12 Landing Gear Conceptual Design and Integration

Aircraft landing gears have three main functions: allow the aircraft to move on the ground, take off run, absorb the landing bump and braking. During cruise they have no function, so that they are often retraced or in some cases they are even dropped after take off.

Landing gear design is ruled by a set or requirements. Some of them are common for all transport aircraft as the they are defined in the airworthiness requirements of FAA and EASA. These requirements refer to safe operation of the aircraft and cover e.g. free fall capability in case of power supply failure or braking capability. Some other requirements result from the operator's interest for an easy operation and maintenance. These requirements differ a lot between the different airplane categories. In this chapter focus is on commercial passenger transport aircraft.

Stable stand on the ground

First set of functionality of the gear is to provide a stable stand on the ground with protection against tipping to the side or to the tail. These two requirements drive the X-position far aft enough behind the aircraft center of gravity, so that tail tipping is prevented (Fig. 12.1.) and wide width (=track) of the main landing gear so that bank stability prevents lateral tipping in fast bends or controlled manoeuvres on the ground (Fig. 12.2.).

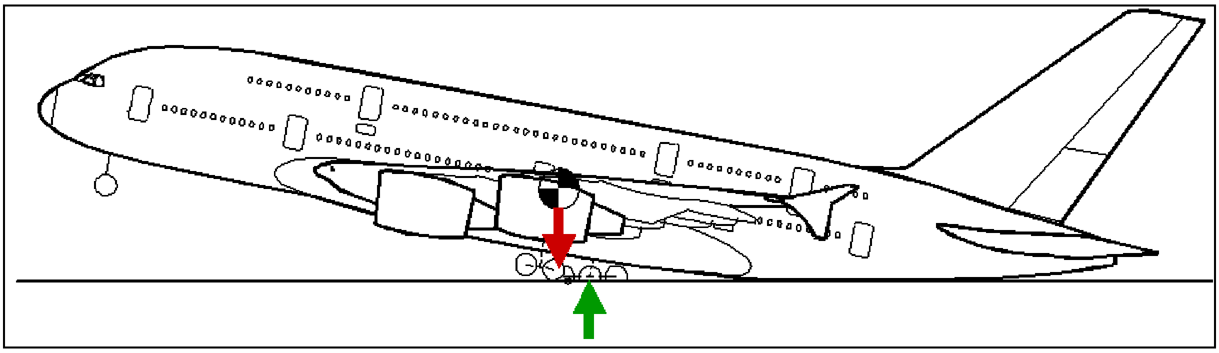

Fig. 12.1 Preventing tail tipping

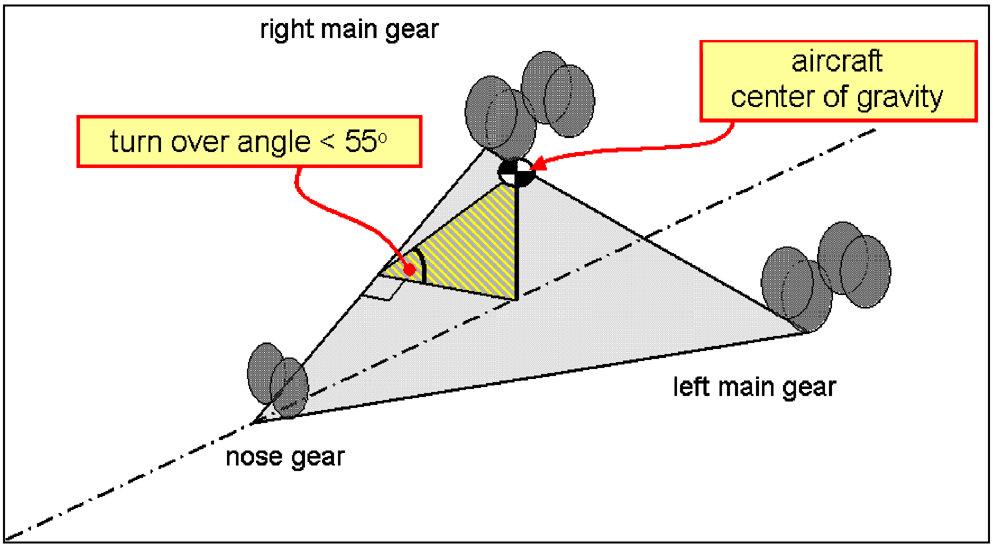

Fig. 12.2. Prevent lateral turn over

In both cases the vertical elevation of the center of gravity from the ground plane does influence the best wheel position. Some remarkable aspects are:

1) on modern turbofan aircraft the trend is towards larger engine bypass ratio for the sake of better fuel efficiency and lower environmental noise. Larger bypass engines have – at the same thrust - greater diameter. As they are mounted underneath the wing in many cases these modern engines require longer landing gears or a closer coupling of the engine to the wing.
2) On high wing aircraft the center of gravity is raised to higher elevation relative to e.g. the cabin floor because wing, engine and fuel weight is loaded up on top of the fuselage. This would request a very wide gear track. If the landing gear is mounted on the fuselage the overall track is very limited. A way out is the usually very low ground line of the aircraft which becomes possible with the greater engine height above the ground. However some attention has to be paid to the tail clearance in this case, as the available rotation angle for take off and landing itself is not affected by the higher wing & engine position.

Tail and bank angle clearance

For safe operation in take off, landing and cross wind conditions the landing gear must allow some nose up pitch angle as well as some lateral bank angle. The potential nose up angle before ground contact of the rear wheels is called tail clearance.(Fig. 12.3.) Greater tail clearance allows to take off and land at higher angle of attack, so that the wing can produce greater lift coefficients. This can lead to smaller wing area or less engine thrust becoming necessary. There are some example aircraft that have no take off rotation (B52, Bade 152) but these aircraft did not make good use of their wing's lift capability and needed significantly longer take off field lengths than comparable aircraft with tail clearance.

Lateral bank angle clearance (Fig. 12.3.) is needed for take off and landing under cross wind conditions. In such case the pilot can align the aircraft centerline with the runway direction and orient the flight path vector into the cross wind direction by flying at sideslip angle. The operator requirement to be able to land at some high cross wind speeds is driven by the majority of airports that have one runway only or two parallel runways in the same direction. Operator's flight schedules shall be not too much affected by inconvenient weather conditions. This requirement usually drives the bank clearance to values greater than the 5° bank landing which the airworthiness regulations require for all aircraft.

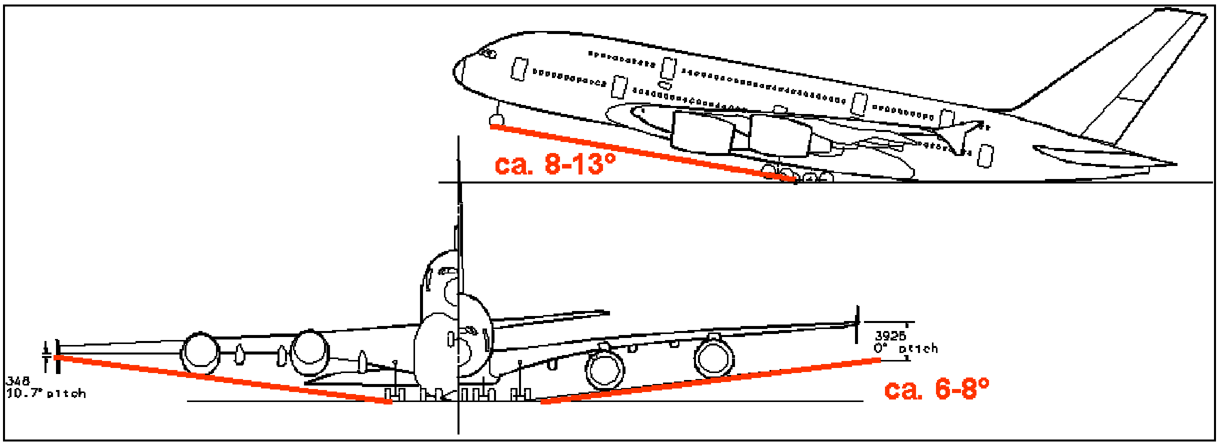

Fig. 12.3 Tail clearance and bank clearance angle

When it comes to measuring the tail clearance for take off and landing, there are typically two angles that can be measured: the static tail clearance with fully loaded landing gear and the fully extended tail clearance that describes the situation at lift off when the last part of the landing gear leaves the ground (Fig. 12.4.). The fully compressed angle is to be used for the landing calculation when it comes to calculating the allowed approach speed from which the pilot can flare out the approach (making the downward flight path horizontal) and touch down without damage to the rear fuselage. The latter, extended angle is used in the take off calculation when the minimum unstick speed is to be calculated or measured. This is the allowed minimum speed for a given weight at which the pilot can pull the aircraft nose up ("rotate") to initiate lift off without damage to the rear fuselage. For both cases it turns out that stretch versions of aircraft families have to be watched very carefully on the tail clearance's effects on performance, while the shorter versions are usually restricted by aerodynamic limits like "stall speed x 1.3" for approach and "stall speed x 1.2 for take off".

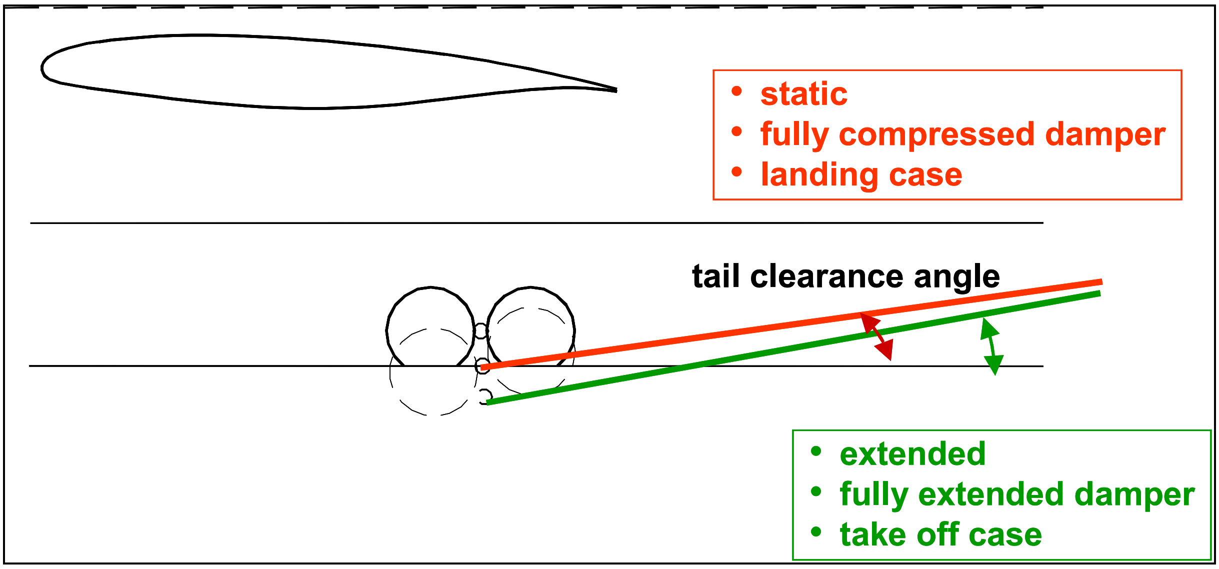

Fig. 12.4 Static and extended tail clearance angle

Nose landing gear load

Another important functionality of the landing gear is to ensure safe and controlled ground run even in the case of engine failure. In most cases the center of gravity is relatively close to the main landing gear wheels so that they carry the lateral force when driving through bends. The nose gear has to initiate control by generating sufficient lateral force. In case of an engine failure this force is approximately engine thrust x engine arm/wheel base. The maximum lateral load that the nose gear tires can generate is (nose gear vertical load x friction coefficient) with the nose gear vertical load being dependant of the relative position of center of gravity, main landing gear (big effect) and nose gear (small effect). (Fig. 12.5.) The direction control ability depends on the (nose gear lateral load x wheel base) and is almost independent of the nose gear position. Hence the main landing gear must be allocated far aft enough to provide sufficient nose gear load. However, the main gear must not be too far aft, because in that case the aircraft can not be rotated any more at take off by a suitable sized horizontal tailplane.

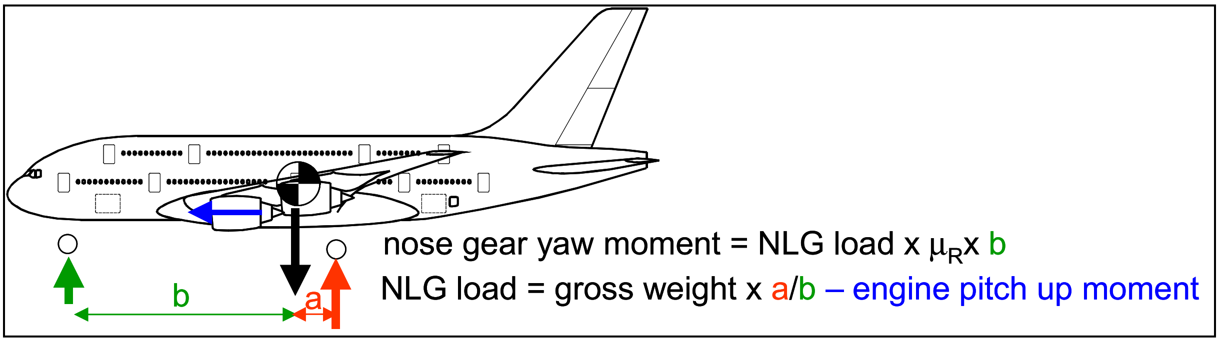

Fig. 12.5. Nose gear load drivers

Integrate wing landing gear into wing plan form

These constraints for the main landing gear position (not too far aft, not too far forward, no too far inboard, not too low) are typically fulfilled with a wing mounted landing gear and wing plan form that gives some extra room on the inner wing behind the rear spar by kinking the trailing edge (Fig. 12.6.) . This extra triangle ("Yehudi" in some literature) gives space between wing rear spar and trailing edge so that the landing gear's retraction pintle can be mounted aft of the rear spar and the gear itself can be retracted with the leg resting in the wing.

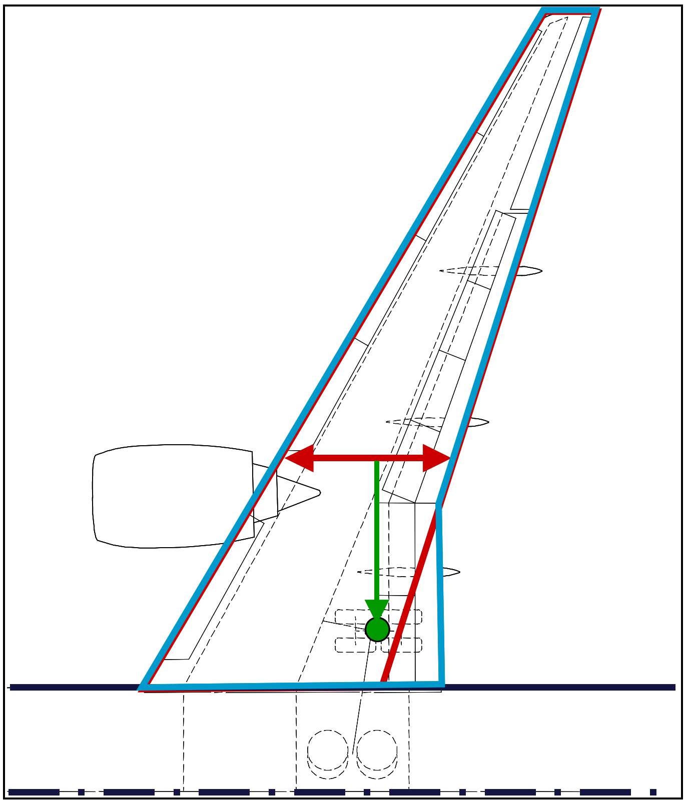

Fig. 12.6. Kinked wing trailing edge to give space for a wing mounted landing gear.

Prevent airport surface damage (ACN)

For the aircraft itself it would be beneficial to introduce the aircraft weight load into the ground surface by a minimum number of wheels. However for the airport surfaces the impact produced by many aircraft tires frequently rolling over can lead to severe damage with high cost and difficult ways to repair, if the airfield is heavily frequented. This fear for damage had lead to some classification of the aircraft's impact to the ground as well as the load carrying capability of typical airfield surfaces. Out of the airfield surfaces it is especially the taxiways that are endangered, because the runways are often made of thicker material. The classification code is called "aircraft classification number" (ACN) and has a value between about 40 to 80. The interpretation is rather simple: if the aircraft has an ACN value for flexible runways of let's say 45 and the airport manual gives for the airport a value of 80 then the pilot can simply land on the airfield without expecting to create severe damage. If the aircraft's ACN was higher than the airfield value, then the airport operator must be contacted before. For the aircraft designer it will be important to know what sort of airfields the future operators wanted to operate at. Will it be grass or sand runways (e.g. for small feeder aircraft, island hoppers or military transports) or smaller local airfields or large international airports? This top level requirement will drive the layout and sizing of the landing gear. The ACN value is approximately two times the single wheel load plus an upgrade for the interference effects of adjacent wheels. Example: an aircraft with about 300t MTOW on 10 wheels has an average load of 30 t per wheel and its ACN on flexible runways will be higher than 60. The correction factor for double wheels on one axle or for more axles mounted on a bogie can will depend on the spacing. Closer spacing will create higher ACN (Fig. 12.7.).

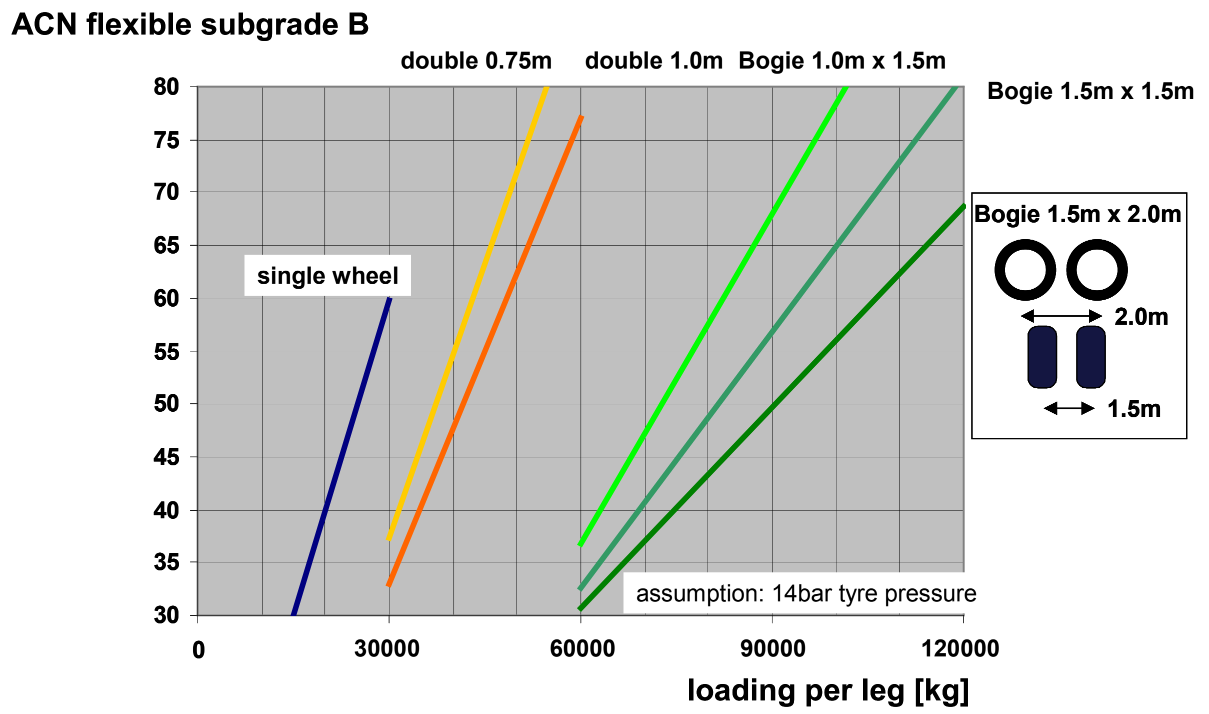

Fig. 12.7 Exemplary ACN effects of wheel and axle spacing

This did drive axle and bogie size to some large values on some aircraft that had a quite high loading per wheel. ACN is calculated for two sorts of pavements. 1) Flexible surfaces, such as tarmac or asphalt, who will show permanent deflections after overload. This is caused by the sandy under construction floating away and the flexible pavement cover following down. In this case the tire pressure is an important parameter for the ACN value, aside by tire load and spacing. 2) Rigid surfaces like e.g. concrete, lying on sandy underground. In this case the typical damage would result from fatigue cracks resulting from too many overruns of high point loads where the sandy under construction is not fully perfect. For rigid ACN tire pressure and tire size has no impact, because it is just that point load and spacing that drives the ACN value.

An easy calculation can be made with the free software from :
http://www.airporttech.tc.faa.gov/naptf/download/index1.asp

Wheel load carrying capability

While the ACN calculation does give an input on the question of how many wheels and how much spacing to have, the single wheel load itself will affect the selection of tire size and weight. Aircraft tires are hollow and filled with nitrogen gas at pressures up to 15bar. The inner pressure chamber is either a circular tube or has already been squeezed towards a rectangle by the reinforcing ply orientation. When loading the tire on the ground it does flatten until the term "contact area x pressure" equals the tire load. When running at high speed, e.g. for take off, this flattened zone is rotating around the tire at high speed. Heat is created due to internal friction inside the tire material from the "walkarbeit". This is usually setting the maximum load carrying capability of a tire. Some extra load is allowed for non standard cases like e.g. the nose landing gear during strong deceleration of the airplane ("breaking load") or in case that the neighbouring tire(s) are deflated due to accidental damage (bottoming load). High tire pressure plus strong reinforcing ply layers is the way to increase tire loading capability, but this finds its limit again in the ACN on flexible runways.

Compact integration

For better flight performance and reduced fuel burn it does pay to retract the landing gear into the aircraft surfaces already for quite short distances. Only some small island hopper and utility aircraft make use of fixed landing gears. When it comes to find a suitable volume where to retract the landing gear into, there are several possibilities offered: On low wing aircraft with cargo holds under the cabin floor it appears useful to retract the wheels into a fuselage bay. If the lower fuselage contour is not big enough then it can be extended by a local belly fairing. On High wing aircraft the landing gear can either be fuselage mounted and retract in the lower fuselage, or in some cases (propeller aircraft) it had been engine nacelle mounted and retracted into those engine cowling bodies. The traditional concepts to retract the wheels find their limits on unconventional configurations like e.g. low wing aircraft with negative wing sweep angle or canard configurations with the main wing sitting at the rear end of the aircraft.

Free fall capability

For the emergency case of energy supply loss during the flight it is requested by FAR and FAR that the landing gear must be able to get extended and safely locked for landing without help of the failed power supply. This free fall capability is easily achieved if the gear retracts against the airflow. In case of emergency the first extension move will be powered by the wheel and tire weight and a soon as the leg is in the airflow the dynamic pressure will help extending the gear (Fig. 12.9).

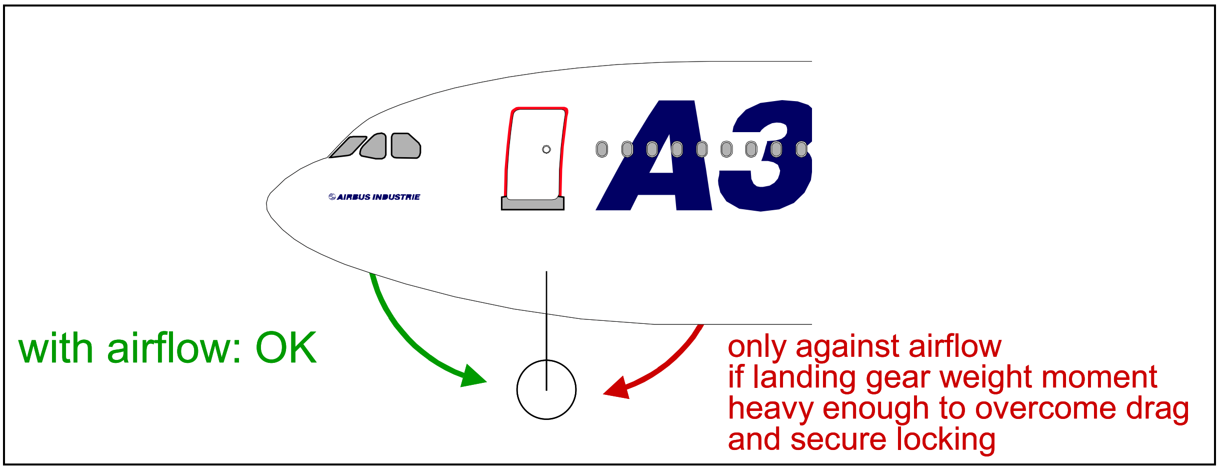

Fig. 12.9 Free fall with help of the airflow

If the gear cannot be retracted against the airflow, then it should at least not retract with the airflow, unless special features ensure safe free fall. In case of the A380 body landing gear it was the very high specific weight and an eccentric pintle position that ensures free fall and lock despite the extension against the airflow (Fig. 12.10).

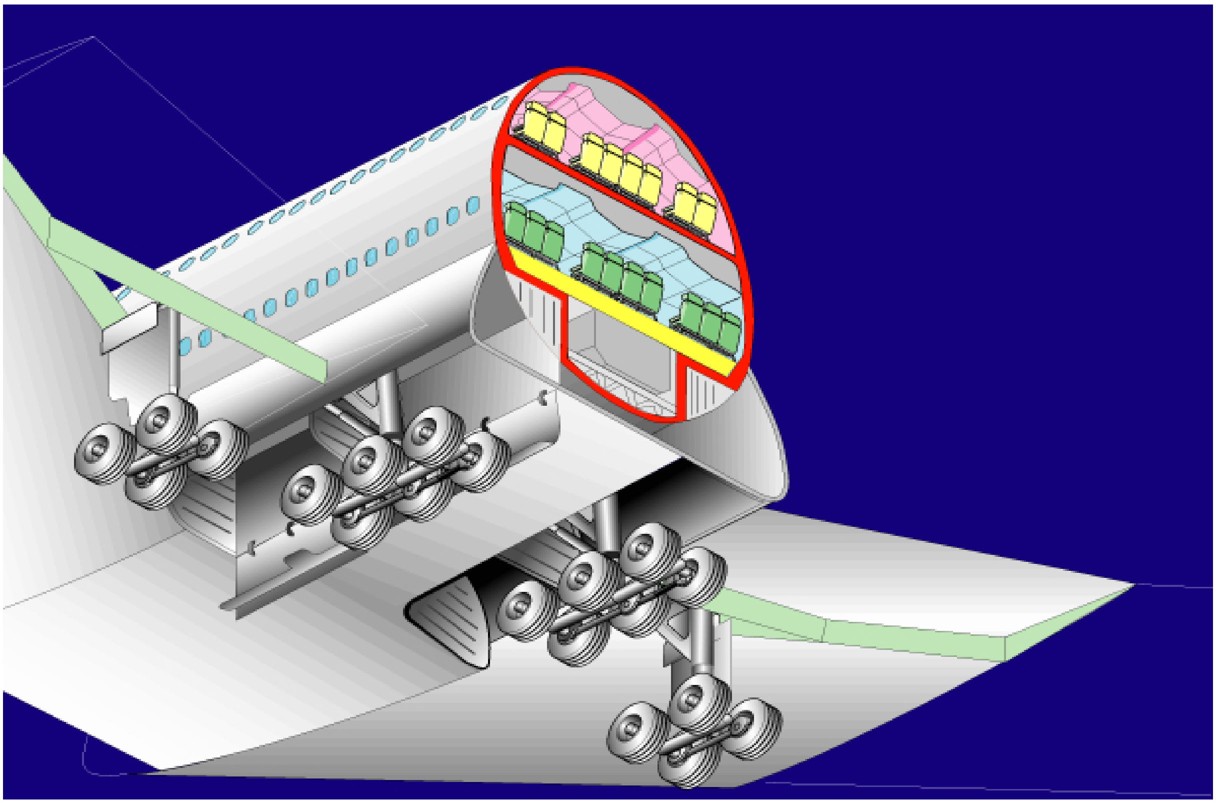

Fig. 12.10 A380 main landing gear with rearward retracting body gear

Absorb touch down energy

To prevent damage form the airframe the landing has to be able to absorb the touchdown energy when landing at a certain sink rate (for passenger aircraft: 10ft/sec) without flare. For robust operation it will as well be useful to avoid spring back of the aircraft after such landing. The way to achieve this functionality are long travel ways of the suspensions and good spring and damping characteristic of the suspension. Typical values are about 500mm oleo travel, with the oil damper being active through the whole 500mm and the gas pressure only acting at the last 200mm. This means that the aircraft will only have a vertical travel motion of let's say 10cm when operating on the ground (loading, unloading, taxi) while having full 500mm travel for landing. A rough principal sketch of the oleo is given in Fig. 12.11.

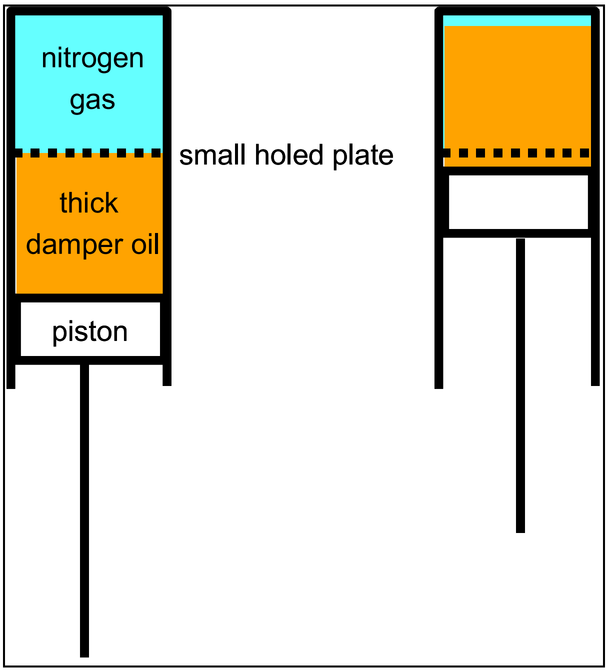

Fig. 12.11 Principle sketch of oleo element in telescopic landing gear leg.

Braking at take off and landing

For good performance characteristic the aircraft needs to have a powerful braking system. There are two cases demanding a certain size of the brakes: 1) Braking after landing. This occurs at every aircraft operation, up to eight times per day on short range aircraft. With the trend to prohibit use of the engine thrust reverser on many airports the majority of the horizontal kinetic energy at landing will end as heat inside the brakes. This frequent use will cause break wear and require some large brake packs to avoid too frequent brake change. 2) Braking at aborted take off. The allowed maximum take off weight to operate an aircraft from a certain airfield at certain meteorological conditions is defined by the capability to either continue take off with one engine failure or the ability to stop within the runway limits. This is why a powerful break helps achieving a fast decision speed V1 in the tale off calculation. However this emergency case does not occur frequently so that it might not drive the brake pack weight in all cases. For weight reduction reason carbon brakes are used on modern long range aircraft. These brake discs have a higher specific energy absorption capability per weight. But on the other hand brake wear is very dependant on the number of brake uses. This makes the choice of carbon brakes less easy for short range aircraft, which are not that much weight critical, but rather driven by maintenance aspects.

General layout of the landing gear

When a project aircraft has to get a conceptual landing gear layout, then the useful sequence to work it out is:

1) number of wheels needed,
2) tire size needed,
3) spacing of axle & bogie,
4) retraction path and gear bay.

Number of wheels for the example of large passenger aircraft can be read from the empirical Fig. 12.12. It shows an average loading of 20t per wheel for smaller short range aircraft (A320/737) and around 30t per wheel for large long range aircraft. These two values are reflecting the operational needs for smaller aircraft to operate from smaller, regional airports with weaker surfaces (=around 20t per wheel) and larger aircraft being requested to operate from larger, "international airports" with stronger pavements that can carry up to 30t per wheel. However this statistical curve can not be used for non-standard aircraft requirements, such as for aircraft that should operate from grass runways or when judging about ultimate stretch aircraft, for which the designer might choose to keep the number of tires and drive ACN to the maximum possible. Another interesting selection appears when the number of wheels from the first estimate is not the standard 4 or 8 main wheel per aircraft, but a number in between or above. This requires a selection from alternatives, such as three, four or five legs or six wheel bogies and no general rule can be given.

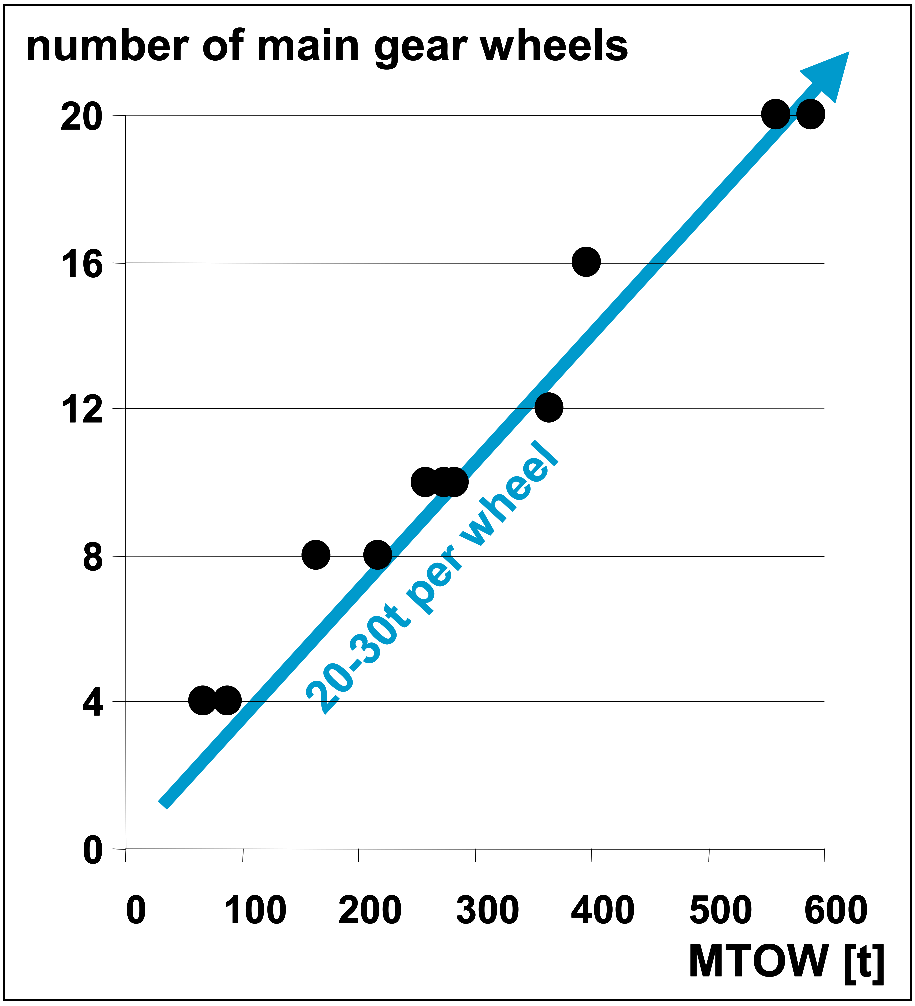

Fig. 12.12 Empirical diagram of number of wheel vs MTOW

Next step will be to select a suitable tire size. If no tire catalogue is at hand, then the empirical Fig. 12.13 does show all shown aircraft tires lying between 32 and 42 of the plotted parameter "a/c weight per wheel per tire diameter per tire width". For the example of an A340 the values used are parameter = 275t MTOW / 10 wheels / 1.4m / 0.53m = 37t/m². Aircraft tires have a ratio between width and diameter of about 0.35 to 0.40, so that the equation can be used to estimate a tire diameter by tire diameter [m] = [MTOW / no of main gear wheels / (32 to 42)t/m² / (0.35 to 0.40)]^0.5

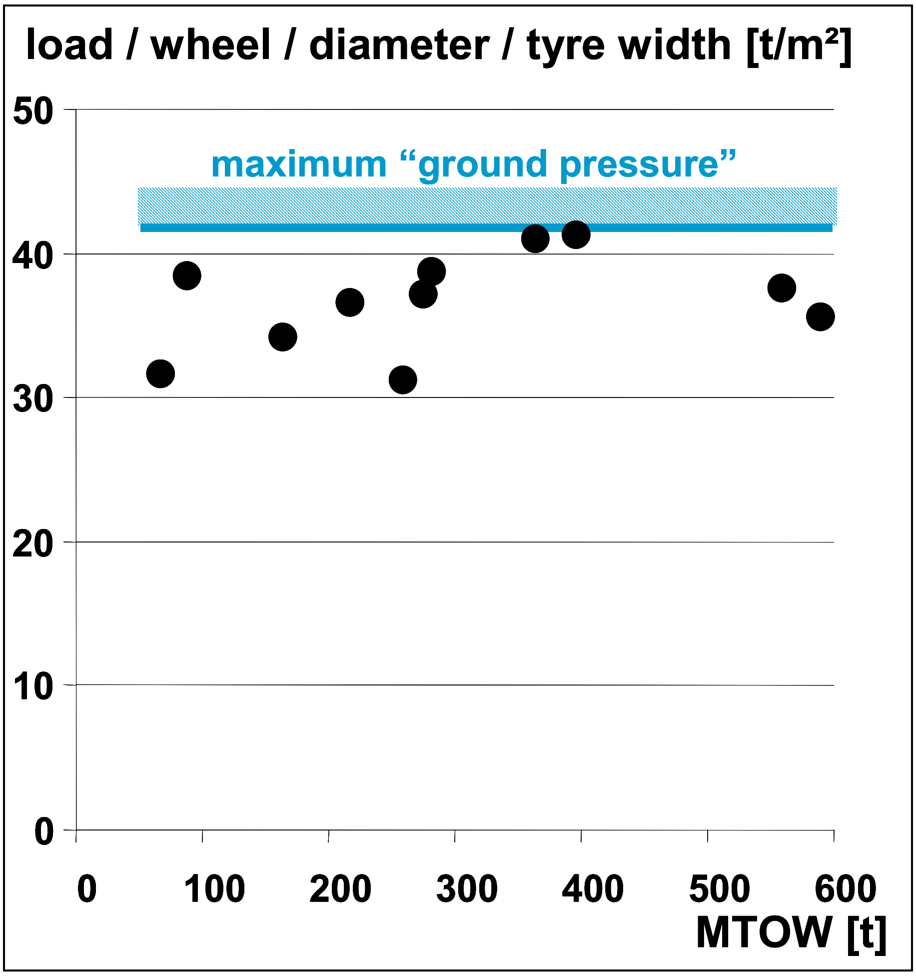

Fig. 12.13 Empirical diagram to show average MTOW load per tire number per tire size

This tire size selection should be validated with help of a tire catalogue. If the desired size is not manufactured and the new aircraft type does offer a substantial business case for a new tire type it appears attractive to negotiate for such optimized tire type with the tore manufacturers.

Next step is to select the spacing of tires on one axle (track) and spacing of the axles (base). The track has to give space to attach the leg or the bogie. Actual values are between 1.0 and 1.5m for tire width of about 0.43m to 0.53m. The bogie base obviously has to be longer than the tire diameter to avoid the tires scrubbing on each other. The total spacing can be selected when using an ACN method that does analyse the ACN for the tire spacing chosen.

Following step will be the selection of the landing gear position on the aircraft. A drawing or other geometric modelling is essential to find a location that does give the required clearance of engine nacelles and rear end to the ground and is located at the right longitudinal position while still being retractable. Fig. 12.14 gives an overview of the clearances on a classic configuration.

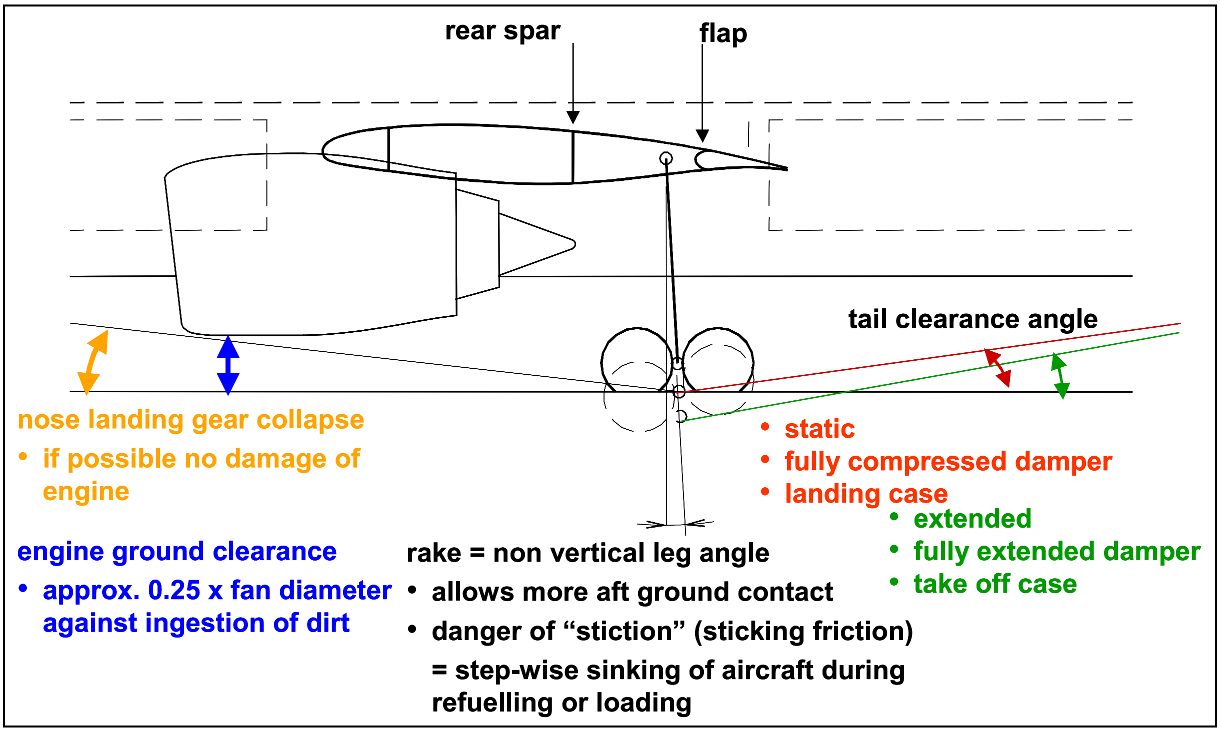

Fig. 12.14 Drivers on main landing gear length and position on conventional aircraft

After these four steps the landing gear concept has roughly been defined. Alternatives could be sketched and compared to find the most suitable concept.

Iterative process

If the aircraft MTOW is not close to the threshold for requiring more wheels or even more legs, then the iteration during the sizing process is limited to finding the consistent combination of wheel and tire size and geometric position.