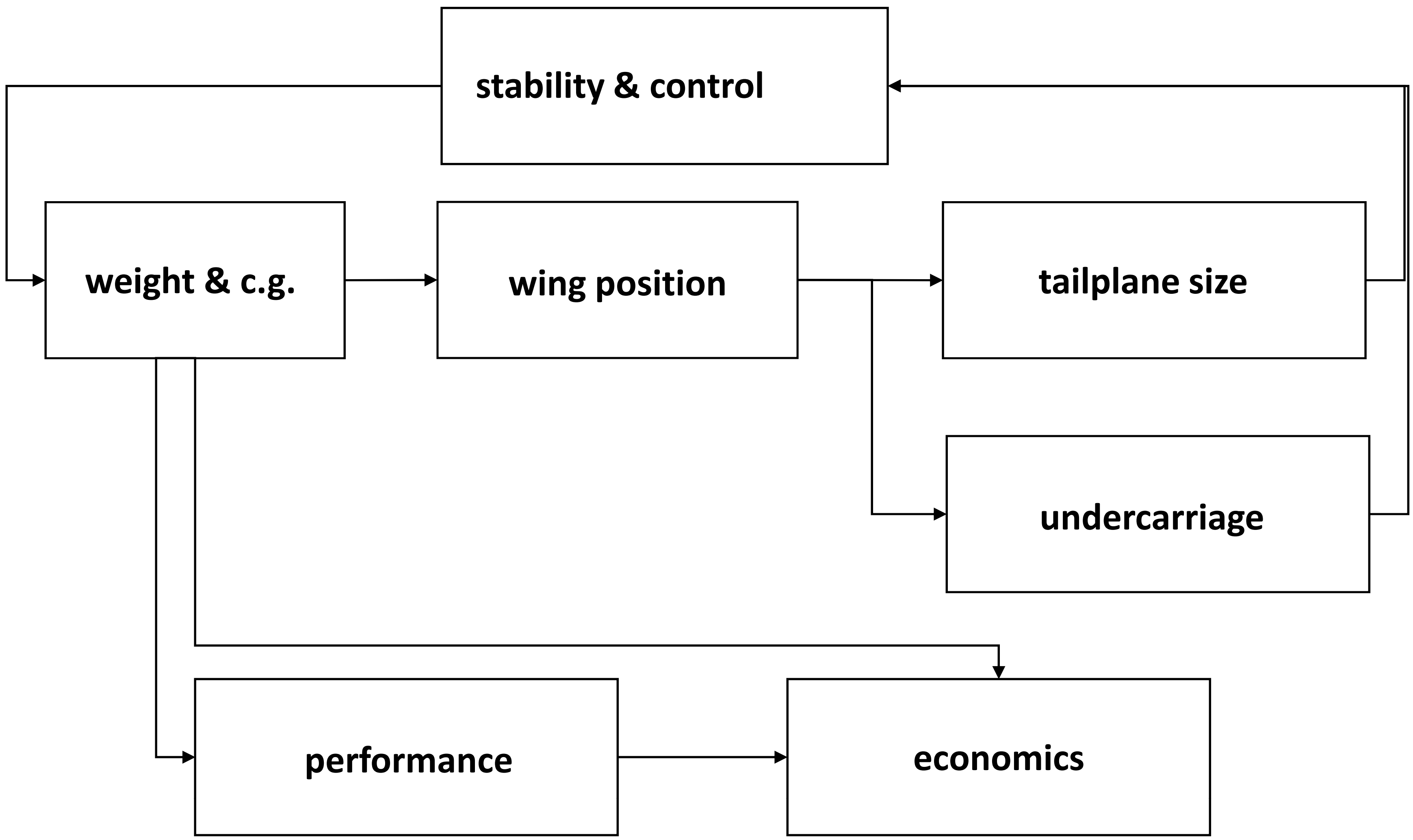
WEIGHT AND BALANCE

Importanza del peso sulle prestazioni e controllo



Sensibilità del Range al peso del velivolo

$$R = \frac{Ma}{c_T}\frac{L}{D}\ln\frac{W_{TO}}{W_{TO} - W_{f,cr}} = \frac{Ma}{c_T}\frac{L}{D}\ln\frac{W_{TO}}{W_0} = \frac{Ma}{c_T}\frac{L}{D}\ln\frac{W_0 + W_{f,cr}}{W_0}$$

B777-300: V=450 kts, C_T=0.55, L/D=20, W_f=124,000kg, W_{TO}=400,000kg

=> R = 6000 nm

if L/D	-5%	=> R = 5700 nm = -5%
if C_T	+5%	=> R = 5714 nm = -5%
if W_0	+5% and W_{TO} constant	=> R = 5273 nm = -12%!!
if W_0	+5% and $\Delta W_{TO} = \Delta W_0$	=> R = 5828 nm = -3%

if R = 6000 nm => $\frac{W_{TO}}{W_0}$ =constant and $\frac{\Delta W_{TO}}{W_{TO}} = \frac{\Delta W_0}{W_0} = \frac{\Delta W_{f,cr}}{W_{f,cr}} = 5\%$

Considerazioni

- se il serbatoio di combustibile deve aumentare => ala di superficie maggiore ?
- a prestazioni costanti (T/W) => + spinta motore (es +5%) => motore + pesante
- a prestazioni costanti (W/S) => ala + grande ed irrobustita, carrello irrobustito => + OEW

Tutto chiarisce il concetto di “snow-ball effect” che può portare ad incrementi notevoli del peso del velivolo (soprattutto rispetto a stime iniziali.

Il **controllo del peso** durante il processo di progettazione preliminare è di fondamentale importanza.

I progettisti devono implementare un sistema di salvaguardia del peso.

Esempio

The Boeing 747-100 was initially designed to carry 350 passengers over 5100 nm with a MTOW of 550,000 lb….

….but was finally certified with a MTOW of 710,000 lb (+29%) engine thrust for the Pratt & Whitney JT9D-7A had to be increased from 41,000 lb to 46,500 lb (13.4%)

take-off field length had increased from 8000 to 11750 ft (+47%)

initial cruise altitude had dropped from FL 350 to FL 310

the later B747-400 carried 416 pax (+19%) over 7670 nm (+50%) with a MTOW of 910,000 lb (+28%) largely due to improved SFC

Weight growth

Component weight has a tendency, just as for human beings, to increase over time and stubbornly refuses to drop.

During the design process, component weight increase leads to time consuming design iterations because all strength computations have to be performed case by case and must be documented extensively for certification purposes.

Therefore, a **highly accurate** (and preferably conservative) first weight estimate is of **paramount importance**.

the weight topic is at least as important as aerodynamics, propulsion and stability and control (but often receives less attention, as reflected in literature!).

weight problems are difficult to cure because they demand more material, which aggravates the problem.

Preliminary weight estimation

During the preliminary design phase, weight is not **determined** but **estimated** using analytical tools, based on a mix of load cases and statistical data.

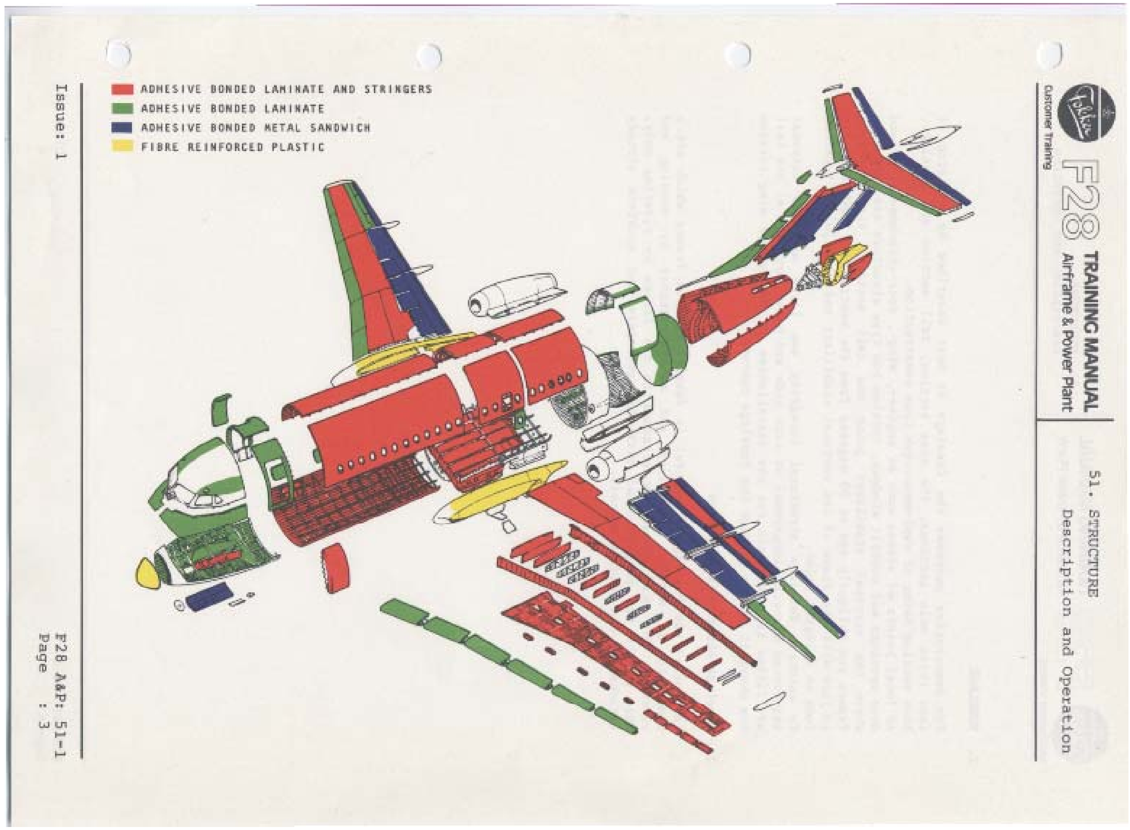
These estimates should be regarded as **design goals** for the structural engineers in the detailed design phase later on.

The preliminary designer does in this respect not **design**, but **predict.**

Weight is an indication of a design(er)'s quality, because that is where all disciplines come together!

Weight estimation accuracy

Aircraft consist of a large number of parts:



Weight estimation accuracy

Due to the lack of detailed information on the often complicated final design, gross simplifications in the geometric model must be made.

For many parts there are many load cases but only one chosen for the computational model.

The critical load case is not always directly apparent.

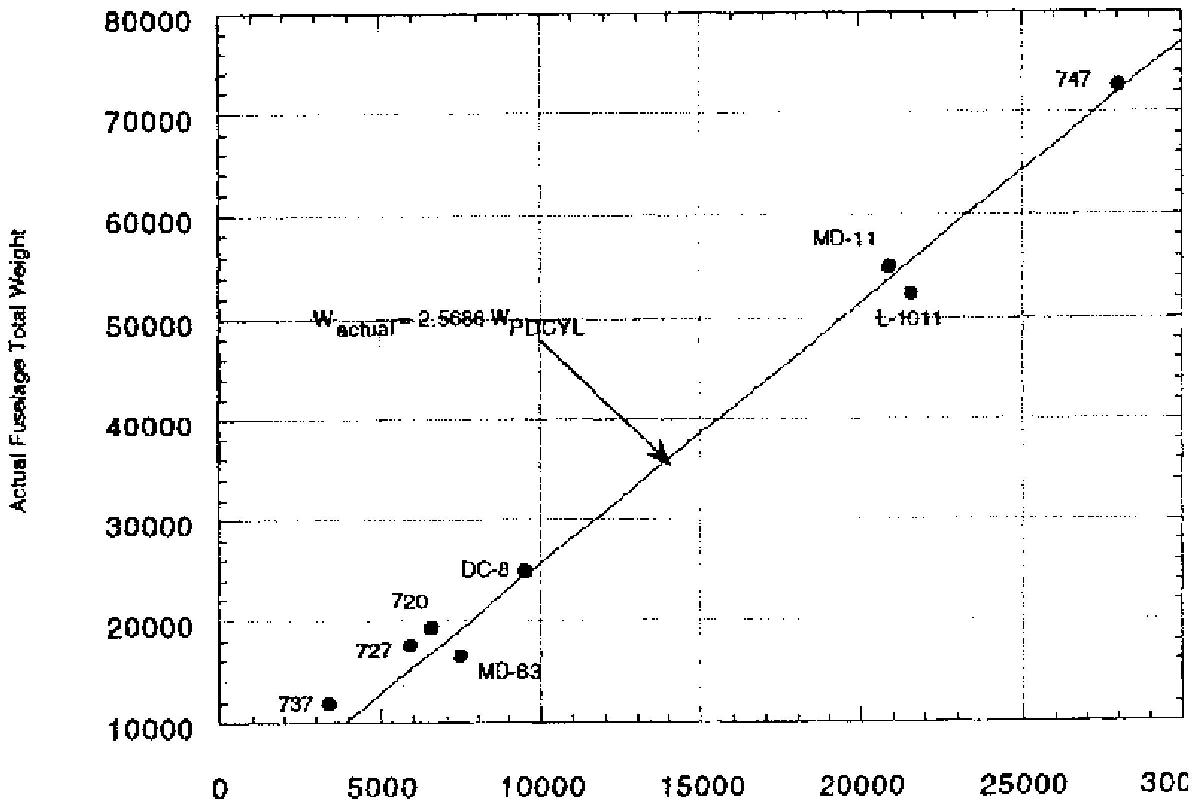
Hence the models for the structural load cases are often tantalizing inaccurate.

In addition, many parts of the aircraft are not sized by load cases (such as avionics, electrical systems, environmental control etc.).

As a result, many weight estimation tools are of highly (semi-)empirical nature with large tailoring factors (up to 2).

Weight estimation accuracy

$$W_{wing} = 0.0103 K_{dw} K_{vs} (W_{dg} N_z)^{0.5} S_w^{\ 0.622} A^{0.785} \left(\frac{t}{c_{root}} \right)^{-0.4} (1+\lambda)^{0.05} (\cos\Lambda)^{-1.0} S_{csw}^{\ 0.04}$$



Weight is a very sensitive issue for aircraft manufacturers and hence detailed data is extremely difficult to obtain.

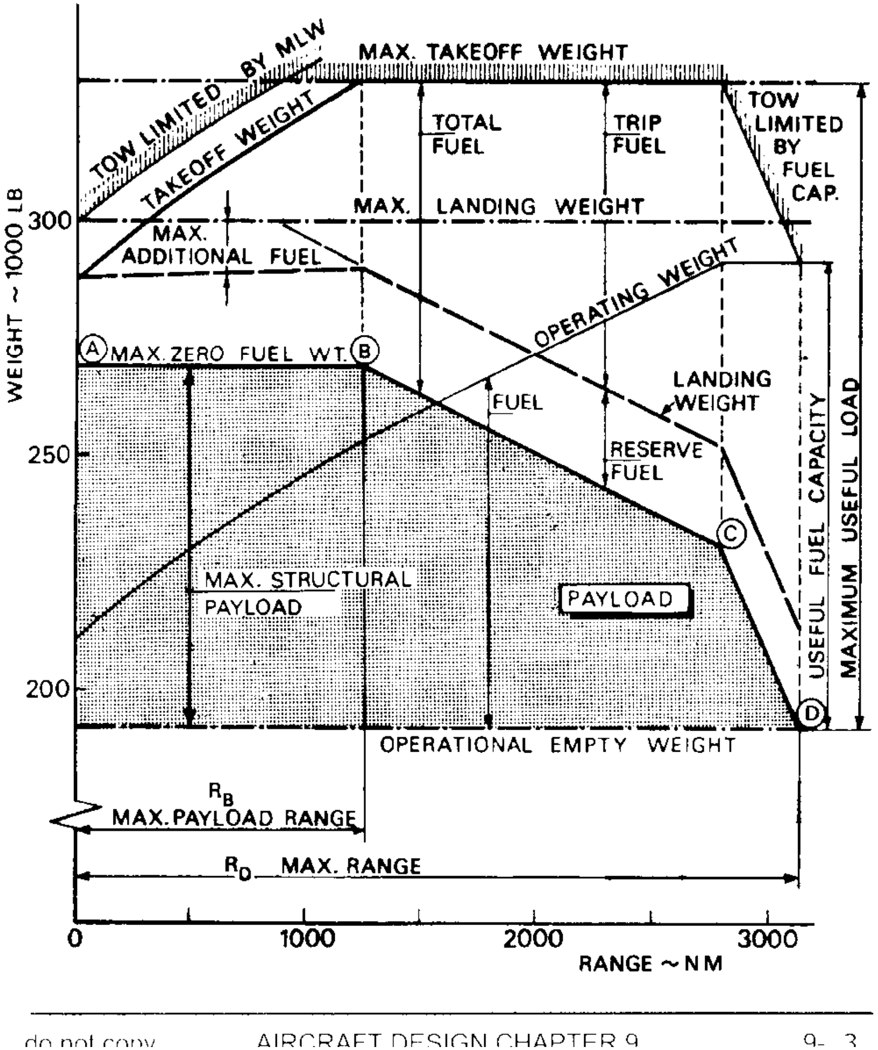
This partially explains why weight **estimation** is by far not as extensively covered in literature as aerodynamics and stability & control.

Often only group weights are available to textbook writers

Consequently, large errors may be observed for component weight estimation but much better correlation is found for their summation (group weights and MEW).

Therefore, component weight estimates from one method shall **never ever** be combined with that from another method! →

Payload-range diagram



- MTOW
- MLW
- MZFW
- OEW

} design weights

- to anticipate shortfalls, aircraft manufacturers give range **guarantees** to airlines that are 5% below the nominally expected values
- reserve fuel is dead weight, ≈4.5% MTOW
- weights must be limited to prevent
  - overloading the structure
  - unacceptable performance
  - unacceptable handling qualities

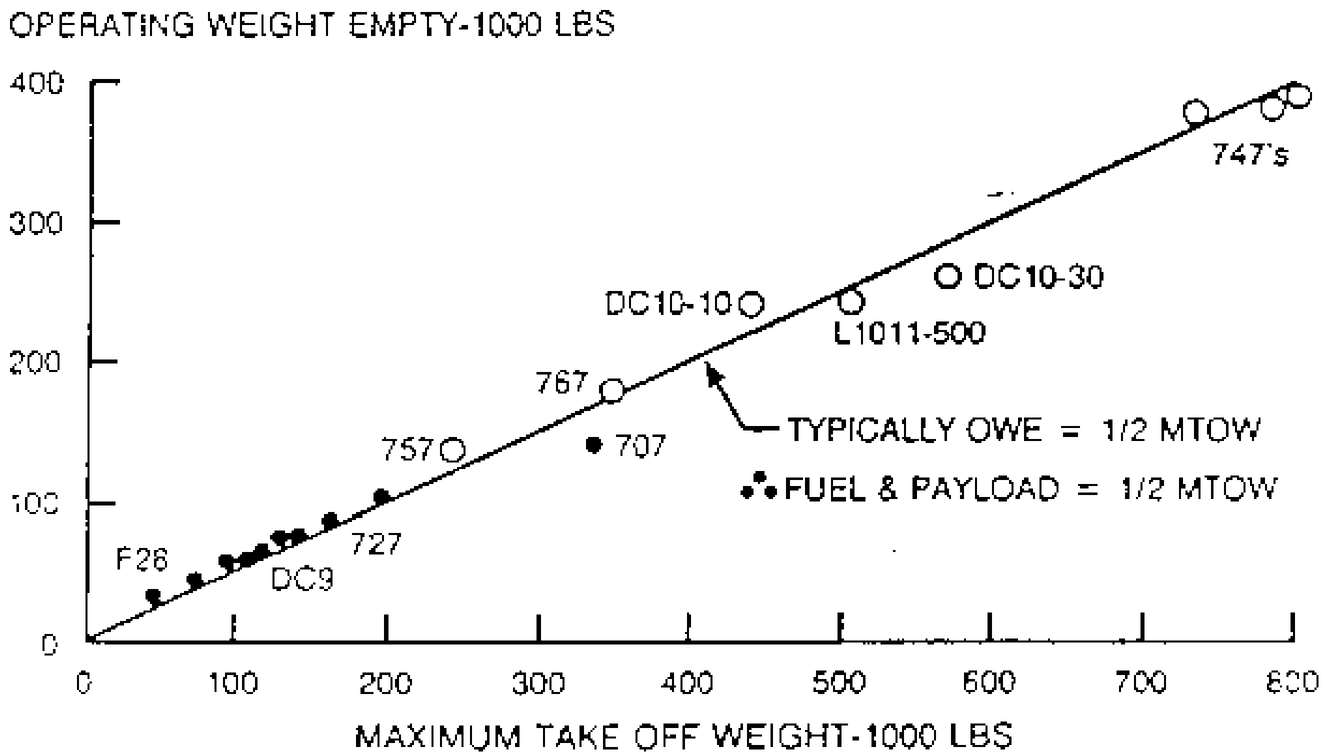
MTOW first estimation

Square Cube Law (SQL): scale aircraft by parameter λ:

- length ~ λ
- area ~ λ^2
- weight ~ λ^3
- W/S ~ $\lambda^3/\lambda^2 = \lambda$

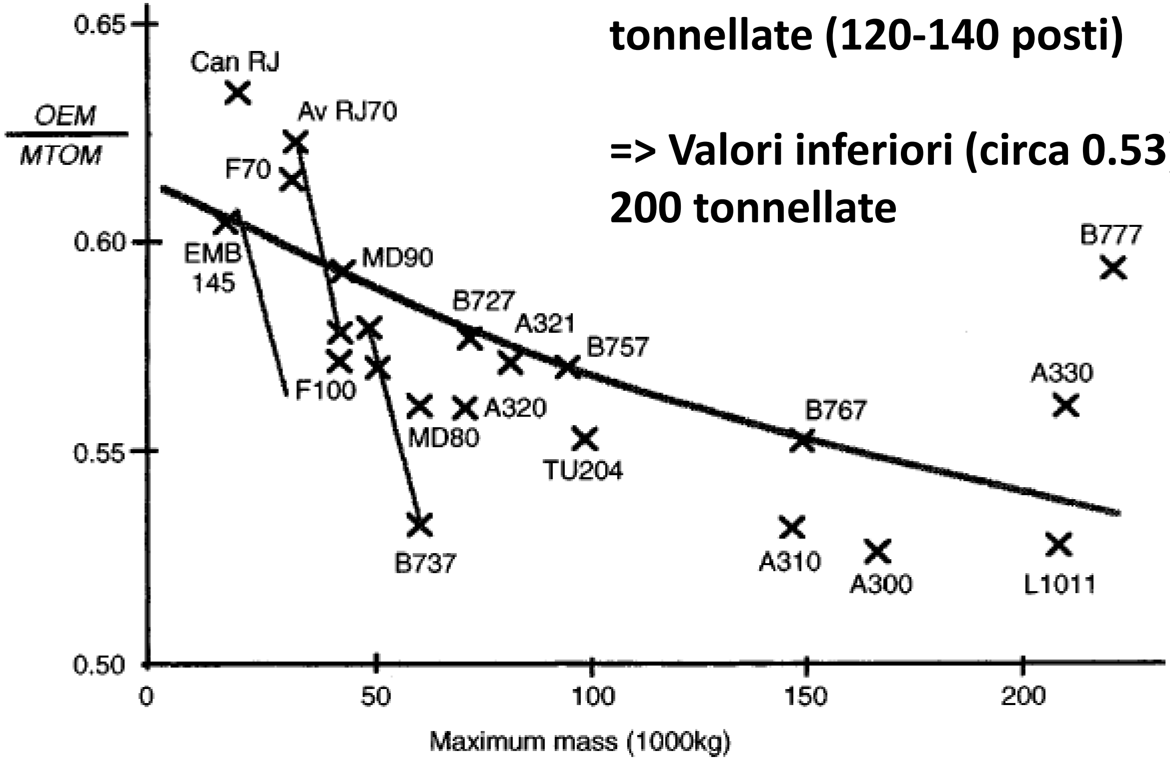
Large a/c are relatively heavy and have high wing loadings, need very effective high-lift devices.

Constant OEW fraction for all transport a/c?



Tipicamente abbiamo un valore del peso a vuoto operativo pari a circa il 50% del peso massimo al decollo.
Ma è proprio 0.50 per tutti I velivoli da trasporto ?

Constant OEW fraction for all transport a/c?



Il valore tende ad essere circa 0.58-0.60 per velivoli da 50 tonnellate (120-140 posti)

=> Valori inferiori (circa 0.53) per velivoli al di sopra delle 200 tonnellate

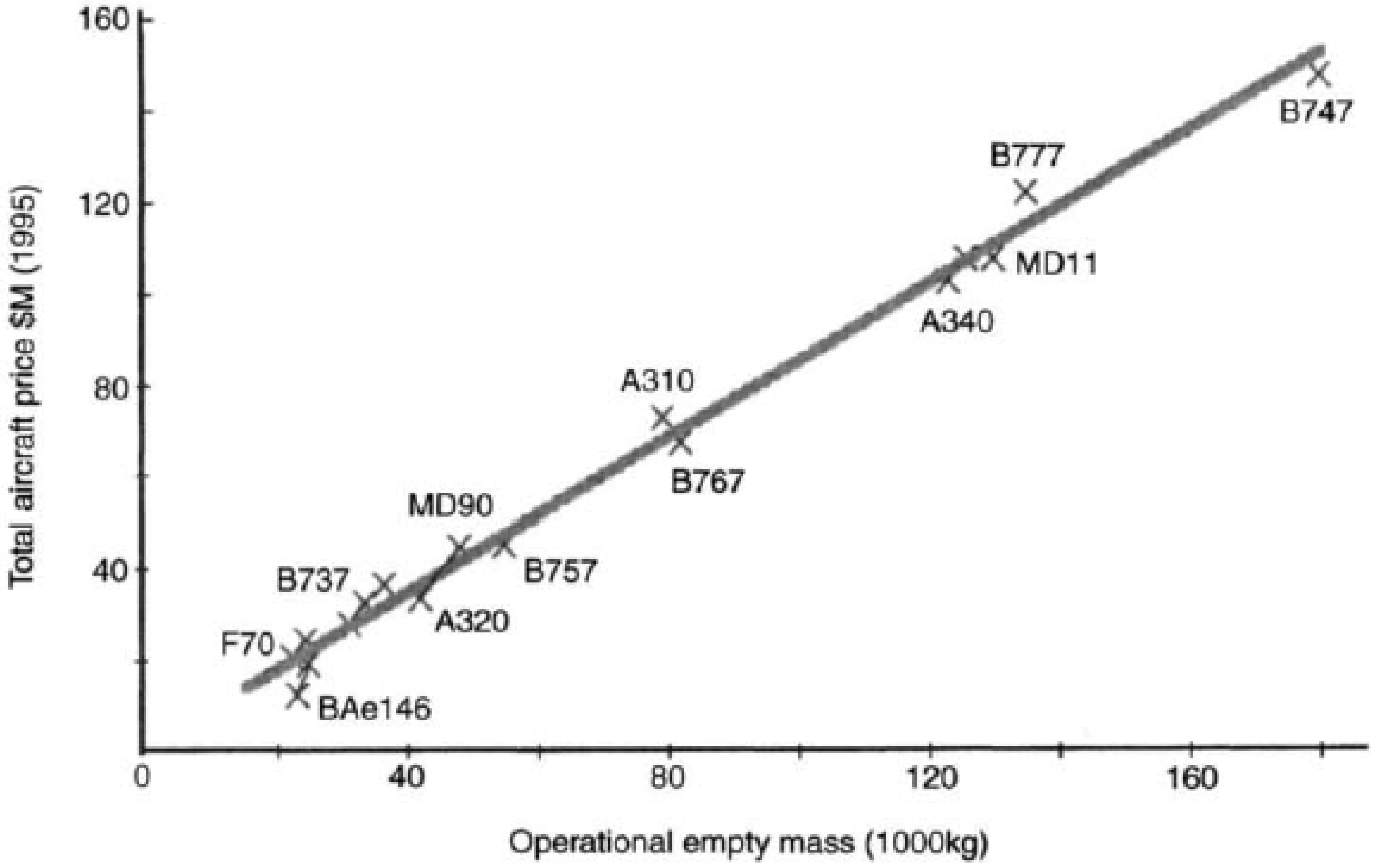
Intorno a 0.50
Per velivoli molto grandi (A380)

Fig. 7.3 Aircraft

AIRBUS A380-800

Maximum take-off weight	560,000 kg (1,200,000 lb)	
Maximum landing weight	386,000 kg (850,000 lb)	
Maximum zero fuel weight	361,000 kg (800,000 lb)	
Typical operating empty weight OEW	276,800 kg (610,000 lb)	**Rapporto =0.49**

Effetto del peso sul COSTO del Velivolo



Incidenza parti su OEW (valido per una certa categoria)

AIRPLANE CATEGORY		PERCENTAGE OF MTOW			
		airframe structure	propulsion group	fixed eq. and serv.	empty weight
PASSENGER TRANSPORTS					
short-haul	jets	31.5	8.0	13.5	53.0
	turboprops	32.0	12.5	13.5	58.0
	pistons	29.5	20.5	15.5	65.5
long-haul	jets	24.5	8.5	9.0	42.0
	turboprops	27.0	12.0	12.0	51.0
	pistons	25.5	17.5	11.0	54.0
FREIGHTERS					
short-haul	turboprops	35.0	13.0	8.0	56.0
long-haul	turboprops	26.5	10.0	7.0	43.5
EXECUTIVE JETS		27.5	8.0	15.5	51.0

Table 8-2. Typical average empty weight fractions for several categories of transport aircraft

Composite materials

At best 20% reductions in component weight can be achieved.
Combat aircraft show the way with 25% overall reduction in structure fraction.
Transport a/c have only attained 15%, so there is potential for another 10% reduction.

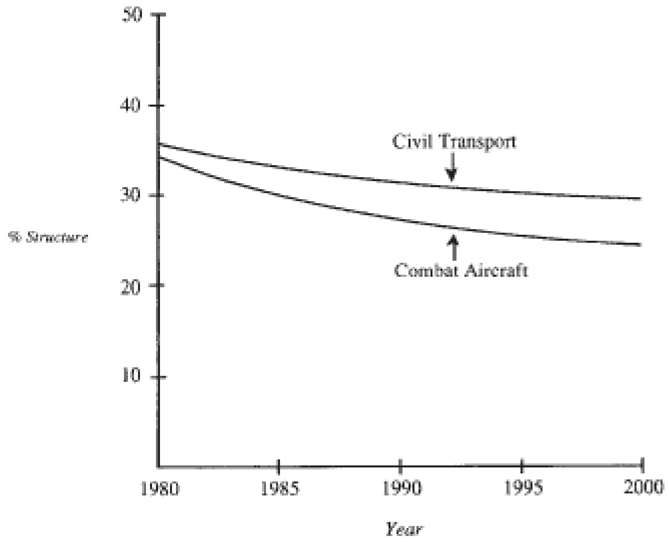


Figure 43. Structural weight as a percentage of maximum take-off weight

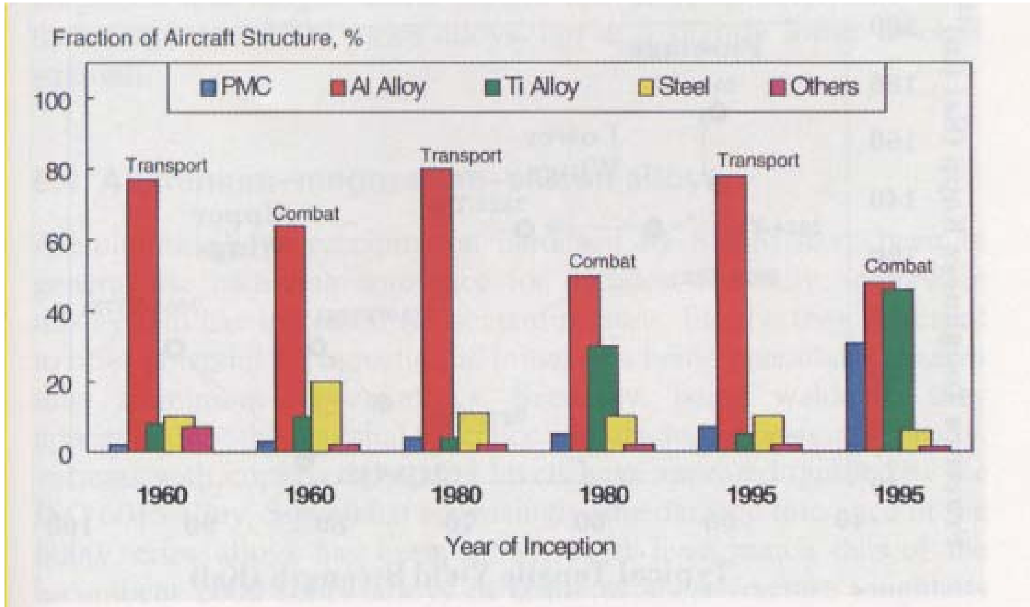


Figure 16. Relative usage (% mass) of materials in combat, civil and military transport aircraft, including landing gear.

Composite materials

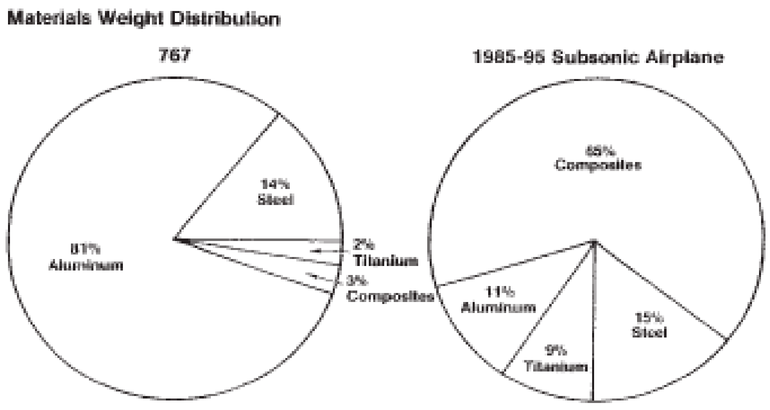


Figure 45. The materials scenario, circa 1983, for future transport aircraft materials: an optimistic forecast

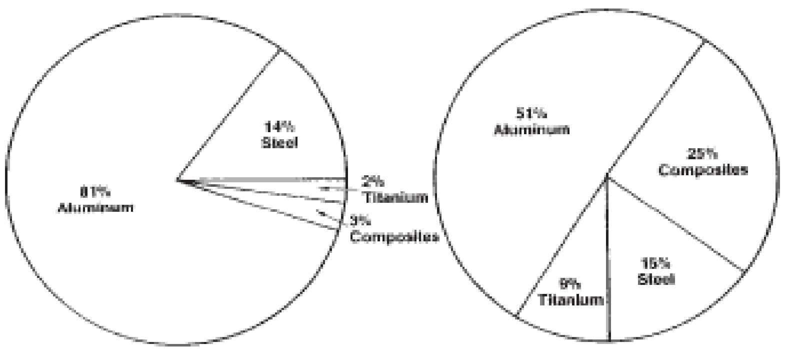


Figure 46. The materials scenario, circa 1983: a supposedly conservative forecast

Composite materials have up to now only been applied to secondary structure such as tailplanes and fairings

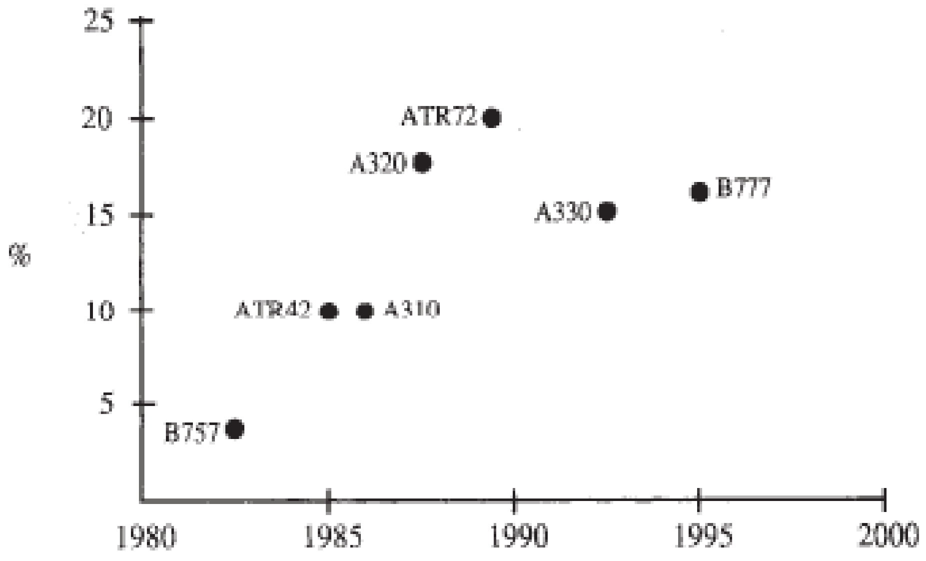
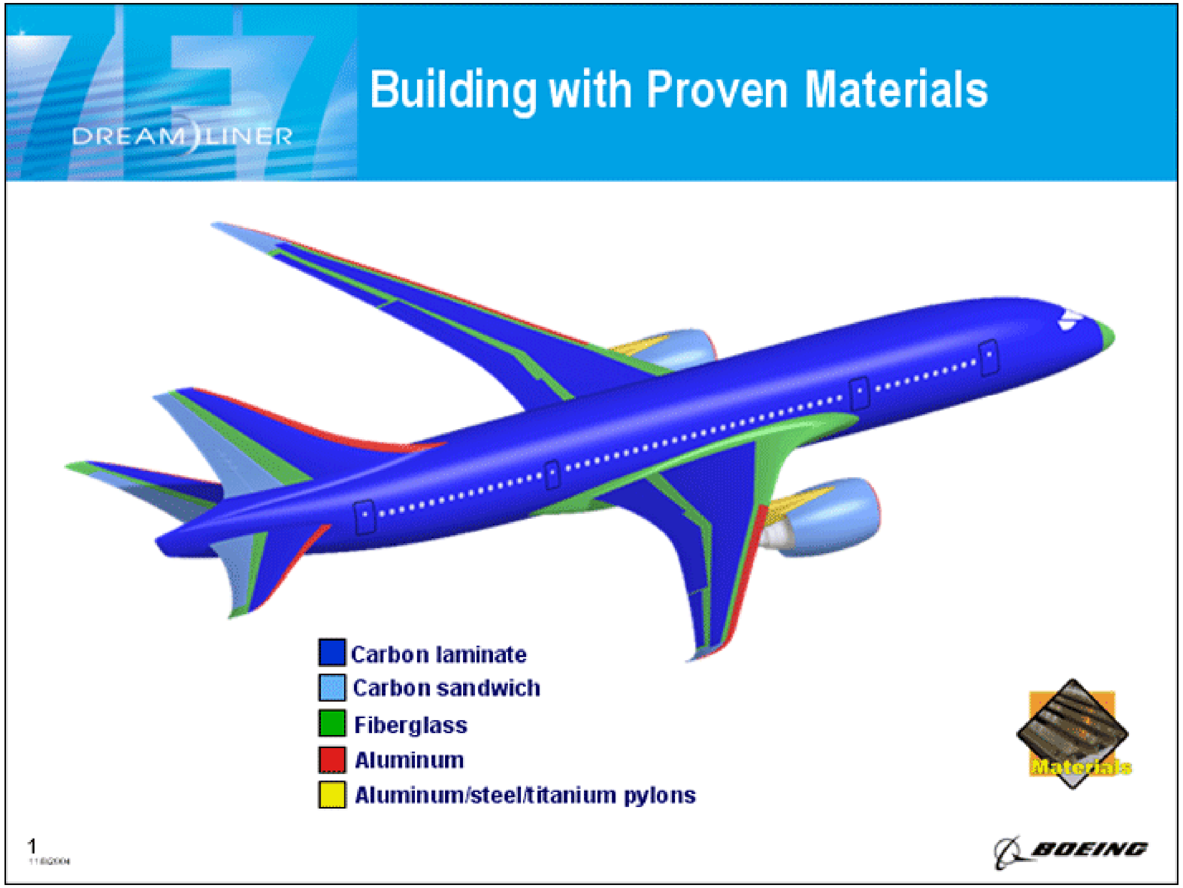


Figure 47. Percentage of civil aircraft structure made up of carbon composite

Composite materials airliners

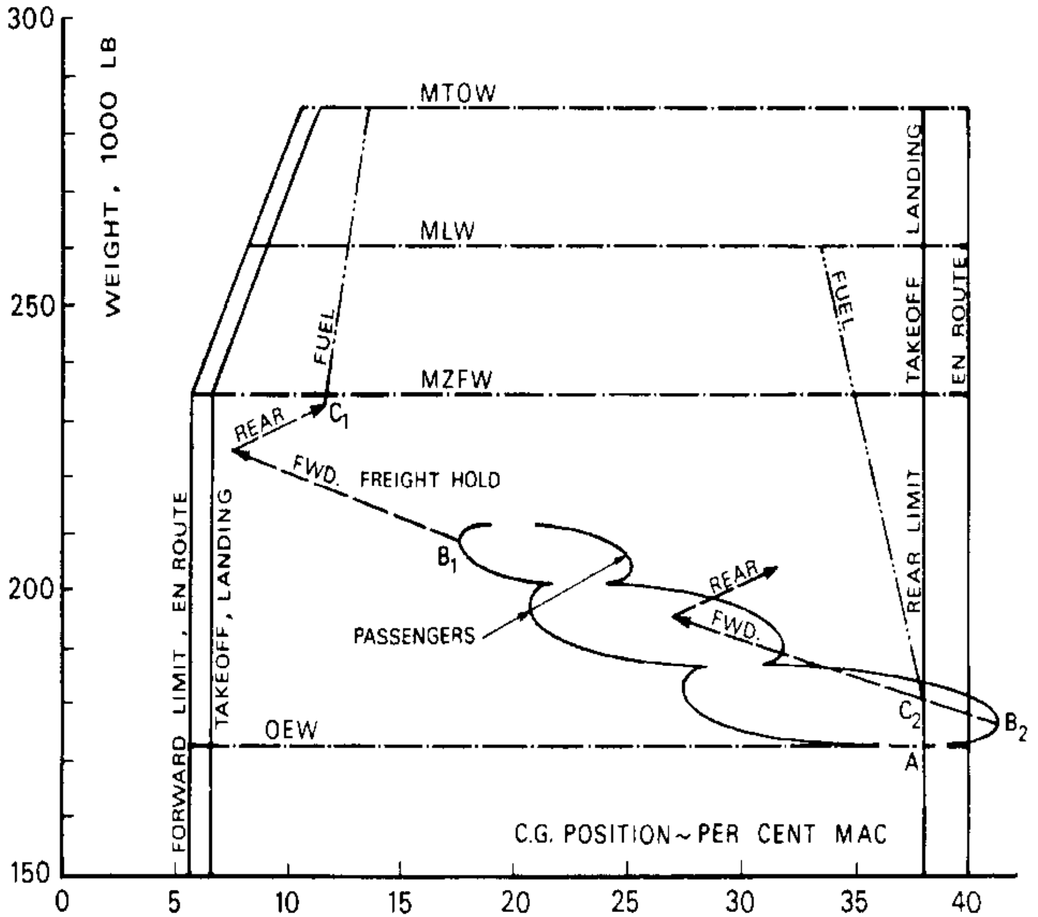
B787: 50% composite fraction!



Balancing

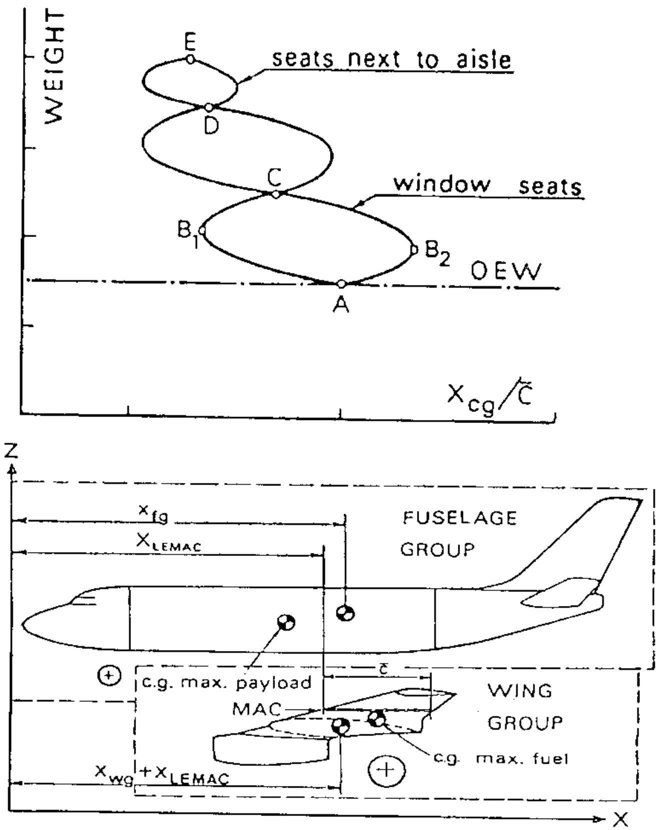
LOAD AND BALANCE DIAGRAM

REAR FUSELAGE MOUNTED ENGINES



Balancing

BALANCING THE AIRCRAFT (1)



Desirable co-ordinate of wing leading-edge (X_{LEMAC} for given position of c.g. @ Operating Empty Weight:

$$X_{LEMAC} = X_{fg} - X_{oe} + \frac{W_{wg}}{W_{fg}}(X_{wg} - X_{oe})$$

Desirable longitudinal wing location

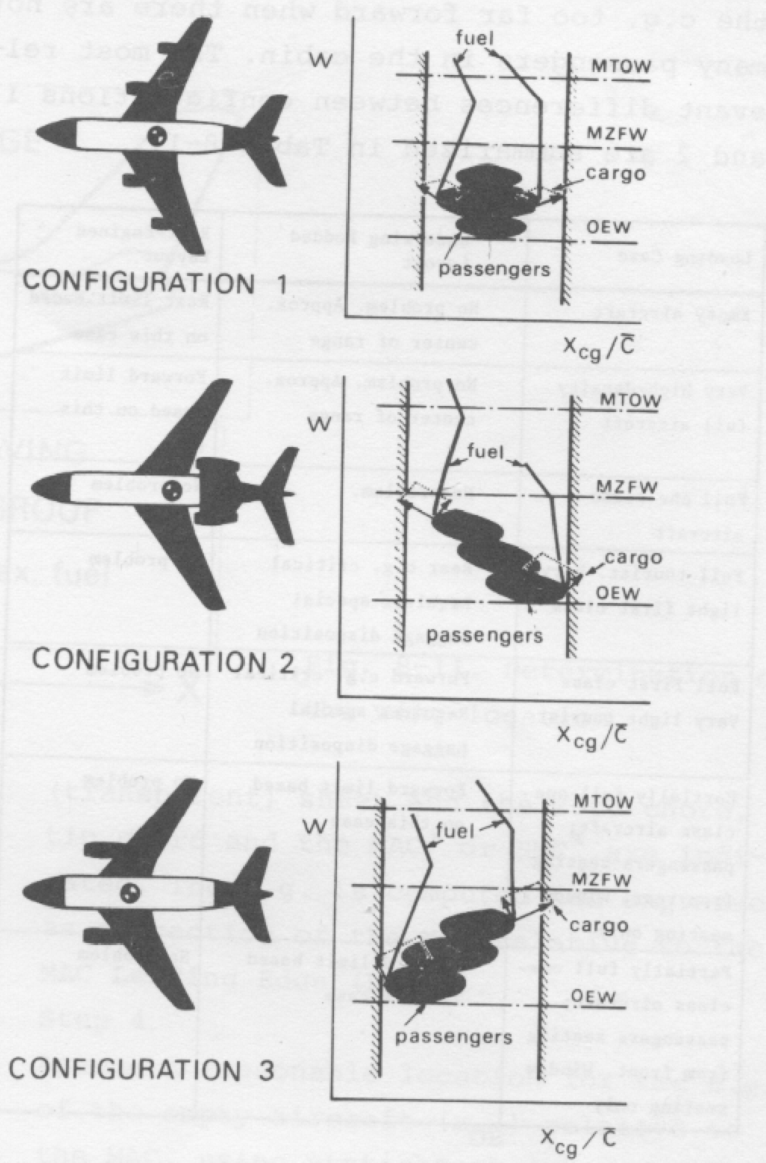
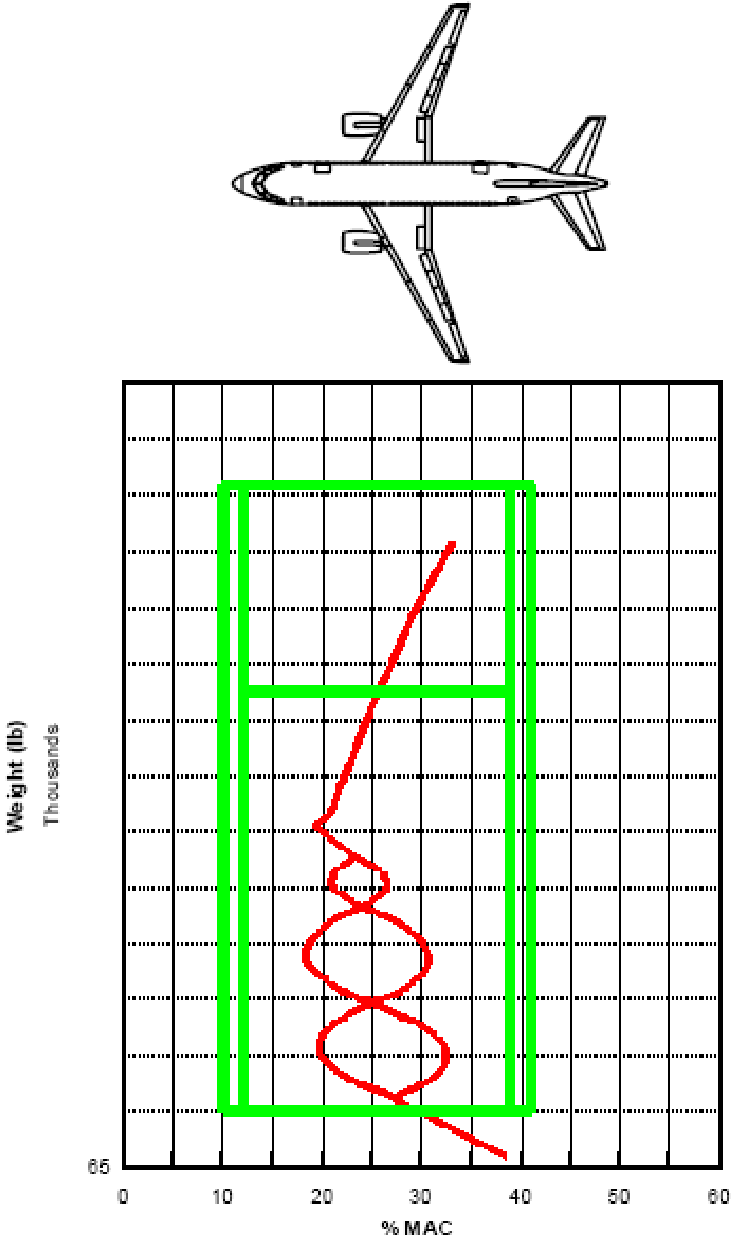
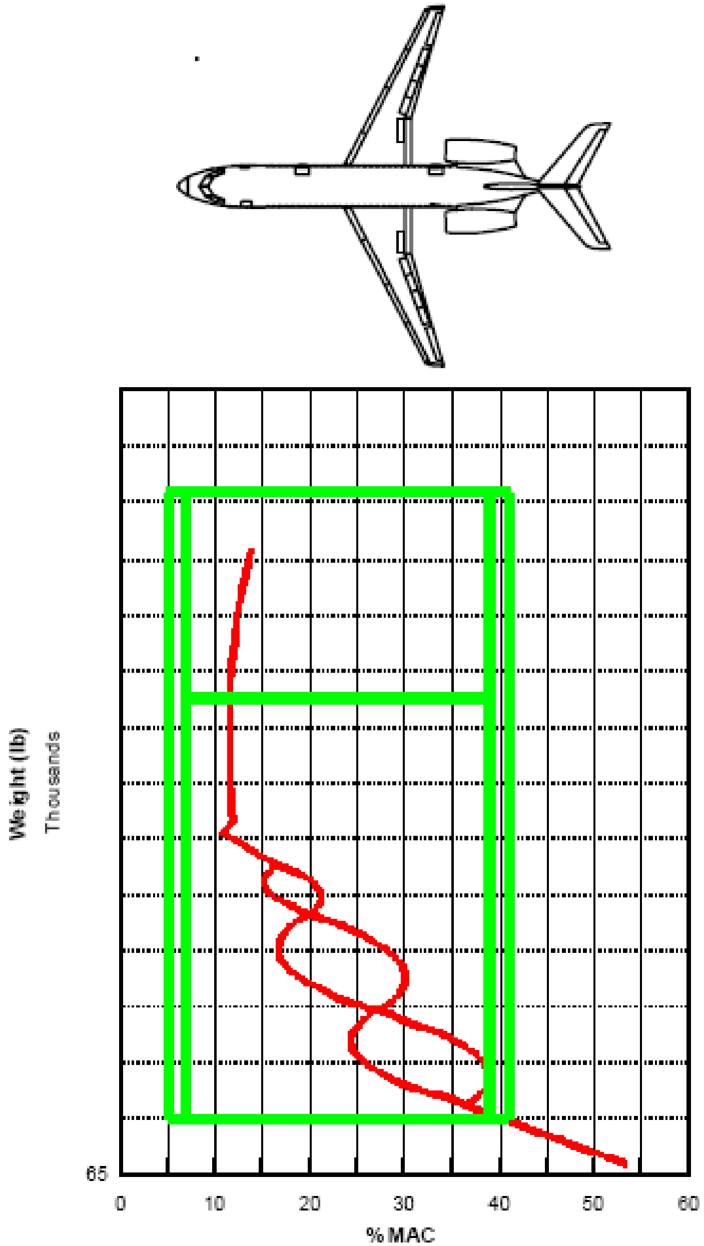


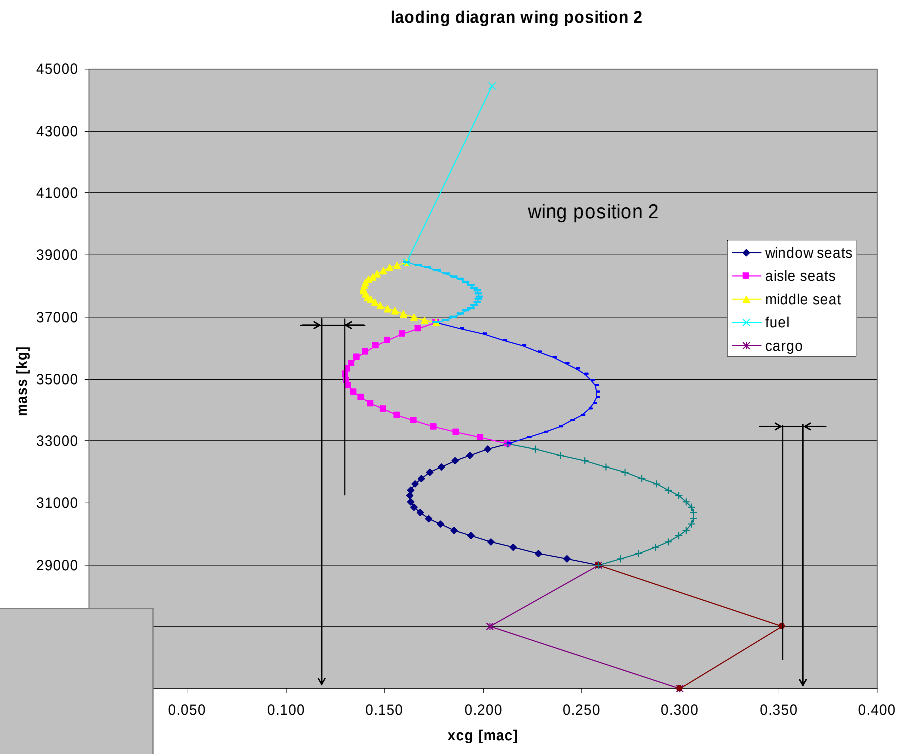
Fig. 8-10. Effect of the general arrangement on load and balance

Load and balance diagram for short-haul wide-body airline

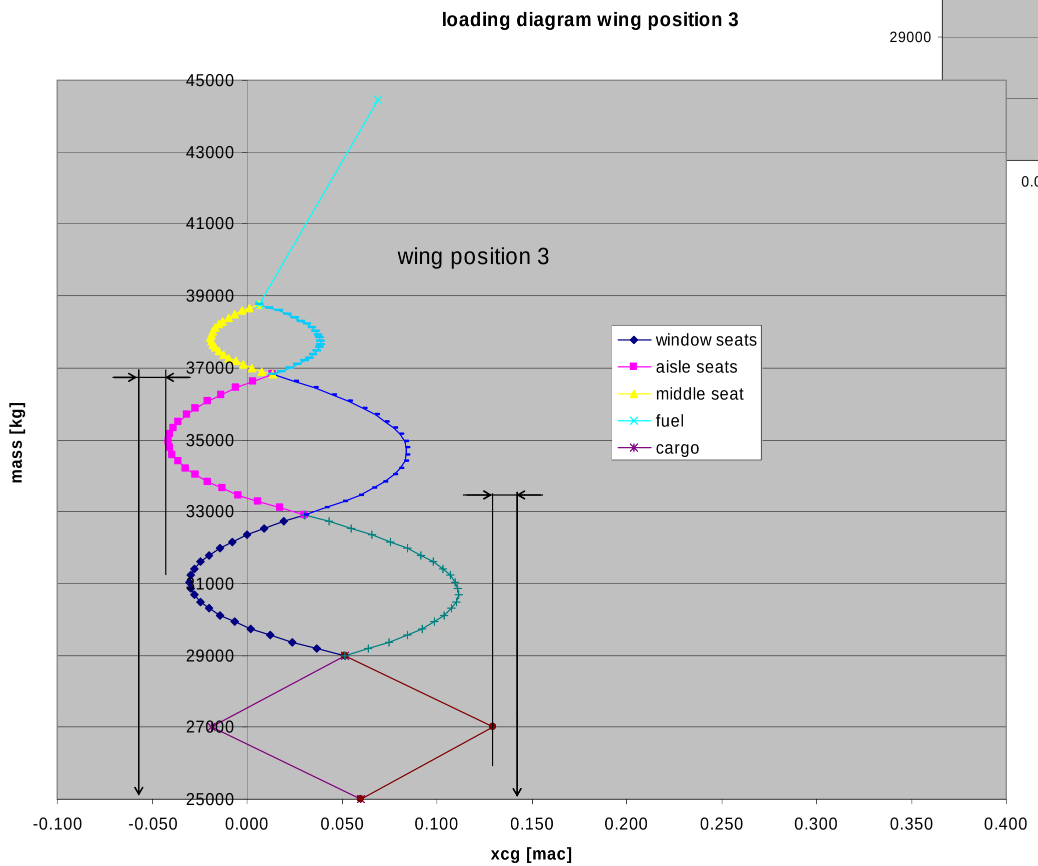




Balancing

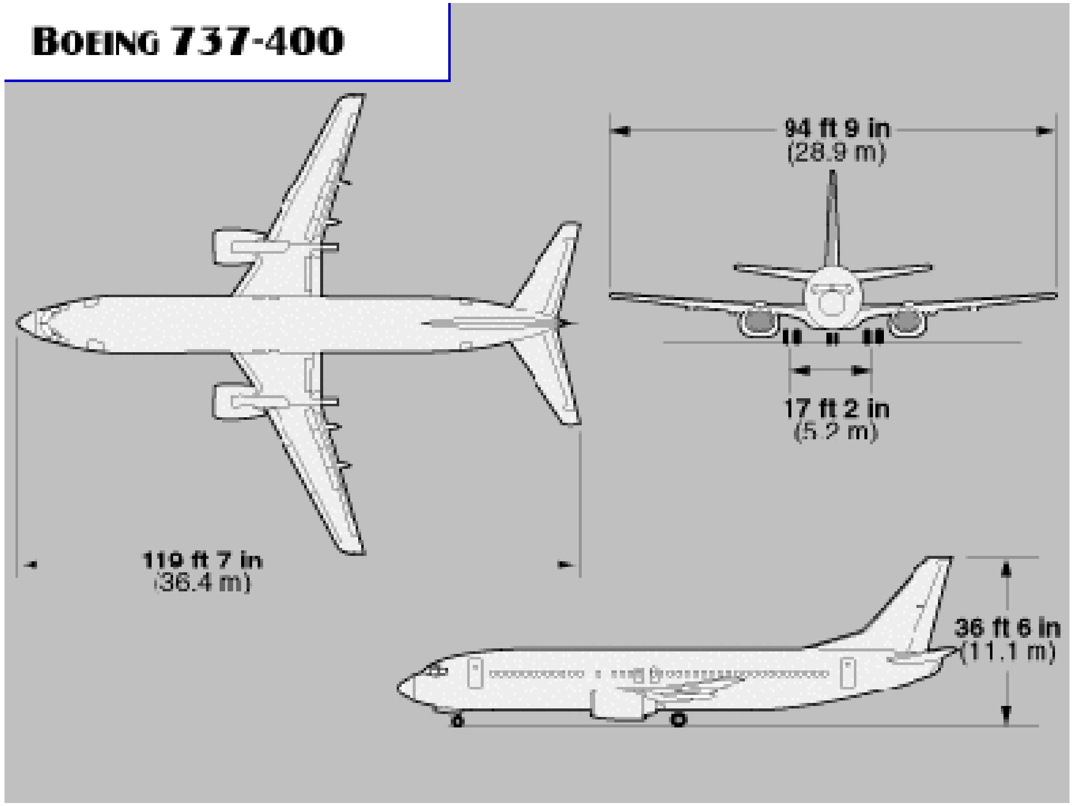


Ala in posizione arretrata rispetto alla fusoliera (CG più avanzato)

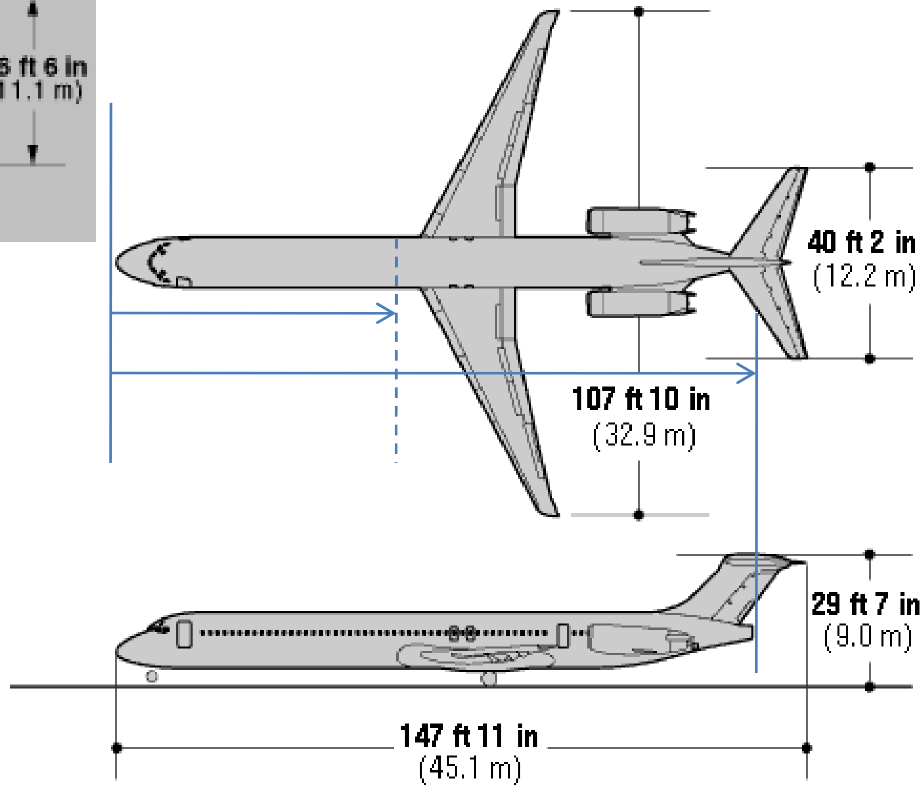


Ala in posizione avanzata rispetto alla fusoliera (CG più arretrato)

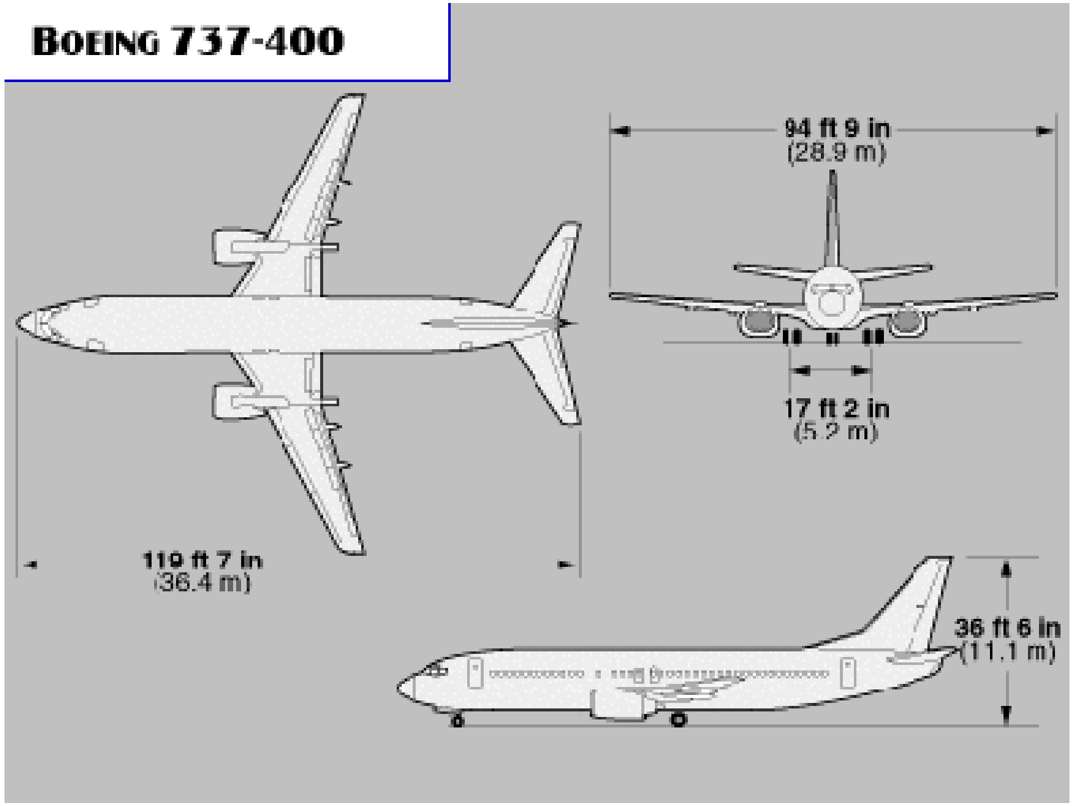
Tipicamente si usa una posizione della corda di radice sulla fusoliera al 35-37% della lunghezza di fusoliera (per velivoli con motori sub-alari).



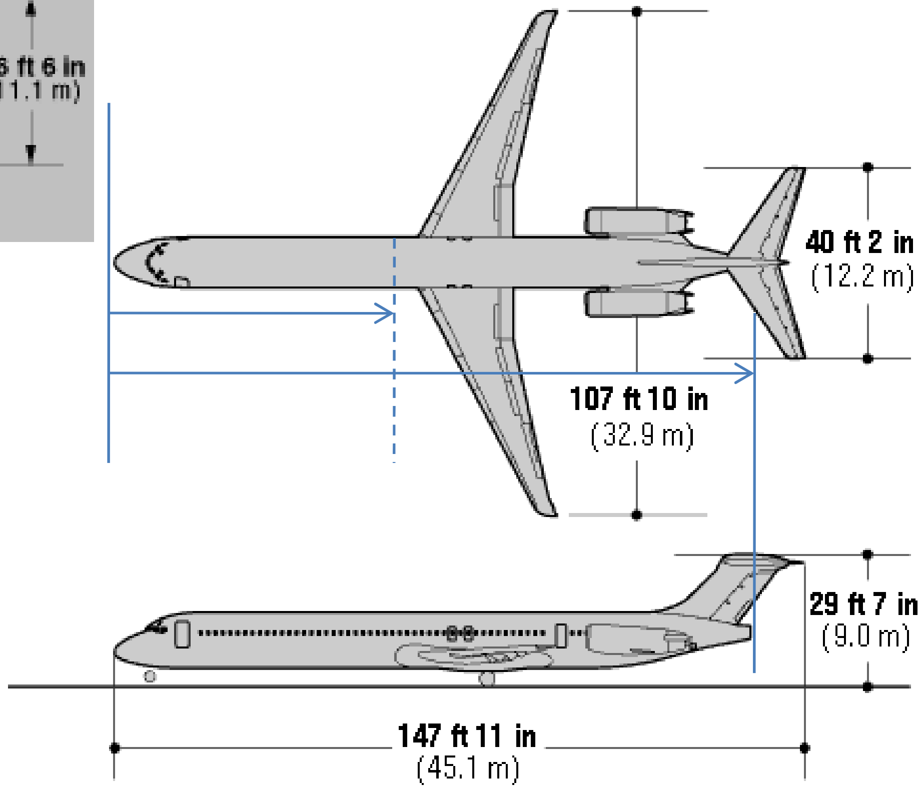
B737-400



MD-80



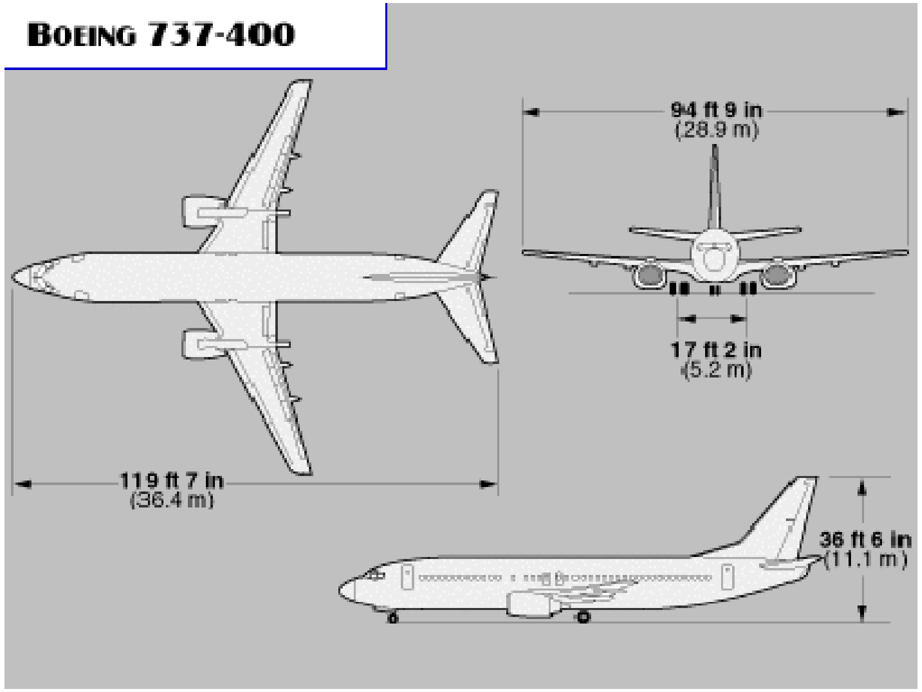
B737-400



MD-80

Weight & Balance

Esempio
B737-400



737 BOEING -400

WEIGHT AND BALANCE
CONTROL AND LOADING MANUAL

CERTIFIED CENTER OF GRAVITY LIMITATIONS