Name: **Enrolment No:**	UPES UNIVERSITY OF TOMORROW

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
End Semester Examination, May 2022

Course: Aircraft Design **Semester: VIII**
Program: B.Tech Aerospace Engineering **Time : 03 hrs.**
Course Code: ASEG 4004 **Max. Marks: 100**

Instructions:Use of aircraft design data is allowed in examination.

SECTION A
(5Qx4M=20Marks)

S. No.		Marks	CO
Q 1	Provide mission requirements of military Drone in diagram.	**4**	**CO1**
Q 2	Derive the relation for Weight Escalation factor (WEF) of aircraft used in aircraft design.	**4**	**CO1**
Q 3	Derive useful weight relation (W_{useful}) if gross take-off weight is given by $W_{TO} = W_{Empty} + W_{Payload} + W_{Fuel} + W_{tfo}$	**4**	**CO2**
Q4	Why multi-stage rocket perform better than SSTO Rocket?	**4**	**CO3**
Q5	Compare different design configurations of multi-stage rocket.	**4**	**CO4**

SECTION B
(4Qx10M= 40 Marks)

S. No.		Marks	CO
Q 6	Consider an aircraft with following characteristics: Cruise Mach number 0.25; cruise altitude 3000 m, wing loading 100 kg/m^2, Takeoff weight 4000 kg. Design the main wing that would be suitable for this aircraft and provide sketches. Compare your results for Mach number 0.8.	**10**	**CO2**
Q 7	An airplane under design has the following features: Weight of payload = 30000 N , Weight of4 crew members = 4000 N, Estimated fuel fraction (W_f/W_O) = 0.38 , Empty weight fraction (We/W_O) = 0.837 $Wo^{-0.7}$ here, W_O is in Newtons. a) Obtain the gross weight (W_O) of the airplane, b) Compute and plot payload trade graph	**10**	**CO2**
Q 8	An aircraft has following deisng characteristics mas fraction structure ($W_{structure}/Wo$)=0.3, Subsystem mass fraction =0.05, and Propulsion mass fraction ($W_{propulsion}/Wo$)=0.1. fuel mass fraction (W_{fuel}/Wo) =0.53,	**10**	**CO4**

	Estimate the weight escalation fraction of aircraft?		
Q 9	Compare advantages and disadvantages of tossback trajectory of Rocket performance over SSTO(Single Stage To Orbit), Also, derive final expression for initial and final mass fractions for *tossback trajectory*.	**10**	**CO3**
SECTION-C (2Qx20M=40 Marks)			
Q 10	Consider small regional jet airplane with gross take off weight 35,000kg, and 5700 kg payload with 1600 km range at 10,000 m altitude. Take off field length 1550 m, a) Design aircraft wing, tail, fuselage, engine propeller), [15 Marks] b) Sketch layout with 3D view [5 Marks]	**20**	**CO4**
Q 11	For problem given in above question Q10, c) Estimate detailed Aerodynamic drag Components, (wing, tail, fuselage, engine propeller, Tire), [15 Marks] d) plot performance graph (L/D vs Velocity, Thrust vs Velocity, Rate of Climb vs Velocity) [5 Marks]	**20**	**CO3**

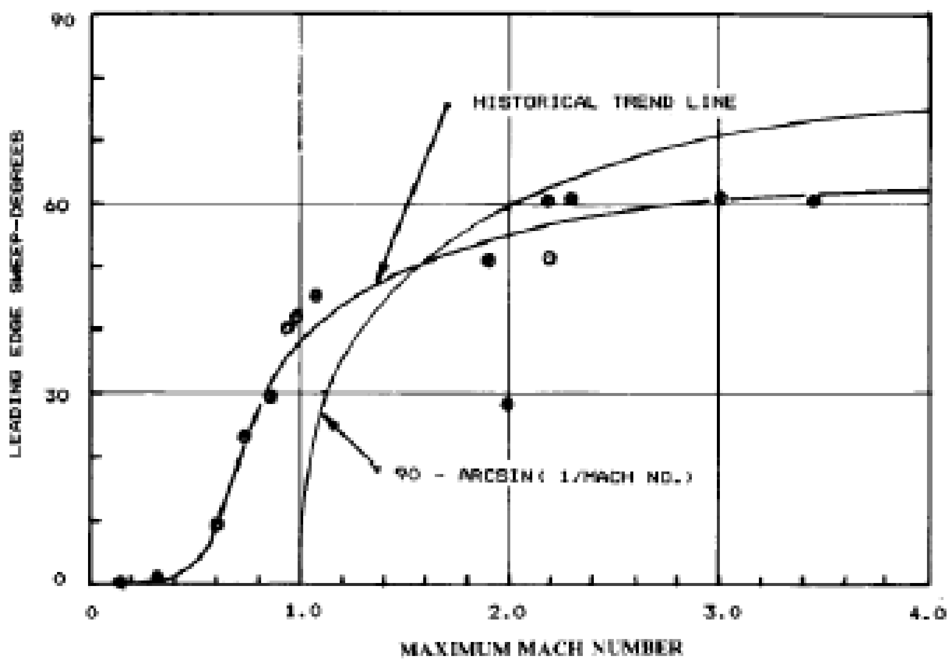
NOTE: Design Data: Aircraft Design by Daniel P. Raymer

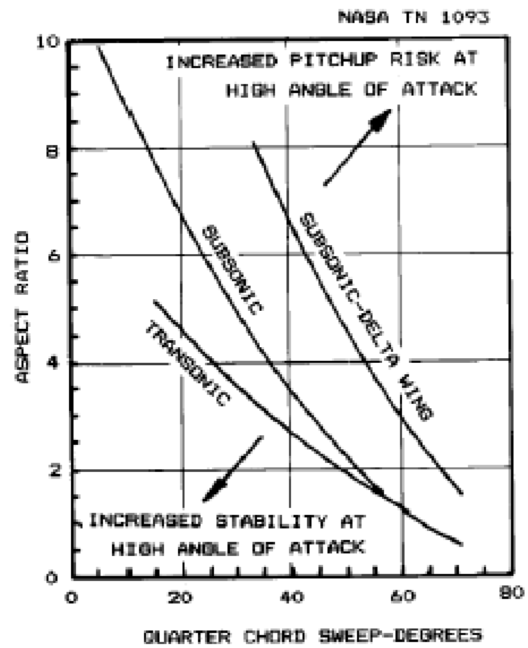
Table 4.1 Aspect ratio

Sailplane equivalent* aspect ratio = 4.464 (best L/D)$^{.69}$

Propeller aircraft	Equivalent aspect ratio	
Homebuilt	6.0	
General aviation—single engine	7.6	
General aviation—twin engine	7.8	
Agricultural aircraft	7.5	
Twin turboprop	9.2	
Flying boat	8.0	
	Equivalent aspect Ratio = aM_{max}^{C}	
Jet aircraft	a	C
Jet trainer	4.737	−0.979
Jet fighter (dogfighter)	5.416	−0.622
Jet fighter (other)	4.110	−0.622
Military cargo/bomber	5.570	−1.075
Jet transport	7.50	0

*Equivalent aspect ratio = wing span squared/(wing and canard areas)





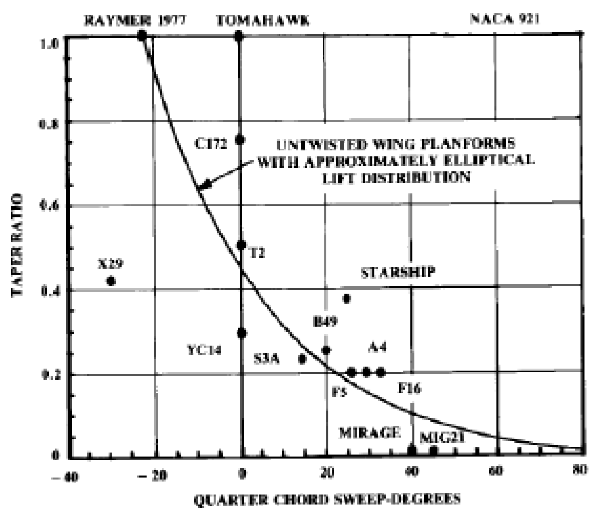
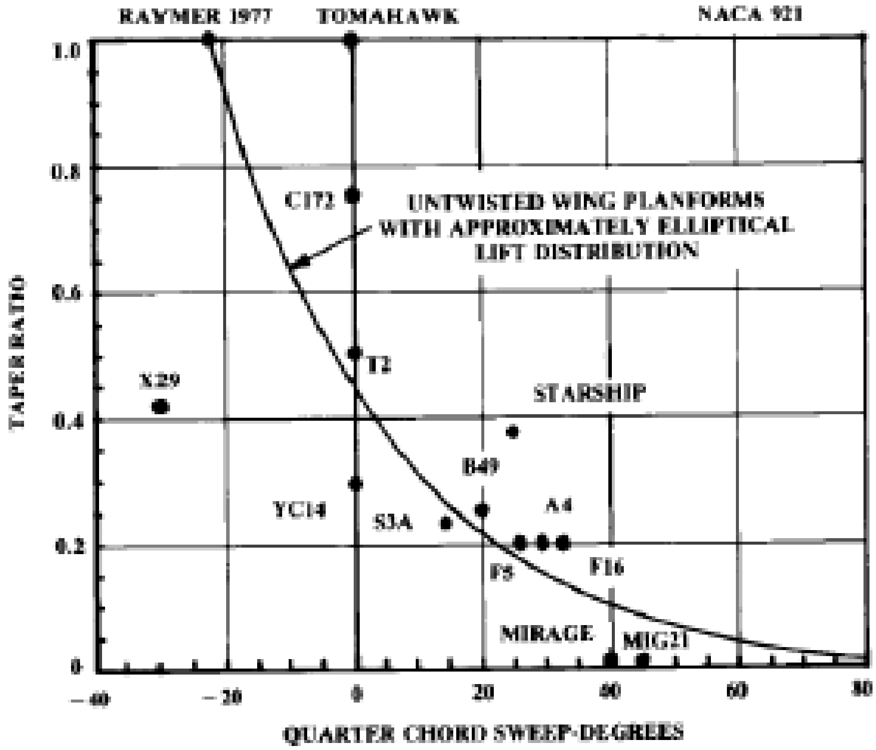


Table 3.2 Historical mission segment weight fractions

	(W_i/W_{i-1})
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

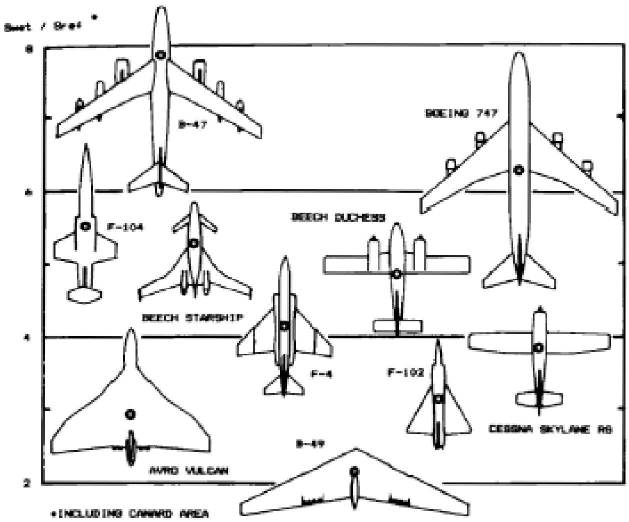


$$E = \frac{L/D}{C} \ln \frac{W_{i-1}}{W_i} \qquad R = \frac{V}{C}\frac{L}{D} \ln \frac{W_{i-1}}{W_i}$$

$$\frac{W_i}{W_{i-1}} = \exp \frac{-EC}{L/D} \qquad \frac{W_i}{W_{i-1}} = \exp \frac{-RC}{V(L/D)}$$

Table 3.4 Propeller specific fuel consumption (C_{bhp})

Propeller: $C = C_{bhp} V/(550\eta_p)$ Typical C_{bhp} and η_p	Cruise	Loiter
Piston-prop (fixed pitch)	0.4/0.8	0.5/0.7
Piston-prop (variable pitch)	0.4/0.8	0.5/0.8
Turboprop	0.5/0.8	0.6/0.8



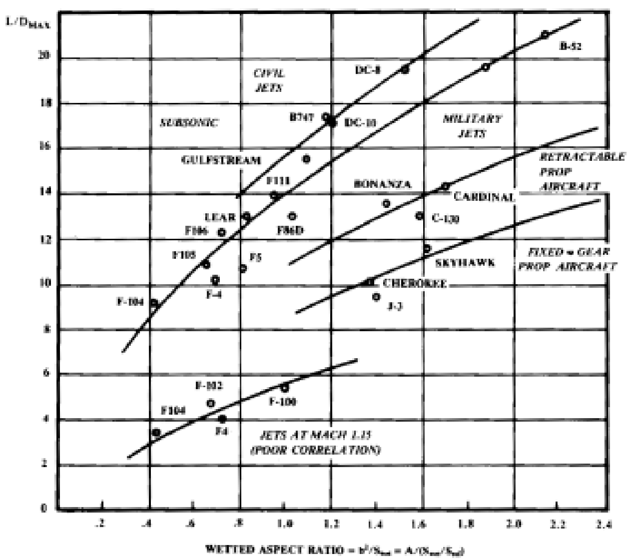


Table 4.3 Tail aspect ratio and taper ratio

	Horizontal tail		Vertical tail	
	A	λ	A	λ
Fighter	3–4	0.2–0.4	0.6–1.4	0.2–0.4
Sail plane	6–10	0.3–0.5	1.5–2.0	0.4–0.6
Others	3–5	0.3–0.6	1.3–2.0	0.3–0.6
T-Tail	–	–	0.7–1.2	0.6–1.0

Table 5.3 T/W_0 vs M_{max}

$T/W_0 = a\, M_{max}^C$	a	C
Jet trainer	0.488	0.728
Jet fighter (dogfighter)	0.648	0.594
Jet fighter (other)	0.514	0.141
Military cargo/bomber	0.244	0.341
Jet transport	0.267	0.363

Table 5.4 hp/W_0 vs V_{max} (mph)

hp/$W_0 = a\, V_{max}^C$	a	C
Sailplane—powered	0.043	0
Homebuilt—metal/wood	0.005	0.57
Homebuilt—composite	0.004	0.57
General aviation—single engine	0.024	0.22
General aviation—twin engine	0.034	0.32
Agricultural aircraft	0.008	0.50
Twin turboprop	0.012	0.50
Flying boat	0.029	0.23

Table 5.5 Wing loading

Historical trends	Typical takeoff W/S (lb/ft²)
Sailplane	6
Homebuilt	11
General aviation—single engine	17
General aviation—twin engine	26
Twin turboprop	40
Jet trainer	50
Jet fighter	70
Jet transport/bomber	120

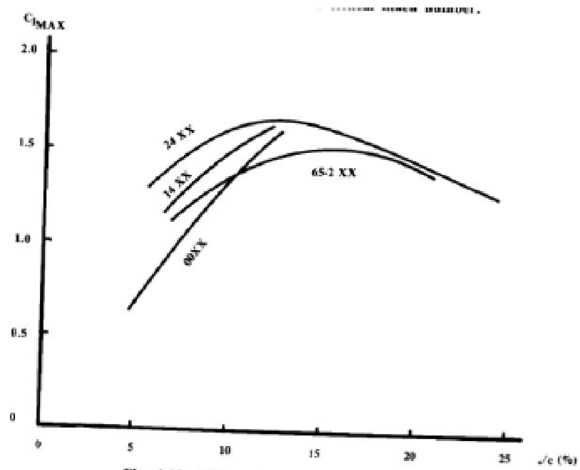
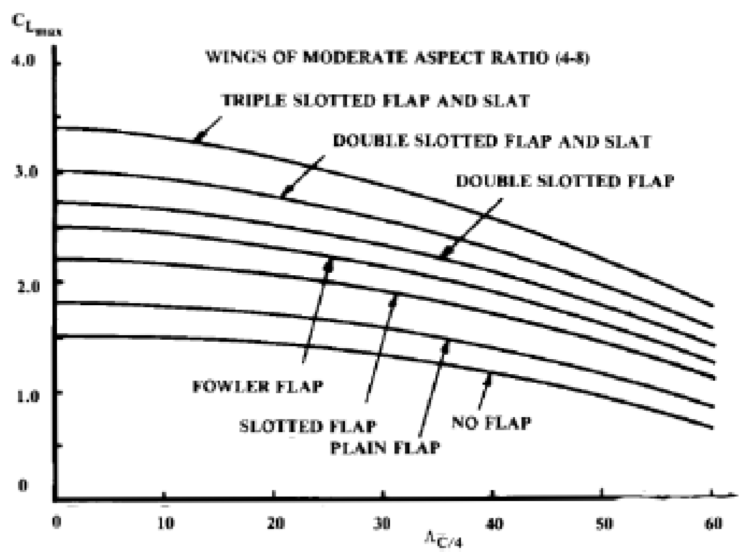


Fig. 4.13 Effect of t/c on maximum lift.



The approach speed is required to be a certain multiple of the stall speed. For civil applications, the approach speed must be at least 1.3 times the stall speed. For military applications, the multiple must be at least 1.2 (1.15 for carrier-based aircraft). Approach speed may be explicitly stated in the design requirements or will be selected based upon prior, similar aircraft. Then the required stall speed is found by division by 1.3, 1.2, or 1.15.

$$W = L = q_{\text{stall}} S C_{L_{\max}} = \tfrac{1}{2}\rho V_{\text{stall}}^2 S C_{L_{\max}} \tag{5.5}$$

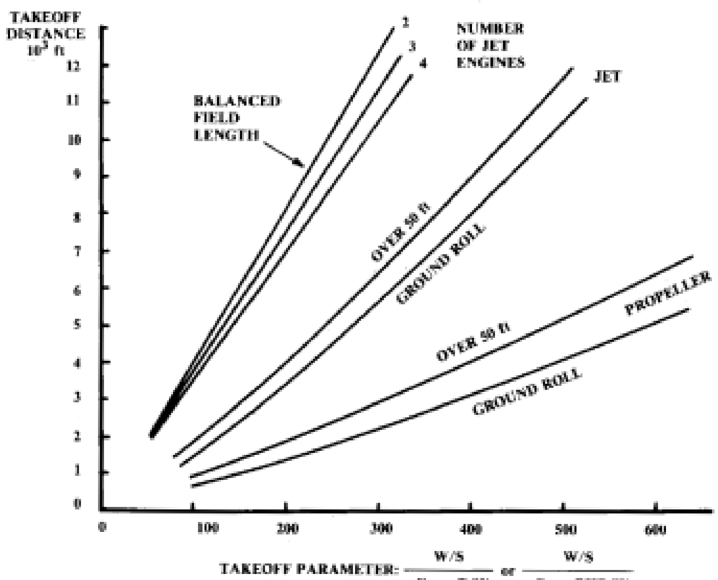
$$W/S = \tfrac{1}{2}\rho V_{\text{stall}}^2 C_{L_{\max}} \tag{5.6}$$

The takeoff lift coefficient is the actual lift coefficient at takeoff, not the maximum lift coefficient at takeoff conditions as used for stall calculation. The aircraft takes off at about 1.1 times the stall speed so the takeoff lift coefficient is the maximum takeoff lift coefficient divided by 1.21 (1.1

following expressions give the maximum allowable wing loading for the given takeoff distance:

$$\text{Prop:} \quad (W/S) = (\text{TOP})\sigma C_{L_{TO}}(\text{hp}/W) \tag{5.8}$$

$$\text{Jet:} \quad (W/S) = (\text{TOP})\sigma C_{L_{TO}}(T/W) \tag{5.9}$$



After Ref. 4 and 5

Climb gradient, "G," is the ratio between vertical and horizontal distance traveled. As will be shown in Chapter 17, at normal climb angles the climb gradient equals the excess thrust divided by the weight, i.e.—

$$G = (T - D)/W \tag{5.27}$$

or

$$\frac{D}{W} = \frac{T}{W} - G \tag{5.28}$$

D/W can also be expressed as in Eq. (5.29), where in the final expression the lift coefficient is replaced by (W/qS).

$$\frac{D}{W} = \frac{qSC_{D_0} + qS(C_L^2/\pi Ae)}{W} = \frac{qC_{D_0}}{W/S} + \frac{W}{S}\frac{1}{q\pi Ae} \tag{5.29}$$

Equating Eqs. (5.28) with (5.29) and solving for wing loading yields:

$$\frac{W}{S} = \frac{[(T/W) - G] \pm \sqrt{[(T/W) - G]^2 - (4C_{D0}/\pi Ae)}}{2/q\pi Ae} \tag{5.30}$$

During cruise, the lift equals the weight, so the lift coefficient equals the wing loading divided by the dynamic pressure. Substitution into Eq. (5.12) allows solution for the required wing loading to maximize L/D for a given flight condition. This result [Eq. (5.13)] is the wing loading for maximum range for a propeller aircraft.

$$\text{Maximum Prop Range:}\quad W/S = q\sqrt{\pi AeC_{D_0}} \tag{5.13}$$

As the aircraft cruises, its weight reduces due to the fuel burned, so the wing loading also reduces during cruise. Optimizing the cruise efficiency while the wing loading is steadily declining requires reducing the dynamic pressure by the same percent [see Eq. (5.13)]. This can be done by reducing velocity, which is undesirable, or by climbing to obtain a lower air density. This range optimizing technique is known as a "cruise-climb."

A jet aircraft flying a cruise-climb will obtain maximize range by flying at a wing loading such that the parasite drag is three times the induced drag (see Chapter 12 for the derivation of this relationship). This yields the following formula for wing-loading selection for range optimization of jet aircraft.

$$\text{Maximum Jet Range:}\quad W/S = q\sqrt{\pi AeC_{D_0}/3} \tag{5.14}$$

Empty-Weight Fraction

The empty-weight fraction is estimated using improved statistical equations. Tables 6.1 and 6.2 were prepared using data from Ref. 1 to provide

Table 6.2 Empty weight fraction vs W_0, A, hp/W_0, W_0/S, and V_{max} (mph)

$$W_e/W_0 = a + bW_0^{C1}A^{C2}(\text{hp}/W_0)^{C3}(W_0/S)^{C4}V_{max}^{C5}$$

	a	b	$C1$	$C2$	$C3$	$C4$	$C5$
Sailplane—unpowered	0	0.75	−0.05	0.14	0	−0.30	0.06
Sailplane—powered	0	1.20	−0.04	0.14	0.19	−0.20	0.05
Homebuilt—metal/wood	0	0.69	−0.10	0.05	0.10	−0.05	0.17
Homebuilt—composite	0	0.59	−0.10	0.05	0.10	−0.05	0.17
General aviation—single engine	−0.25	1.14	−0.20	0.08	0.05	−0.05	0.27
General aviation—twin engine	−0.90	1.32	−0.10	0.08	0.05	−0.05	0.20
Agricultural aircraft	0	1.64	−0.14	0.07	0.10	−0.10	0.11
Twin turboprop	0.37	0.08	−0.06	0.08	0.08	−0.05	0.30
Flying boat	0	0.41	−0.01	0.10	0.05	−0.12	0.18

Table 6.1 Empty weight fraction vs W_0, A, T/W_0, W_0/S, and M_{max}

$$W_e/W_0 = (a + bW_0^{C1} A^{C2} (T/W_0)^{C3} (W_0/S)^{C4} M_{max}^{C5}) K_{vs}$$

	a	b	C1	C2	C3	C4	C5
Jet trainer	0	4.28	−0.10	0.10	0.20	−0.24	0.11
Jet fighter	−0.02	2.16	−0.10	0.20	0.04	−0.10	0.08
Military cargo/bomber	0.07	1.71	−0.10	0.10	0.06	−0.10	0.05
Jet transport	0.32	0.66	−0.13	0.30	0.06	−0.05	0.05

K_{VS} = variable sweep constant = 1.04 if variable sweep
= 1.00 if fixed sweep

Table 6.3 Fuselage length vs W_0

Length $= aW_0^C$	a	C
Sailplane—unpowered	0.86	0.48
Sailplane—powered	0.71	0.48
Homebuilt—metal/wood	3.68	0.23
Homebuilt—composite	3.50	0.23
General aviation—single engine	4.37	0.23
General aviation—twin engine	0.86	0.42
Agricultural aircraft	4.04	0.23
Twin turboprop	0.37	0.51
Flying boat	1.05	0.40
Jet trainer	0.79	0.41
Jet fighter	0.93	0.39
Military cargo/bomber	0.23	0.50
Jet transport	0.67	0.43

Table 6.4 Tail volume coefficient

	Typical values	
	Horizontal c_{HT}	Vertical c_{VT}
Sailplane	0.50	0.02
Homebuilt	0.50	0.04
General aviation—single engine	0.70	0.04
General aviation—twin engine	0.80	0.07
Agricultural	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06
Jet trainer	0.70	0.06
Jet fighter	0.40	0.07
Military cargo/bomber	1.00	0.08
Jet transport	1.00	0.09

$$c_{VT} = \frac{L_{VT} S_{VT}}{b_W S_W} \qquad (6.26)$$

$$c_{HT} = \frac{L_{HT} S_{HT}}{\bar{C}_W S_W} \qquad (6.27)$$

Table 11.1 Statistical tire sizing

Main wheels diameter or width (in.) $= A\ W_W^B$

	Diameter		Width	
	A	B	A	B
General aviation	1.51	0.349	0.7150	0.312
Business twin	2.69	0.251	1.170	0.216
Transport/bomber	1.63	0.315	0.1043	0.480
Jet fighter/trainer	1.59	0.302	0.0980	0.467

W_W = Weight on Wheel

$$(V_{tip})_{static} = \pi n d/60 \qquad \text{(ft/s)} \qquad (10.21)$$

where

n = rotational rate (rpm) obtained from engine data
d = diameter

$$(V_{tip})_{helical} = \sqrt{V_{tip}^2 + V^2} \qquad (10.22)$$

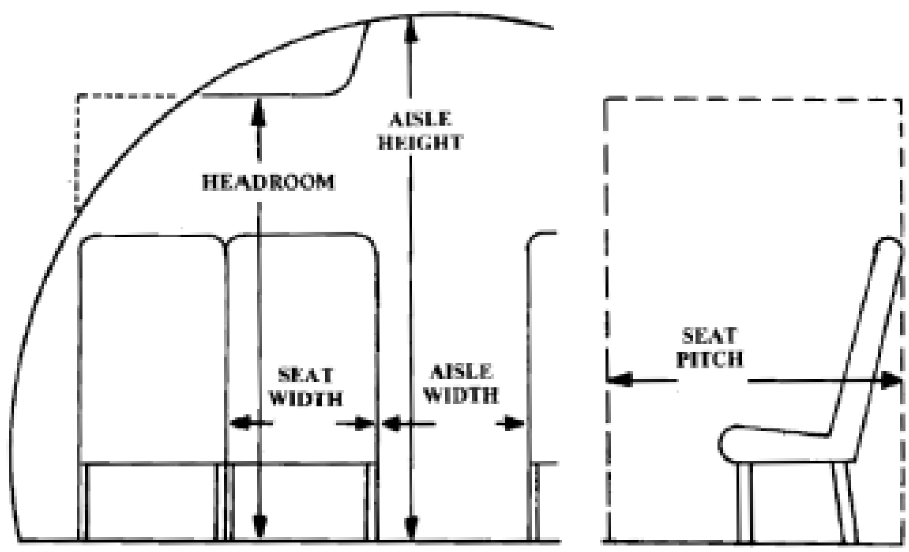
$$\text{Two blade:} \quad d = 22\sqrt[4]{\text{Hp}} \qquad (10.23)$$

$$\text{Three blade:} \quad d = 18\sqrt[4]{\text{Hp}} \qquad (10.24)$$

$$\text{Three blade (agricultural):} \quad d = 20\sqrt[4]{\text{Hp}} \qquad (10.25)$$

Table 9.1 Typical passenger compartment data

	First class	Economy	High density/ small aircraft
Seat pitch (in.)	38–40	34–36	30–32
Seat width (in.)	20–28	17–22	16–18
Headroom (in.)	> 65	> 65	–
Aisle width (in.)	20–28	18–20	≥ 12
Aisle height (in.)	> 76	> 76	> 60
Passengers per cabin staff (international-domestic)	16–20	31–36	≤ 50
Passengers per lavatory (40″ × 40″)	10–20	40–60	40–60
Galley volume per passenger (ft^3/pass)	5–8	1–2	0–1



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W_w = Weight on Wheel

Table 12.3 Equivalent skin friction coefficients

$C_{D_0} = C_{fe}\dfrac{S_{wet}}{S_{ref}}$	C_{fe}-subsonic
Bomber and civil transport	0.0030
Military cargo (high upsweep fuselage)	0.0035
Air Force fighter	0.0035
Navy fighter	0.0040
Clean supersonic cruise aircraft	0.0025
Light aircraft – single engine	0.0055
Light aircraft – twin engine	0.0045
Prop seaplane	0.0065
Jet seaplane	0.0040