5. CLASS II METHOD FOR ESTIMATING STRUCTURE WEIGHT

The airplane structure weight, W_{struct} will be assumed to consist of the following components:

5.1 Wing, W_w 5.2 Empennage, W_{emp}

5.3 Fuselage, W_f 5.4 Nacelles, W_n

5.5 Landing gear, W_g Therefore:

$$W_{struct} = W_w + W_{emp} + W_f + W_n + W_g \tag{5.1}$$

Equations for structure weight estimation are presented for the following types of airplanes:

1. General Aviation Airplanes
2. Commercial Transport Airplanes
3. Military Patrol, Bomb and Transport Airplanes
4. Fighter and Attack Airplanes

5.1 WING WEIGHT ESTIMATION

5.1.1 General Aviation Airplanes

5.1.1.1 Cessna method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts. The equations apply to wings of two types:

Cantilever wings: Eqn.(5.2)
Strut braced wings: Eqn.(5.3)

Both equations include: weight of wing tip fairing
wing control surfaces
Both equations exclude: fuel tanks
wing/fuselage spar carry-through structure
effect of sweep angle

For cantilever wings:

$$W_w = 0.04674(W_{TO})^{0.397}(S)^{0.360}(n_{ult})^{0.397}(A)^{1.712} \tag{5.2}$$

For strut braced wings:

$$W_w = 0.002933(S)^{1.018}(A)^{2.473}(n_{ult})^{0.611} \tag{5.3}$$

Definition of terms:

W_{TO} = take-off weight in lbs,

S = wing area in ft^2,

n_{ult} = design ultimate load factor

A = wing aspect ratio

Note that Eqn.(5.3) does not account for W_{TO}. It should therefore be used with caution. The reader should also realize that wings in this category have maximum thickness ratios of around 18 percent.

5.1.1.2 USAF Method

The following equation applies to light and utility type airplanes with performance up to about 300 kts:

$$W_W = 96.948[(W_{TO}n_{ult}/10^5)^{0.65}(A/\cos\Lambda_{1/4})^{0.57}(S/100)^{0.61}x$$
$$x\{(1+\lambda)/2(t/c)_m\}^{0.36}(1 + V_H/500)^{0.5}]^{0.993} \qquad (5.4)$$

Definition of new terms:

$\Lambda_{1/4}$ = wing quarter chord sweep angle

λ = wing taper ratio

$(t/c)_m$ = maximum wing thickness ratio

V_H = maximum level speed at sealevel in kts

5.1.1.3 Torenbeek Method

The following equation applies to light transport airplanes with take-off weights below 12,500 lbs:

$$W_W =$$
$$= 0.00125W_{TO}(b/\cos\Lambda_{1/2})^{0.75}[1 + \{6.3\cos(\Lambda_{1/2})/b\}^{1/2}]x$$
$$x(n_{ult})^{0.55}(bS/t_rW_{TO}\cos\Lambda_{1/2})^{0.30} \qquad (5.5)$$

See special notes in Section 5.2.2.

Definition of new terms:

b = wing span in ft

$\Lambda_{1/2}$ = wing semi-chord sweep angle

t_r = maximum thickness of wing root chord in ft

5.1.2 Commercial Transport Airplanes

5.1.2.1 GD Method

$$W_w = \frac{\{0.00428(S^{0.48})(A)(M_H)^{0.43}(W_{TO}n_{ult})^{0.84}(\lambda)^{0.14}\}}{[\{100(t/c)_m\}^{0.76}(\cos\Lambda_{1/2})^{1.54}]} \qquad (5.6)$$

Note: This equation is valid only in the following parameter ranges:

M_H from 0.4 to 0.8, $(t/c)_m$ from 0.08 to 0.15, and A from 4 to 12.

Definition of new term:

M_H = maximum Mach number at sealevel

5.1.2.2 Torenbeek Method

The following equation applies to transport airplanes with take-off weights above 12,500 lbs:

$$W_w = 0.0017W_{MZF}(b/\cos\Lambda_{1/2})^{0.75}[1 + \{6.3\cos(\Lambda_{1/2})/b\}^{1/2}] \times (n_{ult})^{0.55}(bS/t_r W_{MZF}\cos\Lambda_{1/2})^{0.30} \qquad (5.7)$$

Definition of new term:

$$W_{MZF} = \text{maximum zero fuel weight} = W_{TO} - W_F \qquad (5.8)$$

Special notes:

1. Eqns.(5.6) and (5.7) include the weight of normal high lift devices as well as ailerons.
2. For spoilers and speed brakes 2 percent should be added.

3. If the airplane has 2 wing mounted engines reduce the wing weight by 5 percent.
4. If the airplane has 4 wing mounted engines reduce the wing weight by 10 percent.
5. If the landing gear is not mounted under the wing reduce the wing weight by 5 percent.
6. For braced wings reduce the wing weight by 30 percent. The resulting wing weight estimate does include the weight of the strut. The latter is roughly 10 percent of the wing weight.
7. For Fowler flaps add 2 percent to wing weight.

5.1.3 Military Patrol, Bomb and Transport Airplanes

For predicting wing weight it is suggested to use Eqns.(5.6) and (5.7) but with the appropriate value for n_{ult}. For this type of military airplane the usual value for n_{ult} is 4.5. Refer to Table 4.1 for a listing of military limit load factors.

Note: wing weight in military airplanes is often based on the flight design gross weight, GW, rather than W_{TO}. Check the mission specification and/or the applicable military specifications to determine which weight value to use in Eqns.(5.6) and (5.7).

5.1.4 Fighter and Attack Airplanes

5.1.4.1 GD Method

For USAF fighter and attack airplanes:

$$W_w =$$
$$= 3.08[\{(K_w n_{ult} W_{TO})/(t/c)_m\}\{(\tan\Lambda_{LE} - 2(1-\lambda)/A(1+\lambda))^2 + 1.0\}\times 10^{-6}]^{0.593}\{A(1+\lambda)\}^{0.89}(S)^{0.741} \tag{5.9}$$

For USN fighter and attack airplanes:

$$W_w =$$
$$= 19.29[\{(K_w n_{ult} W_{TO})/(t/c)_m\}\{(\tan\Lambda_{LE} - 2(1-\lambda)/A(1+\lambda))^2 + 1.0\}\times 10^{-6}]^{0.464}\{(1+\lambda)A\}^{0.70}(S)^{0.58} \tag{5.10}$$

Definition of new terms:

K_w = 1.00 for fixed wing airplanes and
= 1.175 for variable sweep wing airplanes

Λ_{LE} = leading edge sweep angle of the wing

Note: wing weight in military airplanes is often based on the flight design gross weight, GW, rather than W_{TO}. Check the mission specification and/or the applicable military specifications to determine which weight to use in Eqns.(5.9) and (5.10).

5.2 EMPENNAGE WEIGHT ESTIMATION

Empennage weight, W_{emp} will be expressed as follows:

$$W_{emp} = W_h + W_v + W_c, \tag{5.11}$$

where: W_h = horizontal tail weight in lbs

W_v = vertical tail weight in lbs

W_c = canard weight in lbs

Equations for empennage weight components are presented in the remainder of this section.

5.2.1 General Aviation Airplanes

5.2.1.1 Cessna method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts.

Horizontal tail:

$$W_h = \frac{3.184(W_{TO})^{0.887}(S_h)^{0.101}(A_h)^{0.138}}{57.5(t_{r_h})^{0.223}} \tag{5.12}$$

Note that no factor for horizontal tail sweep is included.

Vertical tail:

$$W_v = \frac{1.68(W_{TO})^{0.567}(S_v)^{1.249}(A_v)^{0.482}}{15.6(t_{r_v})^{0.747}(\cos\Lambda_{1/4_v})^{0.882}} \tag{5.13}$$

Canard: For a lightly loaded canard, Eqn.(5.12) may be used. For a significantly loaded canard (such as on the GP180 and the Starship I) it is suggested to use the appropriate wing weight equation.

Definition of terms:

W_{TO} = take-off weight ib lbs

S_h = horizontal tail area in ft^2

A_h = horizontal tail aspect ratio

t_{r_h} = horizontal tail maximum root thickness in ft

S_v = vertical tail area in ft^2

A_v = vertical tail aspect ratio

t_{r_v} = vertical tail maximum root thickness in ft

$_{1/4_v}$ = vertical tail quarter chord sweep angle

5.2.1.2 USAF Method

The following equation applies to light and utility type airplanes with performance up to about 300 kts:

Horizontal tail:

$$W_h = 127\{(W_{TO}n_{ult}/10^5)^{0.87}(S_h/100)^{1.2} \times 0.289(l_h/10)^{0.483}(b_h/t_{r_h})^{0.5}\}^{0.458} \quad (5.14)$$

Note that sweep angle is not a factor in this equation.

Vertical tail:

$$W_v = 98.5\{(W_{TO}n_{ult}/10^5)^{0.87}(S_v/100)^{1.2} \times 0.289(b_v/t_{r_v})^{0.5}\}^{0.458} \quad (5.15)$$

Again, sweep angle is not a factor in this equation.

Canard:

The comments made under 5.2.1.2 also apply.

Definition of new terms:

l_h = distance from wing $\bar{c}/4$ to hor. tail $\bar{c}_h/4$ in ft

b_h = horizontal tail span in ft

b_v = vertical tail span in ft

5.2.1.3 Torenbeek Method

The following equation applies to light transport airplanes with design dive speeds up to 250 kts and with conventional tail configurations:

$$W_{emp} = 0.04\{n_{ult}(S_v + S_h)^2\}^{0.75}, \qquad (5.16)$$

If the airplane also has a canard, the comments made under 'canard' in 5.2.1.2 also apply here.

5.2.2 Commercial Transport Airplanes

5.2.2.1 GD Method

Horizontal tail:

$$W_h = 0.0034\{(W_{TO}n_{ult})^{0.813}(S_h)^{0.584} \times (b_h/t_{r_h})^{0.033}(\bar{c}/l_h)^{0.28}\}^{0.915} \qquad (5.17)$$

Note: sweep angle is not a factor in this equation.

Vertical tail:

$$W_v = 0.19\{(1 + z_h/b_v)^{0.5}(W_{TO}n_{ult})^{0.363}(S_v)^{1.089}(M_H)^{0.601} \times (l_v)^{-0.726}(1 + S_r/S_v)^{0.217}(A_v)^{0.337}(1+\lambda_v)^{0.363} \times (\cos\Lambda_{1/4_v})^{-0.484}\}^{1.014} \qquad (5.18)$$

Canard: Comments made under 5.2.2.2 also apply here.

Definition of new terms:

z_h = distance from the vertical tail root to where the horizontal tail is mounted on the vertical tail, in ft. Warning: for fuselage mounted horizontal tails, set z_h = 0.

l_v = dist. from wing $\bar{c}/4$ to vert. tail $\bar{c}_v/4$ in ft

S_r = rudder area in ft^2

λ_v = vertical tail taper ratio

5.2.2.2 Torenbeek Method

The following equation applies to transport airplanes and to business jets with design dive speeds above 250 kts.

Horizontal tail:

$$W_h = \tag{5.19}$$

$$= K_h S_h [3.81\{(S_h)^{0.2} V_D\}/\{1{,}000(\cos\ _{1/2_h})^{1/2}\} - 0.287]$$

where K_h takes on the following values:

K_h = 1.0 for fixed incidence stabilizers

K_h = 1.1 for variable incidence stabilizers

Vertical tail:

$$W_v = \tag{5.20}$$

$$= K_v S_v [3.81\{(S_v)^{0.2} V_D/1{,}000(\cos\ _{1/2_v})^{1/2}\} - 0.287]$$

where K_v takes on the following values:

K_v = 1.0 for fuselage mounted horizontal tails

for fin mounted horizontal tails:

$$K_v = \{1 + 0.15(S_h z_h/S_v b_v)\} \tag{5.21}$$

Definition of new terms:

V_D = design dive speed in KEAS

$_{1/2_h}$ horizontal tail semi-chord sweep angle

$_{1/2_v}$ vertical tail semi-chord sweep angle

Canard: The comments made under 5.2.2.2 also apply here.

5.2.3 Military Patrol, Bomb and Transport Airplanes

See Sub-section 5.2.4.

5.2.4 Fighter and Attack airplanes

For estimation of empennage weight of airplanes in this category, use the methods of sub-section 5.2.2. Be sure to use the proper values for ultimate load factor. See Table 4.1.

Note: empennage weights of military airplanes are often based on the flight design gross weight, GW, rather than W_{TO}. Check the mission specification and/or the applicable military specifications to determine which weight to use.

5.3 FUSELAGE WEIGHT ESTIMATION

The equations presented for fuselage weight estimation are valid for land-based airplanes only. For flying boats and amphibious airplanes it is suggested to multiply the fuselage weight by 1.65:

$$W_{f_{fl.boat}} = 1.65 W_f \tag{5.22}$$

For float equipped airplanes the weight due to the floats may be found with Eqn.(5.27), by substituting float wetted area for S_{fgs}.

For estimation of tailboom weight it is suggested to use Eqn.(5.27) applied to each tailboom individually, but with $K_f = 1$.

5.3.1 General Aviation airplanes

5.3.1.1 Cessna method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts.

For low wing airplanes:

$$W_f = \tag{5.23}$$

$$= 0.04682 (W_{TO})^{0.692} (N_{pax})^{0.374} (l_{f-n})^{0.590}/100$$

For high wing airplanes:

$$\bar{W}_f = \tag{5.24}$$
$$14.86(W_{TO})^{0.144}(l_{f-n}/p_{max})^{0.778}(l_{f-n})^{0.383}(N_{pax})^{0.455}$$

Definition of terms:

W_{TO} = take-off weight in lbs

N_{pax} = number of passengers

l_{f-n} = fuselage length, not including nose mounted nacelle length in ft

Notes:
1. These equations do not account for pressurized fuselages.
2. There is no explanation for why the fuselage weight of low wing airplanes does not depend on the number of passengers.
3. For this type airplane the crew is counted in the number of passengers.

5.3.1.2 USAF Method

The following equation applies to light and utility type airplanes with performance up to about 300 kts:

$$W_f = 200[(W_{TO}n_{ult}/10^5)^{0.286}(l_f/10)^{0.857}\text{x}$$
$$\text{x}\{(w_f + h_f)/10\}(V_C/100)^{0.338}]^{1.1} \tag{5.25}$$

Definition of new terms:

n_{ult} = ultimate load factor

l_f = fuselage length in ft

w_f = maximum fuselage width in ft

h_f = maximum fuselage height in ft

V_C = design cruise speed in KEAS

5.3.2 Commercial Transport Airplanes

5.3.2.1 GD Method

$$W_f = \tag{5.26}$$
$$= 2\text{x}10.43(K_{inl})^{1.42}(\bar{q}_D/100)^{0.283}(W_{TO}/1000)^{0.95}(l_f/h_f)^{0.71}$$

The factor K_{inl} takes on the following values:

K_{inl} = 1.25 for airplanes with inlets in or on the fuselage for a buried engine installation

K_{inl} = 1.0 for inlets located elsewhere

Definition of new term:

$\bar{q}_D$ = design dive dynamic pressure in psf

5.3.2.2 Torenbeek Method

The following equation applies to transport airplanes and to business jets with design dive speeds above 250 kts.

$$W_f = 0.021K_f\{(V_D l_h/(w_f + h_f)\}^{1/2}(S_{fgs})^{1.2} \quad (5.27)$$

The constant K_f takes on the following values:

K_f = 1.08 for a pressurized fuselage

= 1.07 for a main gear attached to the fuselage.

= 1.10 for a cargo airplane with a cargo floor

These effects are multiplicative for airplanes equipped with all of the above.

Definition of new terms:

V_D = design dive speed in KEAS

l_h = distance from wing $\bar{c}/4$ to hor. tail $\bar{c}_h/4$ in ft

S_{fgs} = fuselage gross shell area in ft^2

5.3.3 Military Patrol, Bomb and Transport Airplanes

5.3.3.1 GD Method

For USAF airplanes, Eqn.(5.26) may be used.

For USN airplanes the following equation should be used:

$$W_f = \quad (5.28)$$

$$= 11.03(K_{inl})^{1.23})(\bar{q}_L/100)^{0.245}(W_{TO}/1000)^{0.98}(l_f/h_f)^{0.61}$$

Values for K_{inl} are as given in 5.3.2.1.

Definition of new term:

$\bar{q}_L$ = design dive dynamic pressure in psf

5.3.4 Fighter and Attack Airplanes

For estimation of fuselage weights Equations (5.26) or (5.28) may be used.

Warning: In using Eqn. (5.26) for fighters, leave off the factor 2 at the beginning of the equation.

5.4 NACELLE WEIGHT ESTIMATION

The nacelle weight is assumed to consist of the following components:

1. For podded engines: the structural weight associated with the engine external ducts and or cowls. Any pylon weight is included.

2. For propeller driven airplanes: the structural weight associated with the engine external ducts and or cowls plus the weight due to the engine mounting trusses.

3. For buried engines: the structural weight associated with special cowling and or ducting provisions (other than the inlet duct which is included in the air induction system under powerplant weight, Section 6.2) and any special engine mounting provisions.

5.4.1 General Aviation Airplanes

5.4.1.1 Cessna Method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts.

$$W_n = K_n W_{TO} \qquad (5.29)$$

The constant K_n takes on the following values:

K_n = 0.37 lbs/hp for radial engines

K_n = 0.24 lbs/hp for horizontally opposed engines

Definition of term:

W_{TO} = take-off weight in lbs

These data should not be applied to turbopropeller nacelles.

5.4.1.2 USAF Method

In this method, the nacelle weight is included in the powerplant weight: refer to Chapter 6.

5.4.1.3 Torenbeek Method

For single engine propeller driven airplanes with the nacelle in the fuselage nose:

$$W_n = 2.5(P_{TO})^{1/2} \tag{5.30}$$

This weight includes the entire engine section forward of the firewall.

For multi-engine airplane with piston engines:

$$W_n = 0.32P_{TO} \text{ for horizontally opposed engines} \tag{5.31}$$

$$W_n = 0.045(P_{TO})^{5/4} \text{ for radial engines} \tag{5.32}$$

$$W_n = 0.14(P_{TO}) \text{ for turboprop engines} \tag{5.33}$$

Notes: 1. Since P_{TO} is the total required take-off horsepower, these weight estimates include the weights of all nacelles.

2. If the main landing gear retracts into the nacelles, add 0.04 lbs/hp to the nacelle weight

3. If the engine exhausts over the wing, as in the Lockheed Electra, add 0.11 lbs/hp to the nacelle weight.

5.4.2 Commercial Transport Airplanes

5.4.2.1 GD Method

For turbojet engines:

$$W_n = 3.0(N_{inl})\{(A_{inl})^{0.5}(l_n)(P_2)\}^{0.731} \tag{5.34}$$

For turbofan engines:

$$W_n = 7.435(N_{inl})\{(A_{inl})^{0.5}(l_n)(P_2)\}^{0.731} \qquad (5.35)$$

Definition of terms:

N_{inl} = number of inlets

A_{inl} = capture area per inlet inft^2

l_n = nacelle length from inlet lip to compressor face in ft

P_2 = maximum static pressure at engine compressor face in psi. Typical values range from 15 to 50 psi.

5.4.2.2 Torenbeek Method

For turbojet or low bypass ratio turbofan engines:

$$W_n = 0.055T_{TO} \qquad (5.36)$$

For high bypass ratio turbofan engines:

$$W_n = 0.065T_{TO} \qquad (5.37)$$

Since T_{TO} is the total required take-off thrust, these equations account for the weight of all nacelles.

5.4.3 Military Patrol Bomb and Transport Airplanes

For all airplanes in this category Eqns.(5.34) and (5.35) may be used.

5.4.4 Fighter and Attack Airplanes

For all airplanes in this category Eqns.(5.34) and (5.35) may be used.

5.5 LANDING GEAR WEIGHT ESTIMATION

5.5.1 General Aviation Airplanes

5.5.1.1 Cessna method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts.

For non-retractable landing gears:

$$W_g = \qquad (5.38)$$

$$0.013W_{TO} + 0.146(W_L)^{0.417}n_{ult.l})^{0.950}(l_{s_m})^{0.183} +$$

wheels + tires m.g. strut assembly m.g.

$$+ 6.2 + 0.0013W_{TO} + 0.000143(W_L)^{0.749}(n_{ult.l})(l_{s_n})^{0.788}$$

wheels + tires n.g. strut assembly n.g.

For retractable landing gears:

$$W_g = W_{g_{Eqn.(5.38)}} + 0.014W_{TO} \qquad (5.39)$$

Definition of terms:

W_{TO} = take-off weight in lbs

W_L = design landing weight in lbs (See Table 3.3, Part I for data relating W_L to W_{TO})

$n_{ult.l}$ = ultimate load factor for landing, may be taken as 5.7

l_{s_m} = shock strut length for main gear in ft

l_{s_n} = shock strut length for nose gear in ft

5.5.1.2 USAF Method

The following equation applies to light and utility type airplanes with performance up to about 300 kts:

$$W_g = 0.054(l_{s_m})^{0.501}(W_L n_{ult.l})^{0.684} \qquad (5.40)$$

Notes: 1) This equation includes nose gear weight.

2) $N_{ult.l}$ may be taken as 5.7.

5.5.2 Commercial Transport Airplanes

5.5.2.1 GD Method

$$W_g = 62.61(W_{TO}/1{,}000)^{0.84} \qquad (5.41)$$

5.5.2.2 Torenbeek Method

The following equation applies to transport airplanes and to business jets with the main gear mounted on the wing and the nose gear mounted on the fuselage:

$$W_g = K_{g_r}\{A_g + B_g(W_{TO})^{3/4} + C_g W_{TO} + D_g(W_{TO})^{3/2}\} \qquad (5.42)$$

The factor K_{g_r} takes on the following values:

K_{g_r} = 1.0 for low wing airplanes

K_{g_r} = 1.08 for high wing airplanes

The constants A_g through D_g are defined in Table 5.1 which is taken from Reference 14.

Table 5.1 Constants in Landing Gear Weight Eqn.(5.42)

Airplane Type	Gear Type	Gear Comp.	A_g	B_g	C_g	D_g
Jet Trainers and Business Jets	Retr.	Main	33.0	0.04	0.021	0.0
		Nose	12.0	0.06	0.0	0.0
Other civil airplanes	Fixed	Main	20.0	0.10	0.019	0.0
		Nose	25.0	0.0	0.0024	0.0
		Tail	9	0.0	0.0024	0.0
	Retr.	Main	40.0	0.16	0.019	1.5×10^{-5}
		Nose	20.0	0.10	0.0	2.0×10^{-6}
		Tail	5.0	0.0	0.0031	0.0

5.5.3 Military Patrol, Bomb and Transport Airplanes

For USAF airplanes, Eqns.(5.41) and (5.42) may be used.

For USN airplanes the following equation should be used:

$$W_g = 129.1(W_{TO}/1{,}000)^{0.66} \qquad (5.43)$$

5.5.4 Fighter and Attack Airplanes

For USAF airplanes, Eqns.(5.41) and (5.42) may be used.

For USN airplanes, Eqn.(5.43) should be used.

6. CLASS II METHOD FOR ESTIMATING POWERPLANT WEIGHT

The airplane powerplant weight, W_{pwr} will be assumed to consist of the following components:

6.1 Engines, W_e: this includes engine, exhaust, cooling, supercharger and lubrication systems.

<u>Note:</u> afterburners and thrust reversers are not always included under engines. They are often treated as a separate powerplant component.

6.2 Air induction system, W_{ai}: this includes inlet ducts other than nacelles, ramps, spikes and associated controls.

6.3 Propellers, W_{prop}

6.4 Fuel System, W_{fs}

6.5 Propulsion System, W_p, this includes:

*engine controls
*starting systems
*propeller controls
*provisions for engine installation

<u>Note:</u> instead of the words 'propulsion system', the words 'propulsion installation' or even 'engine installation' are sometimes used.

Therefore:

$$W_{pwr} = W_e + W_{ai} + W_{prop} + W_{fs} + W_p \qquad (6.1)$$

<u>General Note:</u> for powerplant weight predictions it is highly recommended to obtain actual weight data from engine manufacturers.

Equations for powerplant weight prediction are presented for the following types of airplanes:

1. General Aviation Airplanes
2. Commercial Transport Airplanes
3. Military Patrol, Bomb and Transport Airplanes
4. Fighter and Attack Airplanes

6.1 ENGINE WEIGHT ESTIMATION

6.1.1 General Aviation Airplanes

6.1.1.1 Cessna method

The following equations should be applied only to small, relatively low performance type airplanes with maximum speeds below 200 kts.

$$W_e = K_p P_{TO} \tag{6.2}$$

The factor K_p takes on the following values:

For piston engines: K_p = 1.1 to 1.8, depending on whether or not supercharging is used.

For turbopropeller engines: K_p = 0.35 to 0.55.

These weights represent the so-called engine dry weight. Normal engine accessories are included in this weight but engine oil is not.

Definition of terms:

W_e = weight of all engines in lbs

P_{TO} = required take-off power in hp

6.1.1.2 USAF Method

$$W_e + W_{ai} + W_{prop} + W_p = 2.575(W_{eng})^{0.922}N_e \tag{6.3}$$

Use engine manufacturers data to obtain W_{eng} or use Eqn.(6.2).

Definition of new terms:

W_{eng} = weight per engine in lbs

N_e = number of engines

6.1.1.3 Torenbeek Method

For propeller driven airplanes:

$$W_{pwr} = K_{pg}(W_e + 0.24P_{TO}) \tag{6.4}$$

The constant K_{pg} takes on the following values:

K_{pg} = 1.16 for single engine tractor installations

K_{pg} 1.35 for multi-engine installations

For superchargers the following additional weight is incurred:

$$W_{sprch} = 0.455(W_e)^{0.943} \tag{6.5}$$

For jet airplanes:

$$W_{pwr} = K_{pg}K_{thr}W_e \tag{6.6}$$

The constant K_{pg} takes on the following values:

K_{pg} = 1.40 for airplanes with buried engines

The constant K_{thr} takes on the following values:

K_{thr} = 1.00 for airplanes without thrust reversers

K_{thr} = 1.18 for airplanes with thrust reversers

6.1.2 Commercial Transport Airplanes

Use of actual engine manufactures data is highly recommended. Figure 6.1 provides a graphical summary of engine dry weights versus take-off thrust. Figure 6.2 gives a graphical summary of engine dry weights versus take-off shaft horsepower.

When using Figures (6.1) or (6.2), keep in mind that:

$$W_e = N_eW_{eng}, \tag{6.7}$$

where W_{eng} is the weight per engine.

Equations (6.5) and (6.6) may also be used to obtain an initial estimate.

6.1.3 Military Patrol,Bomb and Transport Airplanes

See Sub-Section 6.1.2.

6.1.4 Fighter and Attack Airplanes

See Sub-Section 6.1.2.

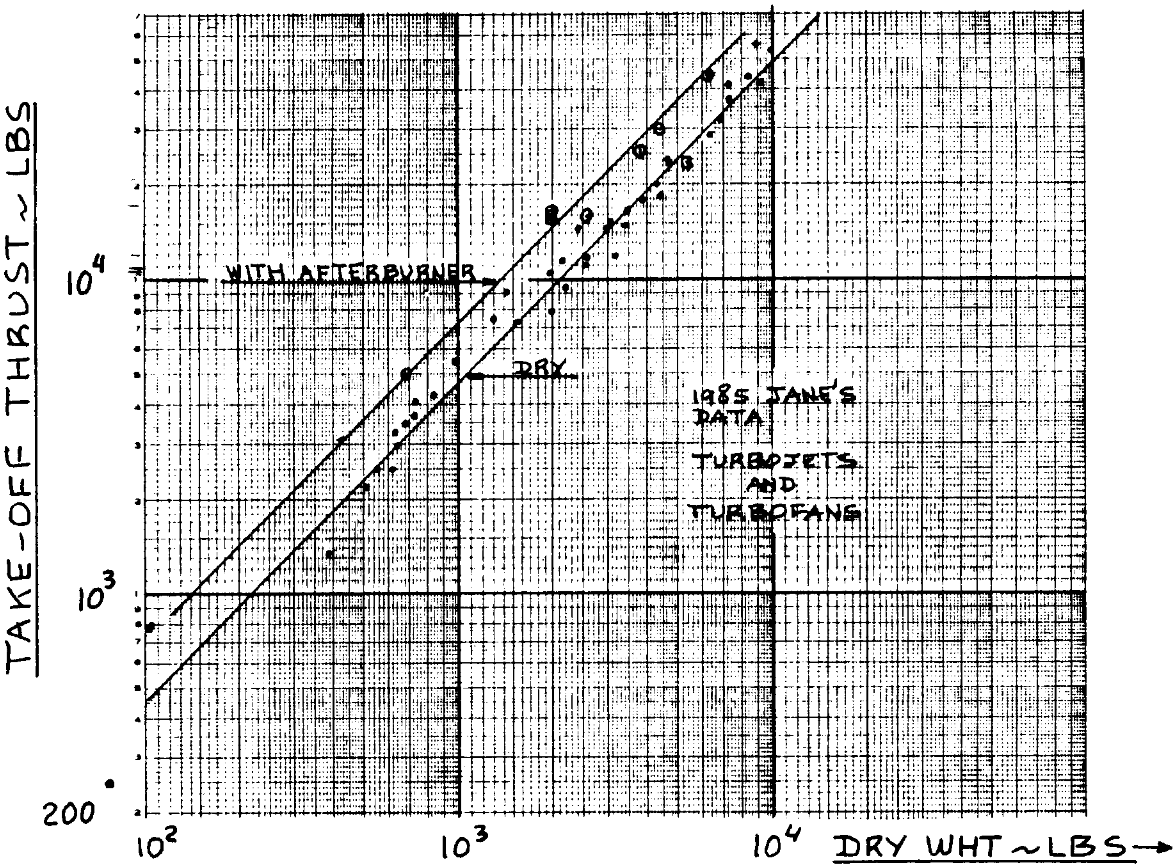


Figure 6.1 Turbojets and Turbofans: Take-off Thrust and Dry Weight Trends

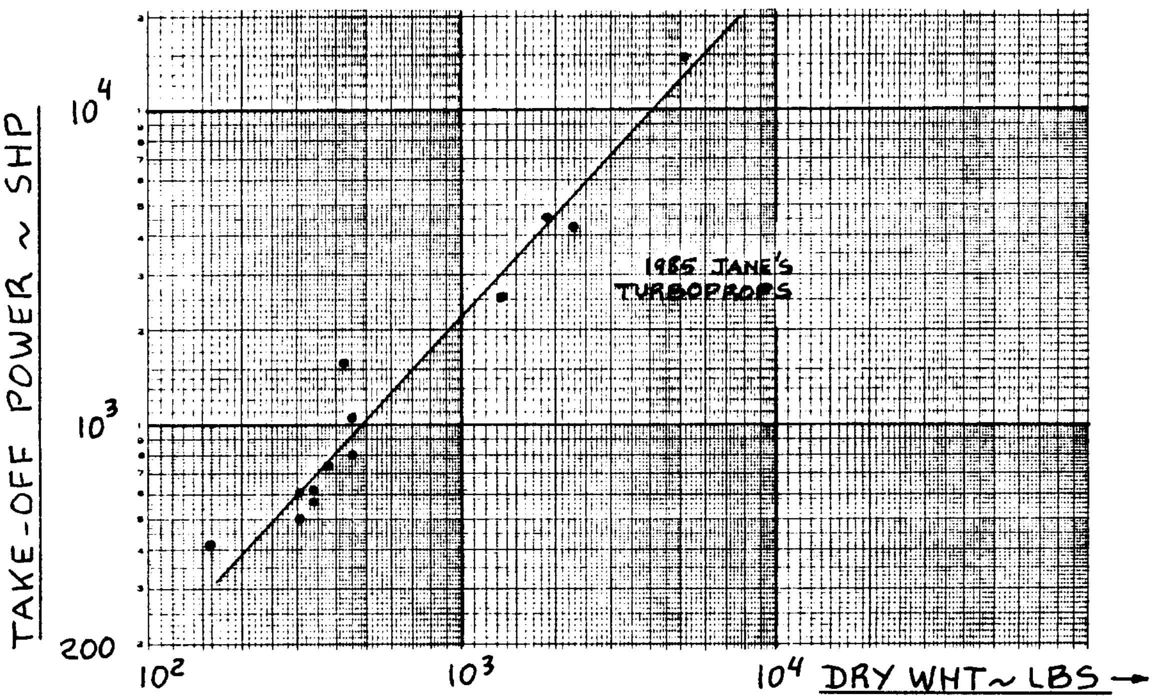


Figure 6.2 Turboprops: Take-off Shaft Horse Power and Dry Weight Trends

6.2 AIR INDUCTION SYSTEM WEIGHT ESTIMATION

6.2.1 General Aviation Airplanes

6.2.1.1 Cessna method

W_{ai} is included in the propulsion system weight, W_p.

6.2.1.2 USAF Method

See 6.2.1.1.

6.2.1.3 Torenbeek Method

$$W_{ai} + W_p = 1.03(N_e)^{0.3}(P_{TO}/N_e)^{0.7} \quad (6.8)$$

6.2.2 Commercial Transport Airplanes

6.2.2.1 GD Method

For buried engine installations:

The air induction system weight is split into two items: the first one for duct support structure, the second one for the subsonic duct leading from the inlet lip to the engine compressor face.

$$W_{ai} = 0.32(N_{inl})(L_d)(A_{inl})^{0.65}(P_2)^{0.6} + \quad (6.9)$$

(duct support structure)

$$1.735\{(L_d)(N_{inl})(A_{inl})^{0.5}(P_2)(K_d)(K_m)\}^{0.7331}$$

(subsonic part of duct)

The factors K_d and K_m are defined as follows:

K_d = 1.33 for ducts with flat cross sections

1.0 for ducts with curved cross sections

K_m = 1.0 for M_D below 1.4

= 1.5 for M_D above 1.4

Definition of terms:

L_d = duct length in ft

N_{inl} = number of inlets

A_{inl} = capture area per inlet in ft^2

P_2 = maximum static pressure at engine compressor face in psi. Typical values range from 15 to 50 psi.

For podded engine installations:

The air induction system weight is included in the nacelle weight, W_n.

6.2.2.2 Torenbeek Method

For buried engine installations:

$$W_{ai} = 11.45\{(L_d)(N_{inl})(A_{inl})^{0.5}(K_d)\}^{0.7331} \qquad (6.10)$$

The constant K_d takes on the following values:

K_d = 1.0 for ducts with curved cross sections

1.33 for ducts with flat cross sections

For podded engine installations:

The air induction system weight is included in the nacelle weight, W_n.

Note: For supersonic installations additional weight items due to the special inlet requirements are needed. See Sub-section 6.2.4.

6.2.3. Military Patrol, Bomb and Transport Airplanes

See Section 6.2.2.

6.2.4 Fighter and Attack Airplanes

6.2.4.1 GD Method

For prediction of the duct support structure weight and the duct weight, Eqn.(6.9) may be used.

Particularly in supersonic applications the following additional weight items due to inlet provisions may be incurred:

For variable geometry ramps, actuators and controls:

$$W_{ramp} = 4.079\{(L_r)(N_{inl})(A_{inl})^{0.5}(K_r)\}^{1.201} \qquad (6.11)$$

The factor K_r takes on the following values:

K_r = 1.0 for M_D below 3.0

= $(M_D + 2)/5$ for M_D above 3.0

Definition of new term:

L_r is the ramp length forward of the inlet throat in ft

For inlet spikes:

$$W_{sp} = K_s(N_{inl})(A_{inl}) \qquad (6.12)$$

The constant K_s takes on the following values:

K_s = 12.53 for half round fixed spikes
= 15.65 for full round translating spikes
= 51.80 for translating and expanding spikes

Note: these weights also apply to supersonic commercial installations.

6.3 PROPELLER WEIGHT ESTIMATION

6.3.1 General Aviation Airplanes

It is recommended to use propeller manufacturer data whereever possible. Lacking actual data the equation of Sub-Section 6.3.2 may be used.

Appendix A contains propeller installation data for a number of airplanes. Propeller installation weights usually include the propeller controls.

6.3.2 Commercial Transport Airplanes

6.3.2.1 GD Method

$$W_{prop} = K_{prop1}(N_p)(N_{bl})^{0.391}\{(D_p)(P_{TO}/N_e)/1,000\}^{0.782} \qquad (6.13)$$

The constant K_{prop1} takes on the following values:

K_{prop1} = 24.0 for turboprops above 1,500 shp

= 31.92 for piston engines and for turboprops below 1,500 shp

Definition of terms:

N_p is the number of propellers

N_{bl} is the number of blades per propeller

D_p is the propeller diameter in ft

P_{TO} is the required take-off power in hp

N_e is the number of engines

6.3.2.2 Torenbeek Method

$$W_{prop} = K_{prop2}(N_p)^{0.218}\{D_p P_{TO}(N_{bl})^{1/2}\}^{0.782} \qquad (6.14)$$

The factor K_{prop2} takes on the following values:

$K_{prop2} = 0.108$ for turboprops

$K_{prop2} = 0.144$ for piston engines

The reader is asked to show that equations (6.13) and (6.14) are in fact the same.

6.3.3 Military Patrol,Bomb and Transport Airplanes

See Sub-Section 6.3.2.

6.3.4 Fighter and Attack Airplanes

See Sub-Section 6.3.2.

6.4 FUEL SYSTEM WEIGHT ESTIMATION

Note: In some airplanes the fuel system is used to control the center of gravity location. Airplanes with relaxed static stability and/or supersonic cruise airplanes frequently require such a system. The weight increment incurred due to such a feature is included in the weight estimation of the flight control system, Section 7.1.

6.4.1 General Aviation Airplanes

6.4.1.1 Cessna method

For airplanes with internal fuel systems (no tiptanks):

$$W_{fs} = 0.40W_F/K_{fsp} \qquad (6.15)$$

For airplanes with external fuel systems (with tiptanks):

$$W_{fs} = 0.70W_F/K_{fsp} \tag{6.16}$$

The constant K_{fsp} takes on the following values:

K_{fsp} = 5.87 lbs/gal for aviation gasoline

= 6.55 for lbs/gal for JP-4

Definition of term:

W_F = mission fuel weight (includes reserves) in lbs

6.4.1.2 USAF Method

$$W_{fs} = \tag{6.17}$$

$$= 2.49[(W_F/K_{fsp})^{0.6}\{1/(1+int)\}^{0.3}(N_t)^{0.20}(N_e)^{0.13}]^{1.21}$$

The factor K_f is defined in 6.4.1.1.

Definition of new terms:

int = fraction of fuel tanks which are integral

N_t = number of separate fuel tanks

N_e = number of engines

6.4.1.3 Torenbeek Method

For turbine engines, see Sub-Section 6.4.2.

For single piston engine installations:

$$W_{fs} = 2(W_F/5.87)^{0.667} \tag{6.18}$$

For multi piston engine installations:

$$W_{fs} = 4.5(W_F/5.87)^{0.60} \tag{6.19}$$

6.4.2 Commercial Transport Airplanes

6.4.2.1 GD Method

For a fuel system with integral tanks see 6.4.2.2.

For a fuel system with self-sealing bladder cells:

$$W_{fs} = 41.6\{(W_F/K_{fsp})/100\}^{0.818} + W_{supp} \quad (6.20)$$

For a fuel system with non-self-sealing bladder cells:

$$W_{fs} = 23.1\{(W_F/K_{fsp})/100\}^{0.758} + W_{supp} \quad (6.21)$$

The factor K_{fsp} is defined in 6.4.1.1.

W_{supp} is the weight of the bladder support structure and is given by:

$$W_{supp} = 7.91\{(W_F/K_{fsp})/100\}^{0.854} \quad (6.22)$$

6.4.2.2 Torenbeek Method

For airplanes equipped with non-self-sealing bladder tanks:

$$W_{fs} = 3.2(W_F/K_{fsp})^{0.727} \quad (6.23)$$

For airplanes equipped with integral fuel tanks (wet wing):

$$W_{fs} =$$

$$80(N_e + N_t - 1) + 15(N_t)^{0.5}(W_F/K_{fsp})^{0.333} \quad (6.24)$$

6.4.3 Military Patrol, Bomb and Transport Airplanes

For basic fuel system weights, see Sub-Section 6.4.2.

Many military airplanes carry in flight refuelling systems. In addition, many are equipped with fuel dumping systems. The weights of these systems may be estimated from:

For in-flight refuelling:

$$W_{inflref} = 13.64\{(W_F/K_{fsp})/100\}^{0.392} \quad (6.25)$$

For fuel dumping:

$$W_{fd} = 7.38\{(W_F/K_{fsp})/100\}^{0.458} \quad (6.26)$$

6.4.4 Fighter and Attack Airplanes

See Sub-Sections 6.4.2 and 6.4.3.

6.5 PROPULSION SYSTEM WEIGHT ESTIMATION

Depending on airplane type, the propulsion system weight, W_p is either given as a function of total engine weight and/or mission fuel or by:

$$W_p = W_{ec} + W_{ess} + W_{pc} + W_{osc}, \text{ where:} \tag{6.22}$$

W_{ec} = weight of engine controls in lbs

W_{ess} = weight of engine starting system in lbs

W_{pc} = weight of propeller controls in lbs

W_{osc} = weight of oil system and oil cooler in lbs

6.5.1 General Aviation Airplanes

6.5.1.1 Cessna method

Use actual data.

6.5.1.2 USAF Method

W_p is included in Eqn.(6.3).

6.5.1.3 Torenbeek Method

W_p is included in Eqn.(6.3).

6.5.2 Commercial Transport Airplanes

6.5.2.1 GD Method

Engine controls:

For fuselage/wing-root mounted jet engines:

$$W_{ec} = K_{ec}(l_f N_e)^{0.792} \tag{6.23}$$

The factor K_{ec} takes on the following values:

K_{ec} = 0.686 for non-afterburning engines
= 1.080 for afterburning engines

For wing mounted jet engines:

$$W_{ec} = 88.46\{(l_f + b)N_e/100\}^{0.294} \tag{6.24}$$

For wing mounted turboprops:

$$\bar{W}_{ec} = 56.84\{(l_f + b)N_e/100\}^{0.514} \quad (6.25)$$

For wing mounted piston engines:

$$W_{ec} = 60.27\{(l_f + b)N_e/100\}^{0.724} \quad (6.26)$$

Definition of terms:

N_e = number of engines

l_f = fuselage length in ft

b = wing span in ft

Engine starting systems:

For airplanes with one or two jet engines using cartridge or pneumatic starting systems:

$$W_{ess} = 9.33(W_e/1,000)^{1.078} \quad (6.27)$$

For airplanes with four or more jet engines using pneumatic starting systems:

$$W_{ess} = 49.19(W_e/1,000)^{0.541} \quad (6.28)$$

For airplanes with jet engines using electric starting systems:

$$W_{ess} = 38.93(W_e/1,000)^{0.918} \quad (6.29)$$

For airplanes with turboprop engines using pneumatic starting systems:

$$W_{ess} = 12.05(W_e/1,000)^{1.458} \quad (6.30)$$

For airplanes with piston engines using electric starting systems:

$$W_{ess} = 50.38(W_e/1,000)^{0.459} \quad (6.31)$$

Propeller controls:

For turboprop engines:

$$W_{pc} = 0.322(N_{bl})^{0.589}\{(N_pD_pP_{TO}/N_e)/1,000\}^{1.178} \quad (6.32)$$

For piston engines:

$$W_{pc} = 4.552(N_{bl})^{0.379}\{(N_p D_p P_{TO}/N_e)/1,000\}^{0.759} \quad (6.33)$$

Definition of term:

W_e = total weight of all engines in lbs

6.5.2.2 Torenbeek Method

For airplanes with turbojet or turbofan engines using cartridge or pneumatic starting systems, the weight for accessory drives, powerplant controls, starting and ignition systems is:

$$W_{apsi} = 36N_e(dW_F/dt)_{TO} \quad (6.34a)$$

The take-off fuel flow rate, $(dW_F/dt)_{TO}$ has the dimension of lbs/sec.

For airplanes with turboprop engines this weight is:

$$W_{apsi} = 0.4K_b(N_e)^{0.2}(P_{TO}/N_e)^{0.8} \quad (6.34b)$$

The factor K_b takes on the following values:

K_b = 1.0 without beta controls
= 1.3 with beta controls

It is usually acceptable to assume that:

$$W_{api} = W_p - W_{osc} \quad (6.35)$$

Definition of new terms:

$(dW_F/dt)_{TO}$ = fuel flow at take-off in lbs/sec

P_{TO} = required take-off power in hp

Thrust reversers for jet engines:

The weight of thrust reversers was already included in the engine weight estimate of Eq.(6.6). To obtain a better estimate of the c.g. effect due to thrust reversers a separate weight estimate is needed:

$$W_{tr} = 0.18W_e \quad (6.36)$$

Water injection system:

Water injection systems are used to increase take-off performance of all types of engines. The installation of such a system is optional.

$$W_{wi} = 8.586 W_{wtr}/8.35 \tag{6.37}$$

W_{wtr} = weight of water carried in lbs

Oil system and oil cooler:

$$W_{osc} = K_{osc} W_e \tag{6.38}$$

The factor K_{osc} takes on the following values:

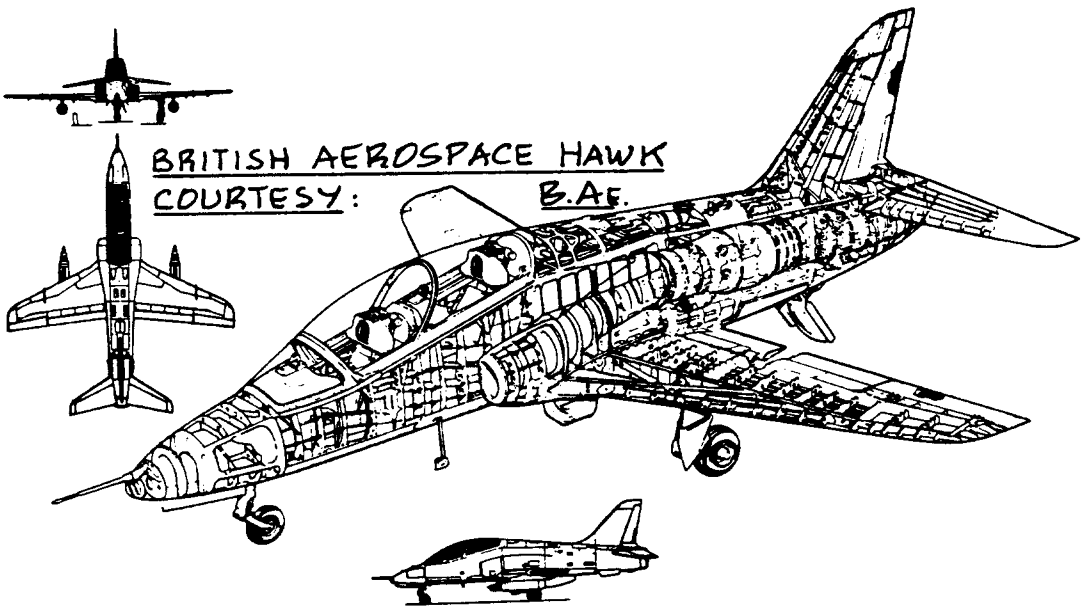
K_{osc} = 0.00 for jet engines (weight incl. in W_e)
= 0.07 for turboprop engines
= 0.08 for radial piston engines
= 0.03 for horizontally opposed piston engines

6.5.3 Military Patrol, Bomb and Transport Airplanes

See Section 6.5.2.

6.5.4 Fighter and Attack Airplanes

See Section 6.5.2.



7. CLASS II METHOD FOR ESTIMATING FIXED EQUIPMENT WEIGHT

The list of fixed equipment carried on board airplanes varies significantly with airplane type and airplane mission. In this chapter it will be assumed that the following items are to be included in the fixed equipment category:

7.1. Flight control system, W_{fc}

7.2. Hydraulic and pneumatic System, W_{hps}

7.3. Electrical system, W_{els}

7.4. Instrumentation, avionics and electronics, W_{iae}

7.5. Air-conditioning, pressurization, anti- and de-icing system, W_{api}

7.6. Oxygen system, W_{ox}

7.7. Auxiliary power unit (APU), W_{apu}

7.8. Furnishings, W_{fur}

7.9. Baggage and cargo handling equipment, W_{bc}

7.10 Operational items, W_{ops}

7.11. Armament, W_{arm}

7.12. Guns, launchers and weapons provisions, W_{glw}

7.13. Flight test instrumentation, W_{fti}

7.14. Auxiliary gear, W_{aux}

7.15. Ballast, W_{bal}

7.16. Paint, W_{pt}

7.17. W_{etc}

Therefore:

$$W_{feq} = W_{fc} + W_{hps} + W_{els} + W_{iae} + W_{api} + W_{ox} + \\ + W_{apu} + W_{fur} + W_{bc} + W_{ops} + W_{arm} + W_{glw} + \\ + W_{fti} + W_{aux} + W_{bal} + W_{pt} + W_{etc} \qquad (7.1)$$

The exact definition of which item belongs in a particular fixed equipment category is hard to find. The category W_{etc} was added to cover any items not specifically listed.

Methods for predicting weights of typical fixed equipment items are presented for the following types of airplanes:

1. General Aviation Airplanes
2. Commercial Transport Airplanes
3. Military Patrol, Bomb and Transport Airplanes
4. Fighters and Attack Airplanes

The reader should always consult actual fixed equipment weight data for similar airplanes. Appendix A presents this information for a large number of airplanes.

7.1 FLIGHT CONTROL SYSTEM WEIGHT ESTIMATION

7.1.1 General Aviation Airplanes

7.1.1.1 Cessna Method

$$W_{fc} = 0.0168 W_{TO}, \tag{7.1}$$

where: W_{TO} = take-off weight in lbs

This equation applies only to airplanes under 8,000 lbs take-off weight with mechanical flight controls. The equation includes all flight control system hardware: cables, pulleys, pushrods, cockpit controls plus any required back-up structure.

Airplanes in this category all tend to have two sets of flight controls in the cockpit.

7.1.1.2 USAF Method

For airplanes with un-powered flight controls:

$$W_{fc} = 1.066(W_{TO})^{0.626} \tag{7.2}$$

For airplanes with powered flight controls:

$$W_{fc} = 1.08(W_{TO})^{0.7} \tag{7.3}$$

7.1.1.3 Torenbeek Method

For airplanes with un-powered, unduplicated flight controls:

$$W_{fc} = 0.23(W_{TO})^{2/3} \tag{7.4}$$

7.1.2 Commercial Transport Airplanes

7.1.2.1 GD Method

The following equation applies to business jets as well as to commercial transport airplanes:

$$W_{fc} = 56.01\ \{(W_{TO})(\bar{q}_D)/100,000\}^{0.576} \tag{7.5}$$

where: $\bar{q}_D$ is the design dive dynamic pressure in psf

7.1.2.2 Torenbeek Method

$$W_{fc} = K_{fc}(W_{TO})^{2/3} \tag{7.6}$$

The constant K_{fc} takes on the following values:

K_{fc} = 0.44 for airplanes with un-powered flight controls
= 0.64 for airplanes with powered flight controls

If leading edge devices are employed, these estimates should be multiplied by a factor 1.2. If lift dumpers are employed, a factor 1.15 should be used.

7.1.3 Military Patrol, Bomb and Transport Airplanes

7.1.3.1 GD Method

For transport airplanes:

$$W_{fc} = 15.96\{(W_{TO})(\bar{q}_L)/100,000\}^{0.815}, \tag{7.7}$$

where: $\bar{q}_L$ is the design dive dynamic pressure in psf

For Bombers:

$$W_{fc} = 1.049\{(S_{cs})(\bar{q})/1,000\}^{1.21}, \tag{7.8}$$

where: S_{sc} is the total control surface area in ft^2

Note: these estimates include the weight of all associated hydraulic and/or pneumatic systems!

7.1.4 Fighters and Attack Airplanes

7.1.4.1 GD Method

For USAF fighters:

$$W_{fc} = K_{fcf}(W_{TO}/1{,}000)^{0.581} \tag{7.9}$$

The constant K_{fcf} takes on the following values:

K_{fcf} = 106 for airplanes with elevon control and no horizontal tail

= 138 for airplanes with a horizontal tail

= 168 for airplanes with a variable sweep wing

For USN fighters and attack airplanes:

$$W_{fc} = 23.77(W_{TO}/1{,}000)^{1.1} \tag{7.10}$$

Note: these estimates include the weight of all associated hydraulic and/or pneumatic systems.

Certain airplanes require a center of gravity control system. This is normally implemented using a fuel transfer system. The extra weight due to a c.g. control system may be estimated from:

$$W_{fc_{cg}} = 23.38\{(W_F/K_{fsp})/100\}^{0.442} \tag{7.11}$$

where: W_F is the mission fuel weight in lbs

K_{fsp} = 6.55 lbs /gal for JP-4

7.2 HYDRAULIC AND/OR PNEUMATIC SYSTEM WEIGHT ESTIMATION

As seen in Section 7.1 the weight of the hydraulic and/or pneumatic system needed for powered flight controls is usually included in the flight control system weight prediction.

The following weight ratios may be used to determine the hydraulic system weight separately:

For business jets: 0.0070 - 0.0150 of W_{TO}

For regional turboprops: 0.0060 - 0.0120 of W_{TO}

For commercial transports: 0.0060 - 0.0120 of W_{TO}

For military patrol, transport and bombers:

0.0060 - 0.0120 of W_{TO}

For fighters and attack airplanes:

0.0050 - 0.0180 of W_{TO}

The reader should consult the detailed weight data in Appendix A for more precise information.

7.3 ELECTRICAL SYSTEM WEIGHT ESTIMATION

The reader should consult the detailed weight data in Appendix A for electrical system weights of specific airplanes.

7.3.1 General Aviation Airplanes

7.3.1.1 Cessna Method

$$W_{els} = 0.0268 W_{TO} \qquad (7.12)$$

7.3.1.2 USAF Method

$$W_{els} = 426\{(W_{fs} + W_{iae})/1{,}000\}^{0.51} \qquad (7.13)$$

Note that the electrical system weight in this case is given as a function of the weight of the fuel system plus the weight of instrumentation, avionics and electronics.

7.3.1.3 Torenbeek Method

$$W_{hps} + W_{els} = 0.0078(W_E)^{1.2}, \tag{7.14}$$

where: W_E is the empty weight in lbs

7.3.2 Commercial Transport Airplanes

7.3.2.1 GD Method

$$W_{els} = 1{,}163\{(W_{fs} + W_{iae})/1{,}000\}^{0.506} \tag{7.15}$$

7.3.2.2 Torenbeek Method

For propeller driven transports:

$$W_{hps} + W_{els} = 0.325(W_E)^{0.8} \tag{7.16}$$

For jet transports:

$$W_{els} = 10.8(V_{pax})^{0.7}\{1 - 0.018(V_{pax})^{0.35}\}, \tag{7.17}$$

where: V_{pax} is the passenger cabin volume in ft^3

7.3.3 Military Patrol, Bomb and Transport Airplanes

7.3.3.1 GD Method

For transport airplanes:

Use Eqn.(7.15)

For Bombers:

$$W_{els} = 185\{(W_{fs} + W_{iae})/1{,}000\}^{1.268} \tag{7.18}$$

7.3.4 Fighters and Attack Airplanes

7.3.4.1 GD Method

For USAF fighters:

$$W_{els} = 426\{(W_{fs} + W_{iae})/1{,}000\}^{0.51} \tag{7.19}$$

For USN fighters and attack airplanes:

$$W_{els} = 347\{(W_{fs} + W_{iae})/1{,}000\}^{0.509} \tag{7.20}$$

7.4 WEIGHT ESTIMATION FOR INSTRUMENTATION, AVIONICS AND ELECTRONICS

The reader should consult the detailed weight data in Appendix A for weights of instrumentation, avionics and electronics for specific airplanes. Another important source of weight data on actual avionics and electronics systems for civil airplanes is Reference 18. For data on military avionics systems the reader should consult Reference 13, Tables 8-1 and 8-2.

Important comment: The weight equations given in this section are obsolete for modern EFIS type cockpit installations and for modern computer based flight management and navigation systems. The equations provided are probably conservative.

7.4.1 General Aviation Airplanes

7.4.1.1 Torenbeek Method

For single engine propeller driven airplanes:

$$W_{iae} = 33N_{pax}, \tag{7.21}$$

where: N_{pax} is the number of passengers, including the crew

For multi-engine propeller driven airplanes:

$$W_{iae} = 40 + 0.008W_{TO} \tag{7.22}$$

7.4.2 Commercial Transport Airplanes

7.4.2.1 GD Method (Modified)

For the weight of instruments:

$$W_i = \underbrace{N_{pil}\{15 + 0.032(W_{TO}/1{,}000)\}}_{\text{flight instruments}} + \underbrace{N_e\{5 + 0.006(W_{TO}/1{,}000)\}}_{\text{engine instruments}} + \underbrace{0.15(W_{TO}/1{,}000) + 0.012W_{TO}}_{\text{other instruments}} \tag{7.23}$$

where: N_{pil} is the number of pilots

N_e is the number of engines

7.4.2.2 Torenbeek Method

For regional transports:

$$W_{iae} = 120 + 20N_e + 0.006W_{TO} \tag{7.24}$$

For jet transports:

$$W_{iae} = 0.575(W_E)^{0.556}(R)^{0.25}, \tag{7.25}$$

where: W_E is the empty weight in lbs

R is the maximum range in nautical miles

7.4.3 Military Patrol, Bomb and Transport Airplanes

Use Sub-section 7.4.2.

7.4.4 Fighter and Attack Airplanes

Use Sub-section 7.4.2.

7.5 WEIGHT ESTIMATION FOR AIR-CONDITIONING, PRESSURIZATION, ANTI- AND-DEICING SYSTEMS

7.5.1 General Aviation Airplanes

7.5.1.1 USAF Method

$$W_{api} = 0.265(W_{TO})^{0.52}(N_{pax})^{0.68} \times$$
$$\times (W_{iae})^{0.17}(M_D)^{0.08}, \tag{7.26}$$

where: N_{pax} is the number of passengers, including the crew

M_D is the design dive Mach number

7.5.1.2 Torenbeek Method

For single engine, unpressurized airplanes:

$$W_{api} = 2.5N_{pax} \tag{7.27}$$

For multi-engine, unpressurized airplanes:

$$W_{api} = 0.018W_E \tag{7.28}$$

7.5.2 Commercial Transport Airplanes

7.5.2.1 GD Method

For pressurized airplanes:

$$W_{api} = 469\{V_{pax}(N_{cr} + N_{pax})/10,000\}^{0.419} \qquad (7.29)$$

7.5.2.2 Torenbeek Method

For pressurized airplanes:

$$W_{api} = 6.75(l_{pax})^{1.28} \qquad (7.30)$$

where l_{pax} = length of the passenger cabin in ft

7.5.3 Military Patrol, Bomb and Transport Airplanes

7.5.3.1 GD Method

$$W_{api} = K_{api}(V_{pr}/100)^{0.242} \qquad (7.31)$$

The constant K_{api} takes on the following values:

K_{api} = 887 for subsonic airplanes with wing and tail anti-icing

= 610 for subsonic airplanes without anti-icing

= 748 for supersonic airplanes without anti-icing

7.5.4 Fighters and Attack airplanes

7.5.4.1 GD Method

For low subsonic airplanes:

$$W_{api} = K_{api}\{(W_{iae} + 200N_{cr})/1,000\}^{0.538} \qquad (7.32)$$

The constant K_{api} takes on the following values:

K_{api} = 212 for airplanes with wing and tail anti-icing

= 109 for airplanes without anti-icing

For high subsonic and for supersonic airplanes:

$$W_{api} = 202\{(W_{iae} + 200N_{cr})/1,000\}^{0.735} \qquad (7.33)$$

7.6 WEIGHT ESTIMATION FOR THE OXYGEN SYSTEM

7.6.1 General Aviation Airplanes

Use Sub-section 7.6.2.

Note: Equation number (7.34) has been intentionally deleted.

7.6.2 Commercial Transport Airplanes

7.6.2.1 GD Method

$$W_{ox} = 7(N_{cr} + N_{pax})^{0.702} \tag{7.35}$$

7.6.2.2 Torenbeek Method

For commercial transport airplanes and for business type airplanes:

For flights below 25,000 ft:

$$W_{ox} = 20 + 0.5N_{pax} \tag{7.36}$$

For short flights above 25,000 ft:

$$W_{ox} = 30 + 1.2N_{pax} \tag{7.37}$$

For extended overwater flights:

$$W_{ox} = 40 + 2.4N_{pax} \tag{7.38}$$

7.6.3 Military Patrol, Bomb and Transport airplanes

Use Sub-section 7.6.2.

7.6.4 Fighters and Attack airplanes

7.6.4.1 GD Method

$$W_{ox} = 16.9(N_{cr})^{1.494} \tag{7.39}$$

7.7 AUXILIARY POWER UNIT WEIGHT ESTIMATION

Auxiliary power units are often used in transport or patrol type airplanes, commercial as well as military.

Actual APU manufacturer data should be used, where possible. Reference 8 contains data on APU systems, under 'Engines'.

From the detailed weight statements in Appendix A it is possible to derive weight fractions for these systems as a function of the take-off weight, W_{TO}. The following ranges are typical of these weight fractions:

$$W_{apu} = (0.004 \text{ to } 0.013)W_{TO} \tag{7.40}$$

7.8 FURNISHINGS WEIGHT ESTIMATION

The furnishings category normally includes the following items:

1. seats, insulation, trim panels, sound proofing, instrument panels, control stands, lighting and wiring
2. Galley (pantry) structure and provisions
3. Lavatory (toilet) and associated systems
4. Overhead luggage containers, hatracks, wardrobes
5. Escape provisions, fire fighting equipment

Note: the associated consumable items such as potable water, food, beverages and toilet chemicals and papers are normally included in a weight category referred to as: Operational Items: W_{ops}, see Section 7.10.

The reader is referred to the detail weight statements in Appendix A for actual furnishings weight data on specific airplanes.

7.8.1 General Aviation airplanes

7.8.1.1 Cessna Method

$$W_{fur} = 0.412(N_{pax})^{1.145}(W_{TO})^{0.489}, \tag{7.41}$$

where: N_{pax} is the number of passengers including the crew

7.8.1.2 Torenbeek Method:

For single engine airplanes:

$$W_{fur} = 5 + 13N_{pax} + 25N_{row}, \tag{7.42}$$

where: N_{row} is the number of seat rows

For multi engine airplanes:

$$W_{fur} = 15N_{pax} + 1.0V_{pax+cargo}, \tag{7.43}$$

where: $V_{pax+cargo}$ is the volume of the passenger cabin plus the cargo volume in ft^3

7.8.2 Commercial Transport Airplanes

The weight of furnishings varies considerably with airplane type and with airplane mission. This weight item is a considerable fraction of the take-off weight of most airplanes, as the data in Appendix A illustrate.

Reference 14 contains a very detailed method for estimating the furnishings weight for commercial transport airplanes.

7.8.2.1 GD Method

$$W_{fur} = \tag{7.44}$$

$$\underbrace{55N_{fdc}}_{\text{fdc sts}} + \underbrace{32N_{pax}}_{\text{pax sts}} + \underbrace{15N_{cc}}_{\text{cc sts}} + \underbrace{K_{lav}(N_{pax})^{1.33}}_{\text{lavs + water}} + \underbrace{K_{buf}(N_{pax})^{1.12}}_{\text{food prov.}}$$

$$+ \underbrace{109\{(N_{pax}(1 + P_c)/100\}^{0.505}}_{\text{cabin windows}} + \underbrace{0.771(W_{TO}/1,000)}_{\text{miscellaneous}}$$

The factor K_{lav} takes on the following values:

K_{lav} = 3.90 for business airplanes
= 0.31 for short range airplanes
= 1.11 for long range airplanes

The factor K_{buf} takes on the following values:

K_{buf} = 1.02 for short ranges
= 5.68 for very long ranges

The term P_c is the design ultimate cabin pressure in psi. The value of P_c depends on the design altitude for the pressure cabin.

7.8.2.2 Torenbeek Method

$$W_{fur} = 0.211(W_{TO} - W_F)^{0.91} \quad (7.45)$$

In commercial transports it is usually desirable to make more detailed estimates than possible with Eqn.(7.45). Particularly if a more accurate location of the c.g. of items which contribute to the furnishings weight is needed, a more detailed method may be needed. Reference 14 contains the necessary detailed information.

7.8.3 Military Patrol, Bomb and Transport Airplanes

7.8.3.1 GD Method

W_{fur} = Sum ↓ in the tabulation below. (7.46)

Type	Patrol	Bomb	Transport
Crew Ej. Seats	$K_{st}(N_{cr})^{1.2}$	$K_{st}(N_{cr})^{1.2}$	
	K_{st} = 149 with survival kit = 100 without survival kit		
Crew Seats	$83(N_{cr})^{0.726}$	same	same
Passenger Seats			$32(N_{pax})$
Troop Seats			$11.2(N_{troop})$
Lav. and Water			$1.11(N_{pax})^{1.33}$
Misc.	$0.0019(W_{TO})^{0.839}$		$0.771(W_{TO}/1,000)$

7.8.4 Fighters and Attack Airplanes

$$W_{fur} = \quad (7.47)$$

$$= \underbrace{22.9(N_{cr}\bar{q}_D/100)^{0.743}}_{\text{ejection seats}} + \underbrace{107(N_{cr}W_{TO}/100,000)^{0.585}}_{\text{Misc. and emergency eqpmt}}$$

7.9 WEIGHT ESTIMATION OF BAGGAGE AND CARGO HANDLING EQUIPMENT

The GD method gives for military passenger transports:

$$W_{bc} = K_{bc}(N_{pax})^{1.456} \tag{7.48}$$

The constant K_{bc} takes on the following values:

K_{bc} = 0.0646 without preload provisions
= 0.316 with preload provisions

The Torenbeek method gives for commercial cargo airplanes:

$$W_{bc} = 3S_{ff}, \tag{7.49}$$

where: S_{ff} is the freight floor area in ft^2.

For baggage and for cargo containers, the following weight estimates may be used:

freight pallets:	88x108 in	225 lbs
(including nets)	88x125 in	262 lbs
	96x125 in	285 lbs

containers: 1.6 lbs/ft^3 (For container dimensions, see Part III.)

7.10 WEIGHT ESTIMATION OF OPERATIONAL ITEMS

Typical weights counted in operational items are:

*Food *Potable water *Drinks

*China *Lavatory supplies

Observe that Eqn. (7.44) includes these operational items. For more detailed information on operational items the reader should consult Reference 14, p.292.

7.11 ARMAMENT WEIGHT ESTIMATION

The category armament can contain a wide variety of weapons related items as well as protective shielding for the crew. Typical armament items are:

•Firing systems •Fire control systems

•Bomb bay or missile doors •Armor plating

•Weapons ejection systems

Note that the weapons themselves as well as any ammunition are not normally included in this item.

Appendix A contains data on 'armament' weight for several types of military airplanes.

7.12 WEIGHT ESTIMATION FOR GUNS, LAUNCHERS AND WEAPONS PROVISIONS

For detailed data on guns, lauchers and other military weapons provisions the reader is referred to Part III, Chapter 7.

Note: Ammunition, bombs, missiles, and most types of external stores are normally counted as part of the payload weight, W_{PL} in military airplanes.

7.13 WEIGHT ESTIMATION OF FLIGHT TEST INSTRUMENTATION

During the certification phase of most airplanes a significant amount of flight test instrumentation and associated hardware is carried on board. The magnitude of W_{fti} depends on the type of airplane and the types of flight tests to be performed. Appendix A contains weight data for flight test instrumentation carried on a number of NASA experimental airplanes (Tables A13.1-A13.4).

7.14 WEIGHT ESTIMATION FOR AUXILIARY GEAR

This item encompasses such equipment as:

•fire axes •sextants •unaccounted items

An item referred to as 'manufacturers variation' is sometimes included in this category as well. A safe assumption is to set:

$$W_{aux} = 0.01W_E \tag{7.50}$$

7.15 BALLAST WEIGHT ESTIMATION

When looking over the weight statements for various airplanes in Appendix A, the reader will make the startling discovery that some airplanes carry a significant amount of ballast. This can have detrimental effects on speed, payload and range performance.

The following reasons can be given for the need to include ballast in an airplane:

1. The designer 'goofed' in the weight and balance calculations

2. To achieve certain aerodynamic advantages it was judged necessary to locate the wing or to size the empennage so that the static margin became insufficient. This problem can be solved with ballast. In this case, carrying ballast may in fact turn out to be advantageous.

3. To achieve flutter stability within the flight envelope ballast weights are sometimes attached to the wing and/or to the empennage.

Note: balance weights associated with flight control surfaces are not counted as ballast weight.

The amount of ballast weight required is determined with the help of the X-plot. Construction and use of the X-plot is discussed in Part II, Chapter 11. The Class II weight and balance method discussed in Chapter 9 of this part may also be helpful in determining the amount of ballast weight required to achieve a certain amount of static margin.

7.16 ESTIMATING WEIGHT OF PAINT

Transport jets and camouflaged military airplanes carry a considerable amount of paint. The amount of paint weight is obviously a function of the extent of surface coverage. For a well painted airplane a reasonable estimate for the weight of paint is:

$$W_{pt} = 0.003 - 0.006W_{TO} \tag{7.51}$$

7.17 ESTIMATING WEIGHT OF W_{etc}

This weight item has been included to cover any items which do not normally fit in any of the previous weight categories.

8. LOCATING COMPONENT CENTERS OF GRAVITY

The purpose of this chapter is to provide guidelines for the determination of the location of centers of gravity for individual airplane components. Knowledge of component c.g. locations is essential in both Class I and Class II weight and balance analyses as discussed in Chapter 10 of Part II and Chapter 4 of this book.

In Part II, Chapter 10, Table 10.2 provides a summary of c.g. locations for the major structural components of the airplane only. In this chapter a slightly more extensive data base is provided. The presentation of component c.g. locations follows the weight breakdowns of Chapters 5-7:

8.1 C.G. Locations of Structural Components
8.2 C.G. Locations of Powerplant Components
8.3 C.G. Locations for Fixed Equipment

8.1 C.G. LOCATIONS OF STRUCTURAL COMPONENTS

Table 8.1 lists the most likely c.g. locations for major structural components. There is no substitute for common sense: if the preliminary structural arrangement of Part III (Step 19 of p.d. sequence 2, Part II) suggests that a given structural component has a different mass distribution than is commonly the case, an 'educated guess' must be made as to the effect on the c.g. of that component.

Example: Looking at the threeview of the GP-180 of Figure 3.47, p.86, Part II it is obvious that there is a concentration of primary structure at the aft end of the fuselage. The fuselage c.g. should therefore not be placed at 38-40 percent of the fuselage length, but probably at 55 to 60 percent.

8.2 C.G. LOCATIONS OF POWERPLANT COMPONENTS

Table 8.2 lists the most likely c.g. locations for powerplant components. Note that for engine c.g. locations manufacturers data should be used. 'Guessing' at engine c.g. locations is not recommended!

8.3 C.G. LOCATIONS OF FIXED EQUIPMENT

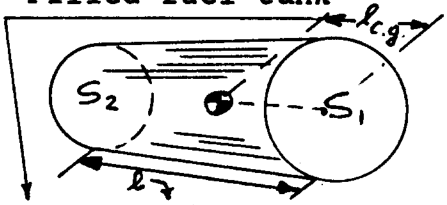
Table 8.3 lists guidelines for locating centers of gravity of fixed equipment components.

Table 8.1 Center of Gravity Location of Structural Components

Component:	Center of gravity location:
Wing (half):	Unswept wing: 38-42 percent chord from the L.E. at 40 percent of the semi-span. Swept wing: 70 percent of the distance between the front and rear spar behind the front spar at 35 percent of the semi-span
Horizontal Tail: (half)	Regardless of sweep angle: 42 percent chord from the L.E. at 38 percent of the semi-span.
Vertical Tail: (low tail)	Regardless of sweep angle: 42 percent chord from the L.E. at 38 percent vertical tail span from the root chord.
Vertical Tail: (T-tail) root	Regardless of sweep angle: 42 percent chord from the L.E. at 55 percent vertical tail span from the root chord.
Vertical Tail: (cruciform)	Regardless of sweep angle: 42 percent chord from the L.E. at between 38 and 55 percent vertical tail span from the root chord. Interpolate according to z_h/b_v.
Fuselage: Caution: Do not count the propeller spinner in fuselage or nacelle length!	Distances are given as a fraction of the fuselage length: Single engine tractors: 0.32-0.35 Single engine pusher: 0.45-0.48 Propeller driven twins: 0.38-0.40 (tractors on wing) Propeller driven twins: 0.50-0.53 (pushers on wing) Jet transports: 0.42-0.45 (wing mounted engines) Jet transports: 0.47-0.50 (rear fuselage mounted engines) Fighters: 0.45 (engines buried in the fuselage)
Tail booms:	0.40-0.45 of boom length starting from most forward structural attachment of the boom.
Nacelles:	0.40 of nacelle length from nacelle nose
Landing gear:	at 0.50 of strutlength for gears with mostly vertical struts

Table 8.2 Center of Gravity Location of Powerplant
Components

Component:	Center of Gravity Location:
Engine(s)	Use manufacturers data
Air induction system	Use the c.g. of the gross shell area of the inlets
Propellers	On the spin axis, in the propeller spin plane
Fuel system	Refer to the fuel system layout diagram required as part of Step 17 in p.d. sequence II, Part II, p.18.
Filled fuel tank	Assuming a prismoidal shape (See figure left), the c.g. is located relative to plane S_1 at:



$$l_{cg} = (1/4)\{S_1 + 3S_2 + 2(S_1S_2)^{1/2}\}/\{S_1 + S_2 + (S_1S_2)^{1/2}\} \quad (8.1)$$

Trapped fuel and oil	Trapped fuel is normally located at the bottom of fuel tanks and fuel lines. Trapped oil is normally located close to the engine case.
Propulsion system	Make a list of which items contribute to the propulsion system weight and 'guestimate' their c.g. location by referring to the powerplant installation drawing required in Step 5.10, pages 133 and 134 in Part II.

Table 8.3 Center of Gravity Location of Fixed Equipment

Component:	Center of Gravity Location:
Flight Control System Hydraulic and Pneumatic System Electrical System Instrumentation, Avionics and Electronics Air-conditioning, Pressurization, Anti-icing and de-icing System Oxygen System	Note: for all systems, the c.g. location can be most closely 'guestimated' by referring to the system lay-out diagrams described in Part IV of this text. These system lay-outs were required as part of Step 17 in p.d. sequence 2, Part II, p.18.
Auxiliary Power Unit	See engine manufacturer data.
Furnishings Baggage and Cargo Handling Equipment	Refer to the fuselage internal arrangement drawing required by Steps 4.1 and 4.2 in Part II, pp 107 and 108.
Operational items	See furnishings
Armament	This item is normally close to the cockpit
Guns, launchers and weapons provisions	From manufacturer data.
Flight test instrumentation	A sketch depicting the locations of sensors, recorders operating systems should help in locating the overall c.g. of this item.
Auxiliary gear	Make a list of items in this category and 'guestimate' their c.g. locations.
Ballast	Ballast weights are normally made from lead. Ballast c.g. is thus easily located.
Paint	Centroid of painted areas.