NOMENCLATURE

AC	alternating current
A_i	capture area of inlet
APS	Aircraft Prepared for Service
APU	Auxiliary Power Unit
AUW	All-Up Weight
a	constant factor in statistical weight equation
BOW	Basic Operating Weight
B_p	number of propeller blades per propeller
b	span (no index: wing span); factor of proportionality in statistical correlation
b_{ref}	reference span
b_s	structural span (b_s=b/cos $\Lambda_{\frac{1}{2}}$)
$\bar{c}$	length of mean aerodynamic chord
c.g.	center of gravity
D	selling price of payload
DC	Direct Current
D_p	propeller diameter
ESHP	Equivalent Shaft Horse Power (takeoff, standard atmosphere)
h	height; depth
h_h	height of horizontal tailplane above fin root
k	factor of proportionality
k_w	factor of proportionality for the weight of a group of items
l	length; moment arm; distance between end faces of a prismoid
l_h	horizontal tail length (cf. Chapter 9)
l_t	distance between 1/4-chord points of wing and horizontal tailplane root (see Fig. D-2)
MAC	Mean Aerodynamic Chord
MLW (MRLW)	Maximum (Regular) Landing Weight
MTOW(MRTOW)	Maximum (Regular) Takeoff Weight
MZFW	Maximum Zero Fuel Weight
m_i	ratio of actual to estimated weight for a sample point
N	number of an item present in the airplane
$n_1,n_2,\ldots,n_m$	exponent of a weight parameter
n_{ult}	ultimate load factor
OEW	Operational Empty Weight
P_{el}	total electrical generator power (kVA)
P_{to}	takeoff horsepower per engine (sea level, static)
R_B	maximum range with maximum payload (Fig. 8-3)
R_D	maximum range with maximum fuel (Fig. 8-3)
R_{ref}	reference range
S	(projected) area of a surface (no index: wing area); standard error of prediction
S_1,S_2	areas of parallel end faces of a prismoid
S_G	gross shell area of the fuselage
S_{he}	exposed horizontal tailplane area
SIV	Standard Item Variations
SMC	Standard Mean Chord
S_{wet}	wetted area
T_{to}	takeoff thrust per engine (sea level, static)
t_r	(absolute) maximum thickness of root chord
U	annual airplane utilisation
u.c.	undercarriage
V	speed; volume
V_b	blockspeed
V_D	Design Dive speed
V_{max}	maximum horizontal flight speed
W	weight
$\dot{W}_{ba}$	rated bleed airflow of APU
$\dot{W}_{f_{to}}$	fuel flow per engine, corresponding to P_{to} or T_{to}
W_{DE}	Delivery Empty Weight
W_{OE}	Operating Empty Weight
W_G	Gross Weight
W_{ZF}	Maximum Zero Fuel Weight
X	X-axis; parameter for wing weight estimation example
X_{LEMAC}	coordinate of MAC leading edge
x	coordinate of weight contribution; sample value of X
Δx	range of x-coordinates for the c.g.
x_{OE}	airplane c.g. position for the OEW
Y	weight of an airplane part
Y_i	actual (measured) value of Y for a sample
δ	maximum deflection angle; incidence variation
$\Lambda_{\frac{1}{2}}$	sweepback angle at 50% chord (no index: wing)
φ	average load factor
$\phi_1,\phi_2,\ldots,\phi_m$	parameters for general weight estimation formula

Subscripts

APU	Auxiliary Power Unit
APUG	APU Group
ba	(APU) bleed airflow
cc	cabin crew
cf	cabin floor
cg	center of gravity
ch	cargo hold
d	intake duct
e	engine(s)
el	electrical system
er	bending moment relief due to engine(s)
f	fuselage; flaps; fuel
fc	flight crew
fg	fuselage group
ft	fuel tank
geo	geometric shape
h	horizontal tailplane
hc	horizontal tail controls
i	inlet; installation; sample
ieg	instruments and electronics group
ld	lift dumper
LEMAC	Leading Edge of MAC
n	nacelle (group)
p	propeller
pax	passengers
pc	passenger cabin
pg	propulsion group
s	structure; slat
sb	speed brake
sc	surface controls group
tail	horizontal plus vertical tai
thr	thrust reverser
to	takeoff
uc	undercarriage
v	vertical tailplane
w	wing; weight
wc	toilet/watercloset compartme
wg	wing group
wt	water tank for injection flu

8.1. INTRODUCTION; THE IMPORTANCE OF LOW WEIGHT

Weight minimization of an airplane design is a subject of the utmost importance. Although reduction of weight is generally obtained only at some initial cost penalty, the effects on total operating costs are paramount for most high-performance designs, particularly for large and complex airplanes. In many cases the increased weight of one component means added weight elsewhere, leading to the well-known snowball effect of weight growth. The opportunities to achieve a weight reduction and the associated costs depend upon the phase of the design process.

a. During the initial conceptual design the choice of the airplane layout, geometry and detailed configuration affects weight. The design layout should be carefully optimized and high accuracy of the initial weight prediction is a prerequisite. Weight prediction is necessary not only to make an assessment of the design qualities, but a so to set a goal for the structural and systems design offices. The initial weig prediction must be a realistic challenge both. This type of work, being the norma task of the preliminary design office, i volves virtually no extra costs.

Weight reductions or increments are gene ally evaluated for constant design perfo ance, unless limited engine performance does not permit this. Any component weig increase is therefore associated with a takeoff weight increase. If, however, th component weight growth is caused by a d sign change to improve performance - e.g improved high-lift devices, increased wi span - the final result may well be a ta off weight reduction.

Sensitivities to structure weight increm are shown in Table 8-1 for some typical sions. In the case considered, a 10% str ture weight growth was followed by a rewhere

$$a=\frac{\sum x_i \sum x_i y_i-\sum y_i \sum x_i^2}{(\sum x_i)^2 - N \sum x_i^2} \tag{8-6}$$

and

$$b=\frac{\sum x_i \sum y_i-N \sum x_i y_i}{(\sum x_i)^2 - N \sum x_i^2} \tag{8-7}$$

For limited ranges of X and Y a linear function may be satisfactory, but if a considerable variation in the actual size of the item exists, a better result is usually obtained with:

$$Y = kX^n \tag{8-8}$$

On a log-log scale this relation is linear:

$$\log Y = \log k + n \log X \tag{8-9}$$

and again linear regression analysis can be used.

The standard error of a prediction method is:

$$S= \sqrt{\frac{1}{N-1}\left[\sum m_i^2- \frac{(\sum m_i)^2}{N}\right]} \tag{8-10}$$

where m_i is the ratio of actual to estimated weight of the sample.

References 8-41 and 8-44 give more information on the use of statistics and various types of regression analysis. A certain amount of care should always be taken when using statistical methods. A check must be made to see if the airplane being analyzed falls within the range of data points that were used to develop the method. The choice of parameters to be used is always somewhat arbitrary and due attention must be paid to data points that are far from the regression line. They may indicate that alternative correlations should be investigated. Finally, all parameters used in weight prediction must be well defined and not give rise to misinterpretation or vagueness.

Finally, it should be realized that many weight prediction methods apply to a limited category of airplanes. Occasionally they may be adapted to other categories simply by modifying the factor of proportionality, provided that the basic expression has a rational background and derivation.

8.4. WEIGHT PREDICTION DATA AND METHODS

8.4.1. Airframe structure

a. Structure weight prediction based on the aircraft specific density. An intriguing approach to structure weight estimation, applicable to conventional configurations, is made by Caddell in Ref. 8-39, who uses the aircraft density, i.e. the design gross weight divided by the total airplane volume. If his line of thought is adopted, the structural weight fraction of transport-type turbine-powered airplanes can be expressed in terms of the ultimate load factor, the fuselage dimensions and the MTOW:

$$\frac{W_s}{W_{to}} = k_s \sqrt{n_{ult}} \left(\frac{b_f h_f l_f}{W_{to}}\right)^{.24} \tag{8-11}$$

where

k_s = .230 for b_f, h_f and l_f in ft and W_s and W_{to} in lb,

k_s = .447 for b_f, h_f and l_f in m and W_s and W_{to} in kg, and

n_{ult} corresponds to the MTOW.

Although this simple expression yields a reasonably accurate prediction, it is useless for design optimization, as the effects of the airplane layout are not accounted for. The only alternative is a detailed assessment of the contributions of all structural components or groups. The subdivision in Table 8-4 can be used to collect structural weight data. A compilation of structure weight data for existing aircraft is presented in Table 8-5. According to (8-11) the ultimate load factor affects structural weight to a considerable extent. The rules for establishing the ultimate load factor (1.5 times the limit load factor) are laid down in the various airworthiness regulations. It should be

WING GROUP		
CENTER SECTION-BASIC STRUCTURE		
INTERMEDIATE PANEL-BASIC STRUCTURE		
OUTER PANEL-BASIC STRUCTURE (INCL. TIPS ....)		
SECONDARY STRUCTURE (INCL. WING FOLD MECH. ....)		
AILERONS (INCL. BALANCE WEIGHT ....)		
FLAPS - TRAILING EDGE		
- LEADING EDGE		
SLATS		
SPOILERS, SPEED BRAKES, LIFT DUMPERS		
FENCES AND VORTEX GENERATORS		
STRUTS		
TAIL GROUP		
STABILIZER-BASIC STRUCTURE		
FINS-BASIC STRUCTURE (INCL. DORSAL ....)		
SECONDARY STRUCTURE (STAB. AND FINS)		
ELEVATOR (INCL. BALANCE WEIGHT ....)		
RUDDERS (INCL. BALANCE WEIGHT ....)		
BODY GROUP		
FUSELAGE OR HULL-BASIC STRUCTURE		
BOOMS-BASIC STRUCTURE		
SECONDARY STRUCTURE - FUSELAGE OR HULL		
- BOOMS		
- SPEED BRAKES		
- DOORS, PANELS AND MISC.		

ALIGHTING GEAR GROUP - LAND (TYPE ....)					
LOCATION	WHEELS, BRAKES, TYRES, TUBES, AIR	STRUCTURE	CONTROLS	TOTAL	
MAIN					
NOSE					
TAIL (BUMPER)					

ALIGHTING GEAR GROUP - WATER					
LOCATION	FLOATS	STRUTS	CONTROLS		

SURFACE CONTROLS GROUP		
COCKPIT CONTROLS		
AUTOMATIC PILOT		
SYSTEM CONTROLS (INCL. POWER AND FEEL CONTR.)		
ENGINE SECTION OR NACELLE GROUP		
INBOARD		
CENTER		
OUTBOARD		
DOORS, PANELS AND MISC.		
TOTAL, AIRFRAME STRUCTURE		

Table 8-4. Airframe Structure Group weight breakdown according to AN-9103-D (modified)

LIGHT AIRCRAFT

Airplane category	Airplane type	MTOW 10^3 lb	Wing group 10^3 lb	Wing group %	Tail group 10^3 lb	Tail group %	Fuselage group 10^3 lb	Fuselage group %	Landing gear 10^3 lb	Landing gear %	Surface controls 10^3 lb	Surface controls %	Nacelle group 10^3 lb	Nacelle group %
LIGHT SINGLES RECIPROCATING	Cessna - 150A	1.50	0.213	14.2	0.041	2.73	0.166	11.1	0.106	7.07	0.031	2.07	0.024	1.60
	- 172B	2.20	0.236	10.7	0.061	2.77	0.253	11.5	0.122	5.55	0.031	1.41	0.031	1.41
	- 180D	2.65	0.254	9.58	0.059	2.23	0.270	10.2	0.119	4.49	0.036	1.36	0.037	1.40
	- 182D	2.65	0.254	9.58	0.061	2.30	0.273	10.3	0.136	5.13	0.036	1.36	0.036	1.36
	- 185	3.20	0.266	8.31	0.071	2.22	0.290	9.06	0.132	4.13	0.036	1.13	0.041	1.28
	- 210	2.90	0.261	9.0	0.071	2.45	0.316	10.90	0.207	7.14	0.044	1.52	0.031	1.07
	Beechcraft J-35	2.90	0.379	13.1	0.058	2.00	0.200	6.90	0.205	7.07	0.056	1.93	0.062	2.14
	Saab Safir	2.66	0.276	10.4	0.060	2.26	0.386	14.5	0.119	4.47	**	-	**	-
LIGHT TWINS RECIPROCATING	Cessna C-310	4.83	0.454	9.40	0.118	2.44	0.319	6.60	0.263	5.45	0.066	1.37	0.129	2.67
	Beechcraft G-50	7.15	0.656	9.17	0.156	2.18	0.495	6.92	0.447	6.25	0.120	1.68	0.261	3.65
	-65	7.37	0.670	9.09	0.153	2.08	0.601	8.15	0.444	6.02	0.132	1.79	0.285	3.87
	-95	4.00	0.458	11.5	0.079	1.98	0.276	6.90	0.218	5.45	0.073	1.83	0.180	4.50
	D-18S	8.75	0.858	9.81	0.177	2.02	0.733	8.38	0.560	6.40	0.115*	1.31	0.311	3.55
	E-18S	9.70	0.874	9.01	0.180	1.86	0.768	7.92	0.585	6.03	0.115	1.19	0.331	3.41
	De Havilland Dove	8.80	0.930	10.6	0.196	2.23	0.745	8.47	0.391	4.44	**	-	0.220*	2.50
JET TRAINERS	Cessna T-37	6.44	0.531	8.24	0.128	1.99	0.839	13.0	0.330	5.12	0.154	2.39	-	-
	Fouga Magister	6.28	1.089	17.3	0.165	2.63	0.743	11.8	0.459	7.31	0.260	4.14	-	-
	Canadair CL-41	6.50	0.892	13.7	0.201	3.09	0.955	14.7	0.318	4.89	0.172	2.65	0.040	0.62
JET EXECUTIVES	H. Siddeley - 125	21.200	1.968	9.28	0.608	2.87	1.628	7.68	0.659	3.11	0.217	1.02	**	-
	Jet Commander 1121	16.000	1.322	8.26	0.425	2.66	1.622	10.1	0.443	2.76	0.223	1.39	0.35	2.19
	N.Am.Sabreliner	16.700	1.753	10.5	0.297	1.78	2.014	12.1	0.728	4.36	0.344	2.06	0.315	1.89
	Lockheed Jetstar	30.680	2.827	9.21	0.879	2.87	3.491	11.4	1.061	3.46	0.768	2.50	0.792	2.58

* estimated　　　　** included in other items

Table 8-5. Weight breakdown of the structure group weight

PROPELLER TRANSPORTS

Airplane category	Engines	Airplane type	MTOW 10^3 lb	Wing group 10^3 lb	Wing group %	Tail group 10^3 lb	Tail group %	Fuselage group 10^3 lb	Fuselage group %	Landing gear 10^3 lb	Landing gear %	Surface controls 10^3 lb	Surface controls %	Nacelle group 10^3 lb	Nacelle group %
RECIPROCATING	2 ENGINES	De Havilland DHC-4	24.000	2.925	12.2	0.790	3.29	2.849	11.9	1.23	5.13	0.326	1.36	0.781	3.25
		Saab Scandia	35.273	4.195	11.9	0.584	1.66	2.773	7.86	1.841	5.22	0.369	1.05	1.479	4.19
		H. Page Herald	37.500	4.365	11.6	0.987	2.63	2.986	7.96	1.625	4.33	0.364	0.97	0.830	2.21
		S.A. Twin Pioneer	14.600	2.121	14.5	0.576	3.95	1.381	9.46	0.703	4.82	0.300	2.05	0.230	1.58
		Canadair CL-21	32.500	3.99	12.3	1.055	3.25	3.260	10.0	1.609	4.95	0.371	1.14	1.29	3.97
	4 ENGINES	Douglas DC-6B	81.500	7.506	9.21	1.406	1.73	5.471	6.71	4.165	5.11	1.052	1.29	2.871	3.52
		DC-7C	143.000	11.100	7.76	1.900	1.33	8.450	5.91	5.130	3.59	1.215	0.85	4.130	2.89
		Lockheed L-749	102.072	11.102	10.9	2.059	2.02	7.407	7.26	4.782	4.68	1.488	1.46	3.869	3.79
		L-1049	137.500	11.542	8.39	2.604	1.89	12.839	9.34	5.422	3.94	1.685	1.23	4.420	3.21
TURBOPROPELLER	2 ENGINES	Nord 262	23.050	2.698	11.7	0.805	3.49	3.675	15.9	1.085	4.71	0.408	1.77	0.236	1.02
		Fokker F-27/100	39.000	4.408	11.3	0.977	2.51	4.122	10.6	1.940	4.97	0.613	1.57	0.628	1.61
		F-27/200	43.500	4.505	10.4	1.501	2.42	4.303	2.89	1.825	4.20	0.620	1.43	0.667	1.53
		F-27/500	45.000	4.510	10.0	1.060	2.35	5.142	11.4	1.865	4.14	0.626	1.39	0.668	1.48
		Grumman Gulfstream	33.600	3.735	11.2	0.874	2.60	3.718	11.1	1.207	3.59	0.461	1.37	1.136	3.38
		Short Skyvan	12.500	1.220	9.76	0.374	2.99	2.154	17.2	0.466	3.73	0.265	2.12	0.254	2.03
	4 ENGINES	Bréguet 941	58.421	4.096	7.01	1.387	2.37	6.481	11.1	2.626	4.94	1.056	1.81	***	-
		H.S. Argosy	82.000	10.800	13.2	1.300	1.59	11.100*	13.5	3.180	3.88	**	-	1.200	1.46
		Vickers Viscount 810	69.000	6.25	9.06	1.245	1.80	6.900	10.0	2.469	3.58	0.824	1.19	1.81[illegible]	2.62
		Bristol Brit. 300	155.000	13.433	8.6[illegible]	3.202	2.07	11.100	7.16	5.785	3.73	1.221	0.79	4.930	3.18
		Brit. 320	184.523	14.199	7.69	3.221	1.75	11.750	6.38	6.500	3.52	2.048	1.11	7.350	3.98
		Canadair CL-44C	205.000	15.710	7.66	3.749	1.83	20.524	10.0	7.083	3.46	2.146	1.05	6.834	3.33
		CL-44D	205.000	15.588	7.60	3.540	1.73	16.047	7.83	7.300	3.56	1.830	0.89	6.043	2.95
		Lockheed Electra	106.700	7.670	7.19	1.924	1.80	9.954	9.33	3.817	3.58	***	-	4.417	4.14
		C-130E	151.522	11.697	7.72	3.425	2.26	14.340	9.46	5.341	3.53	1.702	1.12	2.675	1.77
		C-133A	275.000	27.403	9.96	6.011	2.19	30.940	11.3	10.635	3.87	1.804	0.66	3.512	1.28

* tail booms (2,360 lb) included　　　　** included in other items　　　　*** no data available

Table 8-5. (Continued)

	AIRPLANE CATEGORY AND TYPE	MTOW	WING GROUP		TAIL GROUP		FUSELAGE GROUP		LANDING GEAR		SURFACE CONTROLS		NACELLE GROUP	
		10^3 lb	10^3 lb	%	10^3 lb	%	10^3 lb	%	10^3 lb	%	10^3 lb	%	10^3 lb	%
2 ENGINES	VFW-Fokker 614	40.981	5.767	14.1	1.121	2.74	5.233	12.8	1.620	3.45	0.745	1.82	0.971	2.37
	Fokker-VFW F-28/1000	65.000	7.330	11.3	1.632	2.46	7.043	10.8	2.759	4.24	1.387	2.13	0.834	1.28
	F-28/2000	65.000	7.347	11.3	1.632	2.46	7.649	11.8	2.759	4.24	1.400	2.15	0.834	1.28
	F-28/5000	70.800	8.223	11.6	1.632	2.31	7.043	9.95	2.759	3.90	1.665	2.35	0.849	1.20
	F-28/6000	70.800	8.244	11.6	1.632	2.31	7.649	10.8	2.789	3.94	1.674	2.36	0.849	1.20
	BAC 1-11/300	87.000	9.643	11.1	2.369	2.72	9.713	11.2	2.865	3.29	1.481	1.76	**	-
	1-11/400	87.000	9.670	11.1	2.419	2.78	9.743	11.3	2.899	3.33	1.207	1.39	**	-
	Mc D. Douglas DC-9/10	91.500	9.470	10.3	2.630	2.87	11.206	12.2	3.660	4.00	1.264	1.38	1.417	1.55
	Boeing 737-100M	97.800	9.968	10.2	2.700	2.76	12.380	12.7	3.687	3.77	1.589	1.62	***	-
	737-200	100.000	10.613	10.6	2.718	2.72	12.108	12.1	4.354	4.35	2.348	2.35	1.392	1.39
	Aerospat. Caravelle XIR	110.230	14.735	13.4	1.957	1.77	11.570	10.5	5.110	4.63	2.063	1.87	1.581	1.43
	Airbus A300B/2	304.000	44.131	14.5	5.941	1.95	35.820	11.8	13.611	4.47	5.808	1.94	7.039	2.32
3 ENGINES	H. Siddeley 121-1C	115.000	12.600	11.0	3.225	2.80	12.469	10.8	4.413	3.84	1.792	1.56	**	-
	121-1E	134.000	13.462	10.0	3.341	2.49	13.328	9.95	5.073	3.79	1.689	1.26	**	-
	Boeing 727-100	161.000	17.764	11.0	4.133	2.57	17.681	10.9	7.211	4.48	2.996	1.86	3.864*	2.40
	727-100C	160.000	17.492	10.9	4.142	2.59	20.044	12.5	6.860	4.29	2.957	1.85	3.839	2.40
4 ENGINES	Boeing KC-135	297.000	25.251	8.50	5.074	1.71	18.867	6.35	10.180	3.43	2.044	0.69	2.575	0.87
	707-121	246.000	24.024	9.76	5.151	2.09	20.061	8.15	9.763	3.97	2.044	0.83	4.639	1.89
	707-320	311.000	29.762	9.57	5.511	1.77	21.650	6.96	12.700	4.08	2.400*	0.77	4.497	1.45
	707-320C	330.000	32.255	9.77	6.165	1.87	26.937	8.16	12.737	3.86	3.052	0.92	4.183	1.27
	707-321	301.000	28.647	9.52	6.004	1.99	22.129	7.35	11.122	3.70	2.408	0.80	5.119	1.70
	720-022	203.000	22.850	11.3	5.230	2.58	19.035	9.38	8.110	4.00	2.430	1.21	4.510	2.22
	747-100	710.000	86.402	12.2	11.850	1.67	71.845	10.1	31.427	4.43	6.982	0.98	10.031	1.41
	747-200B	775.000	92.542	11.9	11.842	1.53	72.053	9.30	32.693	4.22	7.073	0.91	10.136	1.31
	Mc D. Douglas DC-8-10	273.000	26.235	9.61	4.740	1.74	21.495	7.87	10.185	3.73	2.000*	0.73	3.505	1.28
	DC-8-55	328.000	34.759	10.6	4.889	1.49	22.248	6.78	11.255	3.43	2.253	0.69	4.685	1.43
	BAC VC-10-1101	312.000	34.672	11.1	6.958	2.23	25.113	8.05	10.489	3.36	***	-	**	-
	G. Dynamics 880	184.500	17.669	9.58	4.247	2.30	13.699	7.42	6.203	3.36	***	-	3.685	2.00
	990	253.000	26.871	10.6	5.326	2.11	16.673	6.59	8.718	3.44	***	-	6.772	2.68

* estimated ** included in other items *** no data available

Table 8-5. (Continued)

taken as the larger of the maximum positive gust or the maneuver load factor for the applicable weight at the most critical flight altitude (approximately 20,000 ft for pressurized transports). For further details see Appendix C.

b. Wing group.

A reasonably accurate wing weight estimate can be made in preliminary design as the loads on the wing are fairly well known at the design stage. Usually the bending moment in flight is assumed to be decisive for most of the primary structure. For a certain category of high-speed aircraft, however, torsional stiffness requirements may become dominant and the extra structure weight required to safeguard against flutter may amount to as much as 20% of the wing weight. The location of the inertia axis of the wing plus wing-mounted engines is of importance. A fairly large portion is also made up of secondary structure and non-optimum penalties, such as joints, non-tapered skin, undercarriage attachments, etc.

The derivation of a typical wing weight prediction method is explained in Ref. 8-101, the results of which are summarized in Appendix C. If sufficient data are not available to apply this method, the following simplified approximation can be used for civil airplanes with Al-alloy cantilever wings. The following basic expression is valid for the case of a wing-mounted retractable undercarriage, but not for wing-mounted engines:

$$\frac{W_w}{W_G} = k_w b_s^{.75}\left\{1+\sqrt{\frac{b_{ref}}{b_s}}\right\} n_{ult}^{.55}\left(\frac{b_s/t_r}{W_G/S}\right)^{.30} \qquad (8\text{-}12)$$

where b_{ref}= 6.25 ft or 1.905 m for b_s in ft or m, respectively, while $b_s = b/\cos\Lambda_{\frac{1}{2}}$, the structural wing span. The factor of proportionality is as follows:

Light aircraft, $W_{to} \leq 12{,}500$ lb (5670 kg):

$k_w = 1.25\times10^{-3}$; $W_G \equiv$ MTOW in lb, b_s in ft, S in ft^2, W_w in lb.

$k_w = 4.90\times10^{-3}$; $W_G \equiv$ MTOW in kg, b_s in m, S in m^2, W_w in kg.

Transport category aircraft W_{to}>12,500 lb (5670 kg):
$k_w = 1.70 \times 10^{-3}$; $W_G \equiv$MZFW in lb, b_s in ft, S in ft^2, W_w in lb.
$k_w = 6.67 \times 10^{-3}$; $W_G \equiv$MZFW in kg, b_s in m, S in m^2, W_w in kg.

The weight given by (8-12) includes high-lift devices and ailerons. For spoilers and speed brakes, if incorporated, 2% should be added. Reduce W_w by 5% or 10% for 2 or 4 wing-mounted engines, respectively and by 5% if the main undercarriage is not mounted to the wing. For braced wings a reduction of approximately 30% relative to (8-12) can be assumed. This figure includes the strut, contributing about 10% of the total wing group weight.

Wing optimization studies must be sensitive to variations in the external geometry, configuration and operational characteristics. It is generally recognized that for modern wing designs the weight of high-lift devices should be determined separately. The method in Appendix C meets these requirements and predicts the wing weights with a standard prediction error of 9.64%.

On inspection of (8-12), the observation can be made that the structural weight fraction, for a given cantilever ratio b_s/t_r and wing loading W_G/S, increases with the wing span. This unfavorable scale effect, associated with the square-cube law (cf. Section 7.2.2.), can be counteracted by increasing the wing loading. This is one of the reasons why large aircraft usually have high wing loadings. Decreasing the cantilever ratio is unfavorable as it results in a drag increment; its value is usually between 35 and 45 (see Fig. 7-8.).

c. Tail group.

This weight is only a small part - about 2 to 3% - of the MTOW but on account of its remote location it has an appreciable effect on the position of the airplane's center of gravity. Accurate weight prediction is difficult due to the wide variety of tailplane configurations and the limited knowledge of strength, stiffness and other conditions which will govern the design.

For relatively low-speed, light aircraft (V_D up to 250 kts EAS), the maneuvering loads are most important and the specific tailplane weight is affected by the load factor as follows:

$$W_{tail} = k_{wt} \left\{ n_{ult} \, S_{tail}{}^2 \right\}^{.75} \qquad (8\text{-}13)$$

where $k_{wt} = .04$; W_{tail} in lb and S_{tail} in ft^2
$k_{wt} = .64$; W_{tail} in kg and S_{tail} in m^2

It is interesting to note that for this category the specific tailplane weight obeys the square-cube law, the weight being proportional to the cube while the area is proportional to the square of the linear dimension. If the tailplane area is not (yet) known, the total tailplane weight may be assumed between 3½ and 4% of the empty weight. For transport category aircraft and executive jets the Design Dive speed appears to have a dominant effect (Fig. 8-5):

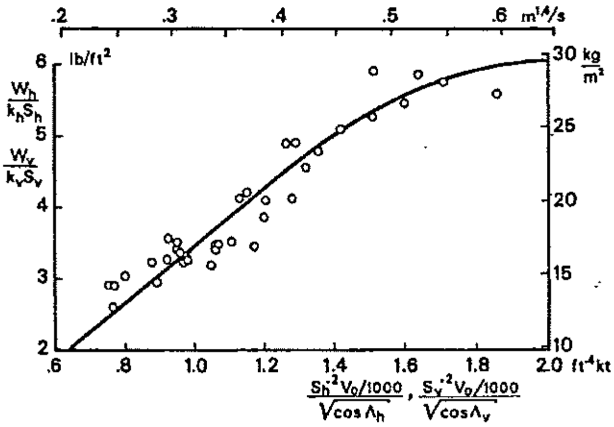

Fig. 8-5. Normalized specific horizontal tailplane weight

$$\frac{W_h}{S_h} = k_h . f \left(\frac{S_h{}^{.2} \, V_D}{\sqrt{\cos \Lambda_h}} \right) \qquad (8\text{-}14)$$

$$\frac{W_v}{S_v} = k_v . f \left(\frac{S_v{}^{.2} \, V_D}{\sqrt{\cos \Lambda_v}} \right) \qquad (8\text{-}15)$$

where V_D is expressed in terms of EAS and k_h and k_v are correction factors for the tailplane configuration:
$k_h = 1.0$ - fixed stabilizer, 1.1 for variable-incidence tails; for a bullet of ap-

preciable size 8% should be added.

$k_v = 1.0$ - fuselage-mounted horizontal tailplanes

$k_v = 1 + .15 \frac{S_h h_h}{S_v b_v}$ - fin-mounted stabilizers (e.g. T-tails) b_v is defined in Fig. 8-20

Fig. 8-5 demonstrates that the scale effect on specific tailplane weight ($S^{.2}$) applies to medium-sized airplanes, but disappears for very large aircraft.

d. Body group.

The fuselage makes a large contribution to the structural weight, but it is much more difficult to predict by a generalized method than the wing weight. The reason is the large number of local weight penalties in the form of floors, cutouts, attachment and support structure, bulkheads, doors, windows and other special structural features.

Fuselage weight is affected primarily by the gross shell area S_G, defined as the area of the entire outer surface of the fuselage. All holes for doors, windows, cutouts, etc. are assumed to be faired over and all local excrescences such as blisters, wheelwell fairings and canopies to be removed and faired over. The gross shell area can be calculated with the methods of Appendix B.

The following simple weight estimation method for Al-alloy fuselages is based on the approach of Ref. 8-113, slightly modified and updated for modern types.

The basic fuselage weight is:

$$W_f = k_{wf} \sqrt{V_D \frac{l_t}{b_f + h_f}} \, S_G^{1.2} \qquad (8\text{-}16)$$

The Design Dive speed V_D is expressed in terms of EAS. For definitions of l_t, b_f and h_f see Appendix D (Fig. D-1). The constant of proportionality is:

$k_{wf} = .021$ - W_f in lb, V_D in kts and S_G in ft^2

$k_{wf} = .23$ - W_f in kg, V_D in m/s and S_G in m^2

To the basic weight given by (8-16), 8% should be added for pressurized cabins, 4% for rear fuselage-mounted engines, 7% if the main landing gear is attached to the fuselage, and an extra 10% for freighter aircraft. If there is no attachment structure for the landing gear for a wheelbay, 4% may be subtracted from the basic weight. Most of the more detailed prediction methods are based on the approach in Ref. 8-115, applicable to semi-monocoque structures. The calculation of the shell weight according to this method, supplemented with some recent data to estimate various weight penalties, is given in Appendix D.

For tail booms (8-16) can be used for each boom separately. In this case l_t is defined as the distance between the quarter-chord points of the local wing chord and the horizontal tailplane. Add 7% for a main landing gear wheelbay and undercarriage attachment.

e. Alighting gear group*.

The undercarriage has a well-defined set of loading conditions and weight prediction can therefore be dealt with on a analytical basis. To this end the weight of each gear must be subdivided into:

- wheels, brakes, tires, tubes and air
- main structure, i.e. legs and struts
- items such as the retraction mechanism, bogies, dampers, controls, etc.

The first part of the weight prediction process is to decide upon tire and wheel size, inflation pressure, location of the gears, length of the legs, etc. This subject will be treated in Chapter 10, an example of a weight prediction method is given in Ref. 8-125.

The weight of conventional undercarriages may be found by summation of the main gear and the nose gear, each predicted separately with the following expression:

$$W_{uc} = k_{uc} \left\{ A + B \cdot W_{to}^{3/4} + C \cdot W_{to} + D \cdot W_{to}^{3/2} \right\} \qquad (8\text{-}17)$$

where $k_{uc} = 1.0$ for low-wing airplanes and

$k_{uc} = 1.08$ for high-wing airplanes

Table 8-6 gives suggested values of the factors A, B, C and D, based on a statistical evaluation of data on undercar-

*Only conventional undercarriages will be dealt with

A/C CATEGORY	U.C. CONFIGURATION		A	B	C	D
JET PROPELLED TRAINERS AND EXECUTIVES	RETRACTABLE	MAIN	33 (15.0)	.04 (.033)	.021	-
		NOSE	12 (5.4)	.06 (.049)	-	-
ALL OTHER CIVIL TYPES	FIXED	MAIN	20 (9.1)	.10 (.082)	.019	-
		NOSE	25 (11.3)	-	.0024	-
		TAIL	9 (4.1)	-	.0024	-
	RETRACTABLE	MAIN	40 (18.1)	.16 (.131)	.019	$1.5\ (2.23).10^{-5}$
		NOSE	20 (9.1)	.10 (.082)	-	$2\ (2.97).10^{-6}$
		TAIL	5 (2.3)	-	.0031	-

COEFFICIENTS CORRESPOND TO WEIGHTS IN LB(KG)

Table 8-6. Coefficients for the calculation of the landing gear weight

riage weights of existing airplanes.
Fig. 8-6 compares the result of (8-17) with data for existing airplanes. Up to 100,000 lb (45,000 kg) takeoff weight the weight fraction decreases with increasing airplane size. The main reasons are that for large airplanes a larger part of the gear structure can be highly stressed, while the use of higher inflation pressures on large aircraft saves some weight as well. For main landing gears the weight fraction does not appreciably decrease at takeoff weights above 100,000 lb (45,000 kg), but for nose gears there is still a reduction of the weight fraction up to very large airplane sizes like the B-747 and C-5A.

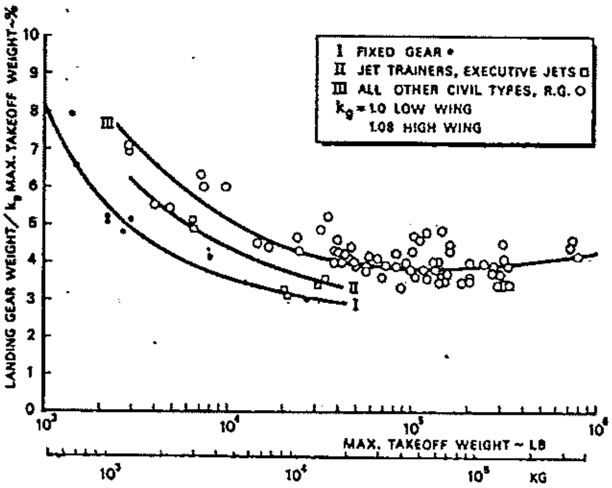

Fig. 8-6. Landing gear weight fraction

It can be argued that in many aircraft the critical load is formed by the landing impact load and that the MLW should therefore be used to predict the undercarriage weight. A reasonable approximation for the weight of retractable undercarriages is 4.7% of the MLW.

f. Surface controls group.
The weight of surface controls is generally of the order of .8 to 2% of the takeoff weight. An approximation is:

$$W_{sc} = k_{sc} W_{to}^{2/3} \qquad (8\text{-}18)$$

The factor k_{sc} can be determined from known weights of airplanes in the same category with a similar flight control system. Alternatively, for W_{sc} and W_{to} in lb, we have:

k_{sc} = .23 – light airplanes without duplicated system controls,
k_{sc} = .44 – transport airplanes and trainers, manually controlled, and
k_{sc} = .64 – transport airplanes, with powered controls and trailing-edge high-lift devices only.

Multiply these values by .768 when W_{sc} and W_{to} are in kg. Add 20% for leading-edge flap or slat controls and 15% for lift dumper controls, if used.
If sufficient data are available, a more detailed analysis can be made. To this end the surface controls group weight is subdivided into:

1. cockpit controls:
$.056\ W_{to}^{3/4}$ lb $(.046\ W_{to}^{3/4}$ kg)
for $W_{to} \leq 25{,}000$ lb (11,340 kg) (8-19)
110 lb (50 kg)
for $W_{to} > 25{,}000$ lb (11,340 kg)
2. automatic pilot:
$17\ W_{to}^{1/5}$ lb $(9\ W_{to}^{1/5}$ kg) (8-20)
for transport and executive aircraft
3. system controls:
$.008\ W_{to}$ for light airplanes with single flight control systems (8-21)

For transport aircraft a prediction of the system controls weight can be made with the aid of Table 8-7. In the absence of better data these formulas may be also used for trainers and executive airplanes.

g. Engine section or nacelle group.
The following statistical data may be used if no details of the engine installation

SYSTEM COMPONENT	METHOD		NOMENCLATURE
MANEUVERING CONTROL SYSTEM (elevator, rudder, ailerons, spoilers)	manually operated duplicated controls	$\frac{.2}{(.154)} \times W_{to}^{.67}$	W_{to} = Max. Takeoff Weight ~ lb (kg)
	duplicated powered controls, single hydr. power system	$\frac{.42}{(.318)} \times W_{to}^{.65}$	
	duplicated powered controls, dual hydr. power system	$\frac{1.06}{(.773)} \times W_{to}^{.60}$	
TRAILING EDGE FLAP CONTROL SYSTEM	rotating flaps (cylinder actuation)	$\frac{1.38}{(5.569)} \times (S_f \sin \delta_f)^{.92}$	S_f = total projected flap area ~ ft^2 (m^2); δ_f = maximum flap deflection angle
	translating (Fowler) flaps (screwjack actuation)	$\frac{2.73}{(11.02)} \times (S_f \sin \delta_f)^{.92}$	
LEADING EDGE FLAP OR SLAT CONTROL SYSTEM	$\frac{3.53}{(11.23)} \times S_s^{.82}$		S_s = total projected slat area ~ ft^2 (m^2)
VARIABLE INCIDENCE STABILIZER CONTROLS	$k_{hc} (S_{he} V_{max}^{.5} \sin \delta_h)^{.88}$ single powered: k_{hc} = .31 (1.52); dual powered: k_{hc} = .44 (2.16); δ_h = total range of hor. tailplane incidence variation		S_{he} = exposed hor. tail area ~ ft^2 (m^2); V_{max} = max. hor. flight speed ~ kts (m/s) TAS
SPEED BRAKE CONTROLS	$\frac{10}{(40.4)} \times S_{sb}^{.92}$		S_{sb} = speed brake wetted area ~ ft^2 (m^2)
LIFT DUMPER CONTROLS	$\frac{5}{(20.2)} \times (S_{\ell d} \sin \delta_{\ell d})^{.92}$		$S_{\ell d}$ = total area of lift dumpers ~ ft^2 (m^2); $\delta_{\ell d}$ = maximum lift dumper deflection angle
DIRECT LIFT CONTROL SYSTEM: no data available			

ALL COMPONENT WEIGHTS IN LB (KG)

NOTES:

1. Most formulas are approximations of the curves in SAWE Technical Paper No 812
2. Coefficients in brackets refer to the metric system

Table 8-7. Weight of system controls (transport aircraft)

WEIGHT CONTRIBUTION	METHOD
ENGINE MOUNTS AND VIBRATION ABSORBERS	5% of engine plus propeller installation weight
NACELLE STRUCTURE, PYLONS AND STRUTS, ENGINE COWLINGS, FLAPS AND BAFFLES	$.03\sqrt{V_D}\, S_{wet}^{1.3}$ (lb); V_D ~ kts EAS; S_{wet} ~ sq.ft $.405\sqrt{V_D}\, S_{wet}^{1.3}$ (kg); V_D ~ m/s EAS; S_{wet} ~ m^2 S_{wet} ~ total area per nacelle wetted by the cold airflow, both internally and externally*
GAS GENERATOR COWLING AND PLUG	3 lb/sq.ft (14.6 kg/m^2) of wetted area
NOISE SUPPRESSION MATERIAL (EXTRA WEIGHT)	.35 lb/sq.ft (1.71 kg/m^2) ~ nacelle walls 1.75 lb/sq.ft (8.53 kg/m^2) ~ splitter plates
FIREWALLS AND SHROUDS FOR FIRE PROTECTION	1.13 lb/sq.ft (5.51 kg/m^2)

*for straight jet engines the external nacelle area plus the inlet duct area

Table 8-8. Data for estimating the nacelle group weight

are available.

Light aircraft, single tractor propeller in the fuselage nose:

$$\left.\begin{array}{l} W_n = 2.5\sqrt{P_{to}}\ \text{(lb)} \\ W_n = 1.134\sqrt{P_{to}}\ \text{(kg)} \end{array}\right| P_{to} \text{ in hp} \qquad (8\text{-}22)$$

This weight refers to the complete engine section in front of the firewall.

Multi-engine aircraft, reciprocating engines:

$$\left.\begin{array}{l} \text{horizontally opposed cylinders -} \\ W_n = .32\ P_{to}\ \text{(lb)} \\ W_n = .145\ P_{to}\ \text{(kg)} \\ \text{Other engine types -} \\ W_n = .0\overset{4}{\cancel{1}}5\ P_{to}^{5/4}\ \text{(lb)} \\ W_n = .0204\ P_{to}^{5/4}\ \text{(kg)} \end{array}\right| \qquad (8\text{-}23)$$

All weights per nacelle

P_{to}: takeoff bhp per engine

Aircraft with turboprop engines:

W_n = .14 lb (.0635 kg) per takeoff ESHP (8-24)

Add .04 lb (.018 kg) per ESHP if the main landing gear is retractable into the nacelle and .11 lb (.05 kg) per ESHP for overwing exhausts (cf. Fig. 2-13, Lockheed Electra). Aircraft with pod-mounted turbojet or turbofan engines:

$$\left.\begin{array}{l} W_n = .055\ T_{to} \\ \text{high bypass turbofans with} \\ \text{short fan duct -} \\ W_n = .065\ T_{to} \end{array}\right| \qquad (8\text{-}25)$$

This value includes the pylon weight and extended nacelle structure for a thrust reverser installation. In the absence of thrust reversing a reduction of 10% may be assumed.

If a more detailed weight analysis taking into account the configuration and geometry of the nacelle and engine mounting is desirable, some degree of structural design must be attempted first. The subdivision and weight data in Table 8-8 may then be used to calculate the weight. The weight penalty due to noise suppression material obviously depends upon the amount of suppression desired; the engine manufacturer should be consulted for detailed data. For a typical "quiet" turbofan pod, acoustic lining may be required over 50% of the nacelle area. A typical weight penalty is 20% of the nacelle weight, apart from the extra weight of the engine itself.

8.4.2. The propulsion group

Project designs are normally based on existing engine types or paper studies of engines in an advanced state of development. Thus a specification of the definitive engine weight W_e is usually available comprising:

1. engine weight, bare and dry,
2. standard engine accessories and
3. additional weight contributions such as gas generator cowling and/or noise suppression material.

During parametric investigations it may be convenient to employ more general information and the engine weight data in Chapter 4 may be used:

- reciprocating engines: Section 4.2.2. and Fig. 4-12,
- turbojet and turbofan engines: Section 4.4.3. and equation 4-36,
- turboprop engines: Section 4.5.2. and equation 4-40.

Detailed methods for the computation of turbojet engine weights will be found in References 8-129 through 8-136.

If sufficient details of the powerplant installation are not available, a first approximation for the propulsion group weight is obtained by assuming that part of this weight contribution is proportional to the engine weight, while propeller weight is proportional to the power to be absorbed:

propeller aircraft -

$$\left.\begin{array}{l} W_{pg}=k_{pg}N_e(W_e+.24P_{to})\ \text{(lb)} \\ W_{pg}=k_{pg}N_e(W_e+.109P_{to})\ \text{(kg)} \end{array}\right| \qquad (8\text{-}26)$$

P_{to}: takeoff hp per engine

jet aircraft -

$$W_{pg}=k_{pg}k_{thr}N_eW_e \qquad (8\text{-}27)$$

where

k_{pg} = 1.16 for single tractor propeller in fuselage
= 1.35 for multi-engine propeller airplanes
= 1.15 for jet transports, podded engines
= 1.40 for light jet airplanes, buried engines

k_{thr} = 1.00 with no thrust reversers
= 1.18 with thrust reversers installed

Add 1.5% for jets and 3% for propeller aircraft with a water injection system. The term .24 (.109) P_{to} in (8-26) for propeller aircraft represents the propeller installation weight in lb (kg).

Instead of the simple approximation given above, Table 8-9 can be used to analyze the powerplant weight in more detail. Weight data for some present-day aircraft are presented in Table 8-10.

A large contribution to the powerplant group included in Table 8-9 is made by the fuel system, comprising:

1. fuel tanks and sealing,
2. pumps, collector tanks and plumbing,
3. distribution and filling system, and
4. fuel dump system (if used).

WEIGHT CONTRIBUTION	METHOD			REMARKS AND NOMENCLATURE
	TURBOJET/TURBOFAN	TURBOPROP	RECIPROCATING	
ENGINE INSTALLATION	$N_e W_e$			consult engine manufacturer's brochure
ACCESSORY GEAR BOXES AND DRIVES, POWER PLANT CONTROLS, STARTING AND IGNITION SYSTEM	$\underset{(.0343)}{.03} \times N_e (\dot{W}_{f_{to}})^{1.168}$ pneumatic or cartridge starting system	$\underset{(.181)}{.4} \times N_e P_{to}^{.8}$ add 30% for beta control		W_e = definitive weight ∿ lb(kg) per engine N_e = number of engines $\dot{W}_{f_{to}}$ = fuel flow/engine during takeoff ∿ lb/sec (kg/sec) P_{to} = takeoff BHP per engine
AIR INDUCTION SYSTEM	podded engines: included in nacelle group buried engines : $\underset{(29.62)}{11.45} \times (\ell_d N_i A_i^{.5} k_{geo})^{.7331}$	included in nacelle group	$\underset{(.467)}{1.03} \times N_e P_{to}^{.7}$	ℓ_d = duct length ∿ ft (m) N_i = number of inlets A_i = capture area per inlet ∿ sq.ft(m^2) k_{geo} = 1.0: round or one flat side = 1.33: two or more flat sides
EXHAUST SYSTEM	tailpipes: 3 lb/sq.ft (14.63 kg/m^2) silencers: $.01\ N_e T_{to}$			T_{to} = takeoff SLS thrust/ engine assumed inlet Mach number: .4
SUPERCHARGERS	-	-	$\underset{(.435)}{.455} \times (N_e W_e)^{.943}$	for separate superchargers
OIL SYSTEM AND COOLER	$(.01 \text{ to } .03)\ N_e W_e$**	$.07\ N_e W_e$	radial: $.08\ N_e W_e$ hor. opposed: $.03\ N_e W_e$	** additional system; basic system supplied by engine manufacturer
FUEL SYSTEM	integral tanks: $\underset{(36.3)}{80} \times (N_e + N_{ft} - 1) + \underset{(4.366)}{15} \times N_{ft}^{.5}\ V_{ft}^{.333}$ bladder tanks: $\underset{(.551)}{3.2} \times V_{ft}^{.727}$		single engine: $\underset{(.3735)}{2} \times V_{ft}^{.667}$ multi engine: $\underset{(.9184)}{4.5} \times V_{ft}^{.60}$	N_{ft} = total number of fuel tanks ($N_{ft} \geqslant N_e$ for airworthiness) V_{ft} = total fuel tank volume, U.S. gal. (liters)
WATER INJECTION SYSTEM	$\underset{(1.561)}{8.586} \times V_{wt}^{.687}$ (optional)			V_{wt} = total water tank capacity ∿ U.S. gal. (liters)
PROPELLER INSTALLATION*	-	$k_p N_p B (D_p P_{to})^{.78174}$ $k_p = .108\ (.124)$	$k_p = .144\ (.165)$	N_p = number of propellers D_p = propeller diameter ∿ ft (m) B_p = number of blades / propeller
THRUST REVERSERS	$.18\ N_e W_e$	-		optional

ALL WEIGHTS IN LB (KG)

*From SAWE Technical Paper No. 970

Note: coefficients in brackets refer to the metric system

Table 8-9. Weight analysis of the propulsion group

It will be observed that, for a given integral fuel tank capacity, the number of fuel tanks and the number of engines are primary parameters for determining the fuel system weight.

8.4.3. Airframe services and equipment

In the pre-design phase, with few details of the design of the airframe services and equipment,* their weight is very difficult to predict. The initial prediction error may be very large, as demonstrated by the examples quoted in Ref. 8-151. As soon as preliminary discussions with system (component) manufacturers have been held, the initial weight prediction must be revised.

*A subdivision is shown in Table 8-3.

	AIRPLANE TYPE / GROUP	ENGINE INSTALL.	FUEL SYSTEM		EXHAUST + THRUST REV.		OTHER ITEMS		PROPULSION GROUP	
		10^3 LB	10^3 LB	%*	10^3 LB	%*	10^3 LB	%*	10^3 LB	%*
JET AIRCRAFT	Atlas Airbus A-300 B2	16.825	1.257	7.47	4.001	23.8	.814	4.84	22.897	136
	Boeing 707/320 C	17.368	2.418	13.9	3.492	20.1	.798	4.59	24.247	140
	727/100	9.325	1.143	12.2	1.744	18.7	.250	2.68	12.759	137
	737/200	6.217	.575	9.25	1.007	16.2	.378	6.08	8.177	132
	747/100	34.120	2.322	6.81	6.452	18.9	.802	2.35	43.696	128
	Fokker VFW F-28 Mk 1000	4.495	.545	12.1	.127	2.82	.215	4.78	5.227	116
	Lockheed Jetstar	1.750	.360	20.6	**	–	.365	20.9	2.475	141
	McDonnell Douglas DC-8/55	16.856	3.107	18.4	4.964	29.4	1.560	9.37	26.507	157
	DC-9/10RC	6.160	.510	8.28	.658	10.7	.409	6.64	7.737	126
	North Am. T-39A Sabreliner	.959	.190	19.8	**	–	.152	15.8	1.301	136
	Aerospatiale Caravelle VI R	7.055	.518	7.34	.975	13.8	.179	2.54	8.727	124
	VFW Fokker 614	3.413	.162	4.75	.119	3.49	.690	20.2	3.763	110
	Cessna T-37	.751	.224	29.8	**	-	.221	29.4	1.196	159
	Northrop T-38A Talon	1.038	.285	27.4	**	-	.307	29.6	1.630	157
PROPELLER AIRCRAFT					PROPELLER(S)					
	Bristol Britannia 300A	11.192	1.329	11.9	3.557	31.8	3.820	34.1	19.898	178
	Canadair CL-44C	12.800	1.755	13.7	5.006	39.1	3.134	24.5	22.695	177
	Fokker VFW F-27 Mk 100	2.427	.390	16.1	.918	37.8	.612	25.2	4.454	184
	Grumman Gulfstream I	2.688	.133	4.95	1.002	37.3	.698	26.0	4.521	168
	Lockheed C-130 E	7.076	1.695	24.0	4.573	64.6	1.874	26.5	15.268	216
	L-1049 E	14.256	.893	6.26	2.980	20.9	2.547	17.9	20.682	145
	Beechcraft 95 Travel Air	.519	.083	16.0	.162	31.2	.109	21.0	.873	168
	G-50 Twin Bonanza	1.008	.137	13.6	.258	25.6	.207	20.5	1.610	160
	E-18S	1.352	.274	20.3	.334	24.7	.321	23.7	2.281	169
	Cessna 310-C	.852	.076	8.92	.162	19.0	.160	18.8	2.250	147
	Beechcraft Bonanza J-35	.432	.030	6.94	.073	16.9	.045	10.4	.580	134
	Cessna 150A	.194	.020	10.3	.025	12.9	.034	17.5	.273	141
	175B	.312	.030	9.61	.038	12.2	.047	15.1	.427	137
	185	.428	.024	5.61	.072	16.8	.056	13.1	.580	135

* percent of engine installation weight   ** not specified; included in other items

Table 8-10. Propulsion group weight breakdown for existing aircraft types

The data and methods in this section are based primarily on statistical correlations. There is, however, not always a functional relationship between the parameter on which the correlation is based and the actual weight contribution. Consequently, if some weight item is related to the takeoff weight or the empty weight and the first and second estimation of these characteristic weights are different, it may be unnecessary to reiterate the complete weight estimation, provided the estimates do not differ greatly.

It should be noted that for several individual weight contributions a marked discrepancy between the calculated value according to the present methods and the actual value for existing aircraft may be observed. This will be caused to a large extent by differences in de definitions of these items. However, the total estimated systems and equipment weight will be reasonably representative of the actual weight of the operational airplane. In some cases, particularly for wide-body aircraft, the weight estimate may be somewhat conservative due to recent improvements in systems design technology.

Typical averages for the total airframe services and equipment weight are:

light single-engine private airplane	: 8% W_{to}
light twin-engined airplanes	:11% W_{to}
jet trainers	:13% W_{to}
short-range transports	:14% W_{to}
medium-range transports	:11% W_{to}
long-range transports	: 8% W_{to}

A collection of weight data is presented in

	AIRPLANE TYPE	MTOW	A.P.U.-GROUP	INSTR. NAV.EQPT.	HYDR. PNEUM.	ELEC-TRICAL	ELEC-TRONICS	FURNISH. EQPT.	AIRCOND. ANTI-ICE	MISC.	TOTAL
JET TRANSPORTS	Atlas Airbus A-300 B2	302,000	983	377	3,701	4,923	1,726	13,161	3,642	732	29,245
	BAC 1-11 Srs 300	87,000	457	182	997	2,317	1,005	4,933	1,579	-	11,465
	Boeing 707/320 C	330,000	151	515	1,086	4,179	2,338	9,527	3,608	-389	21,015
	707/321	301,000	-	561	498	3,959	1,716	14,854	3,290	-	24,878
	720/022	203,000	-	555	505	4,070	1,200	13,055	2,890	-	22,275
	727/100	160,000	60	756	1,418	2,142	1,591	10,257	1,976	85	18,285
	727/100C	160,000	52	802	843	3,617	1,559	6,729	2,401	75	16,078
	737/200	100,400	836	625	873	1,066	956	6,643	1,416	124	13,539
	747/100	710,000	1,130	1,909	4,471	3,348	4,429	37,245	3,969	-421	54,380
	Fokker VFW F-28 Mk 1000	65,000	346	302	364	1,023	869	4,030	1,074	-	8,008
	Mk 2000	65,000	353	309	366	1,045	869	4,614	1,111	-	8,667
	Lockheed Jetstar	30,680	-	153	262	973	318	1,521	510	560	4,297
	McDonnell Douglas DC-8/55	328,000	-	1,271	2,196	2,398	1,551	14,335	3,144	57	24,952
	DC-9/10 RC	91,500	818	719	714	1,663	914	7,408	1,476	24	13,736
	North Am. T-39A Sabreliner	16,700	-	122	116	720	407	857	333	-	2,555
	Aerospatiale Caravelle VI R	114,640	-	236	1,376	2,846	1,187	6,481	1,752	-	13,878
	VFW Fokker - 614	40,981	305	215	403	1,054	436	2,655	719	49	5,836
PROPELLER TRANSPORTS	Bristol Britannia 300A	155,000	-	505	650	1,800	1,040	6,866	3,000	-	13,861
	Canadair CL-44C	205,000	-	858	630	3,040	1,229	12,349	2,536	-	20,662
	CL-44D	205,000	-	783	640	2,875	1,046	3,155	4,090	-	12,589
	Fokker VFW F-27 Mk 100	39,000	-	81	242	835	386	2,291	1,225	-	5,060
	Mk 500	45,000	-	126	256	840	329	3,035	1,257	-	5,843
	Grumman Gulfstream I	33,600	355	97	235	966	99	415	755	6	2,929
	Lockheed C-130 E	151,522	466	665	671	2,300	2,432	4,765	2,126	62	13,487
	L-1049 E	133,000	-	503	654	1,505	1,371	7,405	3,298	-	14,736
	Nord 262	23,050	-	133	765		238	1,324	527	33	3,020
	Vickers Viscount 702	50,044	-	154	331	2,048	447	2,519	1,516	-	7,015
JET TRAINERS	Beechcraft MS 760	7,650	-	70	-	284	158	169	48	30	759
	Cessna T-37	6,436	-	132	56	194	86	256	69	3	796
	Northrop T-38A Talon	11,651	-	211	154	296	246	460	142	24	1,539
LIGHT TWINS	Beechcraft 95 Travel Air	2,900	-	49	-	96	26	194	48	25	438
	G-50	7,150	-	80	-	184	9	333	81	27	834
	E-18 S	9,700	-	100	-	295	63	524	144	58	1,184
	Cessna 310 C	4,830	-	46	-	121	-	154	46	65	498
SINGLE ENGINE A/C	Beechcraft Bonanza J-35	2,900	-	16	-	72	-	174	12	7	281
	Cessna 150A	1,500	-	7	2	41	-	42	4	-	96
	172B	2,200	-	7	3	41	-	99	4	-	154
	180D	2,650	-	8	3	59	-	105	6	-	181
	210A	2,900	-	16	4	60	-	116	12	20	228

ALL WEIGHTS IN LB

Table 8-11. Airframe services and equipment group weight breakdown

Table 8-11. Several items will be discussed in greater detail in the paragraphs below.

a. APU group.

An APU is installed in most modern transport aircraft and also in some jet executives. The installed weight may be based on the dry weight of the APU:

$$\text{Weight} = k_{APU}\, W_{APU} \qquad (8\text{-}28)$$

The installation factor accounts for the inlet and exhaust ducting mounting frames, silencers, fire protection and accessories, and is generally of the order of 2.0 to 2.5. The APU engine weight is mainly a function of the airflow capacity and power delivery. The bleed airflow requirement is approximately .025 lb/min per cu. ft (.4 kg/min per m^3) of passenger cabin volume or 1.1 lb/min (.5 kg/min) per passenger in the high-density layout.

The APU engine weight can be obtained from the APU specification once the engine has been chosen. The following relationship may be used instead:

$$\left.\begin{array}{ll} W_{APU} = 16\ \dot{W}_{ba}^{3/5} & (W_{APU} \text{ in lb, } \dot{W}_{ba} \text{ in lb/min}) \\ W_{APU} = 11.7\ \dot{W}_{ba}^{3/5} & (W_{APU} \text{ in kg, } \dot{W}_{ba} \text{ in kg/min}) \end{array}\right\} \quad (8\text{-}29)$$

Recent APU engines used on wide-body transports have a specific weight of only 65% of this value, due to improved materials and cycle efficiencies and increased cycle pressures and turbine temperatures.

b. Instruments, navigational equipment and electronics groups.

Requirements for the instruments and NAV/COM equipment (avionics) are usually listed in the design specification. The minimum equipment required for safe operation is supplemented by a choice of optional equipment to improve the operational flexibility. The effects of airplane size are found mainly in the weight of wiring and the flight control system, which increases in size and complexity when the aircraft is scaled up. NAV/COM equipment is partly or fully duplicated on modern transports and even triplicated on recent large transports. A weight estimate may be based on the unit weight of each item of equipment, as obtained from manufacturers, as well as on data for airplanes designed for similar operational capabilities. If these data are not available, the following statistical correlations may be used for the combined weight of instruments and avionics.

Single-engine propeller aircraft: 8 lb (3.6 kg) per pilot, for instruments and 20-30 lb (9-13.6 kg) for radio, which is optional on private aircraft but compulsory on trainers, commuters and taxi aircraft.

Propeller-powered utility airplanes up to 12,500 lb (5,670 kg) takeoff weight, VFR operations:

$$\left.\begin{array}{ll} 40 + .008\ W_{to} & \text{(lb)} \\ 18.1 + .008\ W_{to} & \text{(kg)} \end{array}\right\} \quad (8\text{-}30)$$

Low-subsonic transports with manual flight control system, intended for IFR operations and equipped with single NAV/COM equipment:

$$\left.\begin{array}{ll} 120 + 20\ N_e + .006\ W_{to} & \text{(lb)} \\ 54.4 + 9.1\ N_e + .006\ W_{to} & \text{(kg)} \end{array}\right\} \quad (8\text{-}31)$$

where N_e is the number of engines per aircraft. This equation also gives reasonable results for low-subsonic jet trainers.

For high-subsonic jet transports with predominantly duplicated NAV/COM equipment, jet executives and high-subsonic trainers, the weight of the instruments and electronics group is:

$$W_{ieg} = k_{ieg}\ W_{DE}^{5/9}\ R_D^{1/4} \quad (8\text{-}32)$$

where W_{DE} is the Delivery Empty Weight and R_D the maximum range (Fig. 8-3)

k_{ieg}=.575 for W_{DE} and W_{ieg} in lb, R_D in nm
k_{ieg}=.347 for W_{DE} and W_{ieg} in kg, R_D in km

These data do not include the autopilot weight, which is considered part of the surface control system weight in the present subdivision.

c. Hydraulic, pneumatic and electrical groups.

On light aircraft (MTOW up to 12,500 lb or 5,670 kg) the hydraulic system is generally restricted to a brake system and flap and undercarriage operation. For some categories a good correlation was found for the combined weight of hydraulic and electrical systems:

utility aircraft -

$$\left.\begin{array}{l} \text{weight} = .00780\ W_E^{6/5}\ \text{lb}\ (W_E \text{ in lb}) \\ \text{weight} = .00914\ W_E^{6/5}\ \text{kg}\ (W_E \text{ in kg}) \end{array}\right\} \quad (8\text{-}33)$$

jet trainers -

$$\text{weight} = .064\ W_E \qquad (8\text{-}34)$$

propeller transports -

$$\left.\begin{array}{l}\text{weight} = .325\ W_e^{4/5}\ \text{lb}\ (W_E \text{ in lb})\\ \text{weight} = .277\ W_e^{4/5}\ \text{kg}\ (W_E \text{ in kg})\end{array}\right\} \qquad (8\text{-}35)$$

A subdivision for jet transports and jet executives appears desirable. The hydraulic and pneumatic power system weight is mainly affected by:

1. the number of functions to be powered, i.e. powered or non-powered controls, operation of spoilers, etc.,
2. the extent of duplication or even triplication,
3. the operating hydraulic or pneumatic pressure, as well as other details of the system design,
4. the airplane size and geometry as related to the length of the plumbing,
5. the relative quantity of pneumatic functions, if any, and
6. the state of the art.

The combined weight of the hydraulic plus pneumatic system may be assumed to be 1½% of the DEW or, alternatively:

no powered controls -

$$\left.\begin{array}{ll}\text{weight} = .004\ W_{DE} + 100 & \text{(lb)}\\ \text{weight} = .004\ W_{DE} + 45 & \text{(kg)}\end{array}\right\} \qquad (8\text{-}36)$$

boosted controls, only some essential functions duplicated -

$$\left.\begin{array}{ll}\text{weight} = .007\ W_{DE} + 200 & \text{(lb)}\\ \text{weight} = .007\ W_{DE} + 91 & \text{(kg)}\end{array}\right\} \qquad (8\text{-}37)$$

powered controls, fully duplicated system -

$$\left.\begin{array}{ll}\text{weight} = .011\ W_{DE} + 400 & \text{(lb)}\\ \text{weight} = .011\ W_{DE} + 181 & \text{(kg)}\end{array}\right\} \qquad (8\text{-}38)$$

powered controls, triplex system -

$$\left.\begin{array}{ll}\text{weight} = .015\ W_{DE} + 600 & \text{(lb)}\\ \text{weight} = .015\ W_{DE} + 272 & \text{(kg)}\end{array}\right\} \qquad (8\text{-}39)$$

For jet freighters these figures are roughly 30% higher, due partly to the somewhat lower empty weight and partly to the extra services required for loading and unloading. Some weight reduction is possible for an increasing number of pneumatic system functions.

The electrical system weight is affected mainly by:

1. the total electrical power required, which is primaliry determined by the galley power, electronic equipment and fuel system power,
2. whether or not the primary system is an A.C. or D.C. system*,
3. the size of the airplane, in view of the length of wiring,
4. the amount of system duplication and the standby systems,
5. whether or not electrical power is generated by the A.P.U., and
6. the state of the art.

the following statistical relationships are suggested:

primary system D.C. -

$$\left.\begin{array}{ll}W_{el} = .02\ W_{to} + 400 & \text{(lb)}\\ W_{el} = .02\ W_{to} + 181 & \text{(kg)}\end{array}\right\} \qquad (8\text{-}40)$$

primary system A.C., total electrical power generated up to 400 kVA -

$$\left.\begin{array}{ll}W_{el} = 36\ \ P_{el}\ (1-.033\sqrt{P_{el}}) & \text{(lb)}\\ W_{el} = 16.3\ P_{el}\ (1-.033\sqrt{P_{el}}) & \text{(kg)}\end{array}\right\} \qquad (8\text{-}41)$$

In the absence of better information the electrical power generation may be obtained from statistical data in publications like Jane's All the World's Aircraft or from correlations with the passenger cabin volume V_{pc}:

if no electrical power is generated by the APU, V_{pc} up to 8,000 cu.ft (227 m^3) -

$$\left.\begin{array}{ll}P_{el} = .016\ V_{pc} & (V_{pc} \text{ in cu.ft})\\ P_{el} = .565\ V_{pc} & (V_{pc} \text{ in } m^3)\end{array}\right\} \qquad (8\text{-}42)$$

if electrical power generation by the APU is included -

$$\left.\begin{array}{ll}P_{el} = .3\ \ V_{pc}^{.7} & (V_{pc} \text{ in cu.ft})\\ P_{el} = 3.64\ V_{pc}^{.7} & (V_{pc} \text{ in } m^3)\end{array}\right\} \qquad (8\text{-}43)$$

These figures on electrical systems are based on 1950-1965 technology. Recent developments have indicated that considerable improvements in system weights are possible by applying advanced techniques - like multiplexing** and high-speed generators.

*Most present-day transport aircraft feature A.C. primary systems

**Aviation Week of October 28, 1968, pp. 157-161: a weight reduction of 400 lb (181 kg) was achieved on the Boeing 747

GROUP	DESCRIPTION	METHOD		REMARKS
FLIGHT DECK ACCOMMODATIONS	flight crew seats, instrument panels, control stands, sound proofing, insulation, trim, floor covering, lighting and wiring, miscellaneous equipment	jet a/c : $29\,(16.5) \times W_{DE}^{.285}$ propeller a/c: $16\,(9.1) \times W_{DE}^{.285}$		W_{DE} = Delivery Empty Weight∿lb(kg)
PASSENGER CABIN ACCOMMODATIONS	passenger and attendants' seats	Table 3-2		
	galley (pantry) structure and provisions	main meal galley: 250lb(113.4kg) each snack pantry : 100lb(45.3kg) each coffee bar : 65lb(29.5kg) each		galley inserts, potable water and toilet chemicals not included
	lavatory and toilet provisions, water system (dry)	medium/long-haul: 300lb(136.0kg)/toilet short-haul : 165lb(75.0kg)/toilet commuters : 85lb(38.5kg)/toilet		
	floor covering	jet aircraft: $.18\,(1.25) \times S_{cf}^{1.15}$	propeller aircraft: $.135\,(.94) \times S_{cf}^{1.15}$	S_{cf} = cabin floor area, galleys and toilets included∿sq.ft (m^2) V_{pc}= passenger cabin volume, galleys and toilets included∿cu.ft (m^3) V_{ch}= total cargo hold volume ∿ cu.ft (m^3)
PASSENGER CABIN / CARGO ACCOMMODATIONS	soundproofing and insulation, wall covering, curtains, screens, window shades, ceiling, lighting panels, hatracks, partitions and doors; wardrobe and stowage provisions, freight hold linings and partitions	$.30\,(6.17) \times (V_{pc}+V_{ch})^{1.07}$	$.14\,(3.69) \times (V_{pc}+V_{ch})^{1.14}$	
CARGO ACCOMMODATIONS	cargo restraints and handling provisions	.08 lb/cu.ft (1.28kg/m^3) of V_{ch}		
	container or pallet cargo handling provisions	2.8 lb/sq.ft(13.67kg/m^2) of freight floor area for convertible passenger/cargo versions		
(STANDARD) EMERGENCY EQUIPMENT	fixed oxygen system, portable oxygen sets	short or no overwater flights, cruise altitude up to 25,000ft(7620m): 20+ .5N_{pax} ∿ lb(9.1+ .227N_{pax} ∿ kg) above 25,000ft(7620m): 30+1.2N_{pax} ∿ lb(13.6+ .544N_{pax} ∿ kg) extended overwater flights: 40+2.4N_{pax} ∿ lb(18.1+1.09 N_{pax} ∿ kg)		
	fire detection and extinguishing system, portable extinguishers	jet a/c : .0012 W_{to} turboprop a/c: .0030 W_{to} reciproc. a/c: .0060 W_{to}		N_{pax}=max.no. of passengers for certification (pressure cabins)
	escape provisions (evacuation slides and ropes)	1 lb(.453 kg) per occupant		Other provisions in Operational Items

ALL WEIGHTS IN LB (KG)

NOTE: coefficients in brackets refer to the metric system

Table 8-12. Furnishing and equipment group weight for transport and executive aircraft

d. Furnishing and equipment group.
Light single-engine aircraft: this weight group consists mainly of the weight of seats, wall and floor covering, and some miscellaneous contributions. The weight is approximately 13 lb (5.9 kg) per seat, plus 25 lb (11.3 kg) per row of two seats, plus an additional 5 lb (2.3 kg).
Light twin-engine aircraft: 15 lb (6.3 kg) per seat, plus 1 lb per cu.ft (16 kg per m^3) of cabin plus cargo compartment volume.
Jet trainers, equipped with two ejection seats: 6.5% of the Delivery Empty Weight.
Civil freighters: 3 lb per sq.ft (14.7 kg/

ITEM	SUBDIVISION	METHOD	REMARKS, SYMBOLS
CREW PROVISIONS	flight and cabin crew with baggage, flight equipment	$\frac{205}{(93)} \times N_{fc} + \frac{150}{(68)} \times N_{cc}$	N_{fc}, N_{cc} = number of flight/ cabin crew members respectively
PASSENGER CABIN SUPPLIES	removable galley bar equipment, meal service, consumable food, drinks, beverages pillows, papers and magazines, entertainment	commuters: 1 lb (.453 kg) x N_{pax} transport aircraft, snacks only : 5lb (2.27kg).N_{pax} main meal, short-range: 14lb (6.35kg).N_{pax} , long -range: 19lb (8.62kg).N_{pax}	N_{pax} = number of passengers, all-tourist. First class: all data 5lb (2.27kg) per passenger higher
POTABLE WATER AND TOILET CHEMICALS		short range : $80N_{wc}$ or $1.5N_{pax}$ ~lb ($36.3\ N_{wc}$ or $.68N_{pax}$ ~kg) short/medium-range: $120N_{wc}$ or $3.0N_{pax}$ ~lb ($54.4\ N_{wc}$ or $1.36N_{pax}$ ~kg) long-range : $200N_{wc}$ or $6.5N_{pax}$ ~lb ($90.7\ N_{wc}$ or $2.95N_{pax}$ ~kg)	
SAFETY EQUIPMENT	life jackets, fire axes, emergency navigational equipment	short or no overwater sectors: $2N_{pax}$ ~lb ($.907N_{pax}$ ~kg) extended overwater flights: $7.5N_{pax}$ ~lb ($3.4N_{pax}$ ~kg)	N_{wc} = number of toilets/water closets; data based on all- tourist layout
OIL RESIDUAL FUEL WATER/ METHANOL	residual fuel	gas turbine engines: $\frac{.81}{(.151)} \times V_{ft}^{2/3}$ — reciprocating: $.008\ W_{to}$	V_{ft} = total fuel tank capacity ~ U.S. gal. (liters) W_{to} = Max. Takeoff Weight ~ lb (kg) W_f = fuel weight ~ lb (kg)
	residual oil	turboprop engines: $\frac{.81}{(.151)} \times V_{ft}^{2/3}$ — reciprocating: $.008\ W_{to}$	
	engine oil consumed	$.045\ W_f$	
	water/methanol	optional	
CARGO HANDLING EQUIPMENT	pallets, containers, cargo tiedown eqpt.	Fig. 3-20	ALL WEIGHTS IN LB (KG)

NOTE: coefficients in brackets refer to the metric system

Table 8-13. Data for estimating the weight of Operational Items (transport aircraft)

m^2) of main freightfloor area.

•Passenger transports and jet executives: a rough approximation is obtained with the statistical expression:

$$\text{weight} = .211\ W_{ZF}^{.91} \quad \text{(lb)} \qquad (8\text{-}44)$$
$$\text{weight} = .196\ W_{ZF}^{.91} \quad \text{(kg)}$$

where W_{ZF} is the Maximum Zero Fuel Weight. The furnishing and equipment weight forms a very substantial contribution, of the order of half the fuselage structure weight. Instead of using (8-44) the designer may prefer to use a more detailed estimation by breaking down the weight into several individual contributions. A proposed subdivision and calculation methods are presented in Tables 8-12 and 3-2.. It should be noted that several items such as the weight of seats depend on the required standard of comfort and the type of interior; these may be subject to customer requirements (Standard Items Variation).

e. Air-conditioning and anti-icing group. The weight of the air-conditioning and pressurization system depends on many factors:

1. the type of system used: air cycle or vapor cycle, use of ram air or engine bleed air, etc.,
2. design requirements, in terms of air-conditioning airflow per unit of time, air temperature, humidity and cabin pressure differential, cargo compartment air-conditioning,
3. the amount of system duplication,
4. the airplane size, or more specifically the cabin volume and length, and the subdivision into zones,
5. the state of the art.

Factors affecting the anti-icing and de-icing system weight are:
1. type of system (electrical, hot-air, rubber boots),
2. dimensions, mainly the length or span of the airplane parts concerned, and
3. the type of operation, viz. IFR or VFR flights.

For the combined system, the following data can be used:
Light single-engine aircraft - 2.5 lb (1.1 kg) per seat. Multi-engine unpressurized aircraft and jet trainers - 1.8% of the Delivery Empty Weight
pressurized transports and executive aircraft -

$$\left.\begin{array}{l} \text{weight} = 6.75\ l_{pc}^{1.28}\ \text{(lb)} - l_{pc}\ \text{in ft} \\ \text{weight} = 14.0\ \ l_{pc}^{1.28}\ \text{(kg)} - l_{pc}\ \text{in m} \end{array}\right\} \quad (8\text{-}45)$$

f. Miscellaneous.
This item refers to auxiliary gears, photographic equipment, external paint, manufacturing variation, unaccounted items, unexpected weight growth, etc. No systematic data are available, but in general a figure of up to 1% of the Delivery Empty Weight is typical for existing aircraft.

8.4.4. Useful Load and the All-Up Weight

a. Operational Items.
Due to the large variation in operational conditions and requirements applying to passenger service, considerable variations in the weight of operational items can be observed. The data in Table 8-13 are representative of but by no means mandatory for the transport aircraft category. For private aircraft and jet trainers the only item of interest is the residual fuel and oil.
It should be noted that the data of Table 8-13 are generally applicable to modern, gas turbine powered aircraft. Considerably higher weight values are applicable to older piston-engine powered transport aircraft.

b. Payload and fuel.
Some data on specific gravity of fuels and civil payload will be found in Table 8-14.

	LB	KG	
PASSENGERS :	165	75	
PASS. BAGGAGE :	40	18	- TOURIST CLASS
	60	27	- FIRST CLASS
BAGGAGE SPEC. DENSITY :	12 LB/FT^3 (192 KG/M^3)		

FUEL	SPECIFIC HEAT		SPECIFIC WEIGHT*	
	BTU/LB	KCAL/KG	LB/U.S. GAL	KG/LITER
GASOLINE :	18,700	10,389	5.85	.701
JP - 3 :	18,000	10,000	6.32	.767
JP - 4 :	18,550	10,305	6.50	.779
JP - 5 :	18,400	10,222	6.84	.820
LUBRICATING OIL SPECIFIC WEIGHT: 7.5 LB/U.S. GAL (.9 KG/LTR)				

*AT 59°F (15°C)

Table 8-14. Standard weights of payload, fuel and oil

The data presented in this Section 8.4 and Appendices C and D are sufficiently complete to enable the designer to make a fairly accurate prediction of the OEW of a civil airplane. Of necessity, the procedure is based on an initial estimate of the various characteristic weights, as obtained, for example, with Sections 5.2 and 8.2.
The more detailed weight prediction will result in a value for the OEW that is essentially different from the first "guesstimate". The designer must therefore decide whether he should modify the Useful Load (i.e. fuel and/or payload) or the MTOW. Fresh calculations of the weight distribution will then be necessary until the designer is satisfied with the convergence.

	COMPONENT	C.G. LOCATION
STRUCTURE	WING (HALF)	straight wing: 38-42% chord from LE at 40% semi-span from centerline swept wing: 70% local distance between front and rear spar, measured from front spar, at 35% semi-span from centerline
	FUSELAGE	distance from fuselage nose, in % of fuselage length (excl. spinner) single tractor engine : 32 - 35 wing-mounted propeller engines : 38 - 40 wing-mounted jet engines : 42 - 45 rear fuselage mounted pods : 47 jet engine buried in fuselage : 45
	TAILPLANE (HALF)	42% chord from LE at 38% semi-span from root chord. Fin, T-tail configuration: 42% chord from LE at 55% of height from root chord
	NACELLES	40% of nacelle length from nose, spinner excluded
	SURFACE CONTROL SYSTEM	100% MAC from LEMAC, autopilot excluded
	ALIGHTING GEAR	at airplane c.g., or determined from location and weight of main and nose undercarriage
ENGINES AND ACCESSORIES		from engine manufacturer's data
AIRFRAME SERVICES AND EQUIPMENT		from educated guess, taking into account location of main elements and functions to be powered
FURNISHING		from subdivision of Table 8-11 and cabin layout
FILLED FUEL TANK		for prismoid with height l and parallel end faces with area S_1 and S_2 (see Fig. 8-4), at distance $\frac{l}{4}\frac{S_1+3S_2+2\sqrt{S_1S_2}}{S_1+S_2+\sqrt{S_1S_2}}$ from plane S_1

NOTE: more accurate estimates can be made by further breakdown of each item into several contributions

Table 8-15. Approximate location of the center of gravity for several groups

If the designer decides to alter the Useful Load, the specified transport performance (payload-range) may no longer be achieved, while in the second eventuality the takeoff weight may become too high for acceptable takeoff, landing and/or climb performance. Sufficient aerodynamic data must be available to evaluate the design performance (Chapter 11).
In this textbook we will proceed with the layout design, assuming that the previous weight prediction has not entailed major difficulties and that only minor changes in the weight distribution are required. However, there may be occasions when weight evaluation and changes result in a considerable increase of the takeoff weight.

8.5. CENTER OF GRAVITY

Each airplane must be designed in such a way that good stability and control properties and adequate flexibility in loading conditions are obtained. By suitable arrangement of the design layout and acceptable tailplane size, acceptable fore-and-aft limits of the center of gravity must be established, taking into account the following aspects:
1. fore-and-aft position of the wing relative to the fuselage,
2. provision of suitable locations for payload and fuel,
3. design of the horizontal tailplane, the elevator and the longitudinal flight con-

	AIRPLANE TYPE	C.G. LIMITS, PER CENT M.A.C.						PAY-LOAD	$\frac{S_h \ell_h}{S \bar{c}}$	hor. tail type **	$C_{L_{max}}$ ***
		FORWARD		REAR		RANGE					
		takeoff landing	flight	takeoff landing	flight	takeoff landing	flight	% OEW			
2 JET ENGINES	Aerospatiale Corvette SN601	-	20.0	-	36.0	-	16.0	28.3	.64	V	2.40
	A.C. Jet Commander 1121	20.0	20.0	36.0	36.0	16.0	16.0	20.6	.64	F	1.66
	Lear Jet 25	9.0	9.0	30.0	30.0	21.0	21.0	35.6	.64	F	1.39
	H. Siddeley HS-125 1A/1B	18.0 *	18.0 *	37.5 *	37.5 *	19.5 *	19.5 *	14.0	.69	F	2.44
	Dassault Mystère 20F	14.0	16.0	28.5	28.5	14.5	12.5	23.1	.66	V	2.30
	H.F.B. Hansa	13.0	11.7	23.0	21.7	10.0	10.0	30.9	.71	F	2.00
	Fokker VFW F-28 Mk1000	18.0	17.0	35.0	37.0	17.0	20.0	42.0	.97	V	2.53
	BAC 1-11 Srs. 400	15.0 *	14.0 *	39.0 *	41.0 *	24.0 *	27.0 *	35.3	.85	V	2.38
	Sud. Av. Caravelle 10R	25.0	25.0	41.5	41.5	16.5	16.5	32.3	.56	F	2.10
	McD. Douglas DC-9/10	16.3	15.0	39.0	40.0	22.7	25.0	42.4	1.15	V	2.40
	DC-9/33F	5.9	3.1	34.7	34.7	28.8	31.6	70.8	1.18	V	2.98
	Boeing 737/100	15.0	15.0	35.0	35.0	20.0	20.0	49.4	1.14	V	3.10
	Airbus A-300 B2	11.0	11.0	31.0	31.0	20.0	20.0	37.4	1.07	V	2.65
3 OR 4 JET ENGINES	Lockheed 1011 Tristar	-	12.0	-	32.0	-	20.0	36.1	.93	A	2.57
	Boeing 707/120	16.0	16.0	34.0	34.0	18.0	18.0	38.2	.61	V	1.86
	720/022	15.0	15.0	31.0	31.0	16.0	16.0	31.9	.59	V	2.26
	747/200B	-	12.5	-	32.0	-	19.5	45.8	1.00	V	2.55
	McD. Douglas DC-8/21	16.5	16.5	32.0	32.0	15.5	15.5	27.0	.58	V	2.10
	Lockheed C-141A	19.0	19.0	32.0	32.0	13.0	13.0	50.3	.51	V	2.32
	Lockheed C-5A	19.0	19.0	41.0	41.0	22.0	22.0	67.9	.64	V	2.60
1 PROPELLER ENGINE	Fokker S-11 Instructor	21.5	21.5	27.0	27.0	5.5	5.5	22.2	.43	F	1.25
	Cessna 172, Normal Cat.	15.6	15.6	36.5	36.5	20.9	20.9	64.3	.59	F	2.14
	177, Normal Cat.	5.0	5.0	28.0	28.0	23.0	23.0	58.6	.60	A	1.86
	177, Utility Cat.	5.0	5.0	18.5	18.5	13.5	13.5	58.6	.60	A	1.86
	206 Skywagon	12.2	12.2	39.4	39.4	27.2	27.2	67.3	.77	F	2.16
	Beechcraft B-45 Mentor	20.1	19.0	28.0	28.0	7.9	9.0	17.4	.54	F	2.01
	Piaggio P-148 (3 seater)	22.3	22.3	30.7	30.7	8.4	8.4	26.3	.43	F	1.90
	Pilatus PC-6-H2 Porter	11.0	11.0	34.0	34.0	23.0	23.0	79.9	.67	A	2.28
	Saab 91-B Safir	17.9	17.9	27.1	27.1	9.2	9.2	23.9	.64	F	-
	De Havilland DHC-2 Beaver	17.4	17.4	40.3	40.3	22.9	22.9	49.3	.76	F	-
2 PROPELLER ENGINES	Cessna Model 337	17.3	17.3	30.9	30.9	13.6	13.6	37.1	.51	F	1.78
	Piper PA 30C Twin Comanche	12.0	12.0	27.8	27.8	15.8	15.8	40.7	.44	A	1.66
	Beechcraft Queen Air M. 80	16.0	16.0	29.9	29.9	13.9	13.9	44.9	.73	F	1.88
	Dornier Do 28-D-1	10.7	10.7	30.8	30.8	20.1	20.1	34.7	.67	A	2.36
	DHC-6 Twin Otter	20.0	20.0	36.0	36.0	16.0	16.0	74.0	.93	F	2.37
	Nord 262	16.0	16.0	30.0	30.0	14.0	14.0	48.0	.96	F	2.23
	Fokker VFW F-27 Mk 200	20.0	18.7	38.0	40.7	18.0	22.0	55.8	.96	F	2.94
	Hurel Dubois HD 32	23.5	23.5	46.5	46.5	23.0	23.0	36.5	1.32	F	2.70
	Convair 240	15.0	8.5	31.0	33.0	16.0	24.5	33.9	1.07	F	2.33
	340	13.0	8.5	34.0	35.0	21.0	26.5	56.0	1.03	F	2.61
	H. Siddeley Andover C.Mk 1	13.3 *	13.3 *	36.0 *	36.0 *	22.7 *	22.7 *	53.6	1.09	F	2.88
4 PROPELLER ENGINES	Bréguet 941	23.0	23.0	32.0	32.0	9.0	9.0	70.0	1.05	V	7.19
	Douglas DC-6	16.0	12.0	33.0	35.0	17.0	23.0	29.4	1.04	F	2.77
	Lockheed 188C Electra	15.0	13.0	32.0	33.0	17.0	20.0	53.6	.80	F	2.54
	Bristol 175 Britannia	13.0 *	12.0 *	34.5 *	35.5 *	21.5 *	23.5 *	37.3	.97	F	2.56
	Lockheed L-1049 H	18.0	15.0	32.0	34.0	14.0	19.0	44.9	1.15	F	2.60
	L-1649 A	15.0	12.0	32.0	34.0	17.0	22.0	17.5	1.12	F	2.53
	C-130 E	15.0	15.0	30.0	30.0	15.0	15.0	51.4	1.00	F	2.28
	Canadair CL-44 C	12.2	12.2	30.5	31.4	18.3	19.2	22.8	1.14	F	2.56

* per cent SMC

** F = fixed stabilizer, V = variable incidence stabilizer, A = all-movable tail

*** flap angle for landing

Table 8-16. Center of gravity limits for several types of aircraft