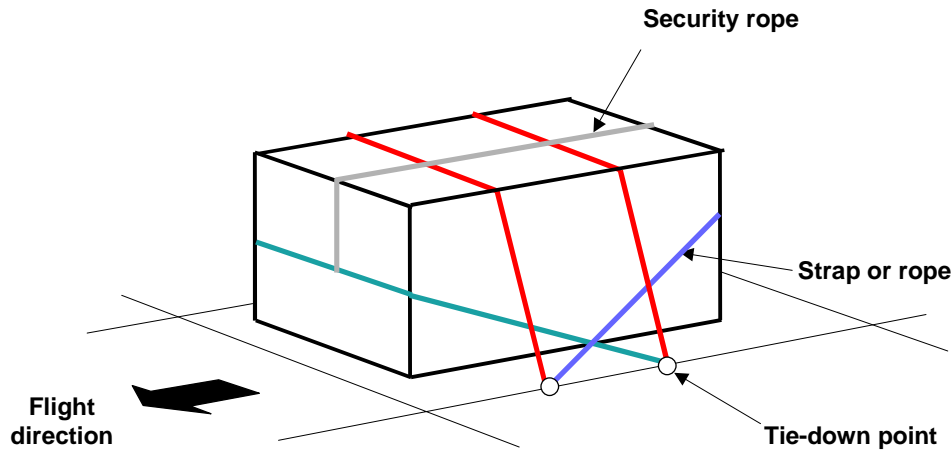

6.3.4. Forces breakdown

In order to compute the number of ropes or straps needed to restrain a load, the force applied to each tie-down point in any direction must be carefully studied. For that purpose, it is necessary to consider a reference axis system (X, Y, Z) in the Forward, Left and Up directions.
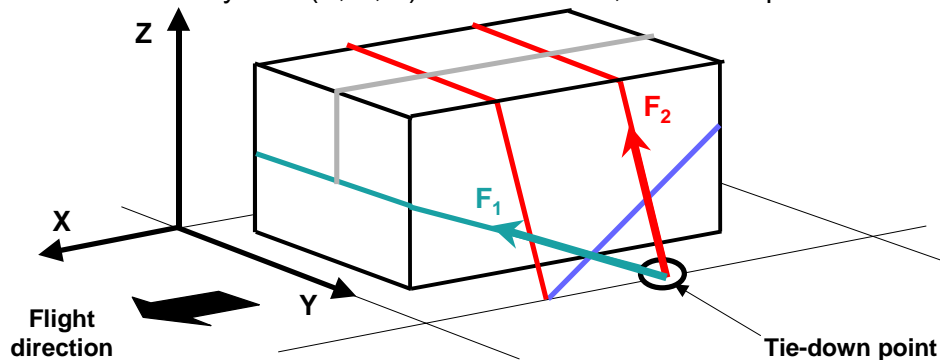
In the above example, two straps are attached to each tie-down point, generating two forces: the force F_1 is generated by a strap restraining the load in the forward direction, whereas the force F_2 is generated by a strap restraining the load in the up direction.

- **Forward strap: F_1 force breakdown**

In X direction
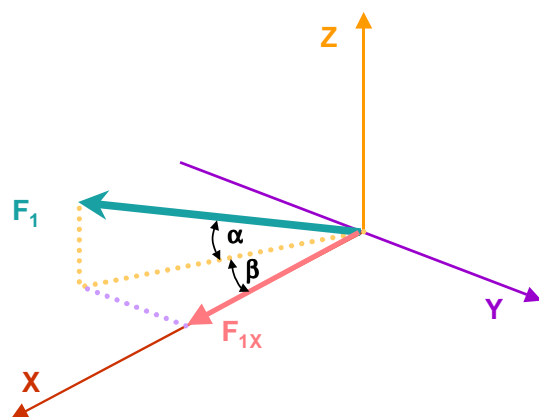
$$F_{1X} = F_1.\cos(\alpha).\cos(\beta)$$

In Y direction
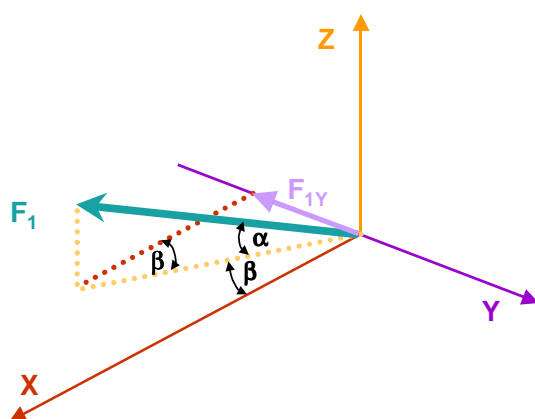
$$F_{1Y} = F_1.\cos(\alpha).\sin(\beta)$$

In Z direction
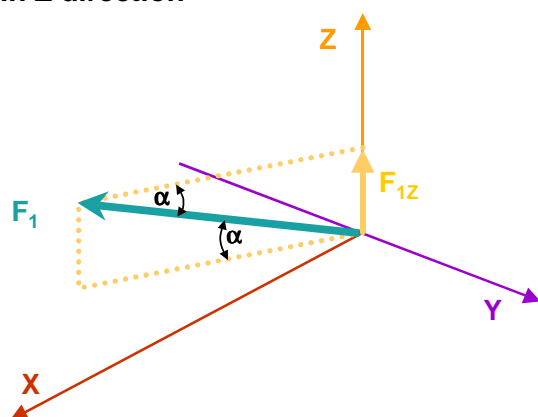
$$F_{1Z} = F_1.\sin(\alpha)$$

As each strap shall make a maximum angle of 30 degrees with the direction of restraint, α and β shall be less than 30°. Consequently, for a FORWARD (or AFT) strap, the minimum restraint force in each direction can be expressed as follows:
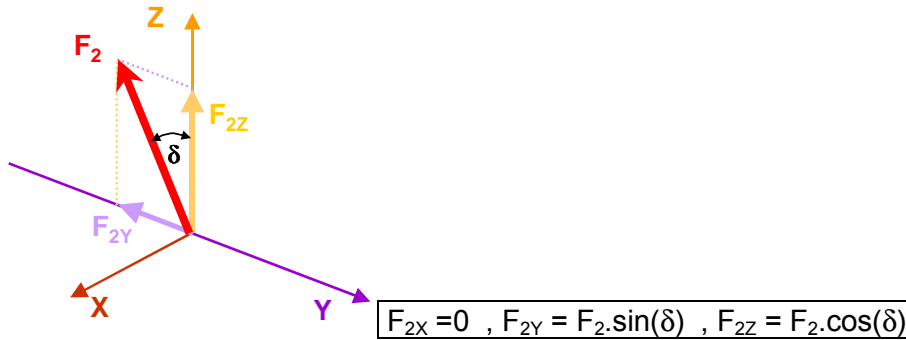
$$F_{1x} = 75\% \ F_1$$
$$F_{1y} = 43\% \ F_1$$
$$F_{1z} = 50\% \ F_1$$

Note : the recommended 30° between the rope or the strap with the main direction of restraint enables a high restrained force in the needed direction, indeed by increasing this angle, one decreases the weight that can be restrained by the item. Nevertheless some operators might choose even when applying the recommended 30° to perform the computation with an angle of 45° in order to take into account a margin in case one of the ropes in not correctly tied down.

In this case the above force breakdown is $F_{1x} = 50\%\ F_1, F_{1y} = 50\%\ F_1, F_{1z} = 70\%\ F_1$

- **Up strap: F_2 force breakdown**

$$\boxed{F_{2X} = 0\ ,\ F_{2Y} = F_2.\sin(\delta)\ ,\ F_{2Z} = F_2.\cos(\delta)}$$

As each strap shall make a maximum angle of 30 degrees with the direction of restraint, δ shall be less than 30º. Consequently, for an UP strap, the minimum restraint force in each direction can be expressed as follows:

$$F_{2x} = 0$$
$$F_{2y} = 50\%\ F_2$$
$$F_{2z} = 86\%\ F_2$$

Note : the recommended 30° between the rope or the strap with the main direction of restraint enables a high restrained force in the needed direction, indeed by increasing this angle, one decreases the weight that can be restrained by the item. Nevertheless some operators might choose even when applying the recommended 30° to perform the computation with an angle of 45° in order to take into account a margin in case one of the ropes in not correctly tied down.

In this case the above force breakdown is $F_{2x} = 0, F_{2y} = 70\%\ F_2, F_{2z} = 70\%\ F_2$

Note2: When the force is applied in the forward, left or up directions, it is considered as positive. It is counted negative in the aft and right directions.

6.3.5. Maximum load

Let's assume, as an example, a sudden deceleration of the aircraft. Without restraining system, the load would slip forward. To prevent it from moving in the forward direction, a strap is tied-down to a single stud on each side of the load, as shown below.

At each tie-down point, a force F is generated in the forward direction with a magnitude proportional to the aircraft deceleration rate. In that case, the load factor in the X direction (n_x) becomes greater than 1, and the lashing equipment shall be able to restrain a load equivalent to the piece's apparent weight: $\mathbf{F = n_x.W}$ (with W = piece's weight).

Moreover, each tie-down point (single stud fitting) can withstand a maximum load of 900 kg. Therefore, **F must be less than 900 kg**.
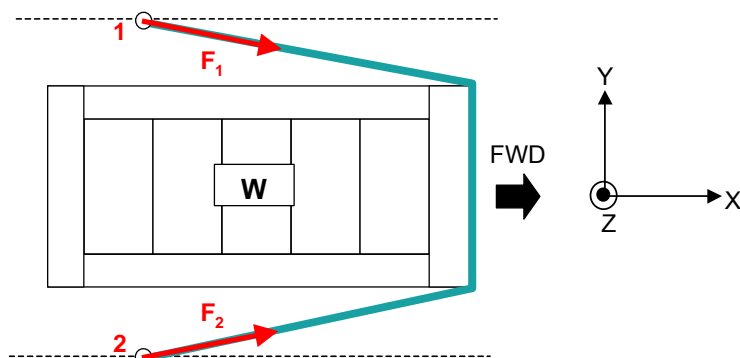
The forces F_1 generated by the deceleration at the tie-down point number 1 can be decomposed into three components F_{1x}, F_{1y} and F_{1z} as shown previously. Considering a force $\mathbf{F_1}$ **of 900 kg**, the maximum force components at tie-down point number 1 are:

$F_{1x\,max} = 75\%\ F_1 = 675$ kg

$F_{1y\,max} = 43\%\ F_1 = 387$ kg

$F_{1z\,max} = 50\%\ F_1 = 450$ kg

6.3.6. Ultimate load

a) Example 1

Let's assume that the previous piece is loaded in the aft cargo hold of an aircraft, COMPARTMENT 3. As shown in the following "Weight & Balance Manual" extract, the lashing must be done so as to be able to restrain any piece submitted to a load factor of 1.69 in the FORWARD direction.

D. **Tie down methods**

Methods of tie down are given in paragraph 1.60.06.

The load factors below must be used when establishing the ultimate load.

COMPARTMENT NUMBER	LOAD FACTOR				
	FWD	AFT	SIDE		UP
			LH	RH	
3 (Aft)	1.69	0.95	1.35	1.35	2.00
4 (Aft)	1.69	0.95	1.54	1.54	2.25

Therefore, if the piece's weight is W, the force that has to be restrained by the lashing equipment in the forward direction is : **Fx = 1.69 W**

As shown in the previous paragraph, the **maximum load** that can be restrained in the forward direction by one strap fastened to two tie-down points (1 and 2) is :
Maximum load = $F_{x\ max}$ = $F_{1x\ max}$ + $F_{2x\ max}$ = 675 kg + 675 kg = 1350 kg

The **Ultimate Load** represents the maximum weight of a piece or a pallet that can be restrained by a lashing equipment in a given direction. In our example, the ultimate load in the forward direction is : **Ultimate load = Maximum Load / Load factor**

Ultimate Load = 1350 / 1.69 = 798 kg

Conclusion : With **ONE strap** restraining the load in the forward direction, the maximum piece's weight must not exceed **798 kg** due to the breaking strength of the tie-down points.

b) Example 2

Let's assume that the load is now restrained in the forward direction by two strap as shown in the next figure.

Note : It is prohibited to use two straps attached to the same tie-down point and restraining the load in the same direction
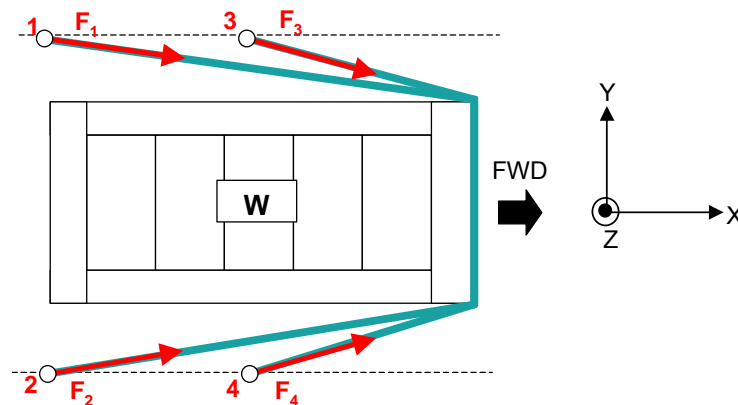
Each strap is fastened to two tie-down points, creating a force of magnitude Fn at each tie-down point n.

The force that has to be restrained by the lashing equipment in the forward direction is still:
Fx = 1.69 x W

The **maximum load** that can be restrained in the forward direction by two straps fastened to four tie-down points (1, 2, 3 and 4) is :
Maximum load = $F_{x\ max}$ = $F_{1x\ max}$ + $F_{2x\ max}$ + $F_{3x\ max}$ + $F_{4x\ max}$ = 4 x 675 kg = 2700 kg

**Ultimate Load = 2700 / 1.69 = 1597 kg**

Conclusion: With **TWO straps** restraining the load in the forward direction, the maximum piece's weight must not exceed **1597 kg** due to the breaking strength of the tie-down points.

6.3.7. Ultimate load for a standard lashing (4 straps)

Let's now consider a standard lashing composed of four straps (1 Forward, 1 Aft, 2 Up) fastened to 4 single stud fittings (see next figure).
As done previously, it is possible to establish the ultimate load in each direction (Forward, Aft, Up, Left, Right).
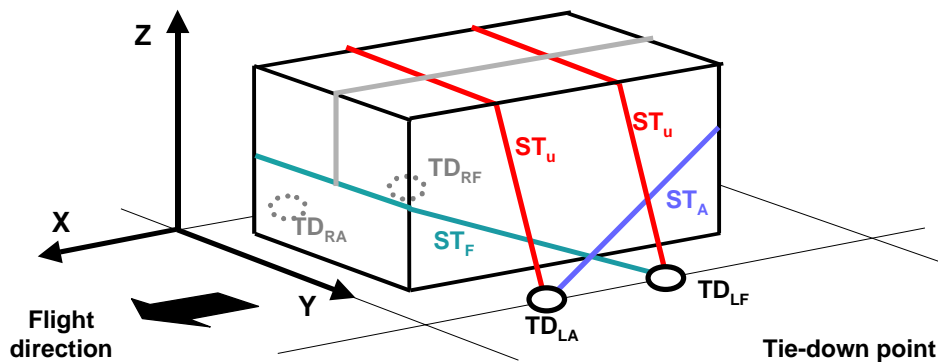
With:
ST_F = Strap Forward
ST_A = Strap Aft
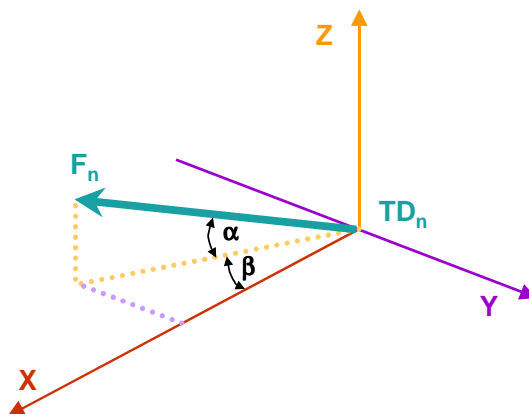*ST_U = Strap Up*

TD_LF = Tie-down point Left Forward
TD_LA = Tie-down point Left Aft
TD_RF = Tie-down point Right Forward
TD_RA = Tie-down point Right Aft

a) <u>Angles definition</u>

The force breakdown needs to be calculated for each tie-down point. So for each point the angles α and β need to be defined.

α : angle between the force direction and the floor.
β : angle between the force direction and the forward direction.

Note : for the following example we assume that each strap shall make a maximum angle of 30 degrees with the direction of restraint.

- **Left Tie Down Points**

  Restraint UP
  $TD_{LF} ST_U : \alpha = 60°, \ \beta = 90°$
  $TD_{LA} ST_U : \alpha = 60°, \ \beta = 90°$
  Restraint FORWARD
  $TD_{LF} ST_F : \alpha = 30°, \ \beta = 30°$
  Restraint AFT
  $TD_{LA} ST_A : \alpha = 30°, \ \beta = 150°$

- **Right Tie Down Points**

  Restraint UP
  $TD_{RF} ST_U : \alpha = 60°, \ \beta = 270°$
  $TD_{RA} ST_U : \alpha = 60°, \ \beta = 270°$
  Restraint FORWARD
  $TD_{RF} ST_F : \alpha = 30°, \ \beta = 330°$
  Restraint AFT
  $TD_{RA} ST_A : \alpha = 30°, \ \beta = 210°$
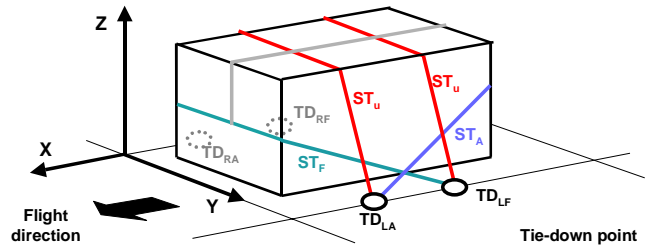
b) Force breakdown

Then for each tie-down point the force breakdown is :

$F_X = F.\cos(\alpha).\cos(\beta)$

$F_Y = F.\cos(\alpha).\sin(\beta)$

$F_Z = F.\sin(\alpha)$

- **Left Tie Down Points**

TD_{LF} : 2 straps : 1 UP and 1 FORWARD

$F_{x\ UP} = 0$	$F_{x\ FORWARD} = 0.75\ F$
$F_{Y\ UP} = 0.5\ F$	$F_{Y\ FORWARD} = 0.43\ F$
$F_{Z\ UP} = 0\ 86\ F$	$F_{Z\ FORWARD} = 0\ 50\ F$

TD_{LA} : 2 straps : 1 UP and 1 AFT

$F_{x\ UP} = 0$	$F_{x\ AFT} = -\ 0.75\ F$
$F_{Y\ UP} = 0.5\ F$	$F_{Y\ AFT} = 0.43\ F$
$F_{Z\ UP} = 0\ 86\ F$	$F_{Z\ AFT} = 0\ 50\ F$

- **Right Tie Down Points**

TD_{RF} : 2 straps : 1 UP and 1 FORWARD

$F_{x\ UP} = 0$	$F_{x\ FORWARD} = 0.75\ F$
$F_{Y\ UP} = -\ 0.5\ F$	$F_{Y\ FORWARD} = -\ 0.43\ F$
$F_{Z\ UP} = 0\ 86\ F$	$F_{Z\ FORWARD} = 0\ 50\ F$

TD_{RA} : 2 straps : 1 UP and 1 AFT

$F_{x\ UP} = 0$	$F_{x\ AFT} = -\ 0.75\ F$
$F_{Y\ UP} = -\ 0.5\ F$	$F_{Y\ AFT} = -\ 0.43\ F$
$F_{Z\ UP} = 0\ 86\ F$	$F_{Z\ AFT} = 0\ 50\ F$

Note : F being the maximum breaking strength allowed at the tie-down point.

c) Maximum load

So the maximum loads in each direction are:

$F_{X\ FORWARD} = 0.75\ F + 0.75\ F = 1.5\ F$

$F_{X\ AFT} = -\ 0.75\ F - 0.75\ F = -\ 1.5\ F$

$F_{Y\ RIGHT} = -\ 0.5\ F - 0.43\ F - 0.5\ F - 0.43\ F = -\ 1.86\ F$

$F_{Y\ LEFT} = 0.5\ F + 0.43\ F + 0.5\ F + 0.43\ F = 1.86\ F$

$F_z = 0.86\ F + 0.5\ F + 0.86\ F + 0.5\ F + 0.86\ F + 0.5\ F + 0.86\ F + 0.5\ F = 5.44\ F$

d) Ultimate load

$$\text{Ultimate Load} = \left[\frac{\text{Maximum Load}}{\text{Load Factor}} \right]$$

So the ultimate loads in each direction are:

Ultimate Load FORWARD = $F_{X\ FORWARD} / n_{FORWARD} = 1.5\ F / n_{FORWARD}$

Ultimate Load AFT = $F_{X\ AFT} / n_{AFT} = 1.5\ F / n_{AFT}$

Ultimate Load RIGHT = $F_{Y\ RIGHT} / n_{RIGHT} = 1.86\ F / n_{RIGHT}$

Ultimate Load LEFT = $F_{Y\ LEFT} / n_{LEFT} = 1.86\ F / n_{LEFT}$

Ultimate Load UP = $F_Z / n_{UP} = 5.44\ F / n_{UP}$

e) Summary

This whole method can be summarized in the following table:

Tie down Point Pos. Restraint		Angle α (°)	β (°)	Force Breakdown FWD +	AFT -	LH +	RH -	UP +
Left	AFT	30	150		75% F	43% F		50% F
	UP	60	90			50% F		86% F
TD$_{LA}$					**75% F**	**93% F**		**136% F**
Left	FORWARD	30	30	75% F		43% F		50% F
	UP	60	90			50% F		86% F
TD$_{LF}$				**75% F**		**93% F**		**136% F**
Right	AFT	30	210		75% F		43% F	50% F
	UP	60	90				50% F	86% F
TD$_{RA}$					**75% F**		**93% F**	**136% F**
Right	FORWARD	30	330	75% F			43% F	50% F
	UP	60	90				50% F	86% F
TD$_{RF}$				**75% F**			**93% F**	**136% F**
Total Maximum Load Allowed				**150% F**	**150% F**	**186% F**	**186% F**	**544% F**
Load Factor				n_{FWD}	n_{AFT}	n_{LEFT}	n_{RIGHT}	n_{UP}
Ultimate Load				**150% F / n_{FWD}**	**150% F / n_{AFT}**	**186% F / n_{LEFT}**	**186% F / n_{RIGHT}**	**544% F / n_{UP}**
ULTIMATE LOAD				**Minimum of the Ultimate loads**				

This method can be applied for as many as needed tie down points, adding each time a strap in the direction which limiting the ULTIMATE LOAD.

Then tables like the following one can be issued and published in the loading manuals of operators.

Load to be restrained	Number of single stud fittings	Number of straps hooked on 2 single stud fittings		
kg		FWD	AFT	UP
less than 800	4	1	1	2
801 to 1420	6	2	1	3
1421 to 1600	6	2	2	3
1601 to 2400	8	3	2	4
2401 to 3200	10	4	3	5
3201 to 4010	12	5	4	6
> 4010	14	6	5	7

Note : the recommended 30° between the rope or the strap with the main direction of restraint enables a high restrained force in the needed direction, indeed by increasing this angle, one decreases the weight that can be restrained by the item. Nevertheless some operators might choose even when applying the recommended 30° to perform the computation with an angle of 45° in order to take into account a margin in case one of the ropes in not correctly tied down.

| Tie down Point | | Angle | | Force Breakdown | | | | |
Pos.	Restraint	α (°)	β (°)	FWD +	AFT -	LH +	RH -	UP +
Left	AFT	45	145		50% F	50% F		70% F
	UP	45	90			70% F		70% F
TD$_{LA}$					**50% F**	**120% F**		**140% F**
Left	FORWARD	45	45	50% F		50% F		70% F
	UP	45	90			70% F		70% F
TD$_{LF}$				**50% F**		**120% F**		**140% F**
Right	AFT	45	225		50% F		50% F	70% F
	UP	60	90				70% F	70% F
TD$_{RA}$					**50% F**		**120% F**	**140% F**
Right	FORWARD	45	315	50% F			50% F	70% F
	UP	45	90				70% F	70% F
TD$_{RF}$				**50% F**			**120% F**	**140% F**
Total Maximum Load Allowed				**100% F**	**100% F**	**240% F**	**240% F**	**560% F**
Load Factor				n_{FWD}	n_{AFT}	n_{LEFT}	n_{RIGHT}	n_{UP}
Ultimate Load				**100% F / n_{FWD}**	**100% F / n_{AFT}**	**240% F / n_{LEFT}**	**240% F / n_{RIGHT}**	**560% F / n_{UP}**
ULTIMATE LOAD				**Minimum of the Ultimate loads**				

SPECIAL LOADING INTRODUCTION

B. SPECIAL LOADING

1. LIVE ANIMALS AND PERISHABLE GOODS

1.1. Generalities

1.1.1. Main difficulties in animals and perishable goods transportation

Live animals and perishable goods are particularly restricting shipments to transport. Several factors must be considered when livestock and perishable goods are transported:

- Each animal specie or perishable good must be transported under specific condition of **temperature**, but they can be grouped into three main categories:
  - *Frozen goods*: transported between –30°C and -12°C
  - *Other perishable goods:* transported between -2°C and 20°C
  - *Live animals:* transported between 0°C and 32°C
- **Condensation** can deteriorate the quality of certain perishable goods, and may cause death of live animals. Moreover, too much condensation may cause false smoke warnings. Condensation can be caused by a moist external ambient air, a descent from high altitude into comparatively warmer air, or by moisture produced by live animals and perishable cargo.
- The presence of a high rate of **carbon dioxide** endangers the health of live animals and reduces the quality of fruits and vegetables. Not only live animals, fruits, vegetables, but also sublimation of dry ice (used as a cooling medium for perishable goods) are the main causes for presence of CO_2.
- **Ethylene** is a gas given off by horticultural products (fruits, vegetables and flowers) and the ground equipment used to load and unload the cargo compartments. With some products, the ripening process is accelerated by the presence of ethylene.

Therefore, in addition to the temperature, several other factors must be considered: on the one hand, animals and perishable goods need a relatively fresh air, but on the other hand they give off substances which can be harmful.

1.1.2. Recommendations

To transport perishable goods and live animals in good conditions, different rules should be applied:

⇒ A **ventilated** cargo compartment is recommended. It allows a removal of moist air, CO_2, and ethylene. Moreover, ventilation limits the accumulation of dust, which may avoid false smoke warnings.

⇒ In addition to the ventilation system, a **heating system** ensures suitable conditions for their transport. Indeed, external temperatures can be very high or very low depending on the phase of the transport considered, whereas the temperature in the compartment must remain stable.

> AIRBUS Industrie provides a range of optional ventilation and heating systems for installation in the FWD and AFT compartments of all the aircraft. Ventilation and heating are provided as basic in the bulk compartments of all the aircraft except the A320 family where it is optional.

⇒ Containers must be **cleaned** thoroughly before and, above all, after the flight. It is recommended to clean the compartments that have transported animals more frequently than given in the Aircraft Maintenance Manual. There are several reasons for this: cleaning compartments avoids the accumulation of dust, hair and feathers in the air extraction system ducts and on the lens of smoke detectors, and it limits corrosion of the aircraft due to animals excreta, sea water, fish slime or blood.

⇒ When transporting live animals and perishable goods, the basic rule is **"Last in – First out"**. For the cargo to arrive in the best condition, it must be loaded as near as possible to the aircraft departure time and collected as soon as possible at the destination airport.

⇒ The most **direct route**, or at least the most favorable route, should be used to transport live animals and perishable goods.

1.1.3. Responsibilities

Transportation of live animals and/or perishable goods is under the sole responsibility of the operator who has to ensure a suitable environment for the load transported.

When any live animal is on board, the form "Special Load - Notification to Captain" gives indications to the pilot about the required action on hold heating and ventilation controls (Refer to the "Operational Loading Documents" part of this manual).

1.2. Live animals transportation

1.2.1. Reference documents

a) SAE AIR 1600

A common reference document for live animals transportation is the norm called SAE AIR 1600 edited by the Society of Automotive Engineers (USA). The purpose of this AIR (Aeronautical Information Report) is to provide information on the environmental conditions, such as temperature, humidity, carbon dioxide, noise, lighting…, that are required for the transportation of various live animals in the cargo compartments of civil commercial aircraft. It provides Air Conditioning engineers guidelines for the design of cargo air conditioning systems.

b) IATA Live Animals Regulations

Another reference book for the transport of live animals is the **"IATA Live Animals Regulations" (LAR)**. This document states general rules for transportation by air of live animals. It specifies the type of container to be used and the handling procedures to be followed for individual animal species. Special attention is given to animal comfort, safety of handling staff and prevention of damage caused to aircraft.

1.2.2. Environmental limitations

Animals give off heat, moisture, carbon dioxide and other gases. Combination of high temperature and high moisture is not recommended because it reduces the animals' ability to withstand the stress. Moreover, too much carbon dioxide is dangerous to the animals' health.

Therefore, limit rates have been imposed to the airlines when live animals are transported:
- Relative humidity < 80%
- Concentration of carbon dioxide < 3% (this limit is going to decrease over the next years)

That's why ventilation is therefore recommended when transporting live animals.

1.2.3. Unventilated cargo compartments

Most of the countries have accepted the IATA Live Animals Regulations (LAR) as the directive for animal transportation by air. Within the EU, live animals transportation is also regulated by the Council of Europe document "European Convention for the Protection of Animals during International Transport (ETS65)". It applies to all airlines of all nationalities, operating into, out of, and transiting through any EU member State.

ETS65 covers the transport of live animals in general, Article 29 is special provisions for transport by air. Paragraph 1 of Article 29 states **"*no animal shall be transported in conditions where air quality, temperature and pressure cannot be maintained in an appropriate range during the entire journey"*.**

It does not specifically ban the transport of live animals in unventilated compartments, but without ventilation supply to the cargo compartment, temperature could not always be maintained in the appropriate range.

1.2.4. Specific containers

Live animals must be transported in suitable clean containers. In the IATA LAR, everything can be found about container's specificity for each animal specie. Some rules are common to all of them. Containers must be:

- Strong enough to be stacked
- Escape-proof for the handling staff to be in safety
- Leak-proof (the use of an absorbent material is recommended, but not straw because of its combustibility)
- Tied down during the flight
- Not closed containers, except for tropical fish

On the four sides of the container, the labels "Live Animals" and "This Way Up" must be placed.
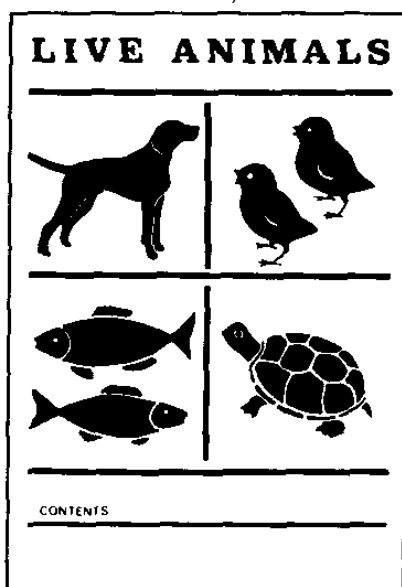
IATA "Live Animals" label
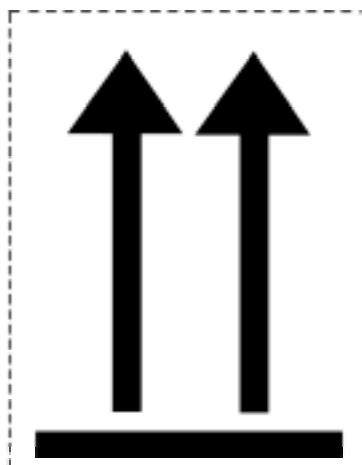
1.2.5. Loading rules

General rules must be respected:

⇒ They must be loaded close to the cargo door
⇒ They must be protected against low temperatures:
  - Not directly loaded on the floor of the aircraft
  - Not directly loaded in front of or below the air inlets
⇒ A special care must be taken concerning the neighbourhood of the animal:
  - Enemy animals such as cats and dogs not in sight of one another
  - Males and females not close to each other
  - Sensitive animals not close to foodstuffs
  - Sensitive animals not close to human remains
  - Sick animals and "laboratory animals" separated from healthy animals
⇒ Animals must not be in close proximity of dangerous goods such as dry ice, cryogenic liquids, radioactive materials, and poisonous and infectious substances.

Note: A table presenting loading incompatibilities of live animals with other cargo loads is proposed in the "Loading Operations" part of this manual.

1.2.6. Live Stock Transportation Manual (LTM)

Airbus has developed a simplified calculation method allowing the calculation of heat load and moisture rate in a cargo hold, while carrying live animals. This method is based on a series of graphs and a Basic Data Form published in the Airbus Live Stock Transportation Manual (LTM). This manual enables to determine whether the planned load can be carried safely under given climatic and flight conditions.

The method proposed permits to calculate:

- **for a ventilated compartment:**

The **Total Animal Heat Load** and the **Total moisture rate** at the departure airport, destination airport and during the flight. Depending on the cargo option (heating or not), the method enables to evaluate if the temperature and humidity rate can be maintained in an appropriate range during the entire journey.

- **for an unventilated compartment:**

The **Compartment temperature** (without heat Load) at the departure airport, destination airport and during the flight, as well as the **Maximum confinement time**.
The confinement time is the time spent in a compartment without ventilation (from door closing to door opening). The maximum confinement time is the maximum time to reach the maximum volumetric concentration of carbon dioxide (CO_2). It is dependent on the free air volume in the cargo compartment and the animal CO_2 production.

1.3. Perishable goods

1.3.1. IATA Perishable Cargo Handling Manual

The reference guide for packaging and handling of perishable goods by air is the IATA Perishable Cargo Handling Manual. This manual is published as an industry service under the authority of the IATA Cargo Service Conference.

1.3.2. Definition

Perishable cargo can be defined as "*goods that will deteriorate over a given period of time, or if exposed to adverse temperatures, humidity or other environmental conditions*". As an example, this concerns different types of products such as meat, hatching eggs, flowers, fresh fruits and vegetables, sea food, vaccines and medical supply, living human organs and blood.

1.3.3. Dehydration

Loss of water is a major cause of deterioration of fruits and vegetables. Since dehydration is caused by both high temperatures and low humidity, it is necessary to store fruits and vegetables under climatic conditions which are as close as possible to the ideal temperature and relative humidity.

The temperature should be maintained constant during the journey, and the relative humidity required is often very high (up to 90%).

1.3.4. Package

Some perishable goods, like meat and sea food, require the use of watertight refrigerated and temperature controlled containers, and must be treated as WET cargo[1]. Indeed, the temperature must remain between the following limits during the whole flight:
- fresh meat or fresh fish: between 0ºC and 5ºC
- frozen meat or frozen fish: below – 12ºC

[1] *Note: WET cargo concerns shipments containing liquids, or which by their nature may produce liquids (except dangerous goods). As an example: liquids in watertight containers, wet materials not packed in watertight containers (eg fish packed in wet ice), live animals…*

- **Refrigerating material:**

> **Dry ice**: the most effective refrigerant but classified as a "dangerous good" because it produces CO_2, which can be dangerous for live animals and can damage some perishable goods. It is used as a cooling medium and must be used for frozen goods.
>
> **Gel ice**: chemically based compound available in 2 forms (powder in plastic envelopes or sheets in plastic sachets). It must be frozen before use and has a gel-like consistency.

Wet ice: ice made of frozen water.

Tº dry ice < Tº gel ice < Tº wet ice

The use of gel ice is recommended for several reasons: contrary to dry ice, it is harmless to food products and more durable. There is no risk of leakage and gel ice can be re-used over and over again: therefore, it is an economically attractive way to keep perishable goods cool.

The labels "Perishable" and "This Way Up" must figure on the 4 sides of the package.
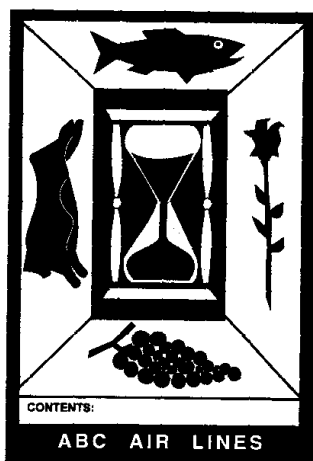
Name of label:	Perishable
Colour:	Blue printing on white background
Size:	Not less than 74 mm (2$^{15}/_{16}$ in.) in width by 105 mm (4$^{1}/_{8}$ in.) in height.

1.3.5. Loading rules

Before loading perishable goods, it is necessary to know the incompatibilities between different product types.

Note: A table presenting loading incompatibilities of perishable goods with other cargo loads is proposed in the "Loading Operations" part of this manual.

- Some are incompatible because of a difference in temperature and/or humidity, others because of vapours or odours released.
- Goods for human consumption must not be in close proximity of non-cremated human remains or live animals.
- There must also be a separation with radioactive materials, dry ice and cryogenic liquids.

Several other rules must be respected for the loading of perishable goods to avoid crushing:
- Not in direct contact with the compartment floor or wall
- A maximum stacking height
- Not heavy package on top of fragile goods (fruits and vegetables, eggs, etc.)
- Interlocking layers are recommended when a lot of ventilation is not needed.

Other rules are specific to each species of perishable goods. They can be found in the IATA Perishable Cargo Handling Manual.

LOADING OPERATIONS

- **Summary:**

Transportation of animals and perishable goods requires specific conditions that can vary depending on the product transported.
Ventilation is necessary to transport live animals, and is recommended to transport perishable goods; **heating** is recommended for both of them. Airbus aircraft can be equipped with these two systems, either as optional or as basic.
But even with ventilation and/or heating systems, a special care must be taken about **incompatibilities** between animals and/or perishable products.

2. DANGEROUS GOODS

2.1. Responsibility

Transportation of dangerous goods is under the sole responsibility of the operator (the shipper).

2.2. References

Two references shall be used for transportation of dangerous goods:
- the **ICAO Technical Instructions For the Safe Transport of Dangerous Goods by Air,** adopted by the Members of the International Civil Aviation Organization (ICAO)
- The **IATA Dangerous Goods Regulations** published annually by IATA. They contain all the requirements of the ICAO Technical Instructions, but IATA has included additional requirements that are more restrictive.

The IATA Dangerous Goods Regulations are more applicable for practical reference by the industry, but as indicated in the preface of the IATA Dangerous Goods Regulations,

*"Annex 18 to the Chicago convention and the associated **Technical Instructions for the Safe Transport of Dangerous Goods by Air** are recognized as the sole authentic legal source material in the air transport of dangerous goods".*

In addition to these two reference manuals, national regulations from e.g. FAA or JAA may also apply as applicable and furthermore the local authorities of the country of departure and country of arrival may have strict regulations which have to be taken into account.

2.3. Definitions

Dangerous goods are "articles or substances which are capable of posing a significant risk to health, safety or property when transported by air" (per IATA Dangerous Goods Regulations).
There are three types of dangerous goods:
- goods too dangerous to be transported by air
- goods transported with cargo aircraft only (called CAO shipments)
- goods transported both with cargo and passenger aircraft

To know to which category belongs a given good, refer to the Limitations section of the IATA Dangerous Goods Regulations. In this section, you will also find the list of state variations concerning dangerous goods.

Some cargo may be **hidden dangerous cargo**: indeed, declared under a general description, some cargo can hide hazards that may not be apparent. Here are some examples of hidden dangerous goods:
- Articles found in passengers' baggage that may contain flammable gas or liquid, matches, aerosols, etc.
- Frozen perishable goods or vaccines that may be packed with Dry Ice (solid carbon dioxide)
- Parts of automobiles that may contain wet batteries or gasoline
- etc.

2.4. Identification

"An operator shall take all reasonable measures to ensure that articles and substances are classified as dangerous goods as specified in the Technical Instructions." (JAR–OPS 1.1170).

A number, in the United Nations classification system, is given to each dangerous article or substance. Each substance has its own UN number. This number is used for all ways of transport (not only air-transport) to identify the substance.

The letters "UN" precede this number (when the UN number is not assigned yet, a temporary "ID" number in the 8000 series is assigned).

Symbol:

2.5. Classification

Moreover, dangerous goods are classified into 9 hazard classes. Each hazard class is divided into several hazards divisions and specific labels are applied to each one of these classes and/or divisions:

2.5.1. Explosives

- **Division 1.1** - Articles and substances having a mass explosion hazard
- **Division 1.2** - Articles and substances having a projection hazard but not a mass explosion hazard
- **Division 1.3** - Articles and substances having a fire hazard, a minor blast hazard and/or a minor projection hazard but not a mass explosion hazard
- **Division 1.4** - Articles and substances presenting no significant hazard
- **Division 1.5** - Very insensitive substances having a mass explosion hazard
- **Division 1.6** - Extremely insensitive articles which do not have a mass explosion hazard

Applicable labels are:
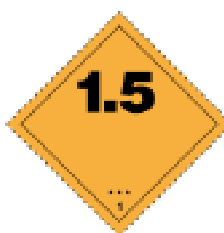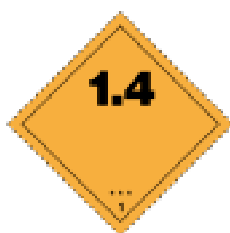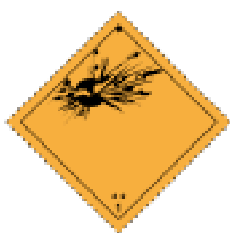
2.5.2. Gases

- **Division 2.1** - Flammable gas
- **Division 2.2** - Non-flammable, non toxic gas
- **Division 2.3** - Toxic gas

Applicable labels are:
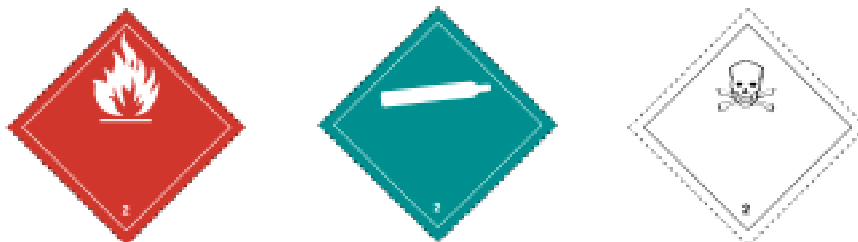
2.5.3. Flammable liquids

Applicable label is:

2.5.4. Flammable solids; Substances liable to spontaneous combustion; Substances which, in contact with water, emit flammable gases

- **Division 4.1** - Flammable solid
- **Division 4.2** - Substances liable to spontaneous combustion
- **Division 4.3** - Substances which, in contact with water, emit flammable gas

Applicable labels are:
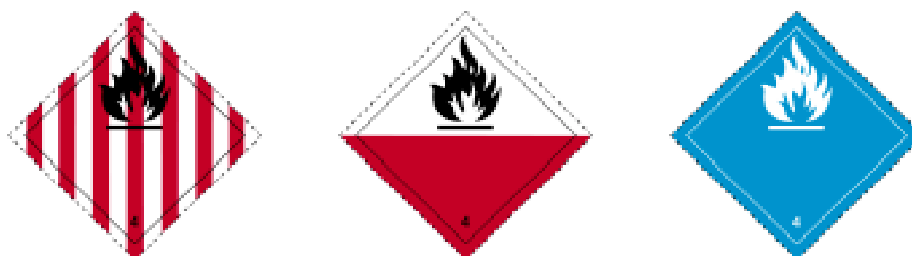
2.5.5. Oxidizing substances and Organic Peroxide

− **Division 5.1** - Oxidizer
− **Division 5.2** - Organic peroxides

Applicable labels are:
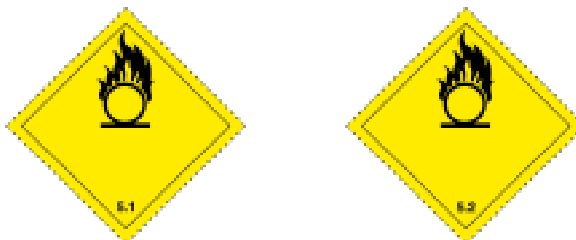
2.5.6. Toxic and infectious substances

− **Division 6.1** - Toxic substances
− **Division 6.2** - Infectious substances

Applicable labels are:
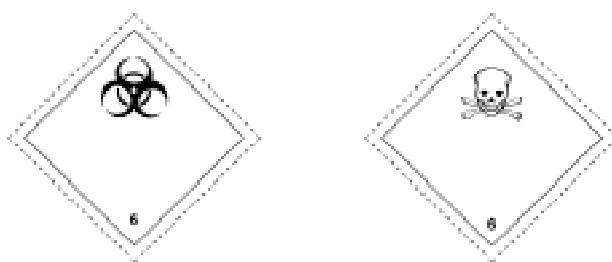
2.5.7. Radioactive material

Applicable labels are:

2.5.8. Corrosives

Applicable label is:
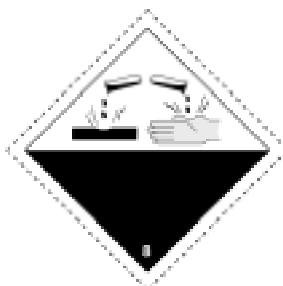
2.5.9. Miscellaneous dangerous goods

Applicable label is:
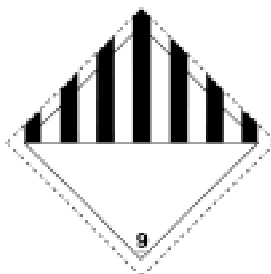
2.6. Packing

The order in which classes and divisions are numbered does not imply a relative degree of danger. The element that gives an indication on the degree of hazard substances present is the **packing group**:

- Packing group I → great danger
- Packing group II → medium danger
- Packing group III → minor danger

Criteria for packing groups have only been developed for some classes and divisions. When a given substance presents more than one hazard, the most stringent class and packing group must be applied to this substance; the least stringent hazard is called the **subsidiary hazard**. A table provided in the 3rd section of the IATA Dangerous Goods Regulations helps in determining which one of the two hazards must be regarded as the primary hazard.

Example:

	CLASS OR DIVISION	PACKING GROUP
A	4.2	II
B	5.1	III
C	5.1	I

- A + B → 4.2, II - Subsidiary risk: 5.1
- A + C → 5.1, I - Subsidiary risk: 4.2

Therefore, before packing any dangerous good, the shipper must:
- Identify correctly and fully all dangerous articles and substances before transportation
- Classify each item by determining its class or division and its subsidiary hazard
- When it is possible, assign each item to one of the three packing groups

The shipper is responsible for all aspects of the packing of dangerous goods in compliance with the IATA Dangerous Goods Regulations.

In the 5th section of the IATA Dangerous Goods Regulation, the shipper can find packing instructions that detail the type of specifications required to transport each product depending on its class. Most dangerous goods must be packed with both an inner and an outer packaging.

Here are general packing requirements (for more details, refer to the 5th section of the IATA Dangerous Goods Regulations):

- Dangerous goods packaging must be of a good quality
- Packaging in direct contact with dangerous goods must be resistant to any chemical action of such goods
- Salvage packaging must be used for damaged, defective or leaking dangerous goods
- Packaging can be reused or reconditioned under specific conditions
- Several dangerous goods may be transported in the same outer packaging under specific conditions

One last condition about package of dangerous goods is that it must be of such a size that there is enough space to affix all required markings and labels.

2.7. Marking and labeling

All packages containing dangerous goods are to be marked and labeled in order to ensure immediate identification during all phases of transportation.

- First of all, the packaging must bear the UN number and the shipping name of the substance it contains.
- Each package is labeled thanks to the dangerous goods hazard labels we have seen above (minimum size: 100 x 100 mm).
- If necessary, handling information shall be shown on the packages thanks to the following labels:

This Way Up
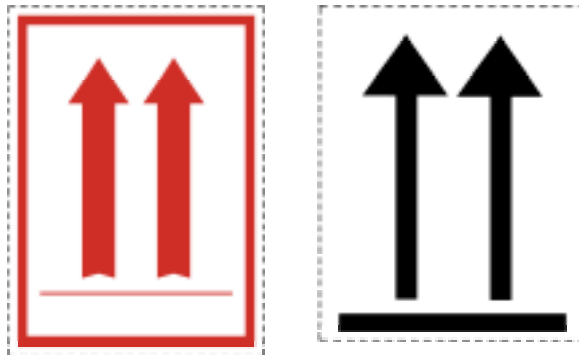
Cargo Aircraft Only
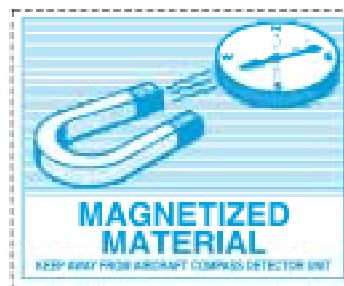
2.8. Documents

The presence of special loads such as dangerous goods should be noted on the load sheet and the load message. Moreover, for each shipment containing dangerous goods, the shipper must fill in special forms:

2.8.1. Air Waybill

The IATA Air Waybill Handbook gives all the instructions necessary to complete an Air Waybill. An Air Waybill is compulsory whenever dangerous goods are transported.

The "Handling information" box of the Air Waybill gives information about:

  − the presence of dangerous goods on board
  − the presence or not of a "Shipper's Declaration for Dangerous Goods"
  − the way the dangerous goods must be transported (Cargo Aircraft Only or Passenger aircraft)

Example: **Dangerous goods for which a Shipper's Declaration is required and transported on a passenger aircraft.**

2.8.2. Shipper's Declaration for Dangerous Goods

Thanks to the "Shipper's Declaration for Dangerous Goods", the shipper certifies that dangerous goods have been properly prepared for shipment. A Shipper's Declaration for Dangerous Goods is provided on the following page.

1 - Information about the shipper
2 - Information about the consignee
3 - Number of the Air Waybill attached
4 - Page number
5 - Enter the full names of the airports (not ICAO codes)
6 - Radioactive material must not be on the same declaration as other dangerous goods, except dry ice (used as a refrigerant for perishable goods — cf. next part).
7 - Information about dangerous goods transported
8 - Particular information about the shipment
9 - The shipper commits himself to respect regulations concerning transportation of the shipment

AIRBUS

2.8.3. Special Load – Notification to Captain

Thanks to this form, the flight crew is aware of the presence of dangerous goods on board. It is also used to indicate the presence of live animals or perishable cargo which transportation is developed below.

The following form is used:

SPECIAL LOAD – NOTIFICATION TO CAPTAIN														
Station of Loading	Flight Number	Date		Aircraft Registration		Prepared by								
DANGEROUS GOODS													Loaded	
Station of Unloading	Air Waybill Number	Proper Shipping Name		Class or Division For Class 1 compat. grp.	UN or ID Number	Sub Risk	Number of Packages	Net quantity or Transp. Ind. per package	Radio-active Mat. Categ.	UN Packing Group	Code (see reverse)	CAO (X)	ULD ID	POSITION
			SUCH AS LIVE ANIMALS OR PERISHABLE GOODS											
		There is no evidence that any damaged or leaking packages containing dangerous goods have been loaded on the aircraft.												
OTHER SPECIAL LOAD													Loaded	
Stat. of Unload	Air Waybill Number	Contents and Description		Number of Packages	Quantity	Supplementary Information					Code (see reverse)		ULD ID	POSITION
Loading Supervisor's Signature		Captain's Signature		Other Information										

* This sentence must be shown on the NOTOC. The location is left to the discretion of the carrier.

2.9. Handling and loading

Competent persons that have received an appropriate training concerning dangerous goods shall only execute handling and loading.

A few rules are to be respected:
- First of all, before loading, it is necessary to inspect the outer packaging of dangerous goods to determine there is no hole or leakage. Moreover, they must always be handled with care.
- Handling instructions on the package must be respected (This Way Up, etc.).
- Dangerous goods must never be carried on the same deck as passengers or crewmembers.
- Some goods may react dangerously with others. To avoid any interaction, other loads or being loaded in different compartments shall physically separate incompatible goods from others. The table of incompatibilities is provided in the AHM 645.
- When an Auxiliary Center Tank (ACT) is installed in a cargo compartment, no combustible, corrosive or explosive material shall be transported in this compartment
- After unloading, the outer packaging must be inspected for evidence of damage or leakage.

2.10. Special shipments

2.10.1. RADIOACTIVE MATERIALS

There are three different categories of radioactive materials depending on the Transport Index (TI) of the package. Its value is shown on the labels affixed on the package.

The TI number expresses the maximum radiation dose rate at 1 meter away from the external surface of a package containing dangerous goods.

- – Category I - no TI
- – Category II – $0 < TI \leq 1.0$
- – Category III – $1.1 \leq TI \leq 10.0$

The transport index of a single package is limited to 10 and the transport index of the whole shipment is limited to 50.

There is no specific restriction concerning radioactive materials from category I. Packaging containing radioactive materials of categories II and III must be separated from live animals, hatching eggs and undeveloped photographic films. Moreover, during the flight, minimum horizontal and vertical distances must separate these radioactive packages from each other and from passengers.

2.10.2. CARBON DIOXIDE, SOLID (DRY ICE)

Dry ice is used as a refrigerant for perishable goods transportation. Loading regulations shall be applied such as:
- – When there is dry ice in a compartment, it must be ventilated before the staff enters in it.
- – Dry ice shall not be loaded in close proximity of live animals or hatching eggs.

2.10.3. CORROSIVES

Corrosives shall not be loaded next to dangerous goods classified as explosives, flammable solids, oxidizing substances or organic peroxides. Moreover, whenever ACTs are installed in the aircraft, no corrosive materials should be transported in close proximity of them.

2.10.4. TOXIC AND INFECTIOUS SUBSTANCES

Such substances shall not be loaded in the same section or ULD as live animals or foodstuffs. Even when they are loaded in different ULDs, the ULDs must be separated

OPERATIONAL LOADING DOCUMENTS INTRODUCTION

IATA AHM part 5 describes in detail all the different types of traffic documents and messages to be used for handling operations. This manual must be used as a reference to help building specific airline policies in accordance with national regulations.

Our goal in this chapter is to provide the reader with a general description of the main documents used in operations for a better understanding of the load control function. These main documents are:

- Loading Instruction / Report form (LIR)
- Container/Pallet distribution message (CPM)
- Loadsheet
- Loadmessage (LDM)
- Balance chart / balance table

In these different documents, codes are used and it is recommended that operators comply with the proposed codification of IATA AHM 510 recalled hereafter.

C. OPERATIONAL LOADING DOCUMENTS

1. LOAD AND VOLUME INFORMATION CODES

1.1. Load Information Codes

The following codes enable to define the type and priority of deadload transported in the cargo holds. To be used on the LIR and the CPM.

Code	Description
B	Baggage
C	Cargo
D	Crew baggage
E	Equipment in compartment
F	First class baggage and/or priority handled baggage
H	ULD and/or its load to be transshipped to a connecting flight (destination or flight number indicated in Supplementary Information part of the CPM)
M	Mail
N	No ULD at position
Q	Courier baggage
S	Sort on arrival
T	Load for transfer to connecting flights
U	Unserviceable ULD
W	Cargo in security controlled ULD
X	Empty ULD
Z	Load deliberately mixed by destination when these destinations are known to be beyond a planned

1.2. ULD Load volume codes

The following codes provide a transit station with information about the available volume in a cargo section or an ULD. To be used on the LIR and the CPM.

Code	Description
0	No volume available
1	Quarter volume available
2	Half volume available
3	Three quarters volume available

LOADING OPERATIONS

1.3. Codes used for loads requiring special attention

The following codes (non exhaustive list) indicate in the LIR, CPM, Loadsheet, and LDM, the content of the dead load requiring special attention.

Code	Description	LDM format	Remark
AOG	Spare part for Aircraft On Ground	.AOG/12L	ULD position 12L
AVI	Live Animals	.AVI/4	Loaded in CPT4
BAL	Ballast hold loaded	.BAL/5/100	100 kg ballast in CPT5
BED	Stretcher installed	.BED/6/2Y	6 seats blocked by 2 pax in Y
BEH	Stretcher in cargo hold	.BEH/33/50	Position 33, 50 kg
BIG	Item loaded on two or more pallets	.BIG/11P12P/2650	2650 kg loaded on 11P + 12P
COM	Company mail	.COM/42L/216	216 kg loaded in 42L
CSU	Catering equipment not used for flight	.CSU/22R/500	500 kg loaded in 22R
DHC	Crew occupying pax seats (not on duty)	.DHC/0/2/5	2 seats in B class, 5 in Y class
DIP	Diplomatic Mail	.DIP/1/2	2 bags loaded in CPT1
EAT	Foodstuff for human consumption	.EAT/31R	Loaded in 31R
EIC	Miscellaneous items not included in DOW	.EIC/4/50	50 kg loaded in CPT4
FIL	Undeveloped Film/Unexposed film	.FIL/3	CPT3
FKT	Flight Kit	.FKT/53/450	450 kg loaded in section 53
HEA	Heavy cargo (above 150 kg per piece)	.HEA/2/216	216 kg loaded in CPT2
HEG	Hatching eggs	.HEG/32L	ULD position 32L
HUM	Human remains in Coffins	.HUM/42P/210	210 kg loaded in 42P
ICE	Carbon dioxide, Dry ice	.ICE/11R	Loaded in 11R
LHO	Live Human Organs/Blood	.LHO/2	Loaded in CPT2
MAG	Magnetized material	Not to be used	Not mentioned in LDM
MOS	Miscellaneous Operational Staff	.MOS/0/2/0	2 seats in B class
NIL	No item loaded		
OBX	Obnoxious deadload	.OBX/12P	Loaded in 12P
PAD	Passenger Available for Disembarkation	.PAD/0/1/5	1 seat in B class, 5 in Y class
PEA	Hunting trophies, skin, …	.PEA/2	Loaded in CPT2
PEF	Flowers	.PEF/4	
PEM	Meat	.PEM/11P	Loaded in 11P
PEP	Fruit and vegetables	.PEP/3	Loaded in CPT3
PER	Perishable goods	.PER/41P	Loaded in 41P
PES	Seafood/Fish for human consumption	.PES/1	Loaded in CPT1
R...	Dangerous goods	.RNG/31L	Loaded in 31L
RRY	Radioactive Category II and III	.RRY/41P/6PT4	Sum of Transport Indexes = 6.4
SOC	Seats occupied by baggage, cargo, mail	.SOC/6/12	6 seats in F/B class, 12 in Y class
VAL	Valuable cargo	Not to be used	
WET	Wet materials not packed in watertight	.WET/41R	Eg : fish packed in wet ice
XPS	Priority small package	.XPS/41P	

2. LOADING INSTRUCTION / REPORT (LIR)

2.1. Introduction

This form is a means of communication between the Load Planner and the Loading Supervisor. On the one hand, it allows the Load Planner to give loading and off-loading instructions to the Loading Supervisor, and on the other hand, it allows the Loading Supervisor to know everything about the shipment (nature, distribution, etc…) and to report the loading distribution is effectively performed.

The Loading Instruction / Report form (LIR), is prepared and filled in by the Load Planner once he knows how much load can be transported. To determine this data, the load planner needs information from :

- Passenger booking : to calculate the forecasted passenger weight and associated
- Baggage weight (number of containers required in case of CLS)
- Dispatch : to know what is the available payload according to the fuel required for the flight
- Incoming LDM/CPM : to know the cargo distribution and if there is transit cargo/mail in case of multi-sector flights
- Cargo department : to know if cargo is available for the flight
- Aircraft type : weight limitations, CG limitations, cargo options (ventilation, heating)

Once the load is known, the Load planner determines its distribution into the cargo holds, taking into account several constraints such as Zero Fuel CG position, weight limitations, loading/off-loading rules, incompatibilities, specific loading constraints (dangerous goods, live animals, perishable goods…).

LOADING OPERATIONS

2.2. Manual LIR

The layout of the LIR may vary with aircraft type or with airline, but for all of them, the following information is required, as stated in IATA AHM 515.

A - Heading: Station, Flight number, Aircraft registration, Destination(s), Local date, name of the Load Planner who prepared it.

B - Compartment number and Weight limitations: clearly indicates the weight limitations for each cargo hold.

C - Arrival (for multi-sector flights only): gives details about the incoming loads for intermediate stops. Cargo that must be off-loaded at the transit station may be encircled, but the loading agent knows what he must off-load, since the destination of each load is clearly indicated on the form. Information contained in this section is copied from the incoming CPM for aircraft equipped with ULDs, and from the incoming LDM for others.

D - Loading Instructions: Gives indications on where the load must be stowed, and of any change in the transit load position in case of multi-sector flights. In this case, the destination must be clearly indicated by the 3-letter IATA airport codes.

E - Loading reports: completed by the Loading Supervisor, it is used to confirm that the aircraft has been loaded in accordance with the given instructions. Information shown in this section reflects the exact state of the shipment loaded in the aircraft before departure. Any deviations from the original Loading Instructions must be noted or transmitted before the flight departure to the loadsheet agent.

F - Special instructions: gives any information that might be considered as important or useful by the Load Planner, such as dangerous goods, live animals, lashing of heavy items, relocation of some cargo to balance the aircraft, airway bill of dangerous goods…

G - Signatures: Two names and two signatures are required:
The Load planner who prepared the Loading Instructions
The Loading Supervisor, who performed the Loading, to confirm that the aircraft is loaded in accordance with the instructions or to advise of any deviations.

The Load Planner has to fill in the header part, the arrival part from the incoming LDM/CPM (in case of multi-sector flights) as well as the Loading Instructions part. To give its loading instructions, the load planner must use, for each hold section, the following items:
- the destination of the shipment (3-letter IATA code)
- the ULD type and ID code (for ULDs aircraft)
- the content of the section (Baggage, cargo, mail…) through a one letter code (as per AHM 510)
- the estimated weight of the load
- the nature of the shipment in case of special loading (as per AHM 510)
- the available volume in the section (as per AHM 510)

Manual LIR example

C. Operational Loading Documents

AIRBUS

Example :

41P	Hold section	41P
JFK/PAG 1234AI/ C/2480/AVI.PER	Destination	JFK
	Pallet ID	PAG 1234AI
	Content	C (Cargo)
	Weight	2480 kg
	Special load	AVI.PER (Live Animals + Perishable goods)
12L	Hold section	12L
JFK/F2	Destination	JFK
	Pallet ID	F (First class/priority baggage)
	Volume	2 (Half volume available

2.3. EDP LIR

Nowadays, integrated load control systems enable to prepare loading instructions and to visualize simultaneously the effect of the load on the center of gravity of the aircraft. To avoid reporting the load distribution on a manual LIR, a computerized "Loading Instruction / Report" form can be directly printed.

According to AHM 514, it is recommended to issue a Loading Instruction/report form for each departing flight. These reports must be signed by the persons responsible for loading and/or off-loading. Note that due to limited space, only the occupied ULD positions or hold sections may be shown.

In case of loads requiring special attention, AHM 514 recommends a "Summary of special loads" to be issued.

- **Example of an EDP LIR:**

A

```
CPT 1MAX 13380
: 12PPAG 2503AI
: ONLOAD:JFK    C /  1850
: SPECS:SEE SUMMARY
: REPORT:1850
```

Cpt capacity	:	13380 kg
Hold section	:	12P
Pallet ID	:	PAG 2503AI
Origin	:	CDG
Destination	:	JFK
Content	:	Cargo (1850 kg)
Special load	:	RFL (See summary : one piece, Airway Bill 034 99222)
Report	:	1850 kg (Actual weight reported by the loading supervisor)

B

```
CPT 2MAX 10206
: 21PPAG 5421AI
: TRANSIT:JFK    C /  3225
: SPECS:SEE SUMMARY
: REPORT:3225
```

Cpt capacity	:	10206 kg
Hold section	:	21P
Pallet ID	:	PAG 5421AI
Origin	:	(Transit in CDG)
Destination	:	JFK
Content	:	Cargo (3225 kg)
Special load	:	RRY (See summary : one piece, Transport Index 2, Airway Bill 055 235324)
Report	:	3225 kg (Actual weight reported by the loading supervisor)

C. Operational Loading Documents

AIRBUS

- **EDP LIR example**

```
LOADING INSTRUCTION/REPORT              PREPARED BY     Jones              EDNO
ALL WEIGHTS IN KILOS                                                       01
FROM /   TO        FLIGHT   A/C REG   VERSION    GATE     TARMAC   DATE      TIME
CDG      JFK       AI0533   OOTPA     C18/Y264   B40      H10      30DEC00   1405
PLANNED JOINING LOAD
JFK      F  0      C 16     Y204      C 10785    M    0   B  4300
JOINING SPECS : SEE SUMMARY
TRANSIT SPECS: SEE SUMMARY
LOADING INSTRUCTIONS
*****************************************************************************************************
CPT 1     MAX  13380                                                       :
: 12P         PAG2503AI        A                                           :
: ONLOAD:     JFK    C / 1850                                              :
: SPECS:      SEE SUMMARY                                                  :
: REPORT:     1850                                                         :
.................................................................................................:
: 13P         PAG3251AI                                                    :
: ONLOAD:     JFK    C / 1980                                             :.....................
REPORT:       1980                               CPT 1 TOTAL    :          3 830
*****************************************************************************************************
CPT 2     MAX  10206                                                       :
: 21P         PAG5421AI        B                                           :
: TRANSIT:    JFK    C / 3225                                              :
: SPECS:      SEE SUMMARY                                                  :
: REPORT:     3225                                                         :
.................................................................................................:
: 22P         PAG4521AI                                                    :
: TRANSIT     JFK    C / 3730                                             :.....................
REPORT:       3730                               CPT 2 TOTAL    :          6 955
*****************************************************************************************************
CPT 4     MAX  10206                                                       :
: 41L     AKE1245AI          : 41R      AKE4567AI                          :
: ONLOAD:  JFK   B / 810     : ONLOAD:  JFK   B / 810                      :
: REPORT:  800               : REPORT:  800                               :
.................................................................................................:
: 42L     AKE4561AI          : 42R      AKE8424AI                          :
: ONLOAD:  JFK   B / 810     : ONLOAD:  JFK   B / 810                      :
: REPORT:  750               : REPORT:  750                               :
.................................................................................................:
: 43L     AKE5624AI          : 43R      AKE4093AI                          :
: ONLOAD:  JFK   B / 810     : ONLOAD:  JFK   F / 480                     :.....................
: REPORT:  800               : REPORT:  400         CPT 2 TOTAL   :        4300
*****************************************************************************************************
: SI


THIS AIRCRAFT HAS BEEN LOADED IN ACCORDANCE WITH THESE INSTRUCTIONS AND THE DEVIATIONS
SHOWN ON THIS REPORT. THE CONTAINERS / PALLETS AND BULKLOAD HAVE BEEN SECURED IN
ACCORDANCE WITH COMPANY INSTRUCTIONS.

                                        SIGNATURE
                                        JONES
```

Italic characters represent the loading supervisor inputs

- **"Summary of special loads" - Example**

FROM / CDG	TO JFK	FLIGHT AI0533	A/C REG OOTPA	VERSION C18/Y264	GATE B40	TARMAC H10	DATE 30DEC00	TIME 1405
LOCN	JOIN/ TRAN	DEST	CAT	IMP	PCS	WEIGHT	TI	AWB
******	******	******	******	******	******	******	******	******
12P	JOIN	JFK	C	RFL	1			034 99222
....	....	....	....	....	....	....	....	....
21P	TRAN	JFK	C	RRY	1		Opt 2	055 234324
******	******	******	******	******	******	******	******	******
SI …..								

3. CONTAINER/PALLET DISTRIBUTION MESSAGE (CPM)

The Container/Pallet distribution message only concerns aircraft equipped with Unit Load Devices (ULDs). This message shall provide the type and the distribution of the ULDs, their destination (for multi-sector flights), as well as their weight and content.

It is not requested to send a loadmessage on a single leg flight or on the last leg of a multi-sector flight. Nevertheless, most of the carriers systematically send CPMs as it enables the destination station to prepare the adequate equipment and manpower for handling containers and pallets.

A need exists for an automatic readable format for the CPM. Indeed, this can allow both automatic transmission and reading of any CPM, as well as automatic distribution of ULDs by EDP systems.

IATA AHM 587 gives information about the standard format of the Container/Pallet distribution message. The codes used for the CPM come from IATA AHM 510. All the ULD positions, including those not occupied by an ULD, must be shown on the message. The message is composed of four parts:
- 1- Teletype addresses and communication reference
- 2- Standard message identifier and flight record
- 3- Distribution and load information
- 4- Supplementary information

C. Operational Loading Documents

AIRBUS

	CPM example
①	QU JFKKLAI JFKKKAI CDGKKAI .CDGKLAI AI/301505
②	CPM AI533/30.OOTPA.C18/Y264
③	-11L/X-11R/X -12P/JFK/1850/C.RRY/1PT5 -13P/JFK/1980/C.FIL -21P/JFK/3225/C.PER -22P/JFK/3730/C -31P/N -32P/N -41L/JFK/800/B0-41R/JFK/800/B0 -42L/JFK/750/B1-42R/JFK/750/H/TB1 -43L/JFK/800/B1-43R/JFK/400/F3
④	SI -42R/UA256/PIT/TB

①

QU	**JFKKLAI**	**JFKKKAI**	**CDGKKAI**
Priority (urgent)	Address 1	Address 2	Address 3
.CDGKLAI	**AI/301505**		
Originator	Facilit / y	D / at e	Time
	AI /	30 /	15h05

②

CPM (Message identifier)		
AI533/30	**.OOTPA**	**.C18/Y264**
Flight number/date	Aircraft registration	Aircraft configuration

③

-11L/X-11R/X
Empty ULD in position 11L – Empty ULD in position 11R
-12P/JFK/1850/C.RRY/1PT5
ULD position 12P, destination JFK, weighing 1850 kg, cargo load containing radioactive materials whose sum of Transport Indexes is equal to 1.5
-31P/N
Position 31P empty (No ULD)
-42L/JFK/750/B1
ULD position 42L, destination JFK, weighing 750 kg, containing baggage, ¼ volume available
-42R/JFK/750/H/TB1
ULD position 42R, destination JFK, weighing 750 kg, containing a load to be transferred to a connecting flight (destination or flight number indicated in SI), transfer baggage, ¼ volume available

④

SI (Supplementary Information)
–42R/UA256/PIT/TB
ULD position 42R, connecting flight UA256 to PIT, baggage to be transferred onto this flight

4. LOADSHEET

4.1. Introduction

The loadsheet is a document prepared and signed by the loadsheet agent at the departure airport. This form gives information about the weight of the aircraft as well as the distribution of the load in the different cargo holds. In case of multi-sector flights, the weight that must be unloaded at the different stations is indicated.

The loadsheet allows to check, before each departure, that the weight of the shipment is consistent with the structural limitations of the aircraft. The loadsheet must reflect the actual state of the aircraft before takeoff. It is often necessary to adjust it after completion to take into account "Last Minutes Changes" (LMC).

The loadsheet must be issued in not more than four-fold, distributed as follows:
- – one copy for the aircraft
- – one copy for the departure station file
- – one or two copies for the carrier, if required

Airlines often use their own loadsheet format. Nevertheless, IATA AHM 516 gives recommendations about the kind of information that must appear on a loadsheet, which can be manual or computerized (EDP loadsheet).

4.2. Manual loadsheet

- **Manual Loadsheet example**

A : Addresses and heading

1 - Priority code (QU = urgent, QD = Standard)
2 - Teletype **address for loadmessage** as required (XXXYYZZ)
    . XXX : destination airport (3 letters IATA code)
    . YY : destination department. As an example:
        . eg KL (K= Operations department, L = Load control department)
        . eg KK (K = Operations department, K = Station manager)
    . ZZ: code of the company (airline code or XH for external handling companies)
3 - Teletype **address of originator** (XXXYYZZ)
4 - Recharge facility/Date/Time : eg AF/251005
    . Recharge facility : AF
    . Date : 25
    . Time : 10h05 AM
5 - Operators initial
6 - Standard message indicator (LDM for loadmessage)
7 - Flight number/identifier : eg SN551/25
    . Flight number : SN551
    . Identifier : 25 (date as an example)
8 - Aircraft registration
9 - Version code of the aircraft used : eg C42Y218
    . C42 : 42 business seats
    . Y218 : 218 economic seats
10 - Number of **cockpit crew / cabin crew** : eg 2/9 or 2/2/7
        . 2/9 : 2 cockpit crew + 9 cabin crew
        . 2/2/7 : 2 cockpit crew + 2 cabin crew male + 7 cabin crew female

B : Operating weight calculation

1 - Dry Operating Weight = Basic weight + Crew + Pantry
2 - Takeoff fuel from fuelling order
3 - Operating weight = Dry operating weight + Takeoff fuel

C : Allowed traffic load calculation

1 - MZFW = Certified Maximum Zero Fuel Weight
2 - MTOW = Certified Maximum TakeOff Weight
3 - MLW = Certified Maximum Landing Weight
4 - Trip fuel from dispatch
5 - Allowed weight for takeoff = Lowest of (MZFW+Takeoff Fuel), MTOW, (MLW+Trip Fuel)
6 - Allowed traffic load = Allowed weight for takeoff (C5) - Operating weight (B3)

LOADING OPERATIONS

D : Load information per destination and totals

This section provides information about the number of passengers as well as on the deadload (weight and distribution) for each destination of the flight.

1 - Destination airports (several in case of multi-sector flights)
2 - Number of **passengers in transit** and continuing to the next destination airport (Males, Adults/Females, Children, Infants, Total cabin baggage weight[1])
3 - Number of **passengers joining at this airport** (Males, Adults/Females, Children, Infants, Cabin baggage[1])
4 - Total **weight of deadload** (Tr: deadload in transit, B: joining baggage, C: joining cargo, M: joining mail)
5 - Weight distribution per cargo hold and per type (Tr, B, C, M)
6 - Total number of seats occupied by outgoing passengers per class, including PADs (Passengers Available for Disembarkation: no firm booking, low priority)
7 - Total number of seats occupied by outgoing PADs per class
8 - Additional remark as per IATA AHM 510 recommendations (HEA, AVI, RRY, RFL, HUM…)
9 - Number of outgoing passengers and outgoing deadload per destination
10 - Total number of outgoing passengers and outgoing deadload

[1] When not included in passenger weight

E : Actual gross weight calculation

1 - Total Traffic Load = Total outgoing deadload (D10) + Total cabin baggage weight[1] (D10) + Total outgoing passenger number (D10) x passenger weight[2]
2 - ZFW = Total traffic Load (E1) + Dry operating weight (B1)
3 - TOW = ZFW (E2) + Takeoff fuel (B2)
4 - LW = TOW (E3) - Trip fuel (C4)
5 - Underload before LMC[3] = Allowed traffic load (C6) – Total traffic load (E1)

[1] Irrelevant when cabin baggage weight is included in the passenger weight
[2] Passenger weight with or without baggage weight (company policy)
[3] The underload before LMC represents the extra weight that can be added at the last minute, while structural limitations are still respected.

F : Last minutes changes (LMC)

As the loadsheet must reflect the actual loaded state of the aircraft before departure, it is often necessary to adjust it after completion. This is the aim of Last Minute Changes (LMC).
Generally, only changes in the weight or distribution of the traffic load (passengers, baggage, cargo and mail) should be mentioned in the LMC box. Nevertheless, any deviation of the DOW conditions could be added as well.

  1 - **Dest :** Destination of LMC
  2 - **Specification :** Kind of LMC (number of passengers, weight of deadload)
  3 - **Cpt:** Cabin section or cargo compartment in which the LMC is added
  4 - **+/-:** Indication of on or off-load
  5 - **Weight :** Weight increment or decrement for the specific LMC
  6 - **LMC Total +/- :** Sum of all LMC weights (on or off-load)

The total weight increase due to LMC (F6) must not exceed the underload before LMC (E5). No subsequent corrections are to be made to the previously calculated ZFW (E2), TOW (E3) and LW (E4), provided the weight increment remains below a pre-determined tolerance. This tolerance should be established per aircraft type (company policy). When the tolerance is exceeded, a new loadsheet must be issued.

G : Supplementary information and notes

  1 - **SI**: supplementary information transmitted with LDM (free format)
  2 - **Notes**: Information not transmitted with LDM
  3 - **Balance condition**: balance conditions according to carriers requirement (MACZFW, MACTOW,…) as per AHM 050.
  4 - **Seating conditions**: according to carrier requirement
  5 - **Total passengers**: Total number of passengers on board (including LMC)
  6 - **Prepared by**: Loadsheet agent's signature
  7 - **Approved by**: Captain's signature

AIRBUS

4.3. EDP Loadsheet

With computerized Load control systems, cargo, mail and passenger boarding information are interconnected. EDP loadsheets can be issued very quickly at the last minute, generally besides the aircraft. That's why it is advisable to adjust passenger and load figures before the final version is printed or sent to the aircraft. This enables to avoid Last Minute Changes on the loadsheet.
According to IATA AHM 517, an EDP loadsheet must look like the following example:

- **EDP loadsheet example**

```
LOADSHEET              CHECKED         APPROVED                   EDNO
ALL WEIGHTS IN KILOS                                              02

FROM/TO       FLIGHT    A/C REG    VERSION      CREW        DATE       TIME
CDG   JFK     AI0533    OOTPA      C18Y264      2/9         30DEC00    1405

                         WEIGHT        DISTRIBUTION
LOAD IN COMPARTMENTS     10785         1/3830 2/6955 4/4300        A

PASSENGER/CABIN BAG      16905     190/ 27/ 3     TTL 220      CAB
                         PAX CY  16/204          SOC           B
                                                 BLKD


***********************************************************************************************************
TOTAL TRAFFIC LOAD              27690
DRY OPERATING WEIGHT            123250
ZERO FUEL WEIGHT               150940     MAX    168000
TAKE OFF FUEL                   65500
TAKE OFF WEIGHT ACTUAL         216440     MAX    230000
TRIP FUEL                       58600
LANDING WEIGHT ACTUAL          157840     MAX    180000

   BALANCE AND SEATING CONDITIONS           LAST MINUTE CHANGES
      According to carrier requirement     DEST   SPEC   CL/CPT   WEIGHT
   (Refer to "Balance calculation methods")


UNDERLOAD BEFORE LMC            13560            LMC TOTAL
***********************************************************************************************************
CAPTAIN INFORMATION/NOTES
.....
LOAD MESSAGE BEFORE LMC
.....
END LOADSHEET EDNO 02  AI0533   30DEC00   140535
```

Deadload information		**Passenger information**	
Cargo 1	: 3830 kg	Adult : 190 / Children : 27 / Infant : 3	
Cargo 2	: 6955 kg	Business class (C)	: 16 pax
Cargo 4	: 4300 kg	Economic class (Y)	: 204 pax
Total	: 10785 kg	Total number	: 220 pax
		Total weight	: 16905 kg

4.4. ACARS loadsheet

The ACARS loadsheet format is designed to provide only essential data. According to IATA AHM 518, the loadsheet must be headed "Prelim" or "Final" to prevent from any confusion. When the ACARS loadsheet is generated by an EDP system, this system must ensure that only one final loadsheet will be transmitted.

The transmission by the loadsheet agent must be done at a time that ensures that no further adjustments will be necessary. It is recommended to get the acknowledgement from the cockpit crew. After transmission of the final loadsheet, any correction should be done verbally.

A copy of the final loadsheet must be printed on ground, signed by the loadsheet agent and stored in the flight's file.

- **ACARS loadsheet example**

```
LOADSHEET FINAL 1505
AI05333/30  30DEC00
CDG  JFK  OOTPA  2/9
ZFW 150940     MAX 168000
TOF 65500
TOW 216440     MAX 230000
TIF 58600
LAW 157840     MAX 180000
UNDLD 13560
PAX /0/16/204     TTL220
```

BALANCE AND SEATING
CONDITIONS
According to carrier requirement
(Refer to "Balance calculation
methods")

```
SI
..
ENDAI0533
```

ACARS loadsheet status	: Final
Sent at	: 15h05
Flight Number/Day	: AI0533/30
Date	: 30 DEC 2000
Departure	: CDG
Arrival	: JFK
A/C Registration	: OOTPA
Crew	: 2 cockpit / 9 cabin
Zero Fuel Weight	: 150940 kg
Max Zero Fuel Weight	: 168000 kg
Take Off Fuel	: 65500 kg
Take Off Weight	: 216440 kg
Max Take Off Weight	: 230000 kg
Trip Fuel	: 58600 kg
Landing weight	: 157840 kg
Max Landing Weight	: 180000 kg
Underload	: 13560 kg
Passengers per class	: 16 B / 204 Y
Total number of pax	: 220
SI	: Supplementary Information

5. BALANCE CALCULATION METHODS

5.1. Introduction

It is necessary to determine, before takeoff, the center of gravity position of the aircraft. The main reason is the flight safety. Indeed, it is necessary to ensure that the aircraft CG will remain within pre-determined limits during the whole flight. Another reason is an operational reason: the crew must be able to correctly trim the aircraft for takeoff by selecting the appropriate THS (Trimmable Horizontal Stabilizer) angle, directly deduced from the center of gravity position of the aircraft.

An aircraft is a combination of several items that have a particular weight and a particular location. Different methods are available to determine the influence of each item on the aircraft balance:

1 Manual method : Balance chart / Balance table
2 EDP method

5.2. Manual balance calculation method

5.2.1. Balance chart

- **Balance chart example**

AIRBUS

LOAD and TRIM SHEET

(A) A330-243
VERSION : 18 BC-264 YC

(H) DRY OPERATING WEIGHT CONDITIONS

WEIGHT (kg)	H-arm (m)

$$I = \frac{(H\text{-arm} - 33.1555) \times W}{2500} + 100$$

DRY OPERATING WEIGHT INDEX

AIRCRAFT REGISTER :

DATE :

PREPARED BY :

FLT Nbr :

CAPT. SIGNATURE :

FROM :

TO :

(J)

DRY OPERATING WEIGHT	
WEIGHT DEVIATION (PANTRY)	
CORRECTED DRY OPERATING WEIGHT	
CARGO	
PASSENGERS	x 84 m
ZERO FUEL WEIGHT	
TOTAL FUEL ONBOARD	
TAKEOFF WEIGHT	

(I)

ZONES	E	F	G	H
WEIGHT DEVIATION (kg)				

BASIC INDEX CORRECTION

DRY OPERAT. WEIGHT DEVIATION	ZONES			
	E	F	G	H
+100 kg	-0.86	-0.55	+0.81	
-100 kg	+0.86	+0.55	-0.81	

INDEX CORRECTION

(B) INDEX CORRECTION ZONES

(C) CORRECTED INDEX — ALL WEIGHTS IN KILOGRAMS

(D)

ZONES	Nbr	WEIGHT(kg)	
CARGO 1			500 kg
CARGO 2			500 kg
CARGO 3			500 kg
CARGO 4			500 kg
CARGO 5			250 kg
CABIN OA			10 PAX
CABIN OB			30 PAX
CABIN OC			10 PAX

(F) FUEL INDEX — SEE TABLE OVERLEAF — INDEX +

(E)

MTOW = 233000 kg
MLW = 182000 kg
MZFW = 170000 kg

OPERATIONAL LIMITS
---- TAKEOFF
—— ZFW

(G)

TAKEOFF	
CG % MAC	

ZPW CDU INPUT

WEIGHT (kg x 1000)	AIRCRAFT CG % MAC

(K)

%MAC — PITCH TRIM — Constant ... Constant
Nose Up ... Nose Down

C. Operational Loading Documents

- **Fuel index table example**

IATA AHM 519 gives information about the kind of information that must appear on a balance chart:

A – The type of aircraft and version

B – A drawing of the aircraft layout showing : . The passenger cabin section . The position and numbering of holds and compartments

C – Index units as the first scale

D – For each compartment or cabin section : . Vertical or sloping lines corresponding to index variations . Arrows indicating direction and value of each pitch

E – A balance diagram with shaded areas outside the forward and aft balance limits

F – The influence of fuel on weight and balance. It can be provided on a separate fuel index table

G – Final ZFW and TOW CG values in percentage of the Mean Aerodynamic Chord (%MAC).

Other optional information may appear on the balance chart, according to carriers requirements:

H – Index formula for DOW Index calculation[1]

I – Weight deviations in galley zones and effect on balance

J – Weight information[2]

K– Pitch Trim scale for THS setting

[1] *For a given aircraft, it's possible to start the balance calculation from the Dry Operating Index (DOI) or from the combination DOW / DOW H-arm. Thus, the index formula is only required for the second case.*

[2] *When this information appears on the balance chart, this one can be called a "Load and Trim sheet"*

- **Numerical example:**

DOW conditions: Weight : 123 500 kg
                H-arm : 33.378 m

⇐ Data coming from the weighing report (refer to WBM)

Weight deviations :   Zone E   : +150 kg
               Zone F: +150 kg
               Zone G   : +200 kg

⇐ Pantry adjustment in the galley zones if not included in DOW

Cargo distribution :   Cargo 1   : 3 500 kg
               Cargo 2   : 4 000 kg
               Cargo 3   : 7 000 kg
               Cargo 4   : 5 500 kg
               Cargo 5   :   750 kg

⇐ Deadload distribution in the cargo holds

Pax distribution :   Cabin OA   : 15 pax
             Cabin OB   : 120 pax
             Cabin OC   : 105 pax
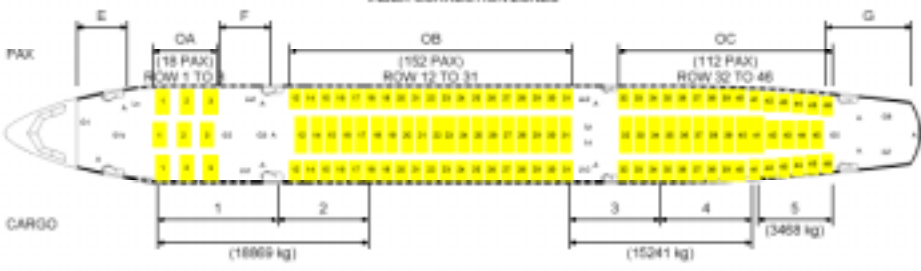
⇐ Passengers distribution in the cabin sections

Fuel data :   Takeoff fuel   : 54 000 kg
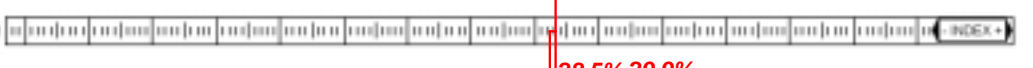   Fuel density : 0.79 kg/l

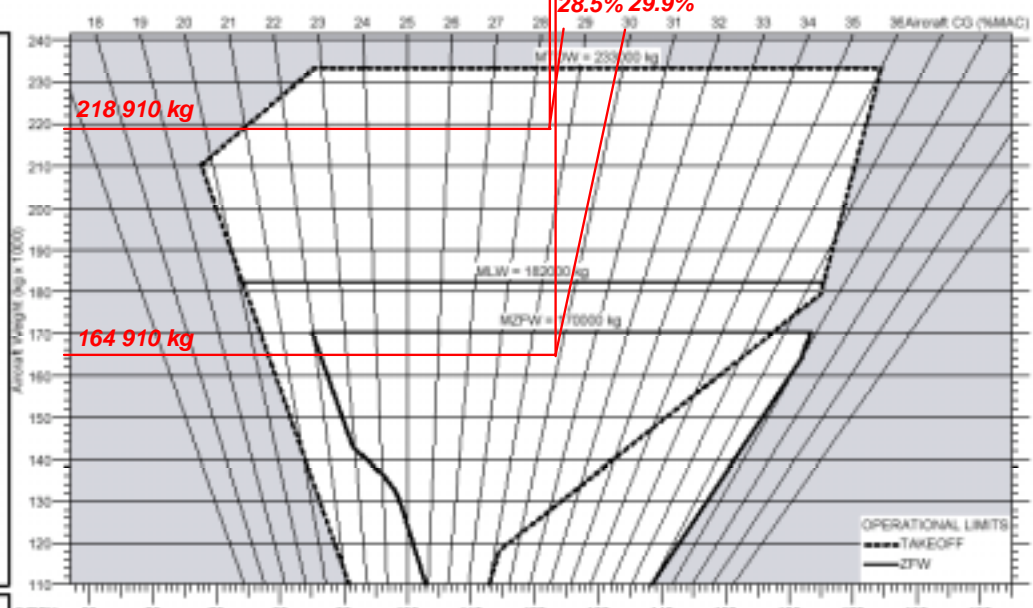⇐ Fuel on board at takeoff and fuel density

C. Operational Loading Documents

AIRBUS | LOAD and TRIM SHEET | A330-243 VERSION : 18 BC-264 YC

DRY OPERATING WEIGHT CONDITIONS	
WEIGHT (kg)	H-arm (m)
123 500	**33.378**

$$I = \frac{(H\text{-}arm - 33.1550) \times W}{2500} + 100$$

DRY OPERATING WEIGHT INDEX	**105.5**

AIRCRAFT REGISTER :

DATE : **12 FEB 2001** — PREPARED BY : **Jones**

FLT Nbr : **AI523** — CAPT. SIGNATURE : *Jones*

FROM : **CDG** — TO : **JFK**

DRY OPERATING WEIGHT		**123 500 kg**
WEIGHT DEVIATION (PANTRY)	+	**500 kg**
CORRECTED DRY OPERATING WEIGHT	=	**124 000 kg**
CARGO	+	**20 750 kg**
PASSENGERS	**2 4 0** x **8 4** = +	**20 160 kg**
ZERO FUEL WEIGHT	=	**164 910 kg**
TOTAL FUEL ONBOARD	+	**54 000 kg**
TAKEOFF WEIGHT	=	**218 910 kg**

ZONES	E	F	G	H
WEIGHT DEVIATION (kg)	**+150**	**+150**	**+200**	

BASIC INDEX CORRECTION

DRY OPERAT. WEIGHT DEVIATION	ZONES			
	E	F	G	H
+100 kg	-0.86	-0.55	+0.81	
-100 kg	+0.86	+0.55	-0.81	

INDEX CORRECTION	**-0.247**

CORRECTED INDEX | **105.2**

INDEX CORRECTION ZONES

ALL WEIGHTS IN KILOGRAMS

ZONES	Nbr	WEIGHT(kg)	
CARGO 1		**3500**	500 kg
CARGO 2		**4000**	500 kg
CARGO 3		**7000**	500 kg
CARGO 4		**5500**	500 kg
CARGO 5		**750**	250 kg
CABIN OA	**15**		10 PAX
CABIN OB	**120**		30 PAX
CABIN OC	**105**		10 PAX

FUEL INDEX	**- 1**

SEE TABLE OVERLEAF

28.5% 29.9%

NOTES

218 910 kg

164 910 kg

TAKEOFF	
CG % MAC	**2 8 . 5**

ZFW CDU INPUT	
WEIGHT (kg x 1000)	AIRCRAFT CG % MAC
1 6 4 . 9	**2 9 . 9**

28.5 %

3.25° UP

5.2.2. Balance table

a) Standard balance table

In a balance table, the index corrections due to a load in a cargo compartment or passengers in a cabin section are indicated thanks to tables, instead of graphical scales as in a balance chart. The user has to start from the DOW Index and then add or subtract the different index corrections to get the ZFW Index.

IATA AHM 519 gives information about the kind of information that must appear on a balance table (refer to next page):

A – The type of aircraft and version

B – A drawing of the aircraft layout showing :   . The passenger cabin section   . The position and numbering of holds and compartments

C – Tabulated index corrections for each passenger cabin section

D – Tabulated index corrections for each cargo compartment

E – A balance diagram with shaded areas outside the forward and aft balance limits

F – A balance diagram with shaded areas outside the forward and aft balance limits

G – The influence of fuel on weight and balance. It can be provided on a separate fuel index table (identical to the one used with a balance chart)

H – Final ZFW and TOW CG values in percentage of the Mean Aerodynamic Chord (%MAC).

I – Index formula for DOW Index calculation

As for the balance chart, optional information may appear on the balance table according to carriers requirements, such as the Index formula for DOW Index calculation (I).

- **Numerical example**

DOI   : 105
CPT2 : 4000 kg
CAB ZONE C : 105 pax

ZFW Index   : 105 – 8 + 19 = 116

COMPT. 2	
WEIGHT	INDEX (–)
0 to 263	0
264 to 790	-1
791 to 1317	-2
1318 to 1844	-3
1845 to 2372	-4
2373 to 2899	-5
2900 to 3426	-6
3427 to 3953	-7
3954 to 4480	-8
4481 to 5007	-9
5008 to 5534	-10
5535 to 6061	-11
6062 to 6589	-12
6590 to 7116	-13
7117 to 7643	-14
7644 to 8170	-15
8171 to 8697	-16
8698 to 9224	-17
9225 to 9751	-18
9752 to 10206	-19

TOTAL NUMBER OF PAX ZONE C	INDEX CORR. (+)
Up to 2	0
3 to 8	1
9 to 13	2
14 to 19	3
20 to 24	4
25 to 30	5
31 to 35	6
36 to 41	7
42 to 46	8
47 to 52	9
53 to 57	10
58 to 62	11
63 to 68	12
69 to 73	13
74 to 79	14
80 to 84	15
85 to 90	16
91 to 95	17
96 to 101	18
102 to 106	19
107 to 111	20

- **Balance table example**

A — TRIM SHEET AIRBUS A330

B — VERSION 30B – 251Y

ZONE A
Row 1 to 5
(30 seats)

ZONE B
Row 6 to 24
(140 seats)

ZONE C
Row 25 to 39
(111 seats)

COMPT 1 COMPT 2 COMPT 3 COMPT 4 COMPT 5

B INDEX EQUATION

$$I = \frac{(H\text{-arm} - 33.1555) \times W}{5000} + 100$$

With:

I = Index
W = Weight in Kg
H-arm = Horizontal arm in m

I
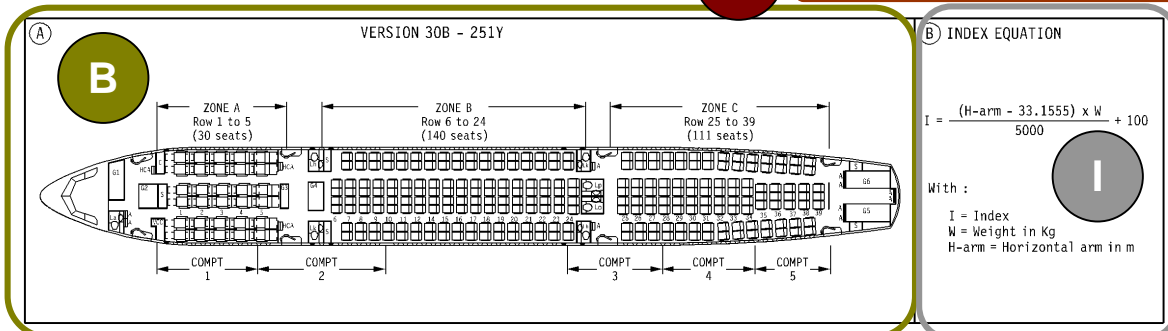
C PASSENGERS

TOTAL NUMBER OF PAX ZONE A	INDEX CORR. (-)	TOTAL NUMBER OF PAX ZONE C	INDEX CORR. (+)
Up to 2	0	Up to 2	0
3 to 6	1	3 to 8	1
7 to 10	2	9 to 13	2
11 to 14	3	14 to 19	3
15 to 18	4	20 to 24	4
19 to 22	5	25 to 30	5
23 to 26	6	31 to 35	6
27 to 30	7	36 to 41	7
		42 to 46	8
		47 to 52	9
		53 to 57	10
		58 to 62	11
TOTAL NUMBER OF PAX ZONE B	**INDEX CORR. (-)**	63 to 68	12
		69 to 73	13
Up to 13	0	74 to 79	14
14 to 39	1	80 to 84	15
40 to 65	2	85 to 90	16
66 to 91	3	91 to 95	17
92 to 117	4	96 to 101	18
118 to 140	5	102 to 106	19
		107 to 111	20

C

D LOAD IN LOWER COMPARTMENTS - UCRC NOT INSTALLED.

COMPT. 1 WEIGHT	INDEX (-)
0 to 164	0
165 to 492	-1
493 to 820	-2
821 to 1148	-3
1149 to 1477	-4
1478 to 1805	-5
1806 to 2133	-6
2134 to 2462	-7
2463 to 2790	-8
2791 to 3118	-9
3119 to 3446	-10
3447 to 3775	-11
3776 to 4103	-12
4104 to 4431	-13
4432 to 4759	-14
4760 to 5088	-15
5089 to 5416	-16
5417 to 5744	-17
5745 to 6072	-18
6073 to 6401	-19
6402 to 6729	-20
6730 to 7057	-21
7058 to 7386	-22
7387 to 7714	-23
7715 to 8042	-24
8043 to 8370	-25
8371 to 8699	-26
8700 to 9027	-27
9028 to 9355	-28
9356 to 9683	-29
9684 to 10012	-30
10013 to 10340	-31
10341 to 10668	-32
10669 to 10996	-33
10997 to 11325	-34
11326 to 11653	-35
11654 to 11981	-36
11982 to 12310	-37
12311 to 12638	-38
12639 to 12696	-39

COMPT. 2 WEIGHT	INDEX (-)
0 to 263	0
264 to 790	-1
791 to 1317	-2
1318 to 1844	-3
1845 to 2372	-4
2373 to 2899	-5
2900 to 3426	-6
3427 to 3953	-7
3954 to 4480	-8
4481 to 5007	-9
5008 to 5534	-10
5535 to 6061	-11
6062 to 6589	-12
6590 to 7116	-13
7117 to 7643	-14
7644 to 8170	-15
8171 to 8697	-16
8698 to 9224	-17
9225 to 9751	-18
9752 to 10206	-19

COMPT. 3 WEIGHT	INDEX (+)
Up to 411	0
412 to 1235	1
1236 to 2059	2
2060 to 2883	3
2884 to 3707	4
3708 to 4530	5
4531 to 5354	6
5355 to 6178	7
6179 to 7002	8
7003 to 7826	9
7827 to 8649	10
8650 to 9473	11
9474 to 10206	12

COMPT. 4 WEIGHT	INDEX (+)
Up to 274	0
275 to 823	1
824 to 1372	2
1373 to 1921	3
1922 to 2470	4
2471 to 3019	5
3020 to 3568	6
3569 to 4117	7
4118 to 4665	8
4666 to 5214	9
5215 to 5763	10
5764 to 6312	11
6313 to 6861	12
6862 to 7410	13
7411 to 7959	14
7960 to 8508	15
8509 to 9057	16
9058 to 9606	17
9607 to 10155	18
10156 to 10206	19

COMPT. 5 WEIGHT	INDEX (+)
Up to 158	0
159 to 475	1
476 to 793	2
794 to 1110	3
1111 to 1427	4
1428 to 1744	5
1745 to 2061	6
2062 to 2379	7
2380 to 2696	8
2697 to 3013	9
3014 to 3330	10
3331 to 3468	11

D

E INDEX CALCULATION TABLE

		-	+		-	+
DOI						
OPERATIONAL ITEMS	CREW					
	PANTRY					
	OTHERS					
ADJ. DOI						
PASSENGER ZONES	OA					
	OB					
	OC					
CARGO & BAGGAGE	CPT1					
	CPT2					
	CPT3					
	CPT4					
	CPT5					
TOTAL						

LIZFW

FUEL INDEX (+/-)

LITOW

MACZF %

MACTO %

E

G

H

F BALANCE DIAGRAM

MTOW = 230 000 Kg
%MAC 25 30 35
MLW = 180 000 Kg
MZFW = 168 000 Kg
ZFW OPERATIONAL LIMITS
TAKEOFF OPERATIONAL LIMIT
AIRCRAFT WEIGHT (Kg x 1000)
INDEX

F

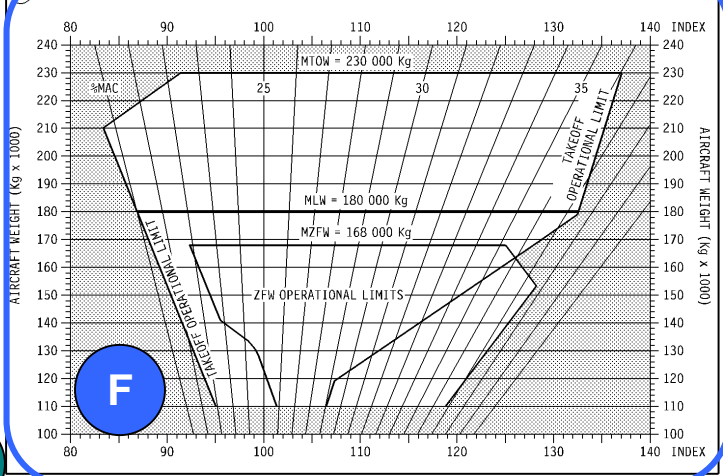## b) Balance table with complement of 1000

To avoid negative index corrections that could be a source of mistake, carriers sometimes prefer to use a balance table with complement of 1000. In this case, index corrections are always positive. As an example, instead of –3, the index correction would be 997 (1000-3).

- **Complement of 1000 - example**
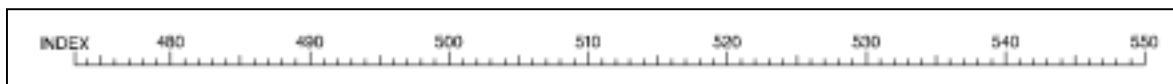

- **Numerical example**

DOI   : 510
CPT 1 : 2000 kg
CPT 4 : 1500 kg
CPT 5 : 300 kg

CAB OA   : 4 pax
CAB OB   : 7 pax
CAB OC   : 10 pax

ZFW Index   : 2,514.2

The thousands figure is suppressed to obtain a final ZFW Index (514.2) consistent with the index scale.

5.3. EDP balance calculation methods

The balance information shall be printed on EDP loadsheet or ACARS loadsheet in a specific box called "Balance and seating condition" according to the carrier requirement as per AHM 560. The system should be able to check the weight and balance limitations, and forbid the print out of the loadsheet when the limits are exceeded.

- **Balance information on an EDP loadsheet – Example**

```
LOADSHEET              CHECKED        APPROVED              EDNO
ALL WEIGHTS IN KILOS                                        02

FROM/TO     FLIGHT     A/C REG    VERSION     CREW      DATE       TIME
CDG   JFK   AI0533     OOTPA      C18Y264     2/9       30DEC00    1405

                            WEIGHT       DISTRIBUTION
LOAD IN COMPARTMENTS         10785       1/3830 2/6955 4/4300

PASSENGER/CABIN BAG          16905      190/ 27/ 3   TTL 220     CAB
                           PAX CY  16/204           SOC
                                                    BLKD
*************************************************************************
TOTAL TRAFFIC LOAD              27690
DRY OPERATING WEIGHT           123250
ZERO FUEL WEIGHT               150940        BALANCE INFORMATION
TAKE OFF FUEL                   65500             (AHM 050)
TAKE OFF WEIGHT ACTUAL         216440
TRIP FUEL                       58600      DOW Index    : 105
LANDING WEIGHT ACTUAL          157840      ZFW Index    : 118
                                           TOW Index    : 117
BALANCE AND SEATING CONDITIONS             ZFW CG       : 32.8% MAC
DOI  105      LIZFW  118                    TOW CG       : 30.5% MAC
LITOW  117    MACZFW  32.8           ⇐     THS setting  : 2.2° NOSE UP
MACTOW   30.5                               Fuel density : 0.79 kg/liter
STAB TO  2.2  NOSE UP                       Cabin OA     : 16 pax
BASED ON FUEL DENSITY .790 KG/LTR          Cabin OB     : 120 pax
A16.B120.C84                                Cabin OC     : 84 pax
CABIN AREA TRIM

UNDERLOAD BEFORE LMC            13560
*************************************************************
```

- **Balance information on an ACARS loadsheet - Example**

```
LOADSHEET FINAL 1505
AI05333/30  30DEC00
CDG  JFK  OOTPA  2/9
ZFW 150940    MAX 168000
TOF 65500
TOW 216440    MAX 230000
TIF 58600
LAW 157840    MAX 180000
UNDLD 13560
PAX /0/16/204  TTL220
LIZFW  118
LITOW  117  MACZFW  32.8
MACTOW  30.5
ENDAI0533
```

```
BALANCE INFORMATION
       (AHM 050)

ZFW Index    : 118
TOW Index    : 117
ZFW CG       : 32.8% MAC
TOW CG       : 30.5% MAC
```