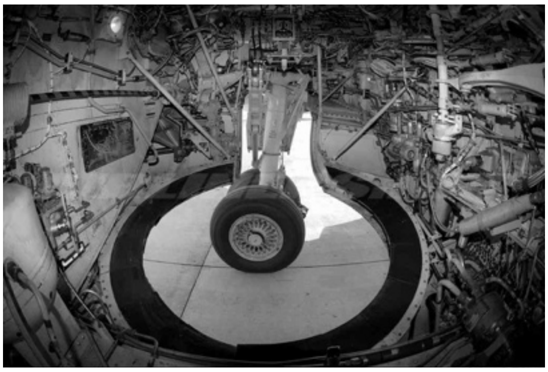
1



Landing gear design

2

Landing gear function

1. Landing gear is one of the more demanding ‘real world’ or non-aerodynamic items that must be dealt with in aircraft design, especially for retractable landing gear, which is now standard for all but the simplest or most rugged aircraft.
2. The primary purpose of the landing gear is to facilitate operation of the aircraft in landing as well as during taxi and take-off. Correct function is determined by landing gear layout and geometry choices.
3. The landing gear must be sized to spread (aircraft weight) loading both onto the runway surface and (reactions) into the aircraft structure. Also it has a cushioning/energy dissipation function at touchdown.
4. Initial sizing of landing gear takes a simplified approach: geometry, number of LG struts and wheels, sizing of the individual wheels, LG strut stroke and diameter.
5. While in initial design the following considerations are usually ignored, in reality the landing gear must also accommodate a range of other reaction loads, e.g. due to:
    a. Cross-wind takeoff/landing
    b. Tail-down landing
    c. Side loads in ground handling
    d. Braking.

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Landing gear arrangements

1. The three basic types of landing gear are tricycle, bicycle and tailwheel/taildragger. The longitudinal CG position is always between the front and rear wheels.
2. Tricycle is the most popular and has the following desirable characteristics:
   a. directional stability during taxi, take-off and landing;
   b. steering during ground operations;
   c. visibility over the nose during ground operations;
   d. level floor attitude on the ground;
   e. simpler take-off and landing procedures.
3. Twin nosewheels are common for tricycle gear layouts to ensure steering function in the event of a flat tyre.
4. Bicycle+outrigger layouts do not allow the aircraft to rotate for take-off, and so typically require (much) greater runway lengths, limiting their use primarily to military types. They are usually combined with a high-wing layout, with very high aspect ratio wings, or both.
5. Taildragger layouts lack directional stability on ground roll but are simple, robust and commonly used with small fixed-gear aircraft.
6. Owing to a significant drag penalty for fixed landing gear, retractable gear is now the most common type, even though it is more complex and costly. Fixed gear wheels may be faired with ‘spats’, although this may be inappropriate for utility aircraft usage, where rough fields are common.

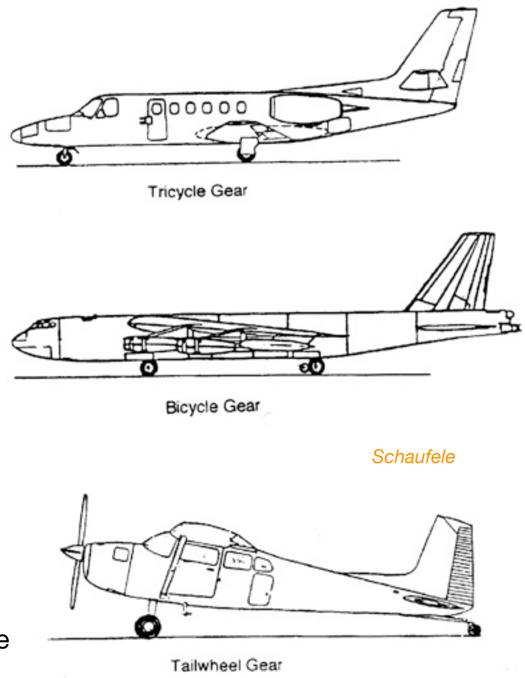
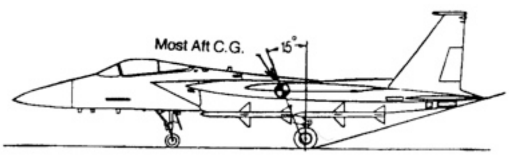


Fig. 7-1 Basic Types of Landing Gear Arrangements

Tip-over criteria — 1

1. A primary consideration of layout is to avoid tip-over during normal ground operations.
2. The key point here is to keep the aircraft weight vector within the pattern of landing gear reaction points.
3. To save weight, cost, and for strength, landing gear struts should be as short as practicable.
4. **For layout one requires the aircraft’s vertical as well as horizontal CG location.**
5. For tricycle gear the main gear reaction point must remain aft of the aircraft weight at the rearmost CG location, even when the aircraft is tipped backwards for landing. Typically the (maximum) tip-back angle is approx. 15°, implying that the main gear contact point must lie at least 15° aft of the rearmost CG location when the gear is fully extended.
6. If the aircraft has a propeller then the landing gear must be long enough to provide it with at least 0.2m ground clearance when the gear is in compressed condition and when the aircraft is in the worst orientation w.r.t. propeller ground-strike during normal operation.
7. The lateral tip-over or overturn angle ψ should be no more than approx. 55° when CG is at its foremost location. This sets the lateral spread of the landing gear.
8. The further aft the main gear, the greater proportion of weight taken by the nose gear in static condition.
9. The amount of static load taken by the nose gear should be no less than 8% (for steering authority) and no more than 25% (otherwise the elevator may have insufficient authority to rotate aircraft on take-off).



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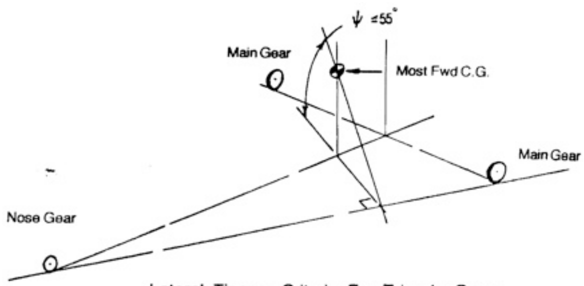
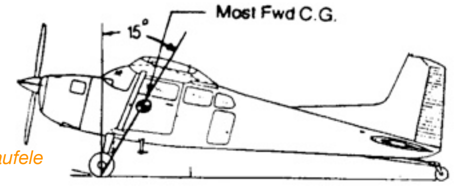
Longitudinal Tipover Criteria For Tricycle Gears



Lateral Tipover Criteria For Tricycle Gears

Tip-over criteria — 2

10. Similar considerations arise for tip-over of aircraft with tailwheel landing gear.
11. Typically the contact patch of the main wheels must lie approx. 15° forward of the foremost CG location.
12. A similar lateral tip-over or overturn angle applies as for tricycle gear, except that the tail wheel replaces the nose wheel in the geometry.
13. Again the gear must be long enough that a propeller has adequate ground clearance in normal operations.
14. Longitudinal tip-over is not normally a consideration for bicycle landing gear. Typically the CG location lies toward the rear set of wheels.
15. Tricycle landing gear must be long enough (in compressed state) to allow the aircraft to rotate to takeoff pitch attitude without striking any part of the aircraft on the ground.
16. Tricycle and taildragger landing gear must also be long enough that the aircraft can roll a reasonable amount (approx. 5°) without striking any part of the aircraft on the ground.



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Longitudinal Tipover Criteria For Tailwheel Gears

Raymer

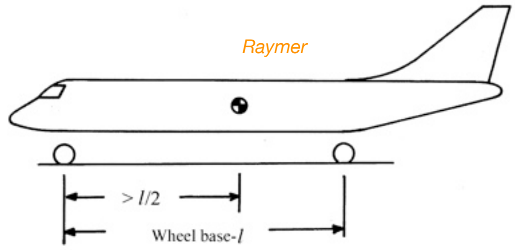
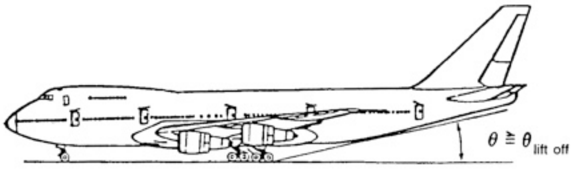


Fig. 11.3 Bicycle landing gear.



Longitudinal Ground Clearance Criteria

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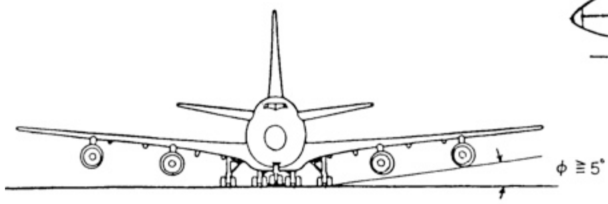

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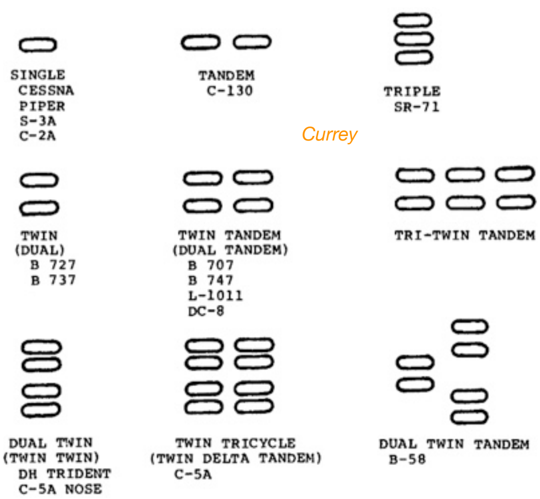
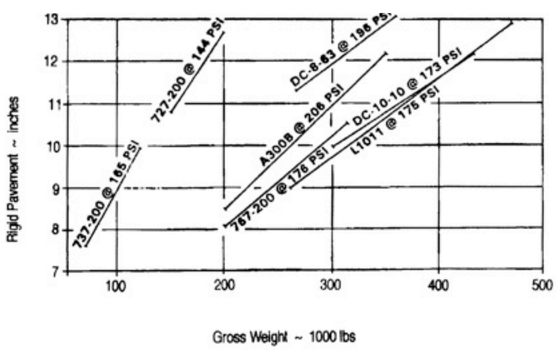
Lateral Ground Clearance Criteria

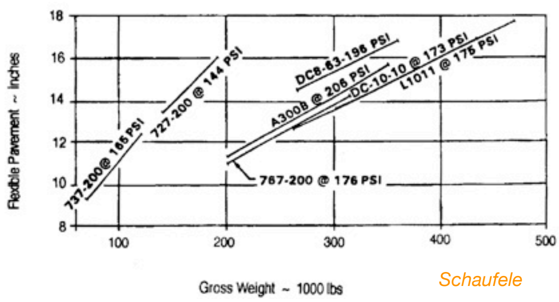
Wheel and tyre sizing — 1

1. Strictly the 'wheel' is the inner metal part on which the rubber 'tyre' is mounted and there may be a separate brake inside the wheel. However, the term 'wheel' is often used to describe the assembly of these components.
2. Tyres are sized in relation to the static load they carry and also to the type of runway the aircraft will operate on.
3. 'Flexible' pavements refer to tarmac runways while 'rigid' pavements are made from concrete and are typically somewhat thinner for the same load capacity.
4. Note that wheels are often grouped into pairs or multiples (on bogeys) in order to spread load and reduce individual tyre diameter.
5. When choosing wheel sizes and multiplicity there is an obvious interplay with wheel well sizing and landing gear mechanics.



Currey





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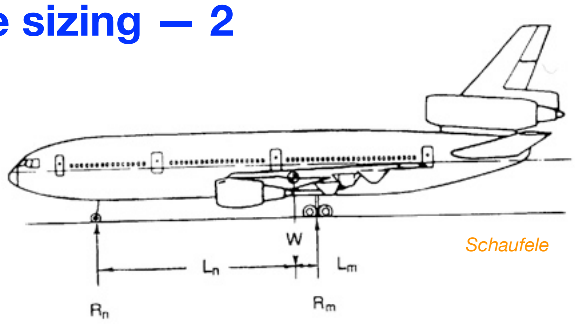
Wheel and tyre sizing — 2

5. Simple statics is the basis for assigning static loads first to undercarriage groups (nose or main), then dividing by the number of tyres available (or chosen!) to share the load in order to estimate the static load per wheel.

Load carried by main gear: $\frac{R_m}{W} = \frac{L_n}{L_m + L_n}$

Load carried by nose gear: $\frac{R_n}{W} = \frac{L_m}{L_m + L_n}$



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$$R_m + R_n = W$$

6. A first-order estimate of main-wheel tyre sizes based on the static load per wheel can be obtained from correlations (here assuming main gear takes about 90% of the aircraft weight).

Table 11.1 Statistical tire sizing

	Diameter		Width	
	A	B	A	B
British units: Main wheels diameter or width (in.) = A W_W^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
Metric units: Main wheels diameter or width (cm) = A W_W^B				
General aviation	5.1	0.349	2.3	0.312
Business twin	8.3	0.251	3.5	0.216
Transport/bomber	5.3	0.315	0.39	0.480
Jet fighter/trainer	5.1	0.302	0.36	0.467

W_W = Weight on wheel.

Raymer

'Weight' *W* in kg.

7. Increase diameters by about 30% if the aircraft is to operate from rough unpaved runways.
8. Nose tyres are typically 60-100% of main wheel diameter.
9. For bicycle layouts the front and rear tyres are typically the same size.
10. For taildragger layouts the aft tyres are typically 25-33% of main tyre diameter.

Wheel and tyre sizing — 3

11. There are a number of different standard tyre types, but only types I, III, VII and VIII are in common use. Each type has a slightly different nomenclature.
12. While manufacturers' catalogues are needed to obtain data for all available sizes, we present a selection of sizes for the different types and example applications.

Type I - Smooth Contour- for fixed gear applications

Type III- Low Pressure- basic low pressure tire, still widely used

Type VII- Extra High Pressure- most widely used type for civil and military jets and turboprops

Type VIII- Low Profile High Pressure- newer type for very high speed takeoff requirements

Aircraft tires are defined by their most important dimensions. These are

D_o	tire outside diameter
W	tire maximum width
D	rim diameter

(often in inches)

Of the several types in use, the size descriptions are given as follows:

Type I	Type III	Type VII	Type VIII
D_o	W-D	D_o x W	D_o x W-D

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Table 11.2 Tire data

Size	Speed, mph	Max load, lb	Infl, psi	Max width, in.	Max diam, in.	Rolling radius	Wheel diam	Number of plies
Type III								
5.00-4	120	1,200	55	5.05	13.25	5.2	4.0	6
5.00-4	120	2,200	95	5.05	13.25	5.2	4.0	12
7.00-8	120	2,400	46	7.30	20.85	8.3	8.0	6
8.50-10	120	3,250	41	9.05	26.30	10.4	10.0	6
8.50-10	120	4,400	55	8.70	25.65	10.2	10.0	8
9.50-16	160	9,250	90	9.70	33.35	13.9	16.0	10
12.50-16	160	12,800	75	12.75	38.45	15.6	16.0	12
20.00-20	174kt	46,500	125	20.10	56.00	22.1	20.0	26
Type VII								
16 × 4.4	210	1,100	55	4.45	16.00	6.9	8.0	4
18 × 4.4	174kt	2,100	100	4.45	17.90	7.9	10.0	6
18 × 4.4	217kt	4,350	225	4.45	17.90	7.9	10.0	12
24 × 5.5	174kt	11,500	355	5.75	24.15	10.6	14.0	16
30 × 7.7	230	16,500	270	7.85	29.40	12.7	16.0	18
36 × 11	217kt	26,000	235	11.50	35.10	14.7	16.0	24
40 × 14	174kt	33,500	200	14.00	39.80	16.5	16.0	28
46 × 16	225	48,000	245	16.00	45.25	19.0	20.0	32
50 × 18	225	41,770	155	17.50	49.50	20.4	20.0	26
Three-Part Name (Type VIII)								
18 × 4.25-10	210	2,300	100	4.70	18.25	7.9	10.0	6
21 × 7.25-10	210	5,150	135	7.20	21.25	9.0	10.0	10
28 × 9.00-12	156kt	16,650	235	8.85	27.60	11.6	12.0	22
37 × 14.0-14	225	25,000	160	14.0	37.0	15.1	14.0	24
47 × 18-18	195kt	43,700	175	17.9	46.9	19.2	18.0	30
52 × 20.5-23	235	63,700	195	20.5	52.0	21.3	23.0	30

Raymer

Wheel and tyre sizing — 4

Example sizes by application.

Type	W_{TO} Lbs	Main Gear $D_t \times b_t$ in.x in	Main Gear R_m/W_{TO}	Main Gear PSI	Main Gear no. tires per strut	Nose Gear $D_t \times b_t$ in.x in	Nose Gear R_n/W_{TO}	Nose Gear PSI	Nose Gear no. tires
Single Engine	1,600	15 x 6	0.80	18	1	16 x 5	0.20	28	1
Prop Driven	2,400	17 x 6	0.84	19	1	12.6 x 5	0.16	22	1
	3,800	16.5 x 6	0.84	55	1	14 x 5	0.16	49	1
Twin Engine	5,000	16 x 6	0.83	55	1	16 x 6	0.17	40	1
Prop Driven	8,000	22 x 6.5	0.88	75	1	17 x 6	0.12	40	1
	12,000	26.6 x 7	0.84	82	1	19.3 x 6.6	0.16	82	1
Regional Turbo-	12,500	18 x 5.5	0.89	105	2	22 x 6.75	0.11	57	1
Propeller Driven	21,000	24 x 7.25	0.90	85	2	18 x 5.5	0.10	65	2
Airplane	26,000	36 x 11	0.92	40	1	20 x 7.5	0.08	40	1
	44,000	30 x 9	0.93	107	2	20.4 x 6.6	0.07	77	2
Business Jets	12,000	22 x 6.3	0.93	90	1	18 x 5.7	0.07	120	1
	23,000	27.6 x 9.3	0.95	155	1	17 x 5.5	0.05	50	2
	39,000	26 x 6.6	0.92	208	2	14.5 x 7.7	0.08	130	2
	68,000	24 x 9.25	0.93	174	2	21 x 7.25	0.07	113	2
Jet Transports	44,000	34 x 12	0.89	75	2	24 x 7.7	0.11	68	2
	73,000	40 x 14	0.92	77	2	29.5 x 6.75	0.08	68	2
	116,000	40 x 14	0.94	170	2	24 x 7.7	0.06	150	2
	220,000	40 x 14	0.94	180	4	29 x 7.7	0.06	180	2
	330,000	46 x 16	0.93	206	4	40 x 14	0.07	131	2
	572,000	52 x 20.5	0.93	200	4*	40 x 15.5	0.07	190	2
	775,000	49 x 17	0.94	205	4**	46 x 16	0.06	190	2
Military Trainers	2,500	17 x 6		36	1	13.5 x 5	0.18	28	1
	5,500	20.3 x 6.5	0.82	60	1	14 x 5	0.09	40	1
	7,500	20.25 x 6	0.91	65	1	17.2 x 5.0	0.08	45	1
	11,000	23.3 x 6.5	0.92	143	1	17 x 4.4	0.10	120	1
Military Fighters									
	9,000	20 x 5.25	0.86	135	1	17 x 3.25	0.14	82	1
	14,000	18.5 x 7	0.87	110	1	18 x 6	0.13	37	1
	25,000	24 x 8	0.91	210	1	18 x 6.5	0.09	120	1
	35,000	24 x 8	0.90	85	2	21.6 x 9.8	0.10	57	1
	60,000	35.3 x 9.3	0.88	210	1	21.6 x 7.5	0.12	120	2
	92,000	42 x 13	0.93	150	1	20 x 6.5	0.07	120	2

*Three main gear struts ** Four main gear struts

Fig. 7-7 Typical Landing Gear Wheel and Tire Data

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Shock absorbers — 1

Typical of commercial aircraft

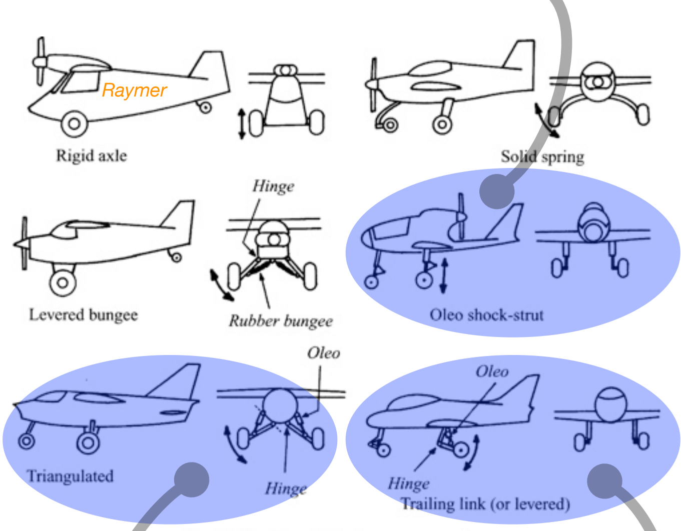


Fig. 11.9 Gear/shock arrangements.

Typical of carrier/rough field aircraft

1. The vertical kinetic energy of poor landings (or of carrier landings which do not use flare-out) must be absorbed (converted to heat) by a spring-damper arrangement.
2. For the simplest kinds of landing gear and lightweight aircraft this can be achieved just via the tyre's compliance and damping but more generally the landing gear must specifically incorporate spring-damper elements.
3. The oleo-pneumatic shock strut, or 'oleo', which combines spring and damper, is the most commonly used device.

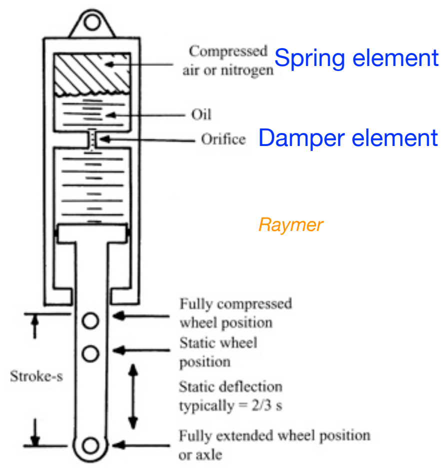


Fig. 11.10 Oleo shock absorber (most simple type).

4. For triangulated and trailing link designs, the stroke of the oleo is lower than that of the wheel, but oleo forces are higher and diameters must be larger.

11

Shock absorbers — 2

1. The stroke required of the shock-absorbing system depends principally on the vertical velocity at touchdown.
2. As a very rough guide, the required stroke in inches is approximately the vertical velocity at touchdown in feet/second (Raymer).
3. Typical vertical velocities for used for design are
   a. 3m/s (standard)
   b. 4m/s (military trainers)
   c. 4.5m/s (STOL)
   d. 6m/s (carrier landings)
4. For comparison a 'bad landing' vertical speed is more like 1.5m/s.
5. The vertical kinetic energy at touchdown

   $$KE_{\text{vertical}} = \frac{1}{2}\frac{W_{\text{landing}}}{\text{g}}V_{\text{vertical}}^2$$

   equals the kinetic energy to be absorbed

   $$KE_{\text{absorbed}} = \eta LS$$

   where η is absorber efficiency, L is the load transmitted through the undercarriage (assumed constant/averaged over stroke) and S is the required stroke.
6. The efficiency expresses how much energy is actually absorbed/dissipated to heat, which is always less than the stroke × load.
7. For tyres (alone), the stroke S_T is taken to be the distance to the outer radius to the rolling radius.

Table 11.4 Shock absorber efficiency

Type	Efficiency η
Steel leaf spring	0.50
Steel coil spring	0.62
Air spring	0.45
Rubber block	0.60
Rubber bungee	0.58
Oleopneumatic	
–Fixed orifice	0.65–0.80
–Metered orifice	0.75–0.90
Tire	0.47

Raymer

12

Shock absorbers — 3

8. Allowing both tyre and shock absorber to contribute to compliance and dissipation gives

$$\frac{1}{2}\frac{W_{\text{landing}}}{\text{g}}V_{\text{vertical}}^2 = (\eta LS)_{\text{shock absorber}} + (\eta_T LS_T)_{\text{tyre}}$$

9. The gear load factor or deacceleration rate N_{gear} is the average total load for all absorbers divided by the landing weight

$$N_{\text{gear}} = \frac{L}{W_{\text{landing}}}$$

or

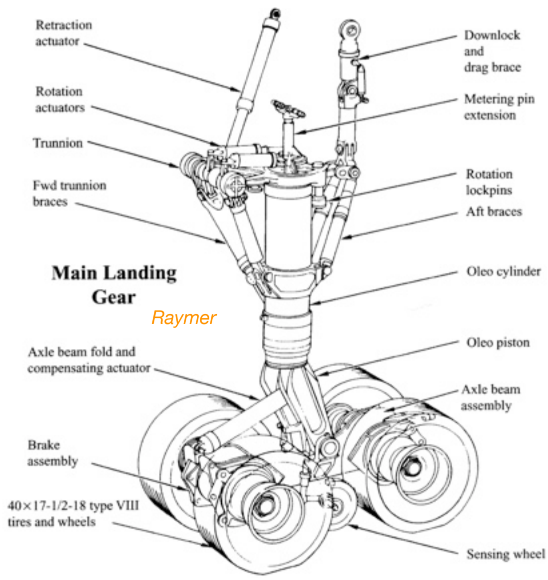
$$L = N_{\text{gear}}W_{\text{landing}}$$

Table 11.5 Gear load factors

Aircraft type	N_{gear}
Large bomber	2.0–3
Commercial	2.7–3
General aviation	3
Air Force fighter	3.0–4
Navy fighter	5.0–6

Raymer

Example oleo shock-strut



Raymer

9. Replacing L in the KE dissipation relation with this value and rearranging gives the required oleo stroke, S:

$$S = \frac{V_{\text{vertical}}^2}{2\text{g}\eta N_{\text{gear}}} - \frac{\eta_T}{\eta}S_T$$

Add approx 25mm safety margin.

10. The above is for an inline shock strut; for triangulated or trailing link arrangements the mechanical advantage needs to be dealt with as well when considering stroke, forces, dissipated energy.
11. Finally, one can show (see Raymer) that the required outer diameter of the oleo is approximated by

$$D_{\text{oleo}} = 1.3\sqrt{\frac{4L_{\text{oleo}}}{P\pi}}$$

Note: L_{oleo} does not include N.

The internal pressure P is typically approx. 12.5 MPa.

Gear-retraction geometry — 1

1. Now we know the sizes of wheels, tyres and shock-absorbers, as well as where the wheels have to end up in the LG-extended configuration.
2. Next we need to consider how and to where they will retract inside the aircraft, and what structural elements they will connect to.
3. Retracting the gear into the wing, fuselage or wing-fuselage junction produces the smallest aerodynamic penalty but may incur a weight penalty to retain structural integrity.
4. Wing-podded is possibly the simplest option and is similar to accommodation within an engine nacelle, which is common for multi-engined propeller aircraft.
5. Fuselage-podded is common for high-wing transports but adds drag.
6. Retracting into the wing-fuselage junction is the most common option on jet transports. Typically the main gear end is then supported on substructure tied to the wing box and fuselage.

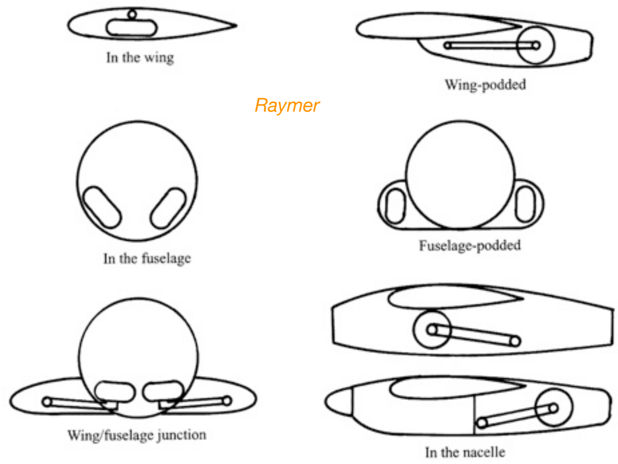


Fig. 11.13 "A home for the gear."

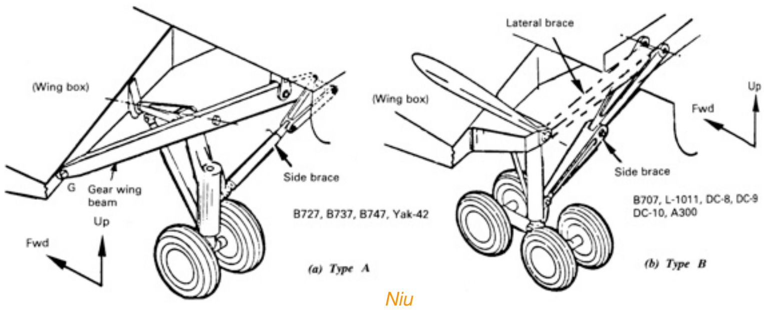


Fig. 12.2.10 Main gear support configuration (transport low wing design).

Gear-retraction geometry — 2

1. The most common retraction geometries are variations on 4-bar planar linkages, where one of the four 'links' is provided by the aircraft structure. The other three links are connected via rotational pivots — a light, robust solution.
2. The examples shown may be rotated by 90° so that the 'drag braces' become 'sway braces'.
3. Gear is usually retracted and stowed with shock absorbers fully extended.
4. In options where the gear main strut basically pivots, the pivot point may lie anywhere along the perpendicular bisector of the line joining the two extreme wheel positions.
5. There are many texts (e.g. by Molian) that deal with synthesis of simple mechanisms of this kind. There are specialist texts (e.g. by Curry) dealing with landing gear design.
6. It is possible to add a rotator link so that e.g. a retracted wheel will lie in a plane perpendicular to the plane it occupies when extended. This may save some space but such solutions add complexity and cost. The best landing gear solutions are typically also the simplest.

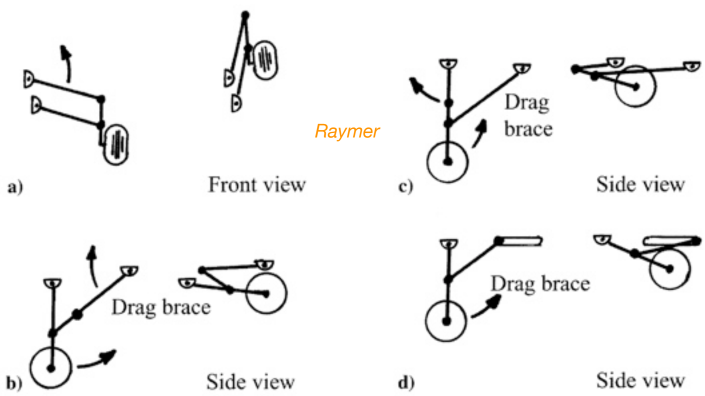


Fig. 11.14 Landing-gear retraction.

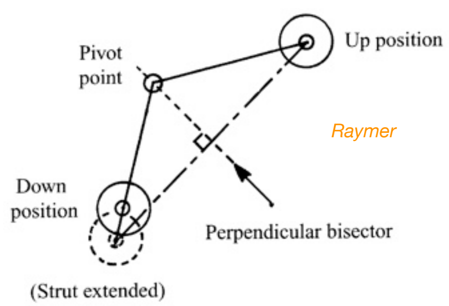
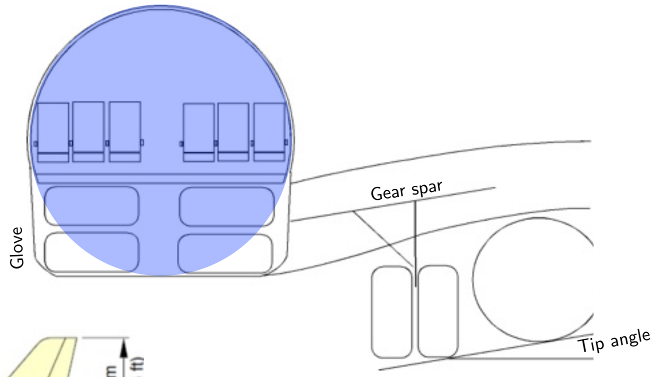


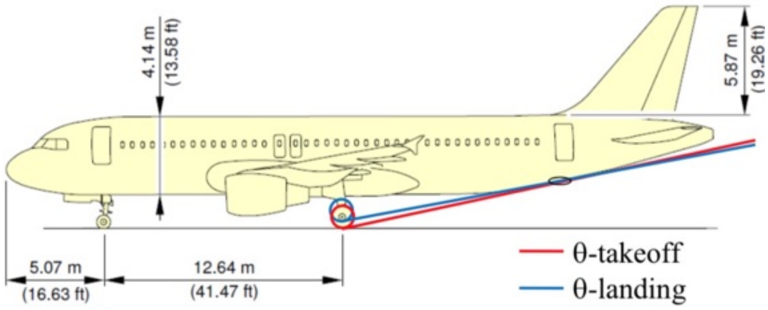
Fig. 11.15 Pivot point determination.

15

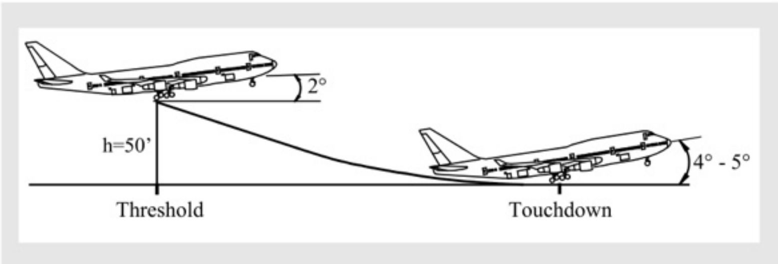
LG stowage and tip-back angle

Tyres must fit inside body with LG uncompressed. This can be aided by using wing shear and adding local wing-root glove shape variation away from basic circular cross-section.





Tip-back angle allowance influences rear fuselage shape/up-sweep. For longer fuselages on 'stretch' models, aft-body clearance will limit takeoff and approach attitudes. Leave 2.5° clearance or 1° with tail skid. Remember to allow for main gear compression during landing impact.



From B747 FCTM

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LG arrangement with wing sweep

Note the very common use of a wing 'Yehudi' or trailing edge extension at the inboard ends of swept wings on jet transports. This has a number of advantages:

1. Increases thickness where bending stresses are highest
2. Increases thickness to aid in LG stowage
3. Helps accommodate a sub-spar for LG hardpoint(s)
4. Adds area to high-lift system
5. Reduces hinge-line sweep for inboard flap (increases effectiveness)

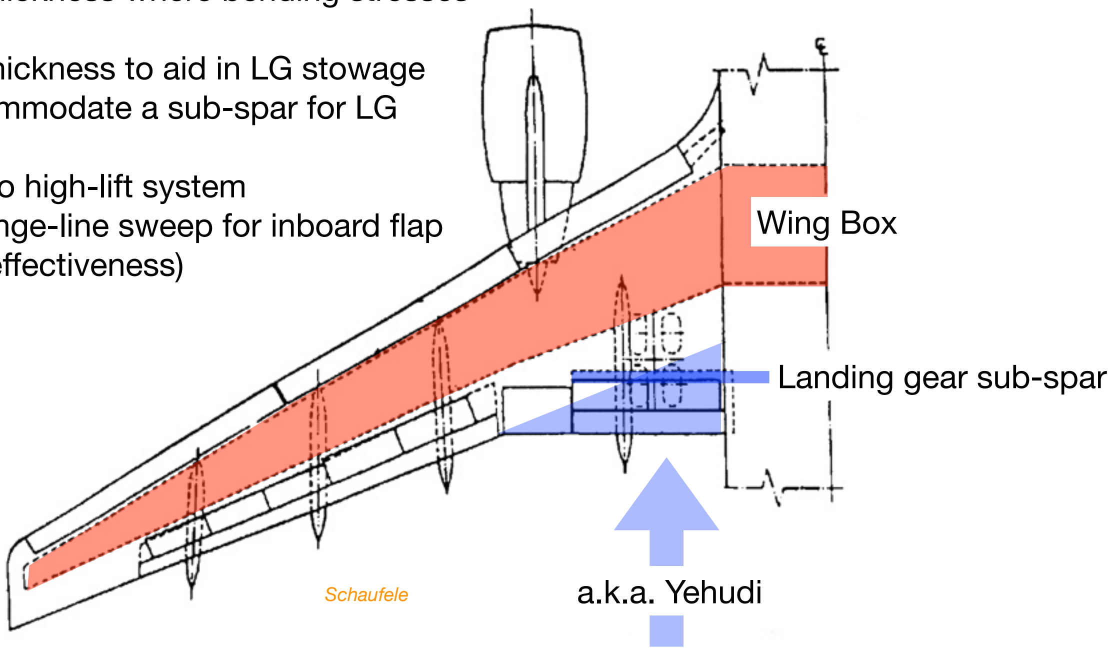

Fig. 4-13 Wing Inboard Trailing Edge Extension for Jet Transport