Estructuras Detalladas
Métodos Estimación Pesos

Tema 13

Sergio Esteban Roncero
Departamento de Ingeniería Aeroespacial
Y Mecánica de Fluidos

Estimación de Pesos - I

- Determinación de forma estadística.
- Previo a tener valores más representativos obtenidos mediante modelado en CAD.
  - 1ª Fase: determinar el peso de las estructuras simplificadas
    - Uso de multiplicadores lineales
      - fuselaje, ala, estabilizadores horizontal, motor, tren de aterrizaje, % de misceláneos
  - **2ª Fase: ajustar los pesos de dichas estructuras simplificadas**
    - **Método literatura**
  - **3ª Fase: incluir pesos de sistemas aplicables:**
    - **Flight Control System, Hydraulic and Pneumatic System, Instrumentation, Avionics and Electronics, Electrical System, Air-conditioning, Pressurization, Anti- and De-icing System, Oxygen System, Auxiliary Power Unit, Furnishings, Baggage and Cargo Handling Equipment, Operational Items**
  - 4ª fase: determinar incremento de pesos asociados a refuerzos estructurales
    - Identificación de zonas de carga
  - 5ª Fase: reducción de peso estructural ateniendo a selección de materiales

Estimación Pesos

Método I

Ref: Aircraft Design: A Systems Engineering Approach,
M. H. Sadraey, Wiley Aerospace Series, 2012.

Estimación Pesos

- Estimación de pesos de las distintas estructuras:
  - Empleo de datos históricos para crear ecuaciones paramétricas que tienen en cuenta:
    - Relaciones directas entre el peso de objetos y su densidad media
    - Datos reales publicados de varios componentes
    - Factores empíricos derivados por Sadraey (ver Bibliografía)
    - Ecuaciones empíricas publicadas (ver Bibliografía)
- Ejemplo de relaciones entre objetos y densidad

No	Engineering Materials	Density kg/m^3
1	Aerospace Alumimum	2711
2	Fiberglass/epoxy	1800 – 1850
3	Graphite/epoxy	1520 – 1630
4	Low-density foam	16 – 30
5	High-density foam	50 – 80
6	Steel alloys	7747
7	Titanium alloys	4428
8	Balsa wood	160
9	Plastics (including monokote)	900 – 1400

Table 1: Density of Various Aerospace Materials

Ecuaciones válidas para unidades en el SI e Imperiales (British) (sólo tener en cuenta el valor de $g = 9{,}81$ ó $g = 32{,}17\ ft/s^2$)

Density of material

Wing Weight - I

- Wing Weight Equation

$$W_W = S_W \cdot MAC \cdot \left(\frac{t}{c}\right)_{max} \cdot \rho_{mat} \cdot K_\rho \cdot \left(\frac{AR \cdot n_{ult}}{\cos(\Lambda_{0.25})}\right)^{0.6} \cdot \lambda^{0.04} \cdot g$$

W_W (British & SI units)

siendo $n_{ult} = 1.5 \cdot n_{max}$

$$\begin{aligned}
S_W &= \text{wing planform area} \\
MAC &= \text{wing mean aerodynamic chord} \\
\left(\frac{t}{c}\right)_{max} &= \text{maximum thickness-to-chord ratio} \\
\rho_{mat} &= \text{density of material (tabla 1)} \\
K_\rho &= \text{wing density factor (table 2)} \\
AR &= \text{Aspect Ratio} \\
n_{ult} &= \text{ultimate load factor} \\
\Lambda_{0.25} &= \text{quarter chord sweep angle} \\
\lambda &= \text{taper ratio} \\
g &= \text{gravitational constant}
\end{aligned}$$

Wing Weight - II

No	Aircraft-wing structural installation condition	Density K_ρ
1	GA, no engine, no fuel tank in the wing	0.0011 – 0.0013
2	GA, no engine on the wing, fuel tank in the wing	0.0014 – 0.0018
3	GA, engine installed on the wing, no fuel tank in the wing	0.0025 – 0.003
4	GA, engine installed on the wing, fuel tank in the wing	0.003 – 0.0035
5	Home-built	0.0012 – 0.002
6	Transport, cargo, airliner (engines attached to the wing)	0.0035 – 0.004
7	Transport, cargo, airliner (engines no attached to the wing)	0.0025 – 0.003
8	Supersonic fighter, few light stores under wing	0.004 – 0.006
9	Supersonic fighter, several heavy stores under the wing	0.009 – 0.012
10	Remotely controlled model	0.001 – 0.0015

Nota: GA → General Aircraft

Table 1: Wing density factor for various aircraft K_ρ

Wing Density Factor

No	Aircraft	Maximum load factor (n_{max})
1	GA normal	2.5 – 3.8
2	GA utility	4.4
3	GA acrobatic	6
4	Home-built	2.5 – 5
5	Remote-controlled model	1.5 – 2
6	Transport	3 – 4
7	Supersonic fighter	7 – 10

Table 1: Maximum positive load factor for various aircraft

Horizontal Tail Weight - I

- Horizontal Tail Weight Equation

$$W_{HT} = S_{HT} \cdot MAC_{HT} \cdot \left(\frac{t}{c}\right)_{max_{HT}} \cdot \rho_{mat} \cdot K_{\rho_{HT}} \cdot \left(\frac{AR_{HT}}{\cos\left(\Lambda_{0.25_{HT}}\right)}\right)^{0.6} \cdot \lambda_{HT}^{0.04} \cdot \bar{V}_{HT}^{0.3} \cdot \left(\frac{c_e}{c_T}\right)^{0.4} \cdot g$$

$$\bar{V}_{HT} = \frac{l}{c}\frac{S_{HT}}{S_W}$$

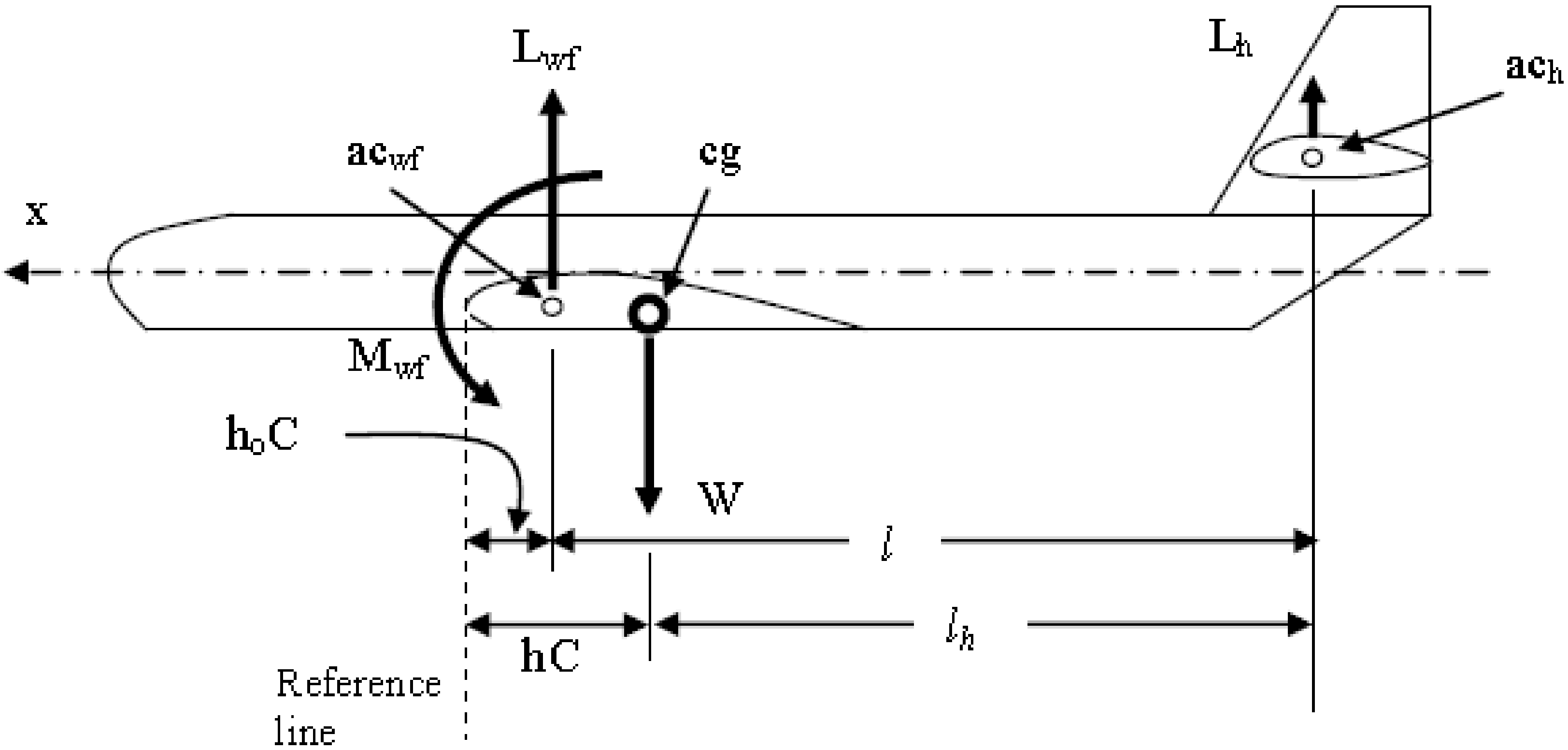
W_{HT} (British & SI units)

siendo

$$\begin{aligned}
S_{HT} &= \text{horizontal tail exposed planform area} \\
MAC_{HT} &= \text{horizontal tail aerodynamic chord} \\
\left(\frac{t}{c}\right)_{max_{HT}} &= \text{horizontal tail maximum thickness-to-chord ratio} \\
\rho_{mat} &= \text{density of material (tabla 1)} \\
K_{\rho_{HT}} &= \text{horizontal tail wing density factor (table 2)} \\
AR_{HT} &= \text{horizontal tail Aspect Ratio} \\
\Lambda_{0.25_{HT}} &= \text{horizontal tail quarter chord sweep angle} \\
\lambda_{HT} &= \text{horizontal tail taper ratio} \\
\bar{V}_{HT} &= \text{horizontal tail volume ratio} \\
\frac{c_e}{c_T} &= \text{elevator-to-tail chord ratio} \\
g &= \text{gravitational constant}
\end{aligned}$$

Horizontal Tail Weight - II

$$\bar{V}_{HT} = \frac{l}{c}\frac{S_{HT}}{S_W}$$



Horizontal Tail Weight - III

- Ajuste del density factor para diferentes tipos de aviones
  - Emplear valor intermedio

No	Aircraft	$K_{\rho_{HT}}$	$K_{\rho_{VT}}$
1	GA, home-built-convenctional tail/canard	$0.022 - 0.028$	$0.067 - 0.076$
2	GA, home-built-T-tail/T-tail	$0.03 - 0.037$	$0.078 - 0.11$
3	Transport-conventional tail	$0.02 - 0.03$	$0.035 - 0.045$
4	Transport-T-tail	$0.022 - 0.033$	$0.04 - 0.05$
5	Remotely controlled model	$0.015 - 0.02$	$0.044 - 0.06$
6	Supersonic fighter	$0.06 - 0.08$	$0.12 - 0.15$

Table 1: Tail density factor for various aircraft

Vertical Tail Weight - I

- Vertical Tail Weight Equation

$$W_{VT} = S_{VT} \cdot MAC_{VT} \cdot \left(\frac{t}{c}\right)_{max_{VT}} \cdot \rho_{mat} \cdot K_{\rho_{VT}} \cdot \left(\frac{AR_{VT}}{\cos(\Lambda_{0.25_{VT}})}\right)^{0.6} \cdot \lambda_{VT}^{0.04} \cdot \bar{V}_{V}^{0.2} \cdot \left(\frac{c_e}{c_T}\right)^{0.4} \cdot g$$

$$\bar{V}_{VT} = \frac{l_v}{b}\frac{S_{VT}}{S_W}$$

W_{VT} (British & SI units)

siendo

$$\begin{aligned}
S_{VT} &= \text{vertical tail exposed planform area}\\
MAC_{vT} &= \text{vertical tail aerodynamic chord}\\
\left(\frac{t}{c}\right)_{max_{VT}} &= \text{vertical tail maximum thickness-to-chord ratio}\\
\rho_{mat} &= \text{density of material (tabla 1)}\\
K_{\rho_{VT}} &= \text{vertical tail wing density factor (table 2)}\\
AR_{VT} &= \text{vertical tail Aspect Ratio}\\
\Lambda_{0.25_{VT}} &= \text{vertical tail quarter chord sweep angle}\\
\lambda_{VT} &= \text{vertical tail taper ratio}\\
\bar{V}_{VT} &= \text{vertical tail volume ratio}\\
\frac{c_r}{c_V} &= \text{rudder-to-vertical tail chord ratio}\\
g &= \text{gravitational constant}
\end{aligned}$$

Vertical Tail Weight - II

- Vertical Tail Weight Equation

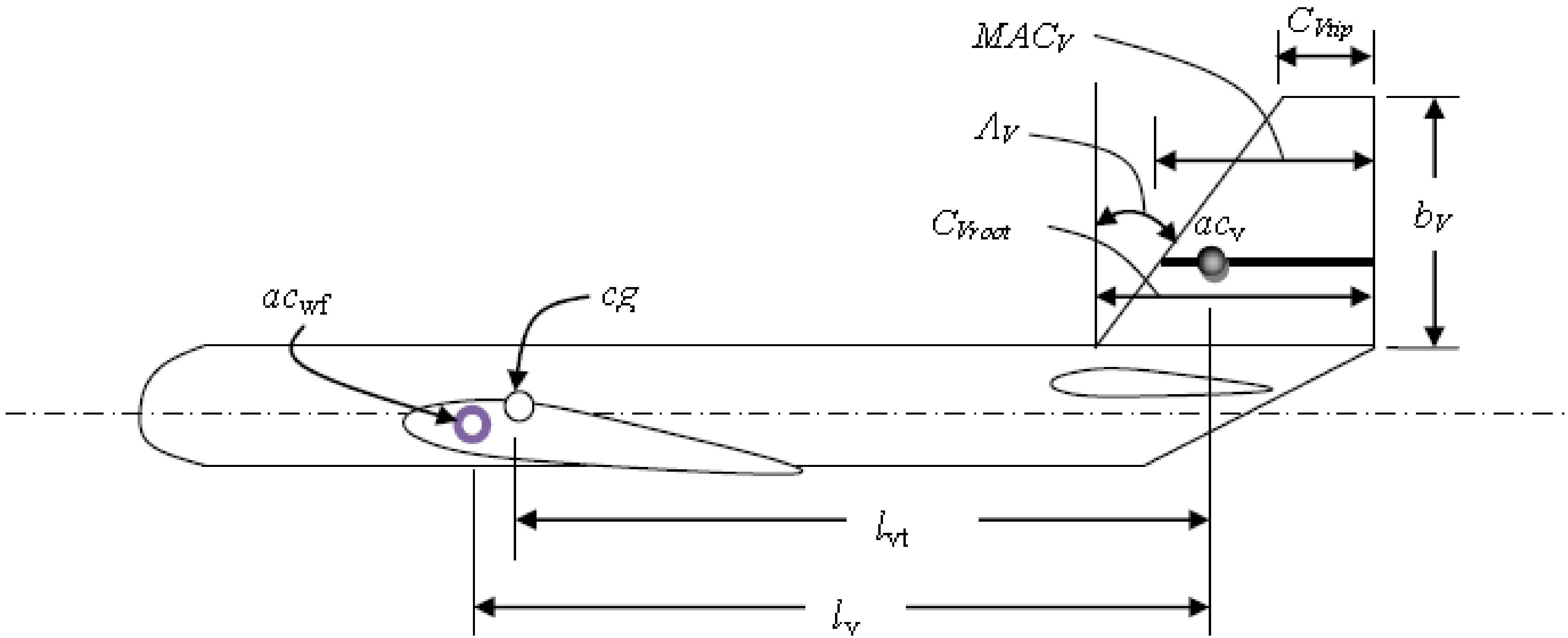


Figure 6.25. The vertical tail parameters

Fusefage Weight - II

- Fuselage Weight Equation

$$W_F = L_f \cdot D_{f_{max}}^2 \cdot \rho_{mat} \cdot K_{\rho_f} \cdot n_{ult}^{0.25} \cdot K_{inlet} \cdot g$$

siendo

L_f = fuselage length

$D_{f_{max}}$ = fuselage maximum diameter of the equivalent circular cross-section

ρ_{mat} = density of material (tabla 1)

K_{ρ_f} = fuselage density factor (table 1)

n_{ult} = ultimate load factor

K_{inlet} = 1.25 for the case of inlets on the fuselage

K_{inlet} = 1 for the case of inlets on the fuselage

W_F (British & SI units)

No	Aircraft	K_{ρ_f}
1	General aviation, home-built	0.002 – 0.003
2	Unmanned aerial vehicle	0.0021 – 0.0026
3	Transport, cargo, airliner	0.0025 – 0.0032
4	Remotely controlled model	0.0015 – 0.0025
5	Supersonic fighter	0.006 – 0.009

Table 1: Fuselage density factor for various aircraft

Landing Gear Weight - II

- Landing Gear Equation

$$W_{LG} = K_L \cdot K_{ret} \cdot K_{LG} \cdot W_L \cdot \left(\frac{H_{LG}}{b}\right) \cdot n_{ult_{land}}^{0.2}$$

siendo

$$\begin{aligned}
K_L &= \text{landing place factor} \Rightarrow 1.8 \text{ for navi aircraft} \\
K_L &= 1.8 \text{ for navy aircraft} \\
K_L &= 1.0 \text{ for other aircraft} \\
K_{ret} &= 1 \text{ for fixed landing} \\
K_{ret} &= 1.07 \text{ for retractable landing gear} \\
K_{LG} &= \text{landing gear weight factor} \\
W_L &= \text{aircraft weight landing} \\
n_{ult} &= \text{landing ultimate load factor} \\
b &= \text{wing span} \\
H_{LG} &= \text{landing gear height}
\end{aligned}$$

W_{LG} (British & SI units)

No	Aircraft	K_{LG}
1	General aviation, home-built	0.48 – 0.62
3	Transport, cargo, airliner	0.28 – 0.35
5	Supersonic fighter	0.31 – 0.36
4	Remotely controlled model	0.35 – 0.52

Table 1: Fuselage density factor for various aircraft

Installed Engine Weight - II

- Installed Engine Equation

$$W_{E_{ins}} = K_E \cdot N_E \cdot (W_E)^{0.9}$$

siendo

$$\begin{aligned} N_E &= \text{number of engines} \\ K_E &= \text{engine weight factor} \\ K_E &= 2.6 \text{ for British units} \\ K_L &= 3 \text{ for metric units} \\ W_E &= \text{weight of each engine} \end{aligned}$$

- Fuel System Weight

GA → $$W_{FS} = K_{fs} \cdot \left(\frac{W_fuel}{\rho_f}\right)^{n_{fs}}$$

W_{f_s} must be in lb (British)

for aviation gasoline $\rho_f = 5.87\ lb/gal$
for JP-4 $\rho_f = 6.55\ lb/gal$

siendo

$$\begin{aligned} W_{fuel} &= \text{weight of fuel} \\ K_{f_s} &= 2 \text{ for single-engine aircraft} \\ K_{f_s} &= 4.5 \text{ for multi-engine aircraft} \\ n_{f_s} &= 0.667 \text{ for single-engine aircraft} \\ n_{f_s} &= 0.6 \text{ for multi-engine aircraft} \\ \rho_f &= \text{fuel density} \end{aligned}$$

Installed Engine Weight - III

- Fuel System Weight: Transport and fighter aircraft
  - Transport and fighter equipped with non-self-sealing tanks:

$$W_{FS} = K_{fs} \cdot \left(\frac{W_fuel}{\rho_f}\right)^{n_{fs}}$$

W_{f_s} must be in lb (British)

siendo

$$\begin{aligned} W_{fuel} &= \text{weight of fuel (must be in lb)} \\ K_{f_s} &= 1.6 \\ n_{f_s} &= 0.727 \\ \rho_f &= \text{fuel density (must be in lb/gal)} \end{aligned}$$

  - Transport and fighter equipped with integral tanks (i.e. wet wing F-111):

$$W_{FS} = 15 \cdot (N_t)^{0.5} \cdot \left(\frac{W_fuel}{\rho_f}\right)^{0.333} + 80\,(N_E + N_t - 1)$$

siendo

$$\begin{aligned} W_{fuel} &= \text{weight of fuel (must be in lb)} \\ N_t &= \text{number of separate fuel tanks} \\ N_E &= \text{number of engines} \\ \rho_f &= \text{fuel density (must be in lb/gal)} \end{aligned}$$

W_{f_s} must be in lb (British)

Estimación Pesos

Método II

Ref:Aircraft Design,

Cambridge Aerospace Series, Ajoy Kumar Kundu, 2010

Método Gráfico Estimación de Pesos - I

Ref: Kundu

Table 8.1. *Smaller aircraft mass fraction (fewer than or 19 passengers – 2 abreast seating)*

Rapid mass estimation method: Summary of mass fraction of MTOM for smaller aircraft. A range of applicability is shown; add another ± 10% for extreme designs.

Permite determinar peso de distintos componentes de manera sencilla en función del porcentaje que representa cada uno de los componentes

Aplicable para aviones pequeños con menos de 19 pasajeros

Aproximación de 2 asientos por línea

		RJ/Midsized aircraft 2 engines		Large aircraft turbofan	
Group		Turboprop	Turbofan	2-engine	4-engine
Fuselage	$Ffu = M_{FU}/MTOM$	9 to 11	10 to 12	10 to 12	9 to 11
Wing	$Fw = M_W/MTOM$	7 to 9	9 to 11	12 to 14	11 to 12
H-tail	$Fht = M_{HT}/MTOM$	1.2 to 1.5	1.8 to 2.2	1 to 1.2	1 to 1.2
V-tail	$Fvt = M_{VT}/MTOM$	0.6 to 0.8	0.8 to 1.2	0.6 to 0.8	0.7 to 0.9
Nacelle	$Fn = M_N/MTOM$	2.5 to 3.5	1.5 to 2	0.7 to 0.9	0.8 to 0.9
Pylon	$Fpy = M_{PY}/MTOM$	0 to 0.5	0.5 to 0.7	0.3 to 0.4	0.4 to 0.5
Undercarriage	$Fuc = M_{UC}/MTOM$	4 to 5	3.4 to 4.5	4 to 6	4 to 5
Engine	$Feng = M_{ENG}/MTOM$	8 to 10	6 to 8	5.5 to 6	5.6 to 6
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0.4 to 0.6	0.7 to 0.9	0.8 to 1
Engine con.	$Fec = M_{EC}/MTOM$	1.5 to 2	0.8 to 1	0.2 to 0.3	0.2 to 0.3
Fuel system	$Ffs = M_{FS}/MTOM$	0.8 to 1	0.7 to 0.9	0.5 to 0.8	0.6 to 0.8
Oil system	$Fos = M_{OS}/MTOM$	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.3 to 0.4
APU		0 to 0.1	0 to 0.1	0.1	0.1
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1 to 1.2	1.4 to 2	1 to 2	1 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0.4 to 0.6	0.6 to 0.8	0.6 to 1	0.5 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	2 to 4	2 to 3	0.8 to 1.2	0.7 to 1
Instrument	$Fins = M_{INS}/MTOM$	1.5 to 2	1.4 to 1.8	0.3 to 0.4	0.3 to 0.4
Avionics	$Fav = M_{AV}/MTOM$	0.8 to 1	0.9 to 1.1	0.2 to 0.3	0.2 to 0.3
ECS	$Fecs = M_{ECS}/MTOM$	1.2 to 2.4	1 to 2	0.6 to 0.8	0.5 to 0.8
Oxygen	$Fox = M_{OX}/MTOM$	0.3 to 0.5	0.3 to 0.5	0.2 to 0.3	0.2 to 0.3
Furnishing	$Ffur = M_{FUR}/MTOM$	4 to 6	6 to 8	4.5 to 5.5	4.5 to 5.5
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.1	0 to 0.1	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1
MEW (%)		53 to 55	52 to 55	50 to 54	48 to 50
Crew		0.3 to 0.5	0.3 to 0.5	0.4 to 0.6	0.4 to 0.6
Consumable		1.5 to 2	1.5 to 2	1 to 1.5	1 to 1.5
OEW (%)		54 to 56	53 to 56	52 to 55	50 to 52
Payload and fuel are traded					
Payload		15 to 18	12 to 20	18 to 22	18 to 20
Fuel		20 to 28	22 to 30	20 to 25	25 to 32
MTOM (%)		100	100	100	100

Notes: Lighter/smaller aircraft would show a higher mass fraction.
A fuselage-mounted undercarriage is shorter and lighter for the same MTOM.
Turbofan aircraft with a higher speed would have a longer range as compared to turboprop aircraft and, therefore, would have a higher fuel fraction (typically, 2,000-nm range will have around 0.26).

Ref: Kundu

Group		Small-piston aircraft		Agriculture aircraft	Small aircraft 2-engine (Bizjet, utility)	
		1-Engine	2-Engine	(1-Piston)	(Turboprop)	(Turbofan)
Fuselage	$Ffu = M_{FU}/MTOM$	12 to 15	6 to 10	6 to 8	10 to 11	9 to 11
Wing	$Fw = M_{W}/MTOM$	10 to 14	9 to 11	14 to 16	10 to 12	9 to 12
H-tail	$Fht = M_{HT}/MTOM$	1.5 to 2.5	1.8 to 2.2	1.5 to 2	1.5 to 2	1.4 to 1.8
V-tail	$Fvt = M_{VT}/MTOM$	1 to 1.5	1.4 to 1.6	1 to 1.4	1 to 1.5	0.8 to 1
Nacelle	$Fn = M_{N}/MTOM$	1 to 1.5	1.5 to 2	1.2 to 1.5	1.5 to 1.8	1.4 to 1.8
Pylon	$Fpy = M_{PY}/MTOM$	0	0	0	0.4 to 0.5	0.5 to 0.8
Undercarriage	$Fuc = M_{E}/MTOM$	4 to 6	4 to 6	4 to 5	4 to 6	3 to 5
Engine	$Fuc = M_{UC}/MTOM$	11 to 16	18 to 20	12 to 15	7 to 10	7 to 9
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0	0	0	0
Engine control	$Fec = M_{EC}/MTOM$	1.5 to 2.5	2 to 3	1 to 2	1.5 to 2	1.7 to 2
Fuel system	$Ffs = M_{FS}/MTOM$	0.7 to 1.2	1.4 to 1.8	1 to 1.4	1 to 1.2	1.2 to 1.5
Oil system	$Fos = M_{OS}/MTOM$	0.1 to 0.3	0.25 to 0.4	0.1 to 0.3	0.3 to 0.5	0.3 to 0.5
APU		0	0	0	0	0
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1.5 to 2	1.4 to 1.6	1 to 1.5	1.5 to 2	1.5 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0 to 0.3	0.3 to 0.6	0 to 0.3	0.5 to 1.5	0.7 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	1.5 to 2.5	2 to 3	1.5 to 2	2 to 4	2 to 4
Instrument	$Fins = M_{INS}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1	0.8 to 1.5
Avionics	$Fav = M_{AV}/MTOM$	0.2 to 0.5	0.4 to 0.6	0.2 to 0.4	0.3 to 0.5	0.4 to 0.6
ECS	$Fecs = M_{ECS}/MTOM$	0 to 0.3	0.4 to 0.8	0 to 0.2	2 to 3	2 to 3
Oxygen	$Fox = M_{OX}/MTOM$	0 to 0.2	0 to 0.4	0	0.3 to 0.5	0.3 to 0.5
Furnishing	$Ffur = M_{FUR}/MTOM$	2 to 6	4 to 6	1 to 2	6 to 8	5 to 8
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0 to 0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	1 to 2	1 to 2	0 to 1	1 to 2	1 to 2
MEW (%)		57 to 67	60 to 65	58 to 62	58 to 63	55 to 60
Crew		6 to 12	6 to 8	4 to 6	1 to 3	1 to 3
Consumable		0 to 1	0 to 1	0	1 to 2	1 to 2
OEM (%)		65 to 75	65 to 70	62 to 66	60 to 66	58 to 64
Payload and fuel are traded						
Payload		12 to 25	12 to 20	20 to 30	15 to 25	15 to 20
Fuel		8 to 14	10 to 15	8 to 10	10 to 20	18 to 28
MTOM (%)		100	100	100	100	100

Método Gráfico Estimación de Pesos - I

Ref: Kundu

Table 8.2. *Larger aircraft mass fraction (more than 19 passengers – abreast and above seating).*

Rapid Mass Estimation Method: Summary of mass fraction of MTOM for larger aircraft. A range of applicability is shown; add another ± 10% for extreme designs.

Permite determinar peso de distintos componentes de manera sencilla en función del porcentaje que representa cada uno de los componentes

Aplicable para aviones con más de 19 pasajeros

		RJ/Midsized aircraft 2 engines		Large aircraft turbofan	
Group		Turboprop	Turbofan	2-engine	4-engine
Fuselage	$Ffu = M_{FU}/MTOM$	9 to 11	10 to 12	10 to 12	9 to 11
Wing	$Fw = M_W/MTOM$	7 to 9	9 to 11	12 to 14	11 to 12
H-tail	$Fht = M_{HT}/MTOM$	1.2 to 1.5	1.8 to 2.2	1 to 1.2	1 to 1.2
V-tail	$Fvt = M_{VT}/MTOM$	0.6 to 0.8	0.8 to 1.2	0.6 to 0.8	0.7 to 0.9
Nacelle	$Fn = M_N/MTOM$	2.5 to 3.5	1.5 to 2	0.7 to 0.9	0.8 to 0.9
Pylon	$Fpy = M_{PY}/MTOM$	0 to 0.5	0.5 to 0.7	0.3 to 0.4	0.4 to 0.5
Undercarriage	$Fuc = M_{UC}/MTOM$	4 to 5	3.4 to 4.5	4 to 6	4 to 5
Engine	$Feng = M_{ENG}/MTOM$	8 to 10	6 to 8	5.5 to 6	5.6 to 6
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0.4 to 0.6	0.7 to 0.9	0.8 to 1
Engine con.	$Fec = M_{EC}/MTOM$	1.5 to 2	0.8 to 1	0.2 to 0.3	0.2 to 0.3
Fuel system	$Ffs = M_{FS}/MTOM$	0.8 to 1	0.7 to 0.9	0.5 to 0.8	0.6 to 0.8
Oil system	$Fos = M_{OS}/MTOM$	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.3 to 0.4
APU		0 to 0.1	0 to 0.1	0.1	0.1
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1 to 1.2	1.4 to 2	1 to 2	1 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0.4 to 0.6	0.6 to 0.8	0.6 to 1	0.5 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	2 to 4	2 to 3	0.8 to 1.2	0.7 to 1
Instrument	$Fins = M_{INS}/MTOM$	1.5 to 2	1.4 to 1.8	0.3 to 0.4	0.3 to 0.4
Avionics	$Fav = M_{AV}/MTOM$	0.8 to 1	0.9 to 1.1	0.2 to 0.3	0.2 to 0.3
ECS	$Fecs = M_{ECS}/MTOM$	1.2 to 2.4	1 to 2	0.6 to 0.8	0.5 to 0.8
Oxygen	$Fox = M_{OX}/MTOM$	0.3 to 0.5	0.3 to 0.5	0.2 to 0.3	0.2 to 0.3
Furnishing	$Ffur = M_{FUR}/MTOM$	4 to 6	6 to 8	4.5 to 5.5	4.5 to 5.5
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.1	0 to 0.1	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1
MEW (%)		53 to 55	52 to 55	50 to 54	48 to 50
Crew		0.3 to 0.5	0.3 to 0.5	0.4 to 0.6	0.4 to 0.6
Consumable		1.5 to 2	1.5 to 2	1 to 1.5	1 to 1.5
OEW (%)		54 to 56	53 to 56	52 to 55	50 to 52
Payload and fuel are traded					
Payload		15 to 18	12 to 20	18 to 22	18 to 20
Fuel		20 to 28	22 to 30	20 to 25	25 to 32
MTOM (%)		100	100	100	100

Notes: Lighter aircraft would show higher mass fraction.
A fuselage-mounted undercarriage is shorter and lighter for the same MTOM.
Turbofan aircraft with a higher speed would have a longer range as compared to turboprop aircraft and, therefore, would have a higher fuel fraction.
Large turbofan aircraft have wing-mounted engines: 4-engine configurations are bigger.

Ref: Kundu

Group		RJ/Midsized aircraft 2 engines		Large aircraft turbofan	
		Turboprop	Turbofan	2-engine	4-engine
Fuselage	$Ffu = M_{FU}/MTOM$	9 to 11	10 to 12	10 to 12	9 to 11
Wing	$Fw = M_W/MTOM$	7 to 9	9 to 11	12 to 14	11 to 12
H-tail	$Fht = M_{HT}/MTOM$	1.2 to 1.5	1.8 to 2.2	1 to 1.2	1 to 1.2
V-tail	$Fvt = M_{VT}/MTOM$	0.6 to 0.8	0.8 to 1.2	0.6 to 0.8	0.7 to 0.9
Nacelle	$Fn = M_N/MTOM$	2.5 to 3.5	1.5 to 2	0.7 to 0.9	0.8 to 0.9
Pylon	$Fpy = M_{PY}/MTOM$	0 to 0.5	0.5 to 0.7	0.3 to 0.4	0.4 to 0.5
Undercarriage	$Fuc = M_{UC}/MTOM$	4 to 5	3.4 to 4.5	4 to 6	4 to 5
Engine	$Feng = M_{ENG}/MTOM$	8 to 10	6 to 8	5.5 to 6	5.6 to 6
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0.4 to 0.6	0.7 to 0.9	0.8 to 1
Engine con.	$Fec = M_{EC}/MTOM$	1.5 to 2	0.8 to 1	0.2 to 0.3	0.2 to 0.3
Fuel system	$Ffs = M_{FS}/MTOM$	0.8 to 1	0.7 to 0.9	0.5 to 0.8	0.6 to 0.8
Oil system	$Fos = M_{OS}/MTOM$	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.3 to 0.4
APU		0 to 0.1	0 to 0.1	0.1	0.1
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1 to 1.2	1.4 to 2	1 to 2	1 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0.4 to 0.6	0.6 to 0.8	0.6 to 1	0.5 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	2 to 4	2 to 3	0.8 to 1.2	0.7 to 1
Instrument	$Fins = M_{INS}/MTOM$	1.5 to 2	1.4 to 1.8	0.3 to 0.4	0.3 to 0.4
Avionics	$Fav = M_{AV}/MTOM$	0.8 to 1	0.9 to 1.1	0.2 to 0.3	0.2 to 0.3
ECS	$Fecs = M_{ECS}/MTOM$	1.2 to 2.4	1 to 2	0.6 to 0.8	0.5 to 0.8
Oxygen	$Fox = M_{OX}/MTOM$	0.3 to 0.5	0.3 to 0.5	0.2 to 0.3	0.2 to 0.3
Furnishing	$Ffur = M_{FUR}/MTOM$	4 to 6	6 to 8	4.5 to 5.5	4.5 to 5.5
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.1	0 to 0.1	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1
MEW (%)		53 to 55	52 to 55	50 to 54	48 to 50
Crew		0.3 to 0.5	0.3 to 0.5	0.4 to 0.6	0.4 to 0.6
Consumable		1.5 to 2	1.5 to 2	1 to 1.5	1 to 1.5
OEW (%)		54 to 56	53 to 56	52 to 55	50 to 52
Payload and fuel are traded					
Payload		15 to 18	12 to 20	18 to 22	18 to 20
Fuel		20 to 28	22 to 30	20 to 25	25 to 32
MTOM (%)		100	100	100	100

Estimación de Pesos de Componentes

Ref: Kundu

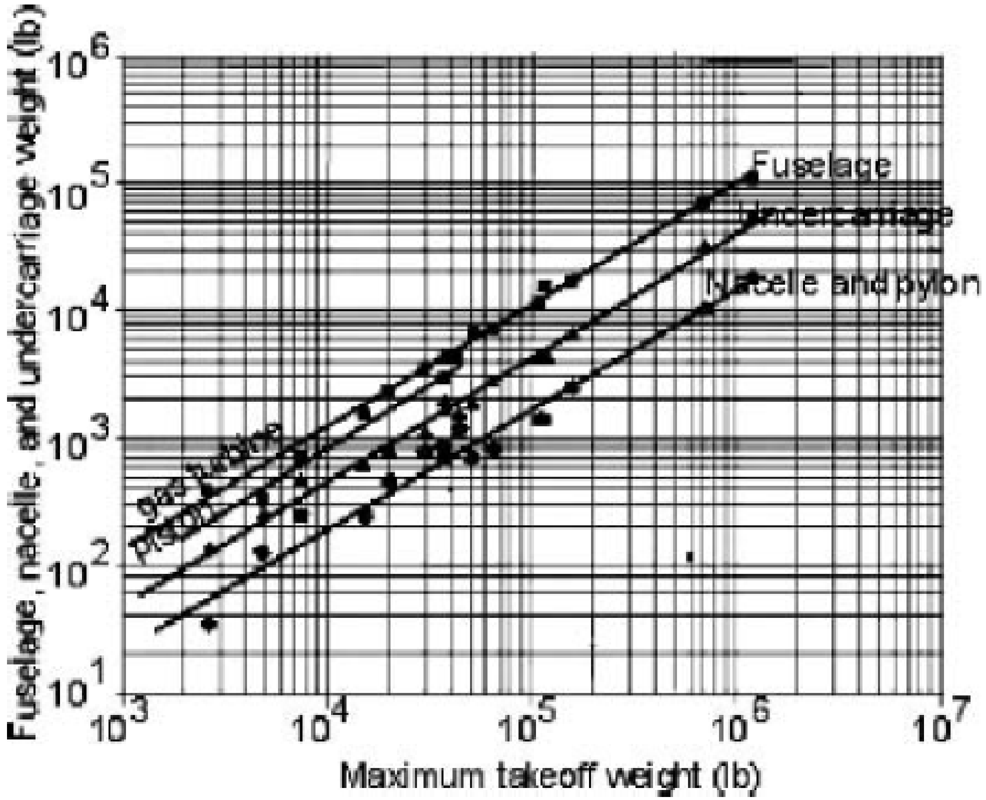
Estimación de pesos de componentes que permite comparar con pesos obtenidos

		Weight (lb)						
Aircraft	MTOW	Fuse	Wing	Emp	Nacelle	Eng	U/C	n
Piston-engined aircraft								
1. Cessna182	2,650	400	238	62	34	417	132	5.70
2. Cessna310A	4,830	319	453	118	129	852	263	5.70
3. Beech65	7,368	601	570	153	285	1,008	444	6.60
4. Cessna404	8,400	610	860	181	284	1,000	316	3.75
5. Herald	37,500	2,986	4,365	987	830		1,625	3.75
6. Convair240	43,500	4,227	3,943	922	1,213		1,530	3.75
Gas-turbine–powered aircraft								
7. Lear25	15,000	1,575	1,467	361	241	792	584	3.75
8. Lear45 class	20,000	2,300	2,056	385	459	1,672	779	3.75
9. Jet Star	30,680	3,491	2,827	879	792	1,750	1,061	3.75
10. Fokker27-100	37,500	4,122	4,408	977	628	2,427	1,840	3.75
11. CRJ200 class	51,000	6,844	5,369	1,001			1,794	5.75
12. F28-1000	65,000	7,043	7,330	1,632	834	4,495	2,759	3.75
13. Gulf GII (J)	64,800	5,944	6,372	1,965	1,239	6,570	2,011	3.75
14. MD-9-30	108,000	16,150	11,400	2,780	1,430	6,410	4,170	3.75
15. B737-200	115,500	12,108	10,613	2,718	1,392	6,217	4,354	3.75
16. A320 class	162,000	17,584	17,368	2,855	2,580	12,300	6,421	3.75
17. B747-100	710,000	71,850	86,402	11,850	10,031	34,120	31,427	3.75
18. A380 class	1,190,497	115,205	170,135	24,104		55,200	52,593	3.75

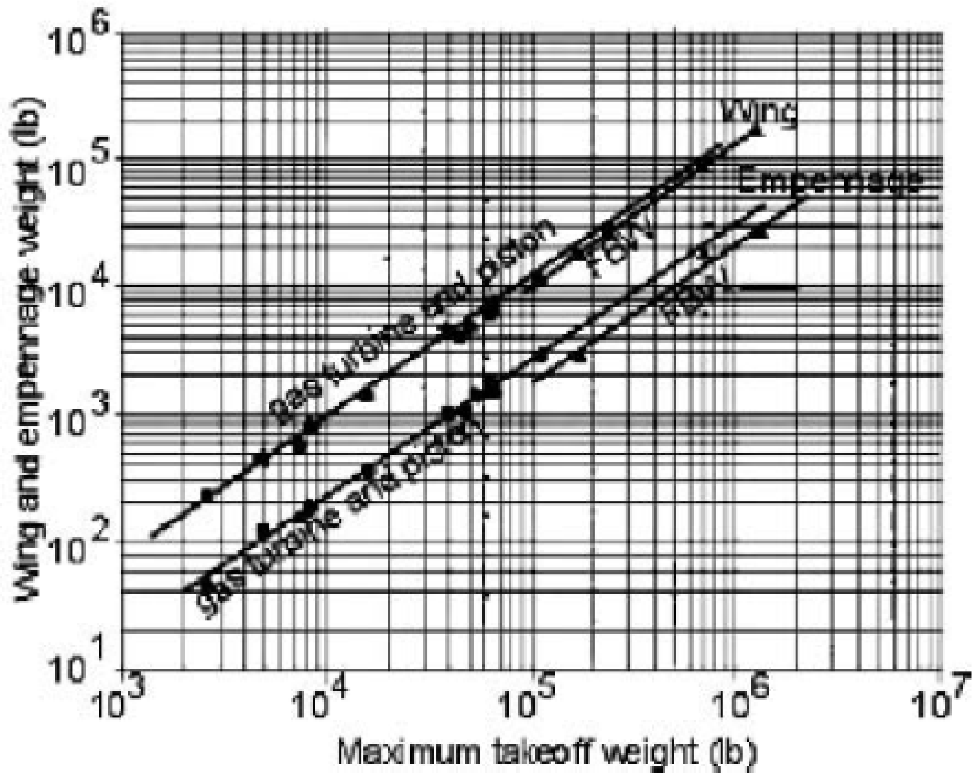
Estimación de Pesos de Componentes

Ref: Kundu

Estimación de pesos de componentes que permite comparar con pesos obtenidos



Fuselage,nacelle, and undercarriage weight (lbs)



Wing and empenage (cola) weight (lbs)

Aircraft component weights in pounds

Fuselaje Contributions - I

Ref: Kundu

Fuselaje Aviones Civiles

1ª estimación

$$M_{Fcivil} = 0.039 \times (2 \times L \times D_{ave} \times V_D^{0.5})^{1.5}$$

L = fuselage length
D_{ave} = fuselage depth average
$MTOW$ = MAXIMUM TAKE OFF WEIGHT
V_D = design dive speed in knots equivalent air speed (KEAS)
n_{ult} = ultimate load factor

Estimación detallada

$$M_{Fcivil} = c_{fus} \times k_e \times k_p \times k_{uc} \times k_{door} \times (MTOM \times n_{ult})^x \times (2 \times L \times D_{ave} \times V_D^{0.5})^y,$$

The value of index *x* depends on the aircraft size:

- 0 for aircraft with an ultimate load (*nult*) < 5
- between 0.001 and 0.002 for ultimate loads of (*nult*) >5 (i.e., lower

values for heavier aircraft).
In general, $x = 0$ for civil aircraft; therefore, $(MTOM \times nult)^x = 1$.
The value of index *y* is very sensitive. Typically, y is 1.5, but it can be as low as 1.45.
It is best to fine-tune with a known result in the aircraft class and then use it for the new design.

Fuselaje Contributions - II

Ref: Kundu

$$M_{Fcivil} = c_{fus} \times k_e \times k_p \times k_{uc} \times k_{door} \times (MTOM \times n_{ult})^{x} \times (2 \times L \times D_{ave} \times V_D^{0.5})^{y},$$

c_{fus} = 0.038 for small unpressurized aircraft (leaving the engine bulkhead forward)
= 0.041 for a small transport aircraft ($\leq$19 passengers)
= 0.04 for 20 to 100 passengers
= 0.039 for a midsized aircraft
= 0.0385 for a large aircraft
= 0.04 for a double-decked fuselage
= 0.037 for an unpressurized, rectangular-section fuselage

All k-values are 1 unless otherwise specified for the configuration, as follows:

k_e = for fuselage-mounted engines = 1.05 to 1.07
k_p = for pressurization = 1.08 up to 40,000-ft operational altitude
= 1.09 above 40,000-ft operational altitude
k_{uc} = 1.04 for a fixed undercarriage on the fuselage
= 1.06 for wheels in the fuselage recess
= 1.08 for a fuselage-mounted undercarriage without a bulge
= 1.1 for a fuselage-mounted undercarriage with a bulge
k_{VD} = 1.0 for low-speed aircraft below Mach 0.3
= 1.02 for aircraft speed 0.3 < Mach < 0.6
= 1.03 to 1.05 for all other high-subsonic aircraft
k_{door} = 1.1 for a rear-loading door

Fuselaje Contributions - III

Ref: Kundu

Para aviones civiles ($n_{ult} < 5$), se simplifica a

$$M_{Fcivil} = c_{fus} \times k_e \times k_p \times k_{uc} \times k_{door} \times (2 \times L \times D_{ave} \times V_D^{0.5})^{1.5}$$

For the club-flying–type small aircraft, the fuselage weight with a fixed undercarriage

$$M_{Fsmalla/c} = 0.038 \times 1.07 \times k_{uc} \times (2 \times L \times D_{ave} \times V_D^{0.5})^{1.5}$$

If new materials are used, then the mass changes by the factor of usage.
For example, x% mass is new material → that is y% lighter;

$$M_{Fcivil\_new-material} = M_{Fcivil} - x/y \times M_{Fcivil} + x \times M_{Fcivil}$$

In a simpler form, if there is reduction in mass due to lighter material, then it is reduced by that factor. For example, if there is 10% mass saving, then

$$M_{Fcivil} = 0.9 \times M_{Fcivil\_all\,metal}$$

Wing Contributions - I

Ref: Kundu

Wing contribution

$$M_W = c_w \times k_{uc} \times k_{sl} \times k_{sp} \times k_{wl} \times k_{re} \times (\text{MTOM} \times n_{ult})^{0.48} \times S_W^{0.78} \times A_R$$
$$\times (1+\lambda)^{0.4} \times (1 - W_{Fuel\_mass\_in\_wing}/\text{MTOW})^{0.4} / [(\text{Cos}\Lambda) \times \text{t/c}^{0.4}]$$

$M_{dg} = MTOM$ (mass)

where $c_w = 0.0215$ and flaps are a standard fitment to the wing.

$k_{uc} = 1.002$ for a wing-mounted undercarriage; otherwise, 1.0

$k_{sl} = 1.004$ for the use of a slat

$k_{sp} = 1.001$ for a spoiler

$k_{wl} = 1.002$ for a winglet (a generalized approach for a standard size)

$k_{re} = 1$ for no engine, 0.98 for two engines, and 0.95 for four engines (generalized)

If new materials are used, then the mass changes by the factor of usage.
For example, x% mass is new material → that is y% lighter;

$$M_{W civil\_nonmetal} = M_{W civil} - \text{x/y} \times M_{W civil} + x \times M_{W civil}$$

In a simpler form, if there is reduction in mass due to lighter material, then it is reduced by that factor. For example, if there is 10% mass saving, then

$$M_{W civil\_nonmetal} = 0.9 \times M_{W civil\_all\ metal}$$

Empenage Contributions - I

Ref: Kundu

Empennage for an H-tail and a V-tail as follows.

- for all H-tail movement, and mid-tail use $k_{conf} = 1.05$
- For a low tail $k_{conf} = 1.0$
- For V-Tail and T-tail configurations, use $k_{conf} = 1.1$

Horizontal tail

$$M_{HT} = 0.02 \times k_{conf} \times (\text{MTOM} \times n_{ult})^{0.48} \times S_W{}^{0.78} \times AR \times (1+\lambda)^{0.4} / (\text{Cos}\Lambda \times \text{t/c}^{0.4})$$

Verticaltail

$$M_{VT} = 0.0215 \times k_{conf} \times (\text{MTOM} \times n_{ult})^{0.48} \times S_W{}^{0.78} \times AR \times (1+\lambda)^{0.4} / (\text{Cos}\Lambda \times \text{t/c}^{0.4})$$

If new materials are used, then the mass changes by the factor of usage. For example, x% mass is new material → that is y% lighter;

$$M_{EMPcivil\_nonmetal} = M_{EMPcivil} - \text{x/y} \times M_{EMPcivil} + x \times M_{EMPcivil}$$

In a simpler form, if there is reduction in mass due to lighter material, then it is reduced by that factor. For example, if there is 10% mass saving, then

$$M_{EMcivil\_nonmetal} = 0.9\, M_{EMcivil\_all\ metal}$$

Nacelle Group Contributions - I

Ref: Kundu

The nacelle group can be classified distinctly as a pod that is mounted and interfaced with pylons on the wing or fuselage, or it can be combined. The nacelle size depends on the engine size and type. The nacelle mass semi-empirical relations are as follow.

Jet Type (Includes Pylon Mass)

For a BPR greater than 4.0, $M_{NAC\_jet} = 6.7 \times thrust\,(kN)$ per nacelle.

For a BPR less than 4.0, $M_{NAC\_jet} = 6.2 \times thrust\,(kN)$ per nacelle.

Turboprop Type

Pods are slung under the wing or placed above the wing with little pylon, unless it is an aft-fuselage–mounted pusher type (e.g., Piaggio Avanti). For the same power, turboprop engines are nearly 20% heavier, requiring stronger nacelles; however, they have a small or no pylon.

For a wing-mounted turboprop nacelle $M_{NAC\_prop} = 6.5 \times SHP$ per nacelle

For a turboprop nacelle housing an undercarriage $M_{NAC\_prop\_uc} = 8 \times SHP$ per nacelle

For a fuselage-mounted turboprop nacelle with a pylon $M_{NAC\_prop} = 7 \times 4 \times SHP$ per nacelle

Nacelle Group Contributions - II

Ref: Kundu

Piston-Engine Nacelle

For tractor types, the nacelle is forward of the engine bulkhead; for pusher types, it is aft of the engine bulkhead – both have an engine mount. This mass is not considered a fuselage mass, even when it is an extension of the fuselage mould line.

For a fuselage-mounted, piston-engine nacelle

$$M_{nac\_piston} = 0.4 \times HP \text{ per nacelle}$$

For a wing-mounted, piston-engine nacelle:

$$M_{nac\_piston} = 0.5 \times HP \text{ per nacelle}$$

If new materials are used, then the mass changes by the factor of usage. For example, x% mass is new material → that is y% lighter;

$$M_{nac\_civil\_nonmetal} = M_{nac\_civil} - \text{x/y} \times M_{nac\_civil} + x \times M_{nac\_civil}$$

Under Carriage Contributions - I

Ref: Kundu

Tricycle Type (Retractable) – Wing-Mounted (Nose and Main Gear Estimated Together)

For a low-wing–mounted undercarriage

$$M_{UC\_wing} = 0.04 \times \text{MTOM}$$

For a midwing-mounted undercarriage:

$$M_{UC\_wing} = 0.042 \times \text{MTOM}$$

For a high-wing–mounted undercarriage:

$$M_{UC\_wing} = 0.044 \times \text{MTOM}$$

Tricycle Type (Retractable) – Wing-Mounted (Nose and Main Gear Estimated Together)

$$M_{UC\_fus} = 0.04 \times \text{MTOM}$$

For a fixed undercarriage, the mass is 10 to 15% lighter; for a tail-dragger, it is 20 to 25% lighter.

Power Plant Group - I

Ref: Kundu

Estimación de los distintos componentes de sistema propulsivo en función de $M_{DRY-ENG}$

$M_{DRY-ENG}$ - Masa en seco proporcionada por el constructor

Turbofans

(1) Equipped dry-engine mass (*ME*)
(2) Thrust-reverser mass (*MTR*), if any – mostly installed on bigger engines
(3) Engine control system mass (*MEC*)
(4) Fuel system mass (*MFS*)
(5) Engine oil system mass (*MOI*)

Turboprops

(1) Equipped dry-engine mass (*ME*) – includes reduction gear mass to drive propeller
(2) Propeller (*MPR*)
(3) Engine control system mass (*MEC*)
(4) Fuel system mass (*MFS*)
(5) Engine oil system mass (*MOI*)

Piston Engines

(1) Equipped dry-engine mass (*ME*) – includes reduction gear, if any
(2) Propeller mass (*MPR*)
(3) Engine control system mass (*MEC*)
(4) Fuel system mass (*MFS*)
(5) Engine oil system mass (*MOI*)

Power Plant Group - II

Ref: Kundu

Turbofan

Civil aircraft power plant (with no thrust reverser):

$$M_{ENG\_tf} = 1.4 \times M_{DRYENG} \text{ per engine}$$

Civil aircraft power plant (with thrust reverser):

$$M_{ENG\_tf} = 1.5 \times M_{DRYENG} \text{ per engine}$$

Turboprop

Civil aircraft power plant: where $1.4 \leq k_{tp} \leq 1.5$

$$M_{ENG\_tp} = k_{tp} \times M_{DRYENG} \text{ per engine}$$

Piston Engine

Civil aircraft power plant: where $1.4 \leq k_p \leq 1.5$

$$M_{ENG\_ps} = kp \times M_{DRYENG} \text{ per engine}$$

APU (if any)

$$M_{APU} = 0.001 \text{ to } 0.005 \times M_{DRYENG} \text{ of an engine}$$

Systems Group - I

Ref: Kundu

Civil Aircraft

The systems group includes flight controls, hydraulics and pneumatics, electrical, instrumentation, avionics, and environmental controls. At the conceptual design stage, these are grouped together to obtain the power plant group.

$$M_{SYS} = 0.1 \text{ to } 0.11 \times \text{MTOW for large aircraft} > 100 \text{ passengers}$$

$$M_{SYS} = 0.11 \text{ to } 0.12 \times \text{MTOW for smaller transport aircraft of} < 100 \text{ passengers}$$

$$M_{SYS} = 0.05 \text{ to } 0.07 \times \text{MTOW for unpressurized aircraft}$$

Furnishing Group - I

Ref: Kundu

Civil Aircraft

This group includes the seats, galleys, furnishings, toilets, oxygen system, and paint. At the conceptual design stage, they are grouped together to obtain the furnishing group.

$$M_{FUR} = 0.07 \text{ to } 0.08 \times \text{MTOW for large aircraft} > 100 \text{ passengers}$$

$$M_{FUR} = 0.06 \text{ to } 0.07 \times \text{MTOW for smaller transport aircraft of} < 100 \text{ passengers}$$

$$M_{FUR} = 0.02 \text{ to } 0.025 \times \text{MTOW for unpressurized aircraft}$$

Contingency,Misc and Crew - I

Ref: Kundu

Contingencies and Misc – Civil Aircraft

$$M_{CONT} = (0.01 \text{ to } 0.025) \times \text{MTOW}$$

$$M_{MISC} = 0 \text{ to } 1\% \text{ of MTOW}$$

Crew – Civil Aircraft

A civil aircraft crew consists of a flight crew and a cabin crew. Except for very small aircraft, the minimum flight crew is two, with an average of 90 kg per crew member. The minimum number of cabin crew depends on the number of passengers. Operators may employ more than the minimum number,

Number of passengers	Minimum number of cabin crew	Number of passengers	Minimum number of cabin crew
$\geq$19	1	200 to $<$250	7
19 to $<$30	2	250 to $<$300	8
21 to $<$50	3	300 to $<$350	9
50 to $<$100	4	350 to $<$400	10
100 to $<$150	5	400 to $<$450	11
150 to $<$200	6	450 to $<$500	12

Comparativa de Pesos de Sistemas - I

Ref: Kundu

Permite determinar peso de distintos componentes del sistema en función de porcentaje con respecto al MTOW

Table 8.1. *Smaller aircraft mass fraction (fewer than or 19 passengers – 2 abreast seating)*

Rapid mass estimation method: Summary of mass fraction of MTOM for smaller aircraft. A range of applicability is shown; add another ± 10% for extreme designs.

Aplicable para aviones pequeños con menos de 19 pasajeros

Aproximación de 2 asientos por línea

		Small-piston aircraft		Agriculture aircraft	Small aircraft 2-engine (Bizjet, utility)	
Group		1-Engine	2-Engine	(1-Piston)	(Turboprop)	(Turbofan)
Engine	$Fuc = M_{UC}/MTOM$	11 to 16	18 to 20	12 to 15	7 to 10	7 to 9
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0	0	0	0
Engine control	$Fec = M_{EC}/MTOM$	1.5 to 2.5	2 to 3	1 to 2	1.5 to 2	1.7 to 2
Fuel system	$Ffs = M_{FS}/MTOM$	0.7 to 1.2	1.4 to 1.8	1 to 1.4	1 to 1.2	1.2 to 1.5
Oil system	$Fos = M_{OS}/MTOM$	0.1 to 0.3	0.25 to 0.4	0.1 to 0.3	0.3 to 0.5	0.3 to 0.5
APU		0	0	0	0	0
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1.5 to 2	1.4 to 1.6	1 to 1.5	1.5 to 2	1.5 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0 to 0.3	0.3 to 0.6	0 to 0.3	0.5 to 1.5	0.7 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	1.5 to 2.5	2 to 3	1.5 to 2	2 to 4	2 to 4
Instrument	$Fins = M_{INS}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1	0.8 to 1.5
Avionics	$Fav = M_{AV}/MTOM$	0.2 to 0.5	0.4 to 0.6	0.2 to 0.4	0.3 to 0.5	0.4 to 0.6
ECS	$Fecs = M_{ECS}/MTOM$	0 to 0.3	0.4 to 0.8	0 to 0.2	2 to 3	2 to 3
Oxygen	$Fox = M_{OX}/MTOM$	0 to 0.2	0 to 0.4	0	0.3 to 0.5	0.3 to 0.5
Furnishing	$Ffur = M_{FUR}/MTOM$	2 to 6	4 to 6	1 to 2	6 to 8	5 to 8
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0 to 0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	1 to 2	1 to 2	0 to 1	1 to 2	1 to 2

Notes: Lighter/smaller aircraft would show a higher mass fraction.
A fuselage-mounted undercarriage is shorter and lighter for the same MTOM.
Turbofan aircraft with a higher speed would have a longer range as compared to turboprop aircraft and, therefore, would have a higher fuel fraction (typically, 2,000-nm range will have around 0.26).

Comparativa de Pesos de Sistemas - II

Ref: Kundu

		Small-piston aircraft		Agriculture aircraft	Small aircraft 2-engine (Bizjet, utility)	
Group		1-Engine	2-Engine	(1-Piston)	(Turboprop)	(Turbofan)
Engine	$Fuc = M_{UC}/MTOM$	11 to 16	18 to 20	12 to 15	7 to 10	7 to 9
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0	0	0	0
Engine control	$Fec = M_{EC}/MTOM$	1.5 to 2.5	2 to 3	1 to 2	1.5 to 2	1.7 to 2
Fuel system	$Ffs = M_{FS}/MTOM$	0.7 to 1.2	1.4 to 1.8	1 to 1.4	1 to 1.2	1.2 to 1.5
Oil system	$Fos = M_{OS}/MTOM$	0.1 to 0.3	0.25 to 0.4	0.1 to 0.3	0.3 to 0.5	0.3 to 0.5
APU		0	0	0	0	0
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1.5 to 2	1.4 to 1.6	1 to 1.5	1.5 to 2	1.5 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0 to 0.3	0.3 to 0.6	0 to 0.3	0.5 to 1.5	0.7 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	1.5 to 2.5	2 to 3	1.5 to 2	2 to 4	2 to 4
Instrument	$Fins = M_{INS}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1	0.8 to 1.5
Avionics	$Fav = M_{AV}/MTOM$	0.2 to 0.5	0.4 to 0.6	0.2 to 0.4	0.3 to 0.5	0.4 to 0.6
ECS	$Fecs = M_{ECS}/MTOM$	0 to 0.3	0.4 to 0.8	0 to 0.2	2 to 3	2 to 3
Oxygen	$Fox = M_{OX}/MTOM$	0 to 0.2	0 to 0.4	0	0.3 to 0.5	0.3 to 0.5
Furnishing	$Ffur = M_{FUR}/MTOM$	2 to 6	4 to 6	1 to 2	6 to 8	5 to 8
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0 to 0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	1 to 2	1 to 2	0 to 1	1 to 2	1 to 2

Comparativa de Pesos de Sistemas - III

Ref: Kundu

Permite determinar peso de distintos componentes del sistema en función de porcentaje con respecto al MTOW

Table 8.2. *Larger aircraft mass fraction (more than 19 passengers – abreast and above seating).*

Rapid Mass Estimation Method: Summary of mass fraction of MTOM for larger aircraft. A range of applicability is shown; add another ± 10% for extreme designs.

Aplicable para aviones con más de 19 pasajeros

		RJ/Midsized aircraft 2 engines		Large aircraft turbofan	
Group		Turboprop	Turbofan	2-engine	4-engine
Engine	$Feng = M_{ENG}/MTOM$	8 to 10	6 to 8	5.5 to 6	5.6 to 6
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0.4 to 0.6	0.7 to 0.9	0.8 to 1
Engine con.	$Fec = M_{EC}/MTOM$	1.5 to 2	0.8 to 1	0.2 to 0.3	0.2 to 0.3
Fuel system	$Ffs = M_{FS}/MTOM$	0.8 to 1	0.7 to 0.9	0.5 to 0.8	0.6 to 0.8
Oil system	$Fos = M_{OS}/MTOM$	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.3 to 0.4
APU		0 to 0.1	0 to 0.1	0.1	0.1
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1 to 1.2	1.4 to 2	1 to 2	1 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0.4 to 0.6	0.6 to 0.8	0.6 to 1	0.5 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	2 to 4	2 to 3	0.8 to 1.2	0.7 to 1
Instrument	$Fins = M_{INS}/MTOM$	1.5 to 2	1.4 to 1.8	0.3 to 0.4	0.3 to 0.4
Avionics	$Fav = M_{AV}/MTOM$	0.8 to 1	0.9 to 1.1	0.2 to 0.3	0.2 to 0.3
ECS	$Fecs = M_{ECS}/MTOM$	1.2 to 2.4	1 to 2	0.6 to 0.8	0.5 to 0.8
Oxygen	$Fox = M_{OX}/MTOM$	0.3 to 0.5	0.3 to 0.5	0.2 to 0.3	0.2 to 0.3
Furnishing	$Ffur = M_{FUR}/MTOM$	4 to 6	6 to 8	4.5 to 5.5	4.5 to 5.5
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.1	0 to 0.1	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1

Notes: Lighter aircraft would show higher mass fraction.
A fuselage-mounted undercarriage is shorter and lighter for the same MTOM.
Turbofan aircraft with a higher speed would have a longer range as compared to turboprop aircraft and, therefore, would have a higher fuel fraction.
Large turbofan aircraft have wing-mounted engines: 4-engine configurations are bigger.

Comparativa de Pesos de Sistemas - IV

Group		RJ/Midsized aircraft 2 engines Turboprop	Turbofan	Large aircraft turbofan 2-engine	4-engine
Engine	$Feng = M_{ENG}/MTOM$	8 to 10	6 to 8	5.5 to 6	5.6 to 6
Thrust rev.	$Ftr = M_{TR}/MTOM$	0	0.4 to 0.6	0.7 to 0.9	0.8 to 1
Engine con.	$Fec = M_{EC}/MTOM$	1.5 to 2	0.8 to 1	0.2 to 0.3	0.2 to 0.3
Fuel system	$Ffs = M_{FS}/MTOM$	0.8 to 1	0.7 to 0.9	0.5 to 0.8	0.6 to 0.8
Oil system	$Fos = M_{OS}/MTOM$	0.2 to 0.3	0.2 to 0.3	0.3 to 0.4	0.3 to 0.4
APU		0 to 0.1	0 to 0.1	0.1	0.1
Flight con. sys.	$Ffc = M_{FC}/MTOM$	1 to 1.2	1.4 to 2	1 to 2	1 to 2
Hydr./pneu. sys.	$Fhp = M_{HP}/MTOM$	0.4 to 0.6	0.6 to 0.8	0.6 to 1	0.5 to 1
Electrical	$Felc = M_{ELEC}/MTOM$	2 to 4	2 to 3	0.8 to 1.2	0.7 to 1
Instrument	$Fins = M_{INS}/MTOM$	1.5 to 2	1.4 to 1.8	0.3 to 0.4	0.3 to 0.4
Avionics	$Fav = M_{AV}/MTOM$	0.8 to 1	0.9 to 1.1	0.2 to 0.3	0.2 to 0.3
ECS	$Fecs = M_{ECS}/MTOM$	1.2 to 2.4	1 to 2	0.6 to 0.8	0.5 to 0.8
Oxygen	$Fox = M_{OX}/MTOM$	0.3 to 0.5	0.3 to 0.5	0.2 to 0.3	0.2 to 0.3
Furnishing	$Ffur = M_{FUR}/MTOM$	4 to 6	6 to 8	4.5 to 5.5	4.5 to 5.5
Miscellaneous	$Fmsc = M_{MSC}/MTOM$	0 to 0.1	0 to 0.1	0 to 0.5	0 to 0.5
Paint	$Fpn = M_{PN}/MTOM$	0.01	0.01	0.01	0.01
Contingency	$Fcon = M_{CON}/MTOM$	0.5 to 1	0.5 to 1	0.5 to 1	0.5 to 1

Estimación Pesos

Método III

Ref:Aircraft Design: A Conceptual Aproach

Daniel P. Raymer

Cargo/Transport Weights - I

Estimación pesos de superficies aerodinámicas

Wing / Canard (si almacena combustible)

$$W_{\text{wing}} = 0.0051\,(W_{dg}N_z)^{0.557}S_w^{0.649}A^{0.5}(t/c)_{\text{root}}^{-0.4}\,(1+\lambda)^{0.1} \times (\cos\Lambda)^{-1.0}S_{csw}^{0.1}$$

Horizontal /V-Tail / Canard

$$W_{\substack{\text{horizontal}\\ \text{tail}}} = 0.0379\,K_{uht}(1+F_w/B_h)^{-0.25}W_{dg}^{0.639}N_z^{0.10}S_{ht}^{0.75}L_t^{-1.0} \times K_y^{0.704}(\cos\Lambda_{ht})^{-1.0}A_h^{0.166}\,(1+S_e/S_{ht})^{0.1}$$

vertical

$$W_{\substack{\text{vertical}\\ \text{tail}}} = 0.0026\,(1+H_t/H_v)^{0.225}W_{dg}^{0.556}N_z^{0.536}L_t^{-0.5}S_{vt}^{0.5}K_z^{0.875} \times (\cos\Lambda_{vt})^{-1}A_v^{0.35}(t/c)_{\text{root}}^{-0.5}$$

Cargo/Transport Weights - II

Fuselaje

$$W_{\text{fuselage}} = 0.3280 K_{\text{door}} K_{\text{Lg}} (W_{\text{dg}} N_z)^{0.5} L^{0.25} S_f^{0.302} (1 + K_{\text{ws}})^{0.04} (L/D)^{0.10}$$

Tren de aterrizaje

$$W_{\substack{\text{main landing}\\ \text{gear}}} = 0.0106 K_{\text{mp}} W_l^{0.888} N_l^{0.25} L_m^{0.4} N_{\text{mw}}^{0.321} N_{\text{mss}}^{-0.5} V_{\text{stall}}^{0.1}$$

$$W_{\substack{\text{nose landing}\\ \text{gear}}} = 0.032 K_{np} W_l^{0.646} N_l^{0.2} L_n^{0.5} N_{nw}^{0.45}$$

Cargo/Transport Weights - III

Sistema Motor

$$W_{\substack{\text{nacelle}\\ \text{group}}} = 0.6724 K_{ng} N_{Lt}^{0.10} N_w^{0.294} N_z^{0.119} W_{ec}^{0.611} N_{en}^{0.984} S_n^{0.224}$$

(includes air induction)

$$W_{\substack{\text{engine}\\ \text{controls}}} = 5.0 N_{en} + 0.80 L_{ec}$$

$$W_{\substack{\text{fuel}\\ \text{system}}} = 2.405 V_t^{0.606} (1 + V_i/V_t)^{-1.0} (1 + V_p/V_t) N_t^{0.5}$$

$$W_{\substack{\text{APU}\\ \text{installed}}} = 2.2 W_{\substack{\text{APU}\\ \text{uninstalled}}}$$

Cargo/Transport Weights - IV

Sistemas

$$W_{\substack{\text{starter}\\ \text{(pneumatic)}}} = 49.19\left(\frac{N_{en}W_{en}}{1000}\right)^{0.541}$$

$$W_{\substack{\text{flight}\\ \text{controls}}} = 145.9 N_f^{0.554}(1 + N_m/N_f)^{-1.0} S_{cs}^{0.20}(I_y \times 10^{-6})^{0.07}$$

$$W_{\text{instruments}} = 4.509 K_r K_{tp} N_c^{0.541} N_{en}(L_f + B_w)^{0.5}$$

$$W_{\text{hydraulics}} = 0.2673 N_f (L_f + B_w)^{0.937}$$

$$W_{\text{electrical}} = 7.291 R_{kva}^{0.782} L_a^{0.346} N_{gen}^{0.10}$$

$$W_{\text{avionics}} = 1.73 W_{uav}^{0.983}$$

Cargo/Transport Weights - V

Sistemas

$$W_{\text{furnishings}} = 0.0577 N_c^{0.1} W_c^{0.393} S_f^{0.75}$$

$$W_{\substack{\text{air}\\\text{conditioning}}} = 62.36 N_p^{0.25} (V_{pr}/1000)^{0.604} W_{\text{uav}}^{0.10}$$

$$W_{\text{anti-ice}} = 0.002 W_{\text{dg}}$$

$$W_{\substack{\text{handling}\\\text{gear}}} = 3.0 \times 10^{-4} W_{\text{dg}}$$

$$W_{\substack{\text{military cargo}\\\text{handling system}}} = 2.4 \times (\text{cargo floor area, ft}^2)$$

Cargo/Transport Weights - VI

A	= aspect ratio
B_h	= horizontal tail span, ft
B_w	= wing span, ft
D	= fuselage structural depth, ft
D_e	= engine diameter, ft
F_w	= fuselage width at horizontal tail intersection, ft
H_t	= horizontal tail height above fuselage, ft
H_t/H_v	= 0.0 for conventional tail; 1.0 for "T" tail
H_v	= vertical tail height above fuselage, ft
I_y	= yawing moment of inertia, lb-ft^2 (see Chap. 16)
K_{cb}	= 2.25 for cross-beam (F-111) gear; = 1.0 otherwise
K_d	= duct constant (see Fig. 15.2)
K_{door}	= 1.0 if no cargo door; = 1.06 if one side cargo door; = 1.12 if two side cargo doors; = 1.12 if aft clamshell door; = 1.25 if two side cargo doors and aft clamshell door
K_{dw}	= 0.768 for delta wing; = 1.0 otherwise
K_{dwf}	= 0.774 for delta wing aircraft; = 1.0 otherwise
K_{Lg}	= 1.12 if fuselage-mounted main landing gear; = 1.0 otherwise
K_{mc}	= 1.45 if mission completion required after failure; = 1.0 otherwise
K_{mp}	= 1.126 for kneeling gear; = 1.0 otherwise
K_{ng}	= 1.017 for pylon-mounted nacelle; = 1.0 otherwise
K_{np}	= 1.15 for kneeling gear; = 1.0 otherwise
K_p	= 1.4 for engine with propeller or 1.0 otherwise
K_r	= 1.133 if reciprocating engine; = 1.0 otherwise
K_{rht}	= 1.047 for rolling tail; = 1.0 otherwise
K_{tp}	= 0.793 if turboprop; = 1.0 otherwise

Cargo/Transport Weights - VII

K_{tpg} = 0.826 for tripod (A-7) gear; = 1.0 otherwise
K_{tr} = 1.18 for jet with thrust reverser or 1.0 otherwise
K_{uht} = 1.143 for unit (all-moving) horizontal tail; = 1.0 otherwise
K_{vg} = 1.62 for variable geometry; = 1.0 otherwise
K_{vs} = 1.19 for variable sweep wing; = 1.0 otherwise
K_{vsh} = 1.425 if variable sweep wing; = 1.0 otherwise
K_{ws} = $0.75[1 + 2\lambda)/(1 + \lambda)] (B_w \tan\Lambda/L)$
K_y = aircraft pitching radius of gyration, ft ($\cong 0.3L_t$)
K_z = aircraft yawing radius of gyration, ft ($\cong L_t$)
L = fuselage structural length, ft (excludes radome, tail cap)
L_a = electrical routing distance, generators to avionics to cockpit, ft
L_d = duct length, ft
L_{ec} = length from engine front to cockpit—total if multiengine, ft
L_f = total fuselage length
L_m = length of main landing gear, in.
L_n = nose gear length, in.
L_s = single duct length (see Fig. 15.2)
L_{sh} = length of engine shroud, ft
L_t = tail length; wing quarter-MAC to tail quarter-MAC, ft
L_{tp} = length of tailpipe, ft
M = Mach number
N_c = number of crew
N_{ci} = 1.0 if single pilot; = 1.2 if pilot plus backseater; = 2.0 pilot and copassenger
N_{en} = number of engines
N_f = number of functions performed by controls (typically 4–7)
N_{gen} = number of generators (typically = N_{en})
N_l = ultimate landing load factor; = $N_{gear} \times 1.5$
N_{Lt} = nacelle length, ft
N_m = number of mechanical functions (typically 0–2)
N_{mss} = number of main gear shock struts
N_{mw} = number of main wheels
N_{nw} = number of nose wheels

Cargo/Transport Weights - VIII

N_p = number of personnel onboard (crew and passengers)
N_s = number of flight control systems
N_t = number of fuel tanks
N_u = number of hydraulic utility functions (typically 5–15)
N_w = nacelle width, ft
N_z = ultimate load factor; = 1.5 × limit load factor
q = dynamic pressure at cruise, lb/ft^2
R_{kva} = system electrical rating, kv · A (typically 40–60 for transports, 110–160 for fighters & bombers)
S_{cs} = total area of control surfaces, ft^2
S_{csw} = control surface area (wing-mounted), ft^2
S_e = elevator area, ft
S_f = fuselage wetted area, ft^2
S_{fw} = firewall surface area, ft^2
S_{ht} = horizontal tail area
S_n = nacelle wetted area, ft^2
S_r = rudder area, ft^2
S_{vt} = vertical tail area, ft^2
S_w = trapezoidal wing area, ft^2
SFC = engine specific fuel consumption—maximum thrust
T = total engine thrust, lb
T_e = thrust per engine, lb
V_i = integral tanks volume, gal
V_p = self-sealing "protected" tanks volume, gal
V_{pr} = volume of pressurized section, ft^3
V_t = total fuel volume, gal

W = fuselage structural width, ft
W_c = maximum cargo weight, lb
W_{dg} = design gross weight, lb
W_{ec} = weight of engine and contents, lb (per nacelle), $\cong 2.331\, W_{engine}^{0.901} K_p K_{tr}$
W_{en} = engine weight, each, lb
W_{fw} = weight of fuel in wing, lb
W_l = landing design gross weight, lb

W_{press} = weight penalty due to pressurization, $= 11.9 + (V_{pr} P_{delta})^{0.271}$, where P_{delta} = cabin pressure differential, psi (typically 8 psi)
W_{uav} = uninstalled avionics weight, lb (typically = 800–1400 lb)
Λ = wing sweep at 25% MAC

Bibliografía

- Aircraft Design: A Systems Engineering Approach, M. H. Sadraey, Wiley Aerospace Series, 2012.
- Aircraft Design: a conceptual approach, D.P. Raymer, AIAA Education Series, 2006.
- Synthesis of subsonic airplane design, E. Torenbeek, Springer, 1982
- Airplane Design, J. Roskam, DAR Corporation, 1989
- Nicolai, L.M. Carichner, G.E. Fundamentals of Aircraft and Airship Design: Vol 1, 2010
- Ajoy Kumar Kundu, Aircraft Design, Cambridge Aerospace Series, 2010