Introduction to Aircraft Systems

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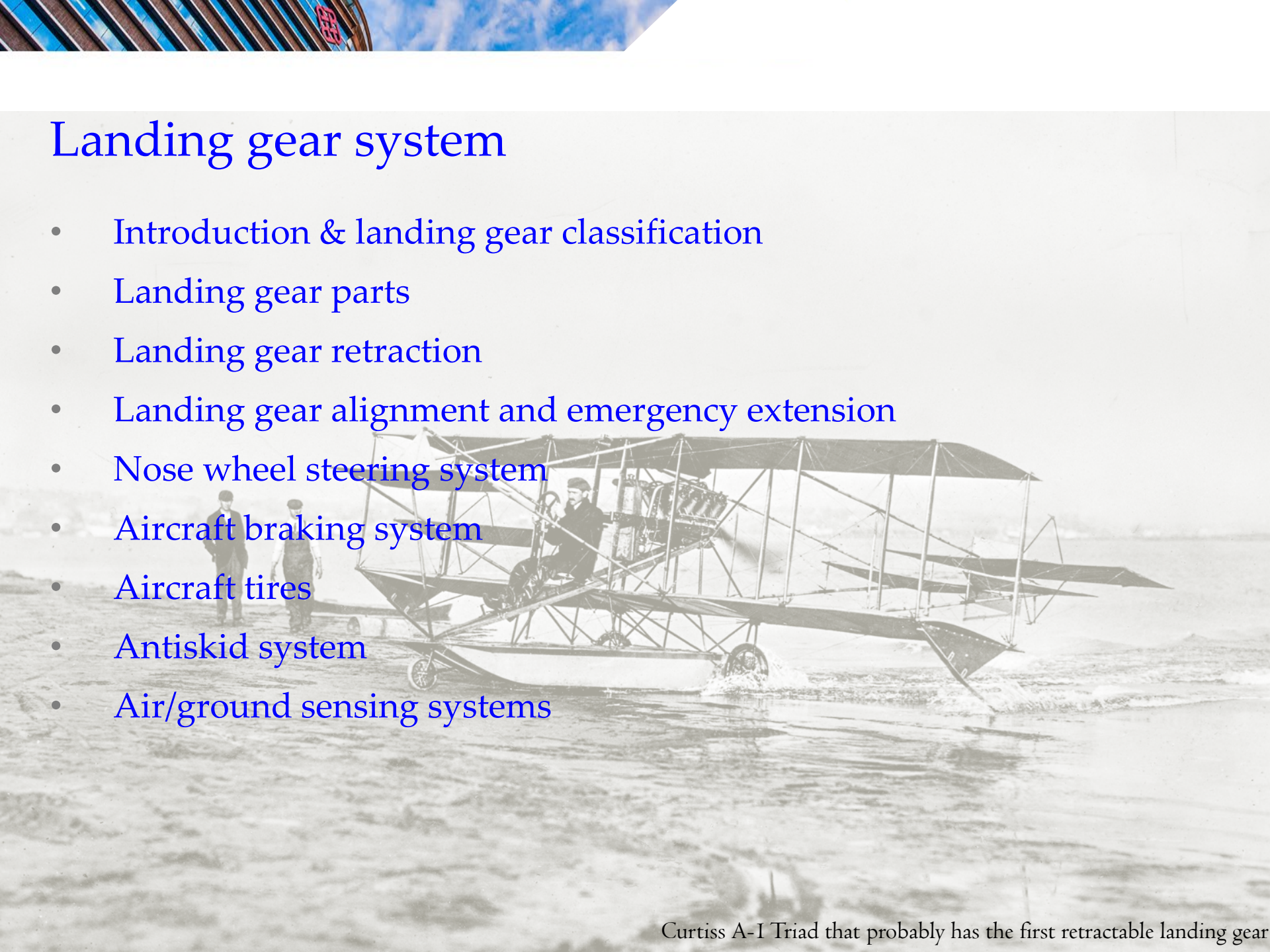
Landing gear system

- Introduction & landing gear classification
- Landing gear parts
- Landing gear retraction
- Landing gear alignment and emergency extension
- Nose wheel steering system
- Aircraft braking system
- Aircraft tires
- Antiskid system
- Air/ground sensing systems



Curtiss A-1 Triad that probably has the first retractable landing gear

Introduction

Jeju Air Flight 2216

Jeju Air Flight 2216 crash

- On 29 December 2024, the Boeing 737-800 operating the flight was approaching Muan, when a bird strike occurred.
- The collision killed all 175 passengers and 4 of 6 crew members. The surviving 2 cabin crew were seated in the rear of the plane
- "Shortly after takeoff, a signal indicating a landing gear issue was detected on the aircraft's monitoring system," Song Kyung-hoon, head of the management support office at Jeju Air

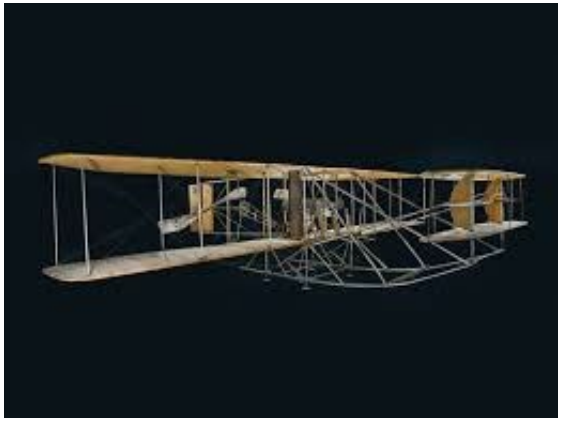
Landing gear related aviation accidents

- Red Air-McDonnel Douglas MD80 RAE203 (2022): left main landing gear collapse during landing at Miami
- Jazz Aviation Flight JZA8481 (2016): the right main landing gear collapsed.
- Air France B-747-228-B-Combi (1985): landing gear folded aft with the left wing gear completely separating.

Landing gear/起落架

- Landing gear is the undercarriage of an aircraft that is used for take off, landing and ground operation.
  - It is attached to the main body of the aircraft.
  - It is used to support the weight of the aircraft

- In the 19th century, it was the pilot's own body that was tasked for the weight supporting
- In 1903, the Wright Flyer used a kind of sled to support the height around 220 kg.
- The first landing gear with small wheels was designed in 1906 for the Santos Dumont 14-bis model.



Landing gear classification

Classifications: based on application

- Type of the landing gear can depend on the application. Usually, it can be classified to:
  - For snow & in helicopters: may of skids type
  - For water: may of pontoon type/浮筒式起落架
  - For ground: retractable wheels

Other types of flying vehicles such as launch vehicles and drones also contain landing gears.

Depending on the layout of the arrangement on an aircraft

Classification: based on layout

- Tail wheel type/后三點式起落架 (conventional landing gear):
  - It contains two main wheels forward of the centre of gravity and a small wheel to support the tail
- Tricycle landing gear/前三點式起落架 (commonly used in modern aircraft):
  - It contains one or more nose wheels and two or more main wheels after the centre of gravity. It is now widely used.
- Tandem loading gear:
  - With the increased weight, more wheels are employed and installed in the tandem manner. It is common in large aircraft.

Tail wheel type

Tricycle landing gear

Tandem loading gear

Main landing gear

- It is located **near the centre of gravity** of the aircraft, taking most of the aircraft's weight
- Multiple wheels spread the weight of the aircraft. They also provide a safety margin if the tail fails
- When more than two wheels are attached to one landing gear strut, the attaching mechanism is commonly called a **bogie**.

Example of a triple bogie

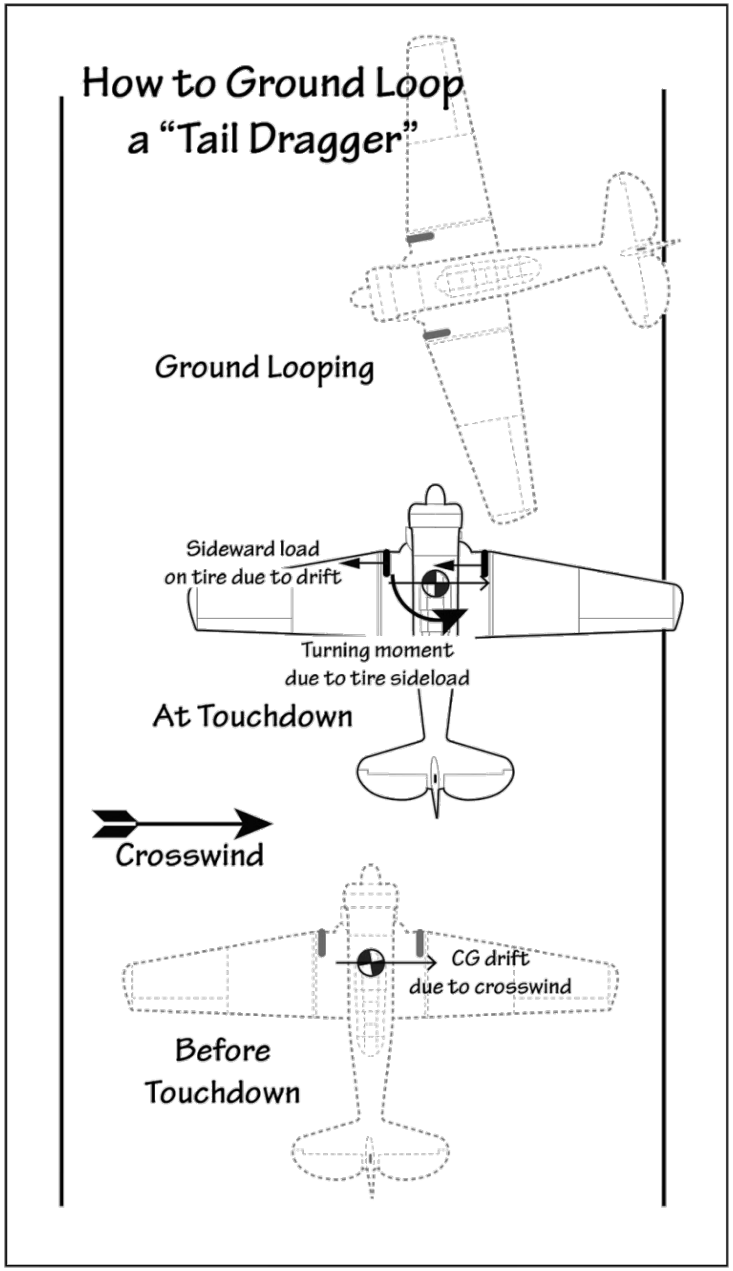
Tail wheel type V.S. Nose gear type

- For the tail wheel type (tail dragger design):
  - It can employ smaller tires, which means less drag compared to nose-wheel aircrafts.
  - Cheaper to buy and maintain compared to nose-wheel.
  - Easier to handle and maneuver on the ground.
  - Difficult to see over the nose from the pilot seat position
  - Susceptible to group looping, which spins the aircraft

- The tricycle landing gear is also referred to as **nose gear type**.
  - Allows for more forceful application of brakes during landings at high speeds without causing the aircraft to nose over.
  - Permits better forward visibility for the pilot during takeoff, landing, and taxiing.
  - Tends to prevent ground looping.

Ground looping

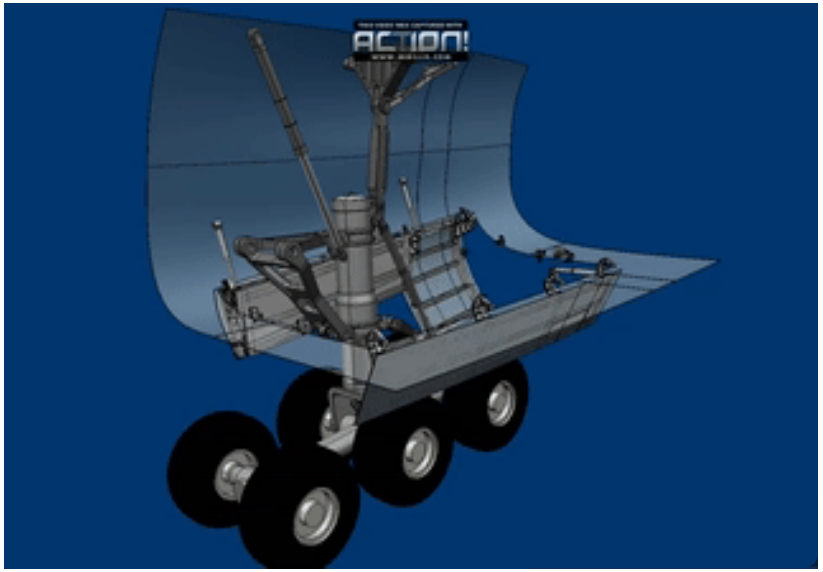
- Ground looping is an inherent problem of the tail-dragger design.
- With the C.G. located behind the main landing gear, tail dragger design is an unstable design for ground operation.
- As the aircraft swerves, it has a tendency to ground loop due to the destabilizing moment between the C.G. and the gear's center of friction.



Classification: fixed or retractable

- Fixed landing gear:
  - it is attached to the aircraft and remains exposed to the oncoming stream during the aircraft flight
- Retraction type:
  - It is opened during the take-off, landing and ground operation.
  - It is stored in the fuselage of wind components during the flight.
  - The landing gear is a bluff body, and the induced drag is high

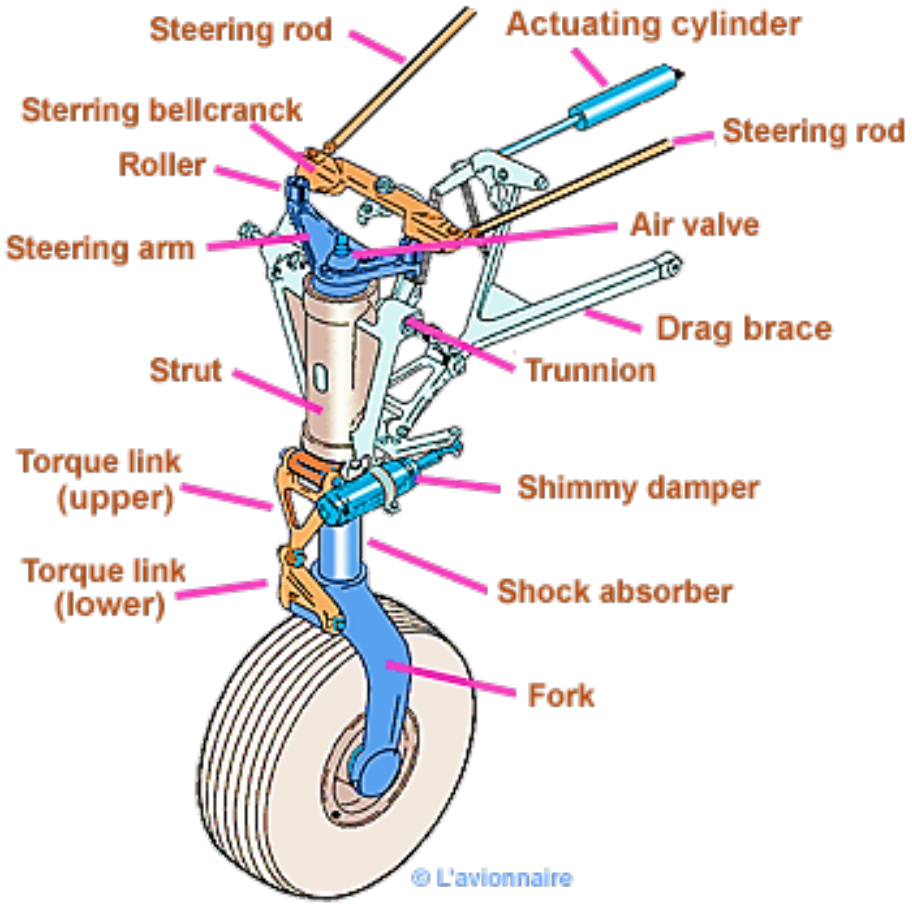
It is not common in modern high-performance aircraft.



Landing gear parts (for retractable LGs)

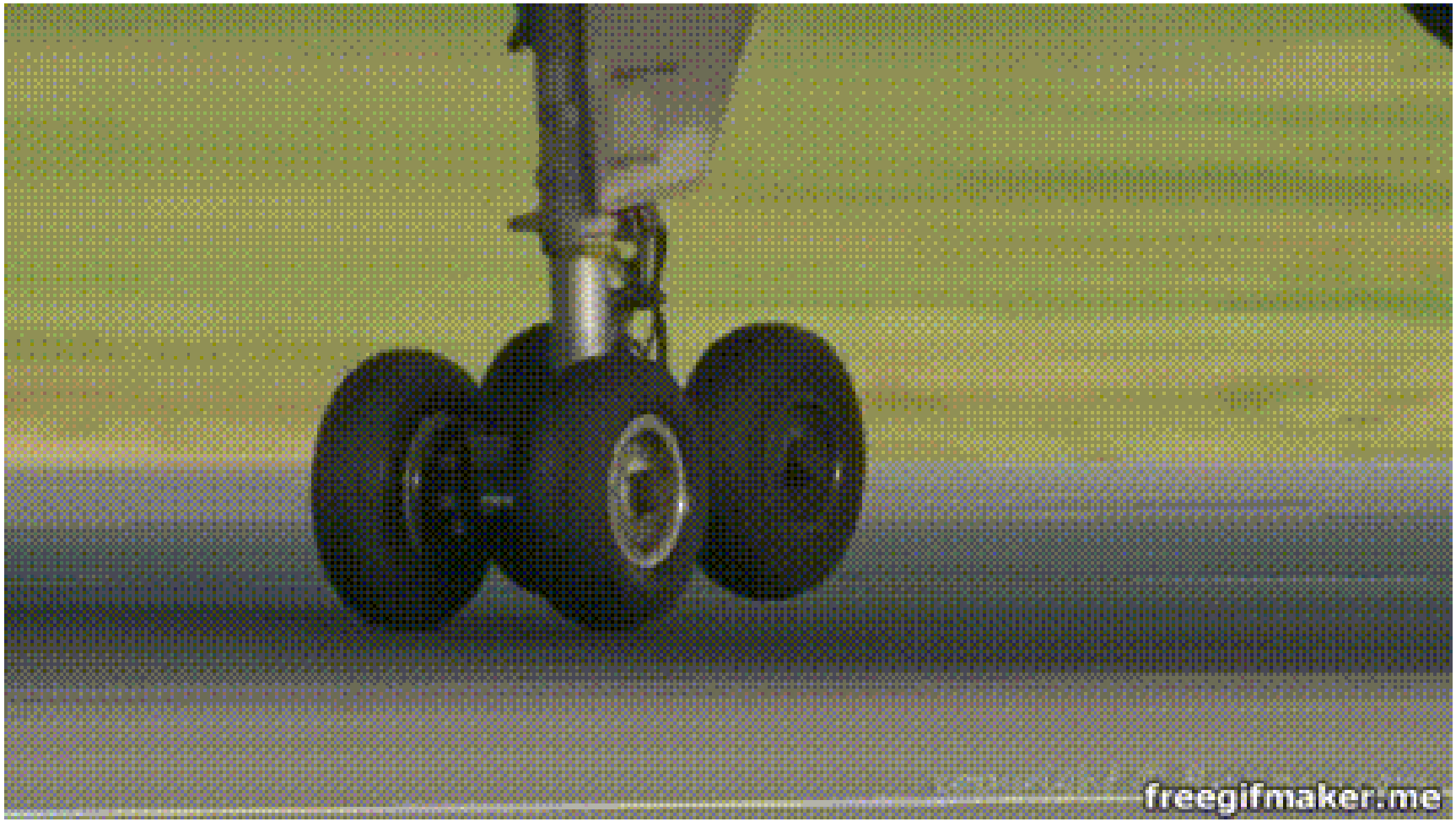
Landing gear parts

- The naming could be different in different contexts.
- Usually, a complete landing gear system includes:
  - Shock absorbing system
  - Brake systems
  - Retraction mechanisms
  - Drag struts
  - Fairings
  - Steering mechanisms, etc.



Shock absorbing

- During the landing phase, the impact from ground on the aircraft should be controlled by the landing gear
  - The shock energy is moderated and transferred to the airframe
  - The shock energy is absorbed
- For the fixed landing gear with flexible struts, they are made from steel, aluminium or composite materials with great flexibility. The impact energy is moderated and transferred to the airframe.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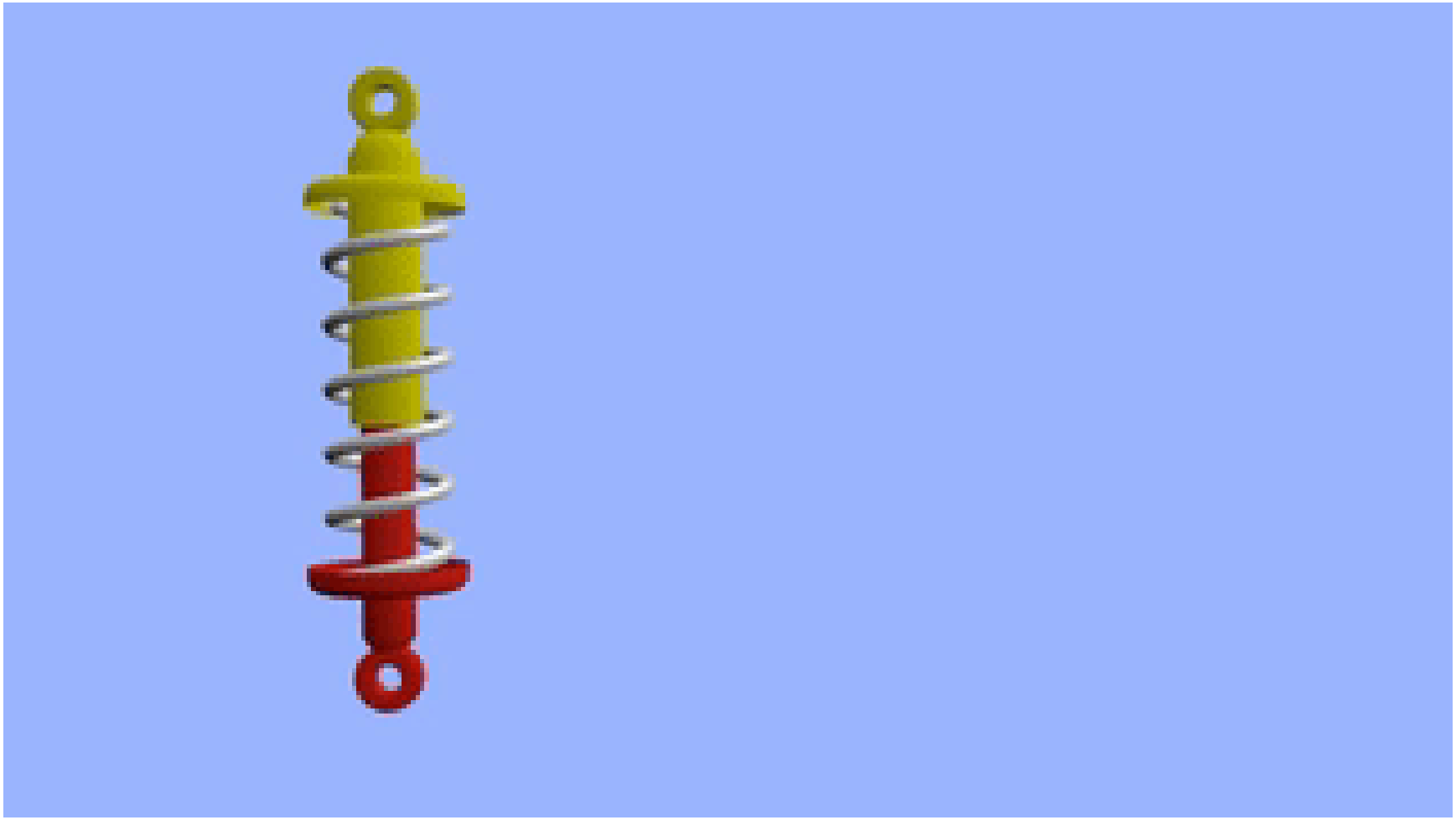
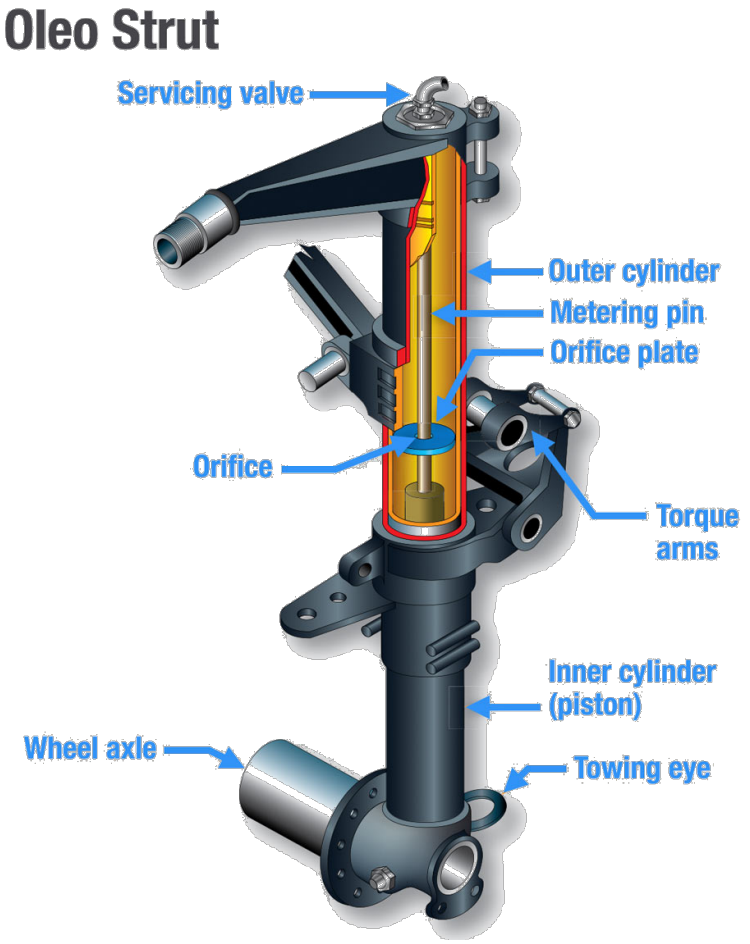


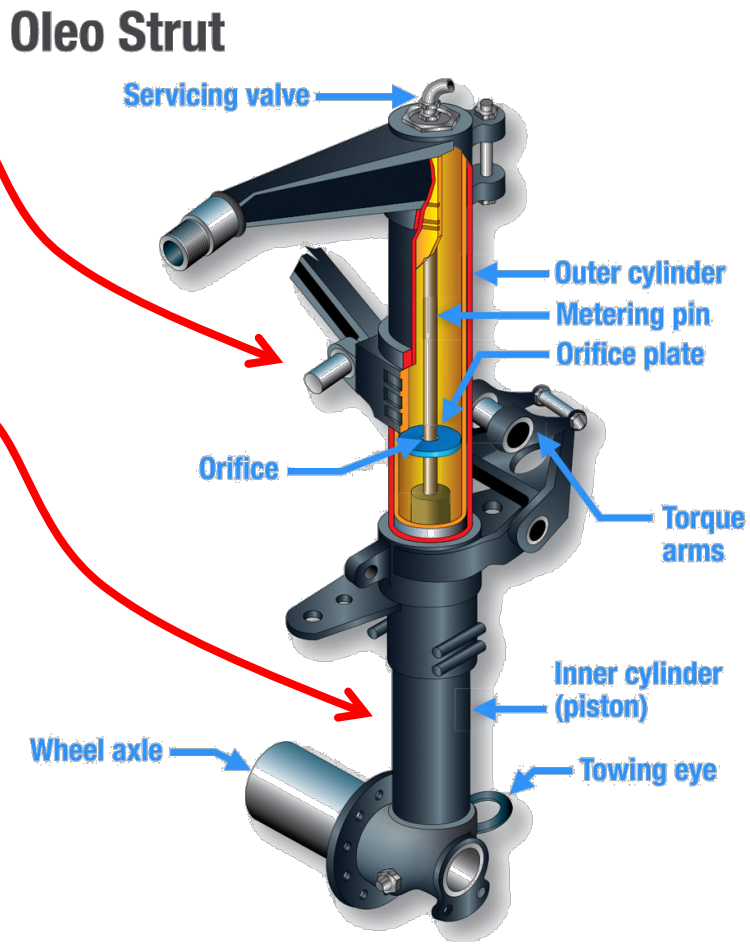
Shock absorber/減震器

- The shock strut (Oleo strut) employs the shock absorbers to convert shock energy into heat.
- A typical design in a shock strut uses pneumatic or hydraulic methods to compressed air or nitrogen combined with hydraulic fluid to absorb and dissipate the load.



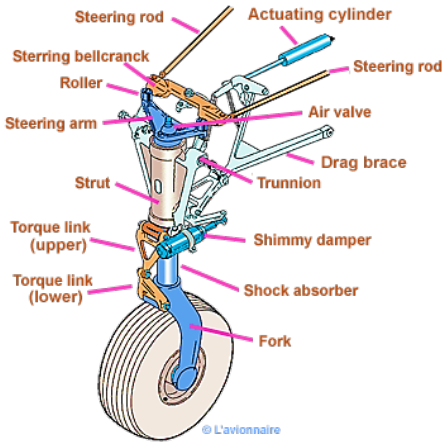
Shock absorber/減震器

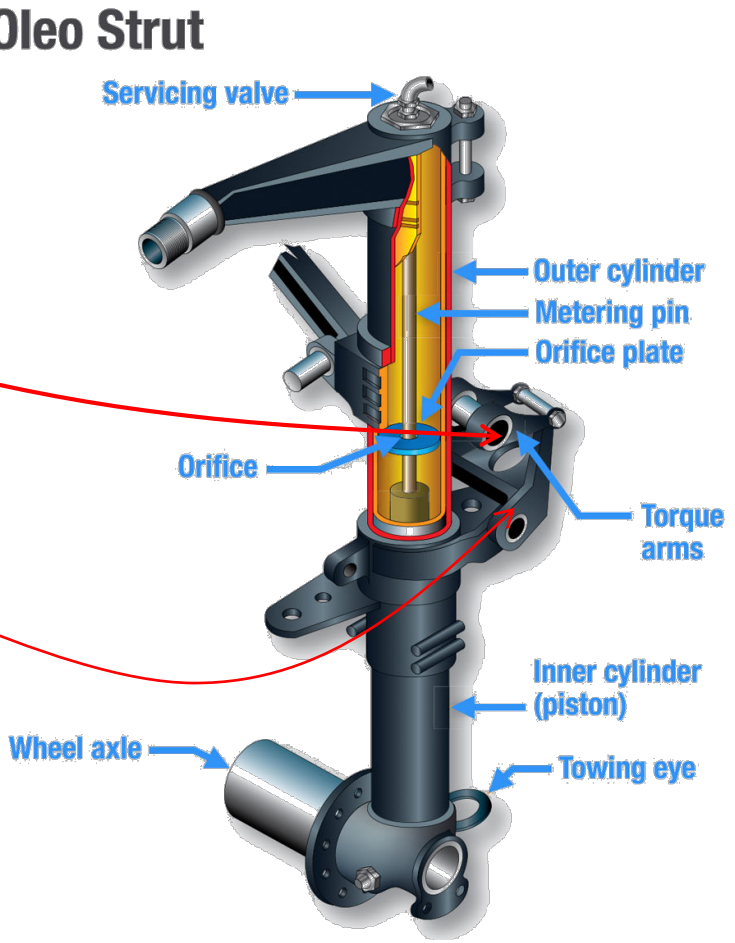
- The upper cylinder/outer cylinder is linked to the airframe:
  - It is filled with nitrogen with small holes called orifice
- The lower cylinder/inner cylinder/piston is linked to the wheel:
  - It is filled with hydraulic fluids
- Pressure from the wheels hitting the ground forces hydraulic fluid up, crossing the orifice, filling the chamber with nitrogen.
  - Heat is generated so that the kinematic energy is dissipated.



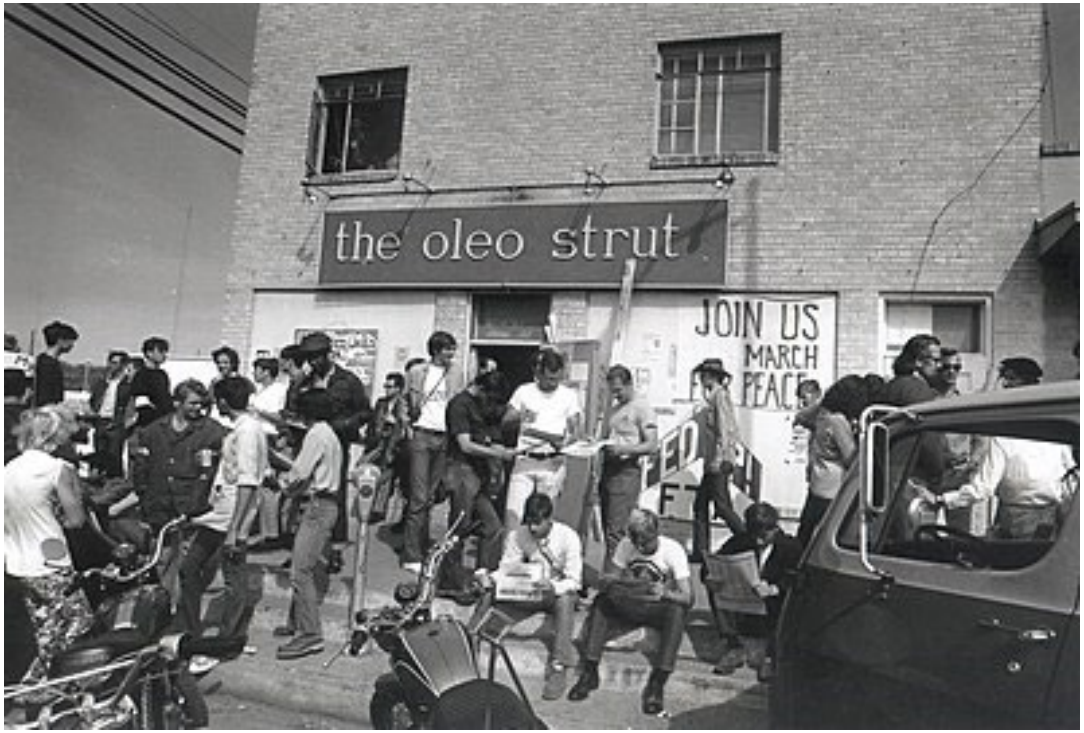
Shock absorber/減震器

- The torque links keep the piston and wheels aligned.
  - One end of the links is attached to the fixed upper cylinder.
  - The other end is attached to the piston so it cannot rotate





Oleo strut



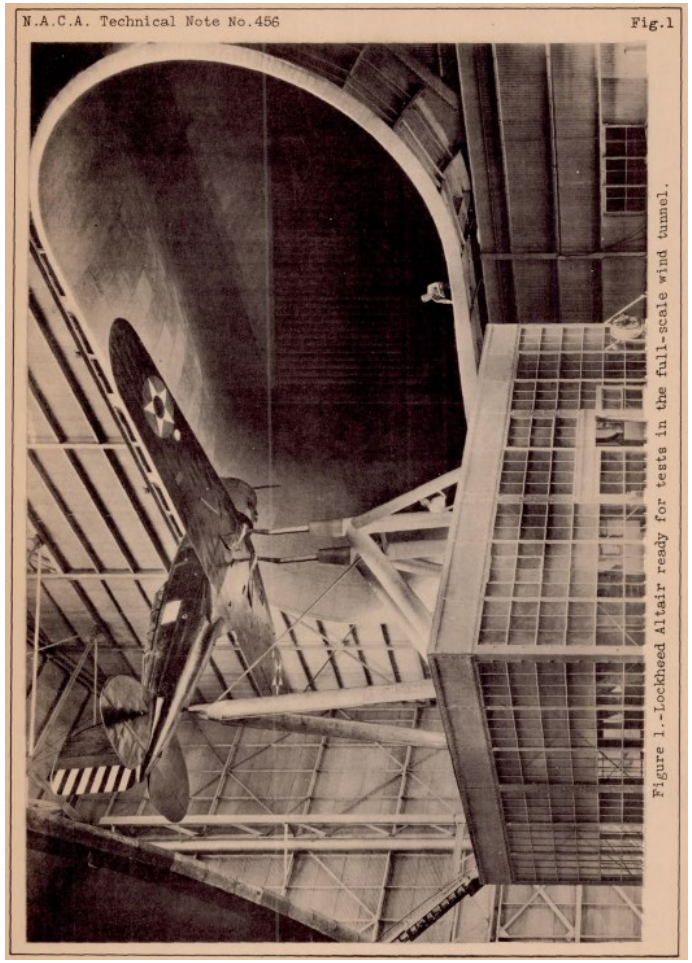
- The Oleo strut was a GI coffeehouse, which was set-up as part of the anti-war movement during the Vietnam War, in Texas from 1968 to 1972.
- Like the nickname, the Oleo strut represents the shock absorber in landing gear to reduce the shock impact during landing.

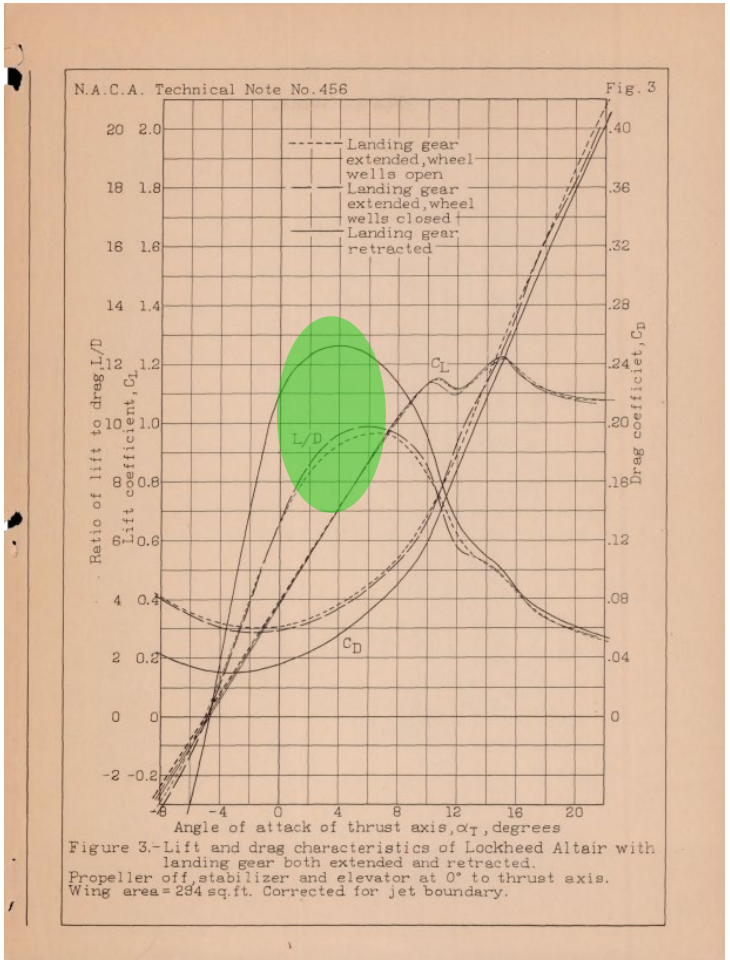
Landing gear retraction

Landing gear retraction: background

- In early aircraft, landing gears are fixed in an open position. The fixed landing gears are protruded at all times.
- Advantages of the fixed landing gear:
  - Easy to design
  - Strong
  - Light-weighted
- However, the wind tunnel test showed that landing gear can contribute 40% of the total drag of the fuselage drag.
- There come up with the idea of landing gear retraction to reduce the flow separation and frontal area during cruise.

Landing gear drag





Breguet Range Equation

- For an aircraft at the level flight speed V, the lift to drag ration is L/D, the initial and final weights are W_i and W_f.
- The flight range R can be estimated as:

$$R = V \cdot \left(\frac{L}{D}\right) \cdot \left(\frac{1}{g \cdot b_f}\right) \cdot \ln\left(\frac{W_i}{W_f}\right)$$

- b_f is determined by the propulsion system.
- For given flight distance,

$$\frac{m_i}{m_f} = \frac{W_i}{W_f} = \exp\left(\frac{R \cdot g \cdot b_f}{V \cdot L/D}\right)$$

Breguet Range Equation

- Take an A320 aircraft for example, we take:
  - flight speed of V=260 m/s and flight distance as R=5000km
  - Fuel burn $b_f = 0.00002\ \mathrm{kg} \cdot \mathrm{N}^{-2} \cdot \mathrm{s}^{-1}$ and $g = 10\ \mathrm{m} \cdot \mathrm{s}^{-2}$
  - Final mass $m_2 = 64\mathrm{t}$
- If we take L/D=18, then the initial weight is

$$m_1 = m_2 \cdot \exp\left(\frac{R \cdot g \cdot b_f}{V \cdot \frac{L}{D}}\right) = 80t$$

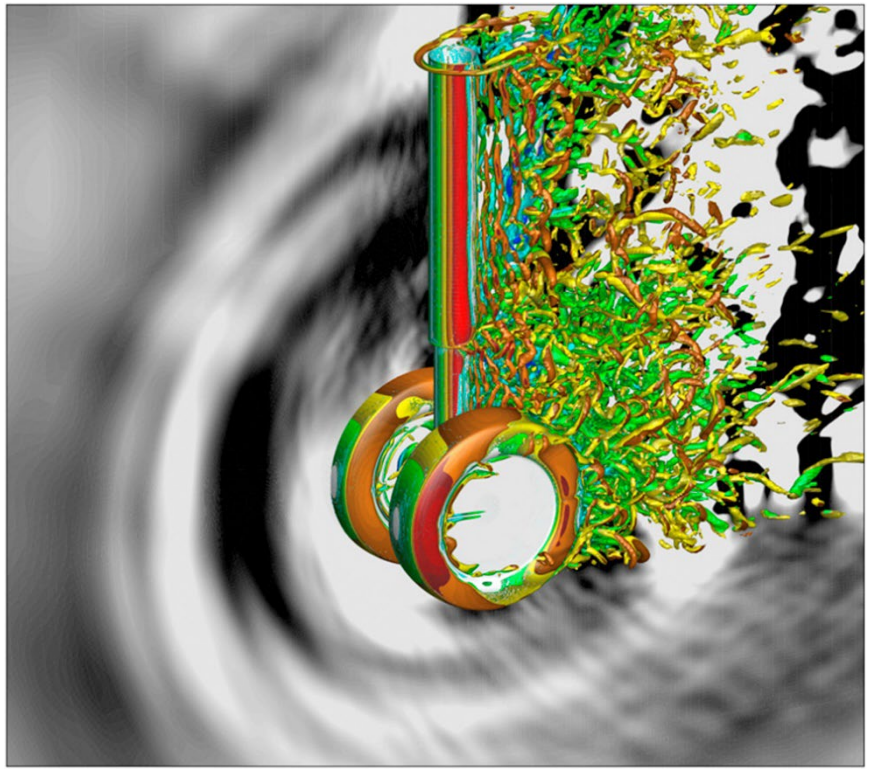
- If the L/D is reduced by 10%, i.e., L/D=16.2, then

$$m_1 = m_2 \cdot \exp\left(\frac{R \cdot g \cdot b_f}{V \cdot \frac{L}{D}}\right) = 81.9\mathrm{t}$$

Flow separation of deployed landing gear

Noise emission of the landing gear deployment

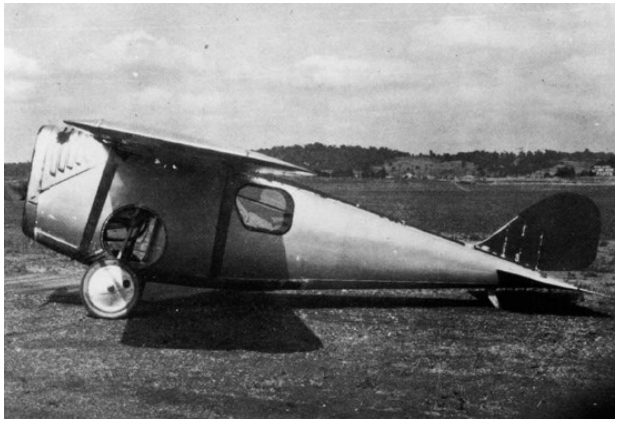
- Another issue of the landing gear deployment is the noise emission due to the interaction of landing gear and the aerodynamic flows.
- Landing gear noise is one of the major aircraft noise during the take-off and landing phases.



Source: S. Redonnet, et al., J. Sound Vib., vol. 403, p. 214-233, 2017

Early aircraft with retractable landing gear

J.V. Martin K.III Kitten (1917), the aircraft in US with retractable landing gear



Dayton-Wright RB-1(1920), a single-engine racing aircraft.

Verville-Sperry R3 (1922), racing airplane with fully retractable landing gear

At that age, despite of the good aerodynamic performance of the retractable landing gear, most airplanes had the fixed landing gears due to their advantages in cost, reliability, weight, and maintenance.

Pioneers in practical retractable landing gear

- Boeing Monomail (1930)

Boeing's first all-metal monoplane for cargo and mail services. It has an aerodynamic low-wing design, streamlined fuselage, engine with cowling and retractable landing gear.

- Lockheed Orion (1931)

A wooden monoplane that could carry a pilot and 6 passengers. It was featured by its NACA cowling and retractable landing gear.

Retractable landing gear

- Historically, different ways to achieve the retractable landing gear were explored.
  - In some aircraft the gears were pulled straight up.
  - In some aircraft the gears were folded inward into the bottom of the fuselage.
- The landing gears should be ensured as locked when they are locked. Otherwise, any collapse can cause damage or killings

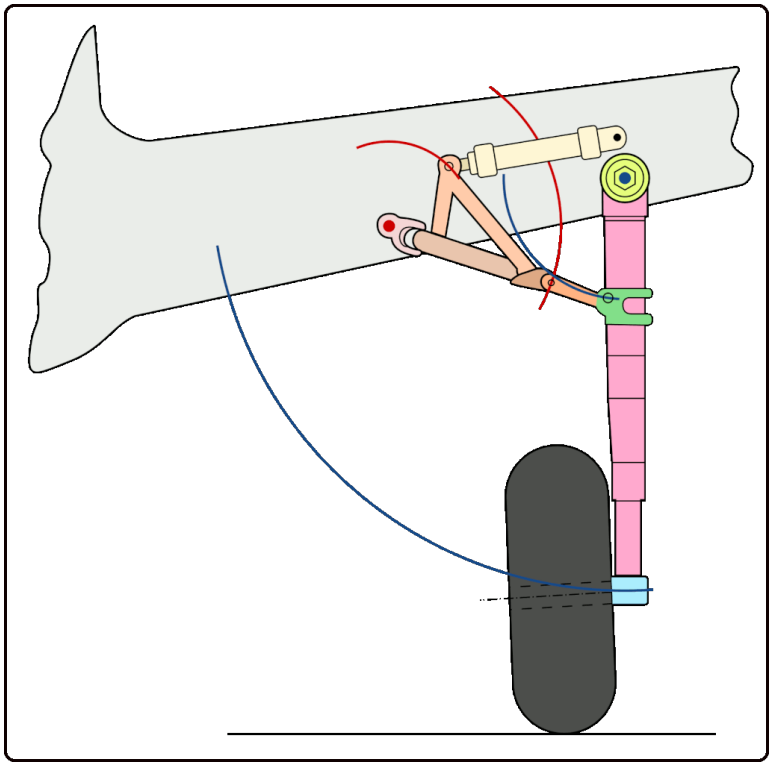
Retractable landing gear

- Early retractable landing gears did not show significant performance improvement since the motors and associated mechanical parts add much more weight. This means more lift is needed, making the benefit of drag reduction not so attractive.
- Meanwhile, efforts were made to reduce the drag of the fixed landing gears with streamlined shapes, etc. This is the reason why the small aircraft still employ fixed landing gears.
- However, with the increase of flight speed and distance, the impact of the drag on the fuel efficiency become dominated. The added weight of the retractable landing gear become less significant.

$$\frac{m_i}{m_f} = \frac{W_i}{W_f} = \exp\left(\frac{R \cdot g \cdot b_f}{V \cdot L/D}\right)$$

Landing gear retraction

- In modern high-performance aircraft, landing gears are retracted into the main body with complex mechanical mechanisms.
- The landing gear is stored in a compartment called wheel well/輪艙.



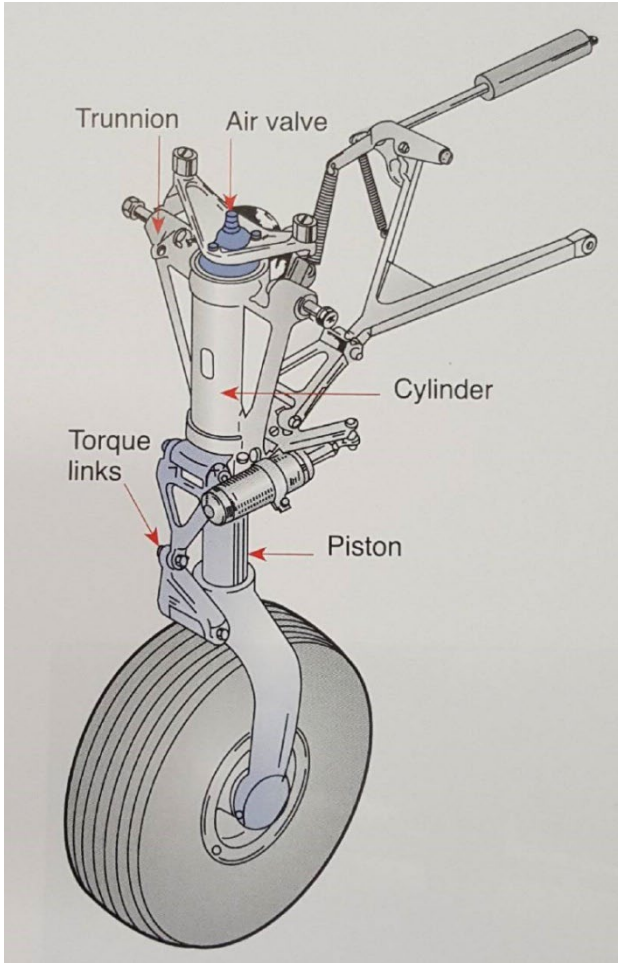
Components to realize the retraction

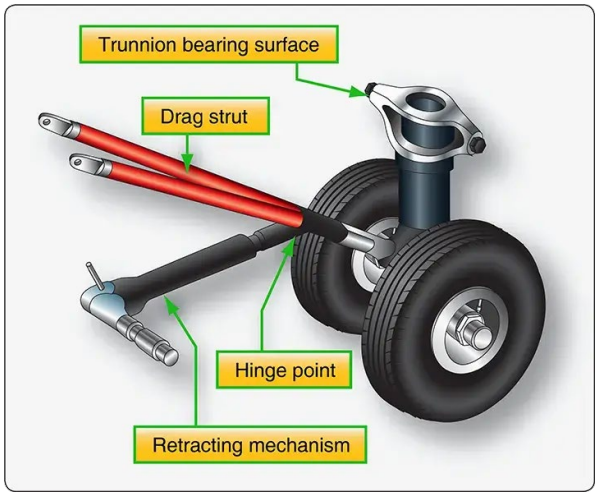
- Landing gear support → Realize the function
- Retractable landing gear consists many mechanical components to realize the function, including: → Mechanical design
  - torque links, trunnion, bracket arrangement, drag strut linkage, etc.
- It also contains the electrical and hydraulic retraction devices. → Actuation
- The locking, sensing and indicating components are also needed. → Control
- For nose gear, there are also steering mechanisms attached to the gear.
  - The steer the taxi direction

Mechanical mechanisms are needed to realize the retraction.

Landing gear support

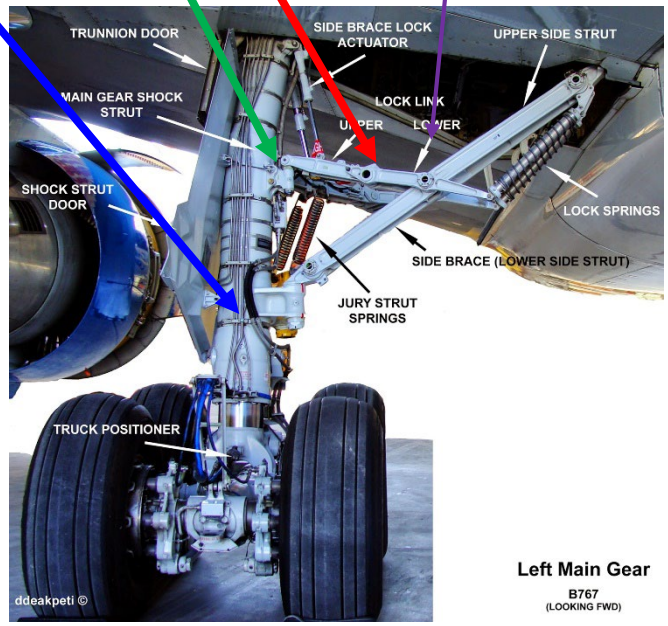
- The retractable landing gear should be able to:
  - provide strong attachment to the aircraft when deployed
  - move into the wheel well when stored.
- The trunnion is a fixed structural extension of the upper struct cylinder with bearing surfaces to allow the gear assembly





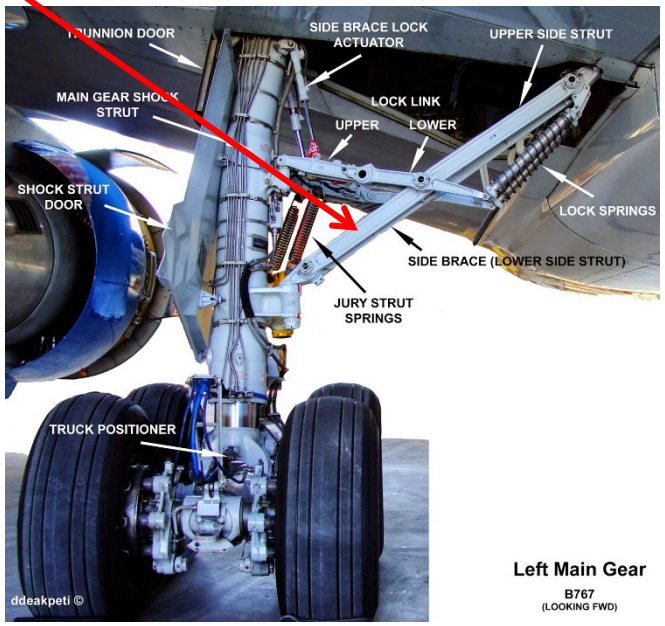
Typical landing gear arrangement

- To enable the retraction, a landing gear consists of upper and lower lock links hinged at the centre.
  - The shock strut is connected to the lower end of the lock link.
  - The upper end pivots on a trunnion attached to the wheel well



Typical landing gear arrangement

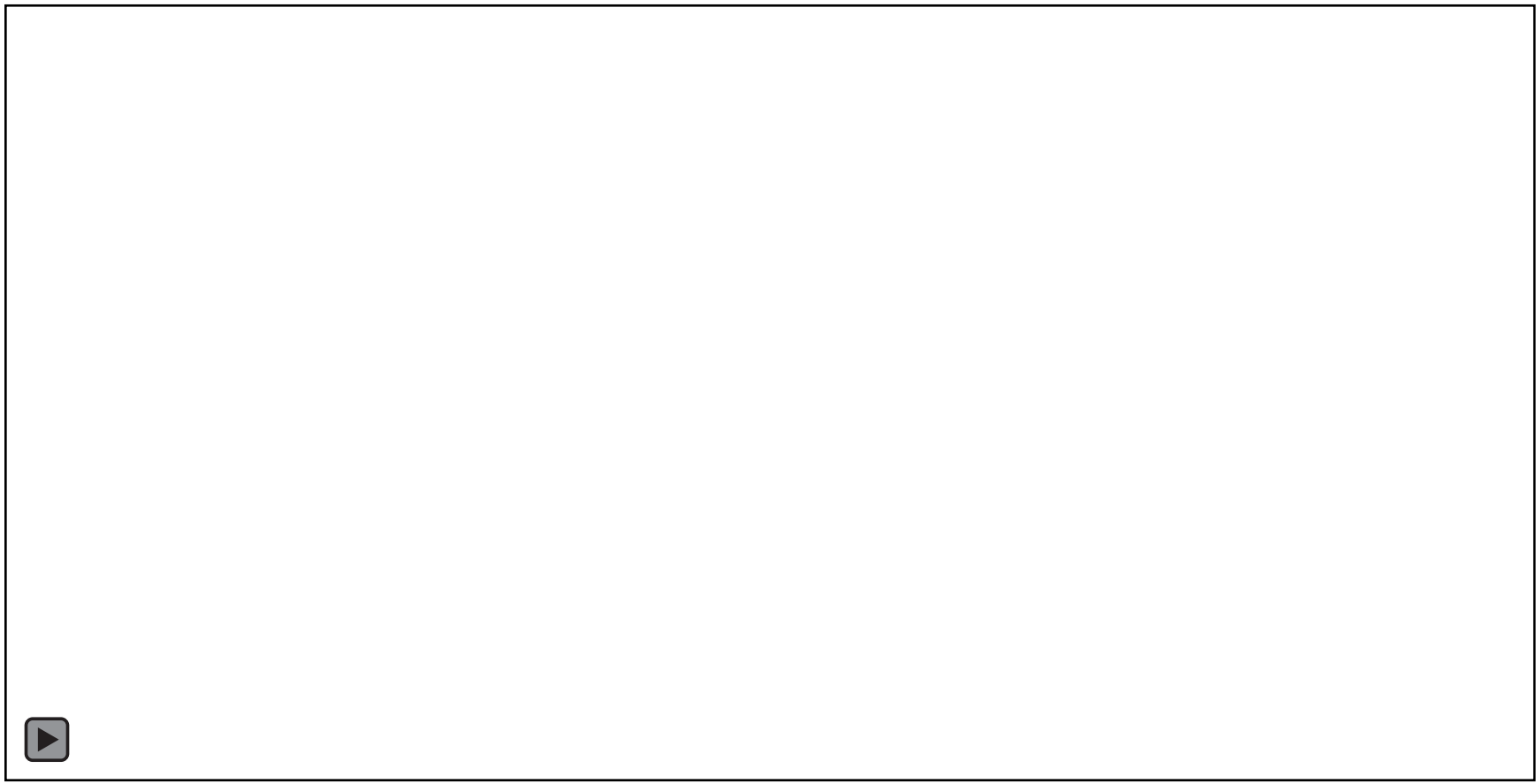
- The lock link is necessary to prevent the collapse of the landing gear
- For the landing gear in down position, the lock link is fitted to ensure the side brace are held firmly.



Up, down and off positions of a landing gear

- Up position: it refers to the status when the landing gear is retracted into the aircraft's fuselage or wings. It's used during flight to reduce drag and improve aerodynamic efficiency.
- Down position: In this position, the landing gear is extended and locked in place, ready for landing or taxiing. This ensures the aircraft can safely touch down and maneuver on the ground.
- Off position: This term is less commonly used, but it generally refers to the landing gear being retracted and not in use, similar to the up position. Essentially, the landing gear is stowed away and not deployed.

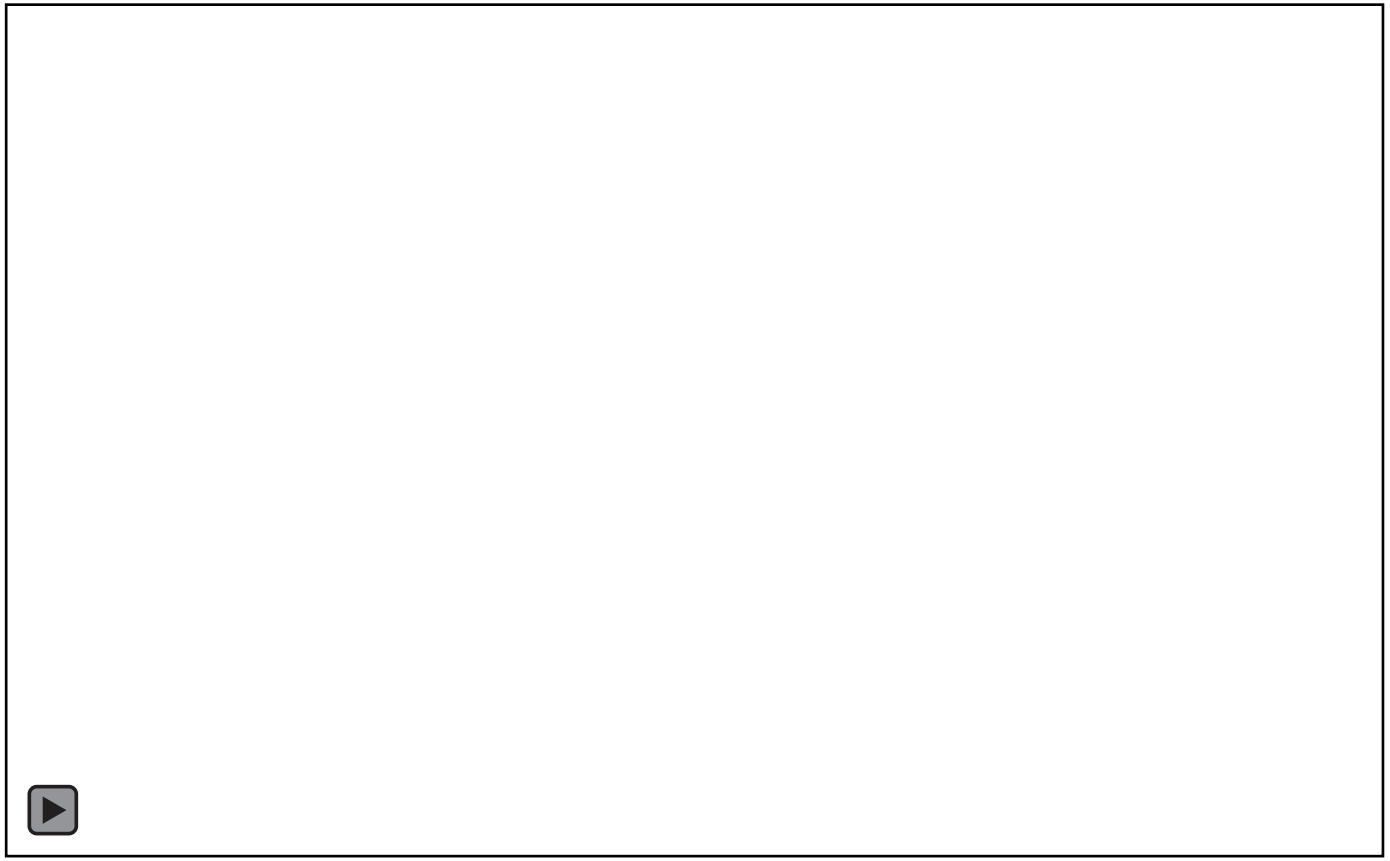
Landing gear retraction of a Boeing 747



Alignment and emergency extension system

Example: Boeing B737-800 Gear Manual Extension

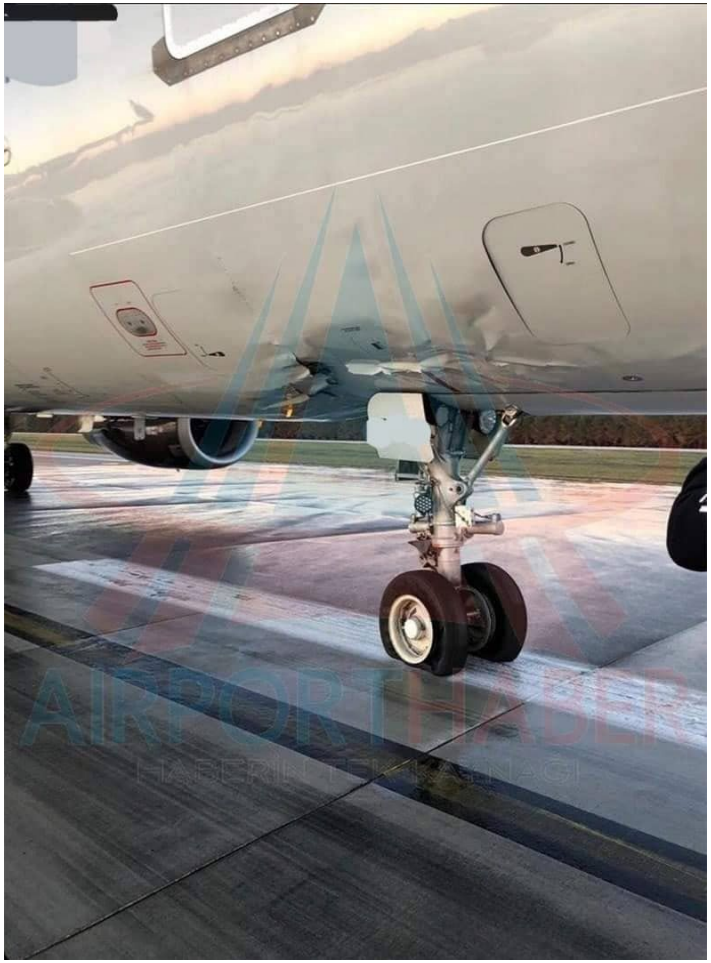
- Source: https://www.youtube.com/watch?v=Do2pIjz6zA4



Landing gear alignment & hard landing

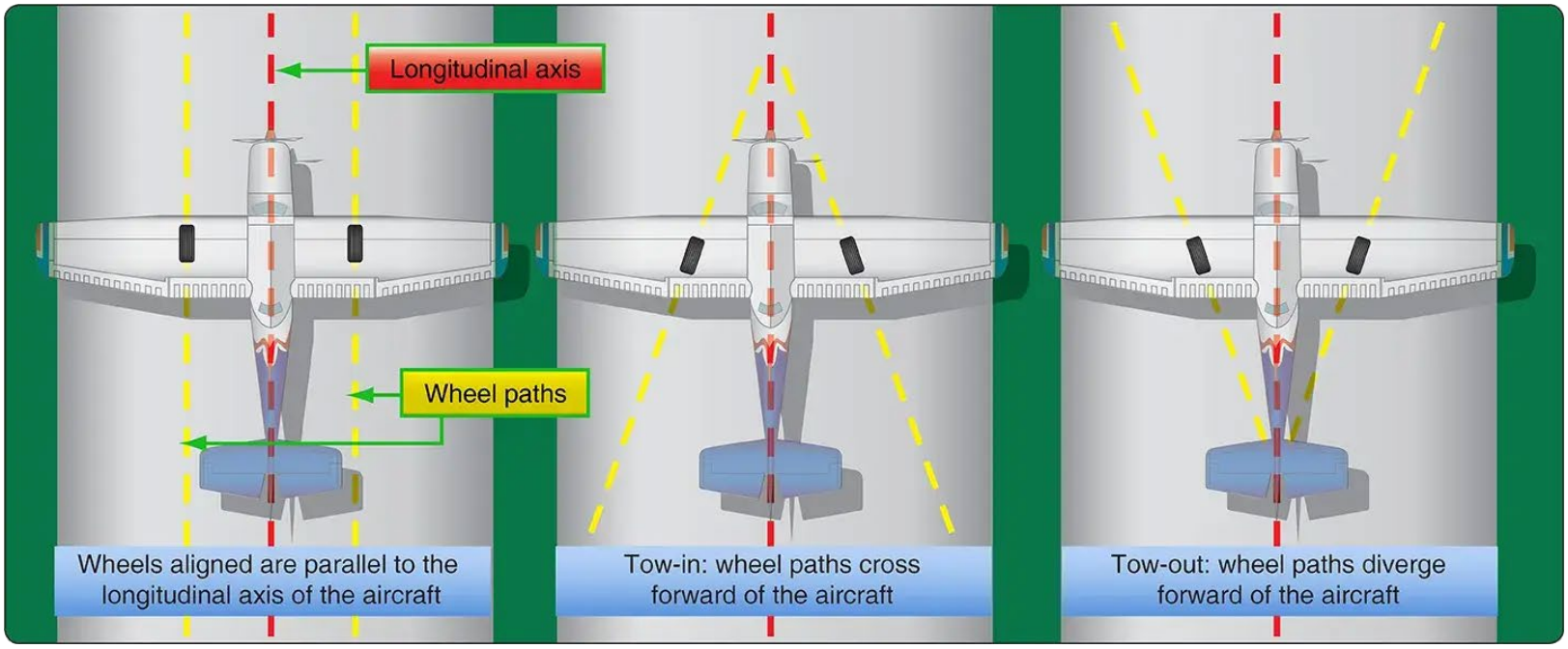
- Alignment of wheels is considered by the aircraft manufacturers for occasions such as hard landing.
- A hard landing occurs when an aircraft hits the ground with a greater vertical speed and force than in a normal landing.
  - Landing is the final phase in flight, in which the aircraft returns to the ground. The average vertical speed in a landing is around 2 m/s
- Hard landings can be caused by weather conditions, mechanical problems, overweight aircraft, pilot decision and/or pilot error.
- Hard landings can cause extensive damage to aircraft.

Hard landing



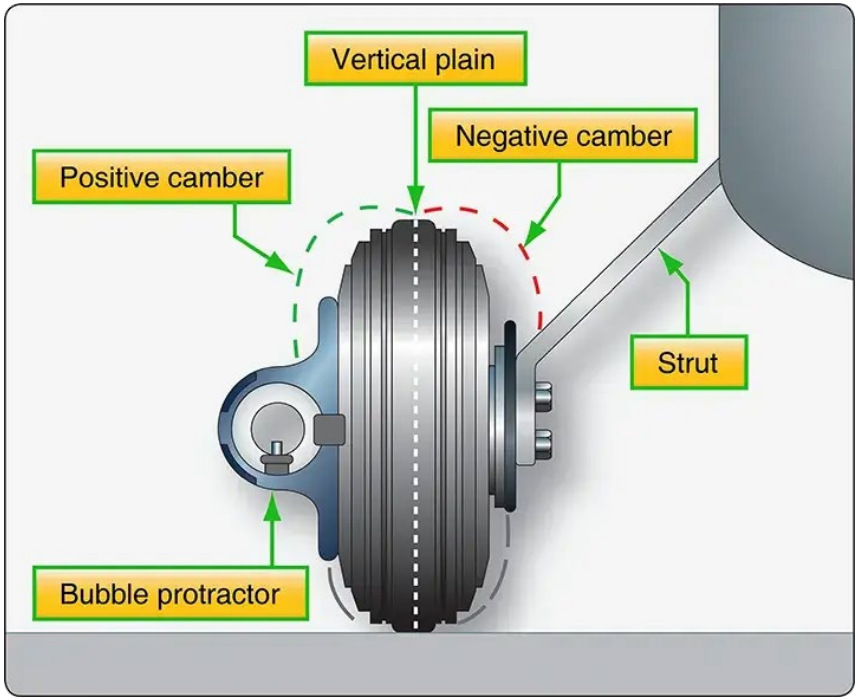
Landing gear alignment

- Alignment of wheels : The main wheels must be inspected and adjusted to maintain the proper motion of the wheel when it is free to roll

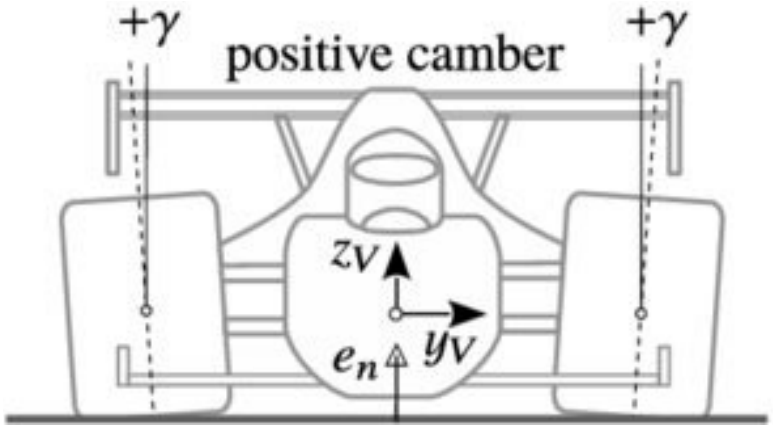


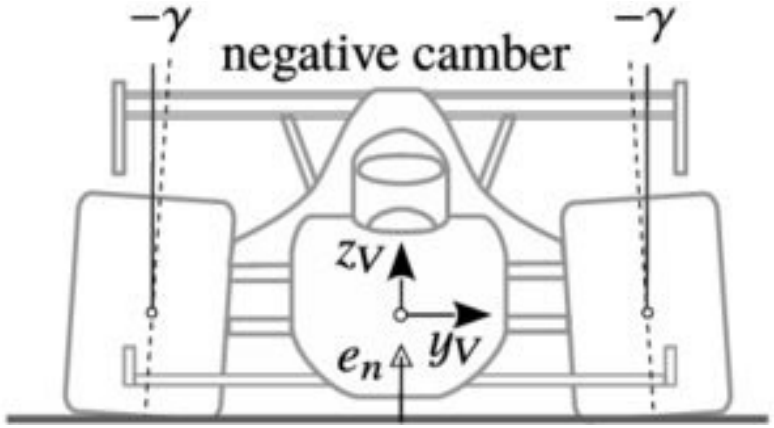
Landing gear alignment

- Camber indicates the alignment of a main wheel in the vertical plain.
- It can be checked with a bubble protractor held against the wheel assembly.
  - The wheel camber is said to be positive if the top of the wheel tilts outward from vertical.
  - Camber is negative if the top of the wheel tilts inward.



Positive camber and negative camber



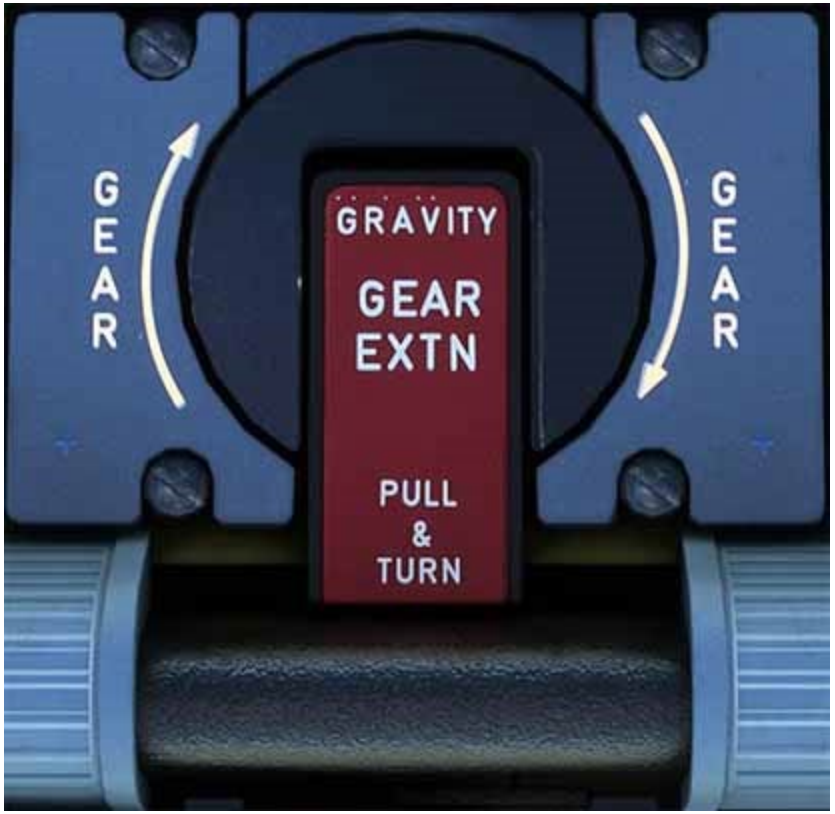


Emergency extension system

- It is also called the emergency gravity gear extension system
- The emergency extension system lowers the landing gear if the main power system fails
- Some aircraft have the emergence extension system in the flight deck linked to the gear through mechanical linkages
- When operated, it allows the gear to free fall to the extended position under the gravity force

Emergency extension system

- When the crew turns the crank, it:
  - Isolates the landing gear hydraulics from the overall hydraulic system
  - Opens hydraulic vent valves and unlocks the doors of the wheel well
  - Unlocks the main and noise gear that will be extended with gravity



Issues in Jeju Air Flight 2216

- For modern aircraft, there is sufficient redundancy for the landing gear issue emergency.
- In the case of Jeju Air Flight 2216, no such preparations were evident. Emergency services arrived only after the crash, suggesting the landing was neither planned nor communicated as a gear-up emergency.

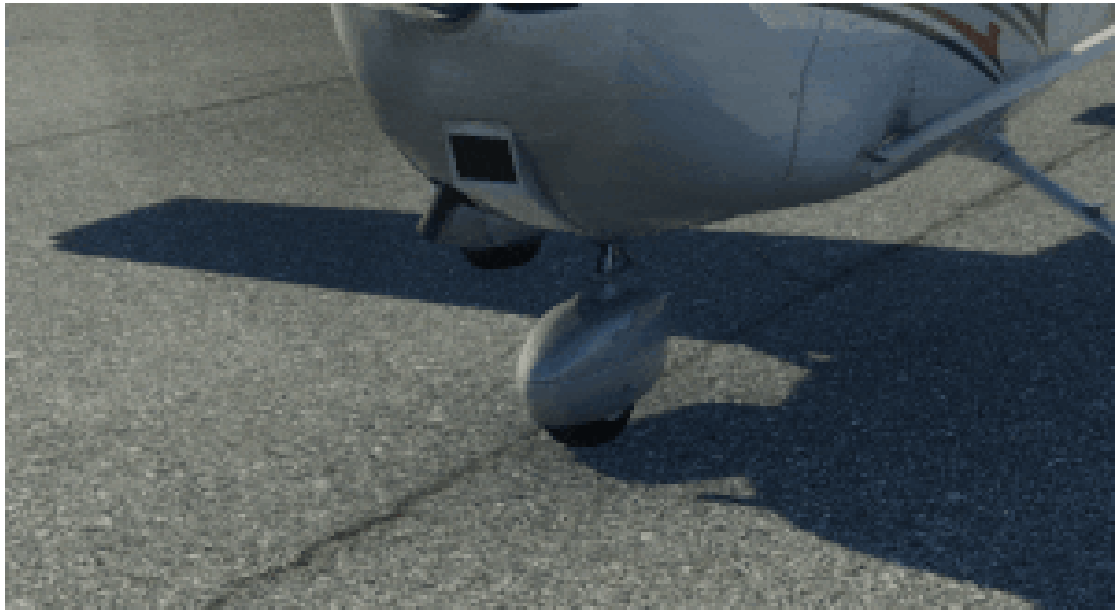
It seems that there is a gear collapse for the Jeju Air Flight 2216

Nose wheel steeling system/前輪操縱系統

Apart from supporting the weight, the landing gears are also used for taxiing of the aircraft on the ground.

Nose wheel steering system

- The nose wheel on most aircraft is steerable from the flight deck via a nose wheel steering system.
- The nose wheel steering operation allows the aircraft to be directed during the ground operation.



Nose wheel steering system: small aircraft

- For small aircraft, the steering capability is achieved by using a simple system of mechanical linkages connected to the rudder pedals.
- Push-pull tubes are connected to pedal horns on the lower strut.
  - As the pedals are depressed, the movement is transferred to the strut piston and wheel assembly that rotates to the left or right.

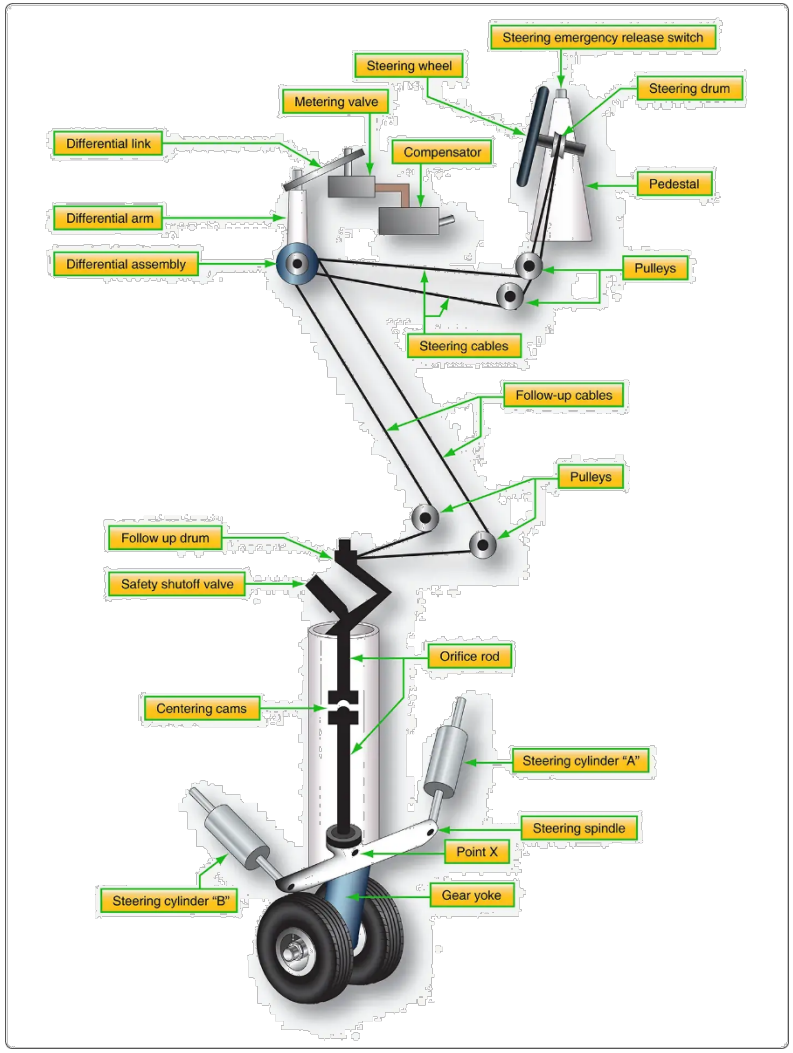
Direction/yaw control

Nose wheel steering system: large aircraft

- On heavy aircraft, the tricycle configuration is often used. A steering till is often used to steer the nose gear.

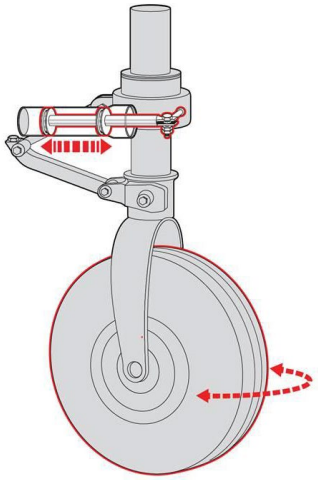
Nose wheel steering system: large aircraft

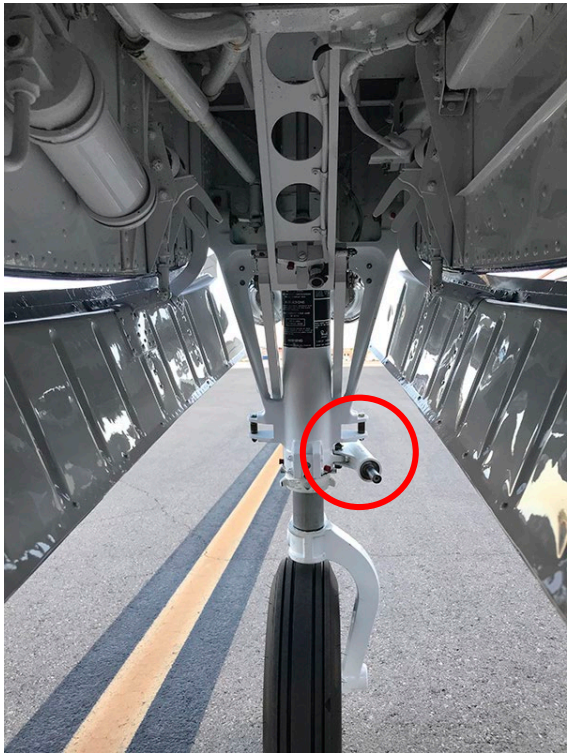
- For large aircraft, hydraulic power is often needed to realize the wheel steering:
  - Control of steering from flight deck through small wheel, tillers, or joystick
  - The control is directed to the hydraulic fluid via various linkages to rotate the lower strut
  - An accumulator and relief valve keep the fluid in the actuators under pressure.
  - Follow-up mechanisms consist of various gears, cables, rods, etc.

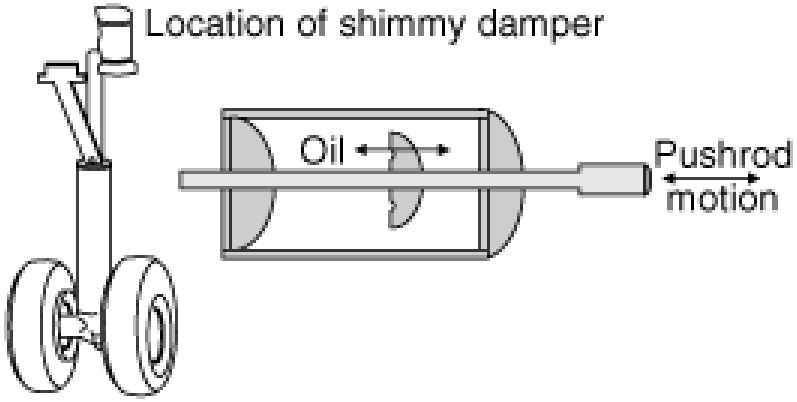


Shimmy dampers/减摆器

- In the steering system, shimmy dampers are necessary to prevent the landing gear from rapid oscillation (shimmy).
- A shimmy damper often consists of an oil filled cylinder with a push-pull rod. When the rod moves from side to side, oil is forced to flow the holes, leading to damping
- It is also used to reduce the shimmy related to the shock energy







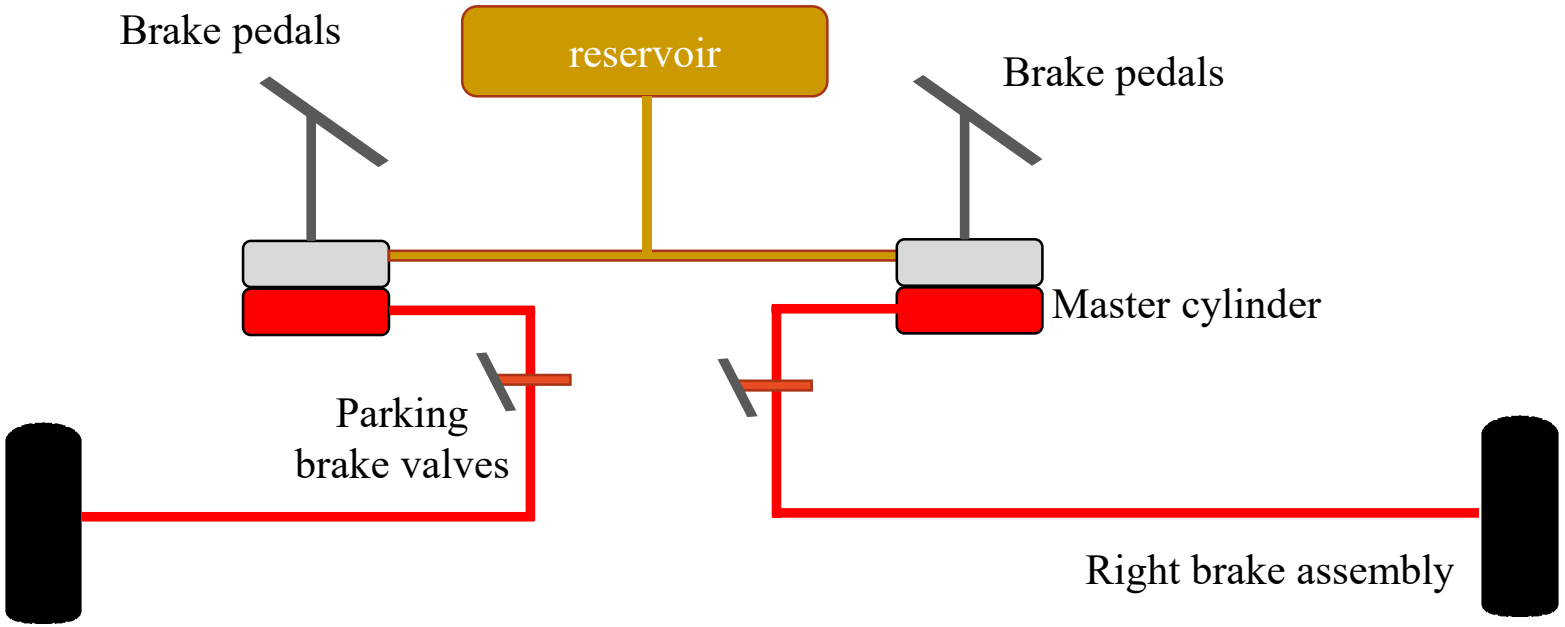
Aircraft braking system/煞車

Brakes

- All modern aircraft are equipped with brakes.
- The main purposes of brakes are to:
  - decelerate the aircraft and hold the aircraft stationary.
  - In some cases, differential braking helps to steer the aircraft during taxi.

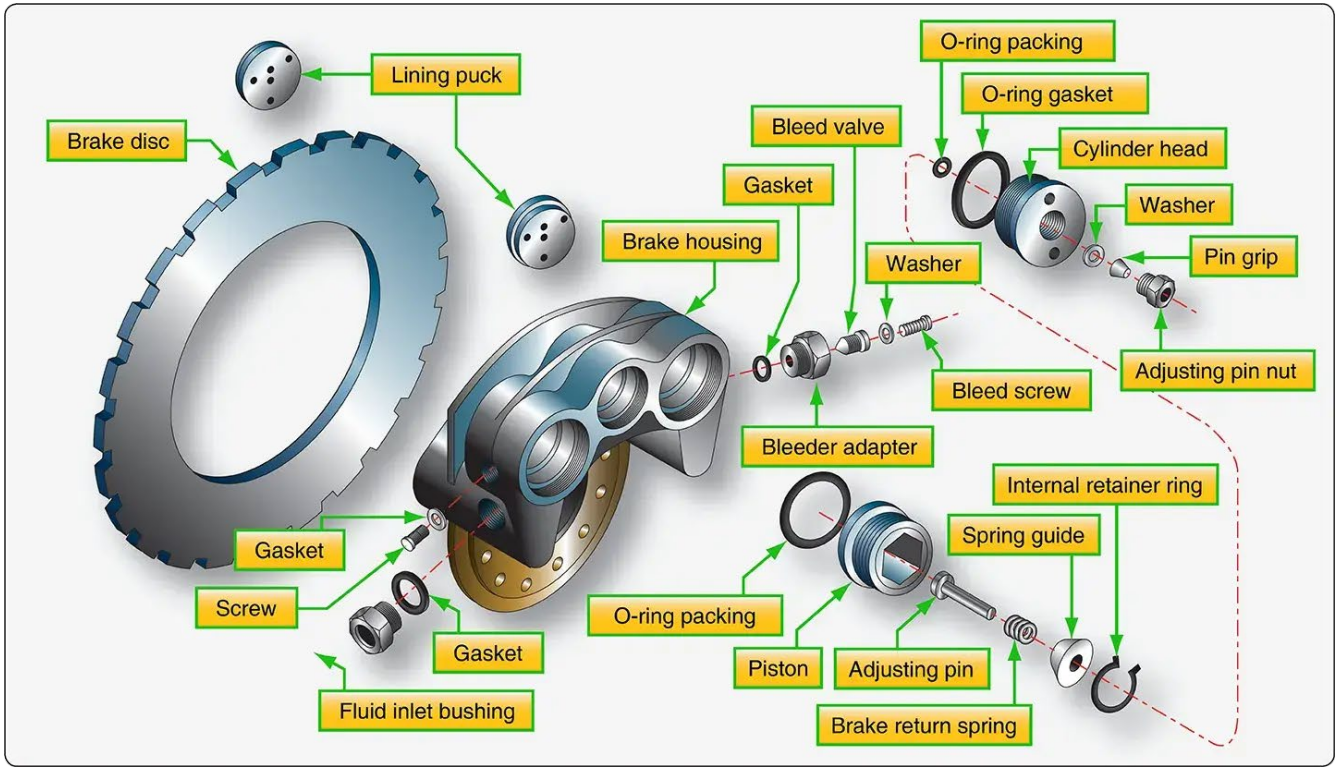
Brakes: locations

- On most aircraft, each main wheel is equipped with a brake unit.
- The nose wheel may have or not have a brake, depending on the design:
  - Mechanical and hydraulic linkages to the rudder pedals allow the pilot to control the brakes.



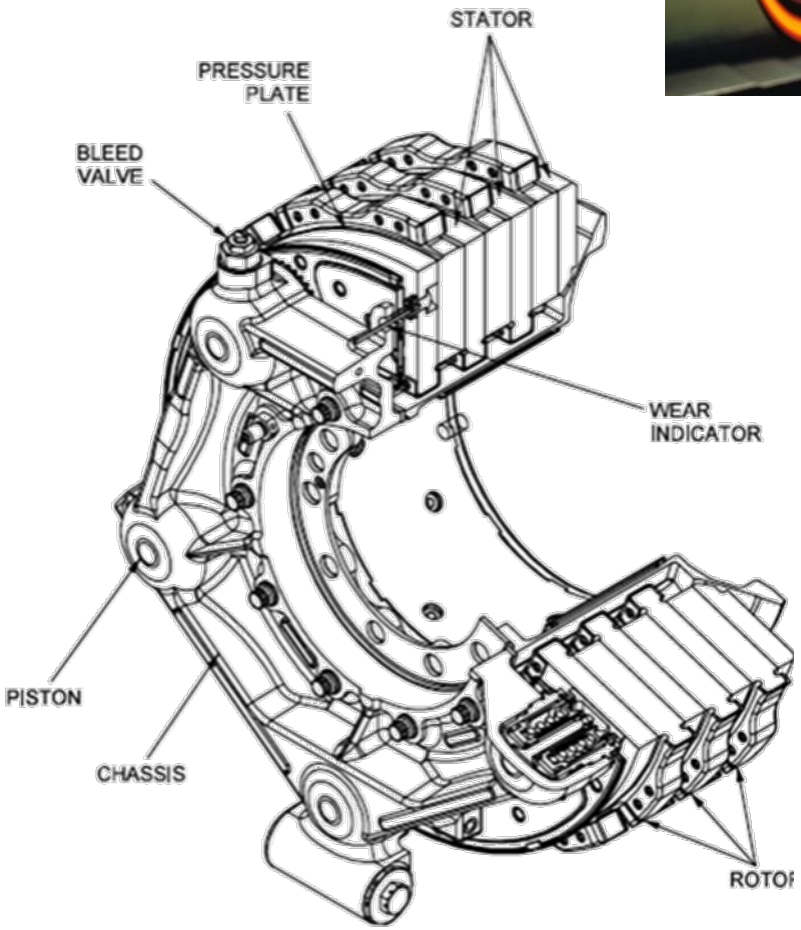
Aircraft brakes

- Brake principle: to convert the kinetic energy of motion into heat through the creation of friction
- Modern aircrafts use disc brakes.

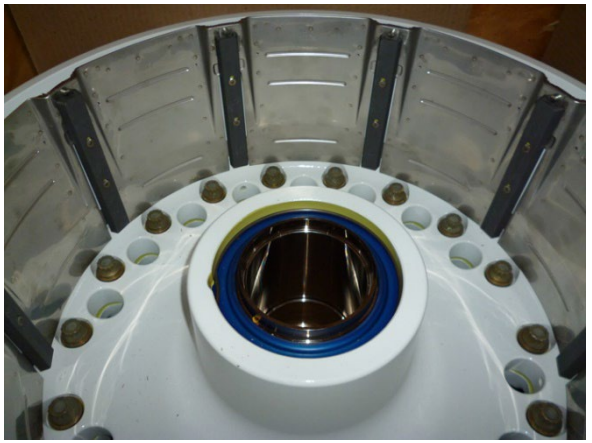


Brakes

- A disc brake is a wheel brake that slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers.
- The size, weight, and landing speed of the aircraft influence the design and complexity of the disc brake system.
  - Single, dual, and multiple disc brakes are common types of brakes.
  - Segmented rotor brakes are used in large aircrafts.



Wheel and brake assembly



Aircraft tires/輪胎

Aircraft tires

- Aircraft tires are necessary to:
  - support the weight of the aircraft on the ground
  - provide the necessary traction for braking and stopping.
- The tires also help to:
  - absorb the shock of landing
  - cushion the roughness of ground operations.

Aircraft tires

- Unlike automobile or truck tire, it does not have to carry a load for a long period of continuous operation.
- However, an aircraft tire must absorb the high impact loads of landing and be able to operate at high speeds even if only for a short time.
- For this reason, aircraft tires are designed with high deflection.

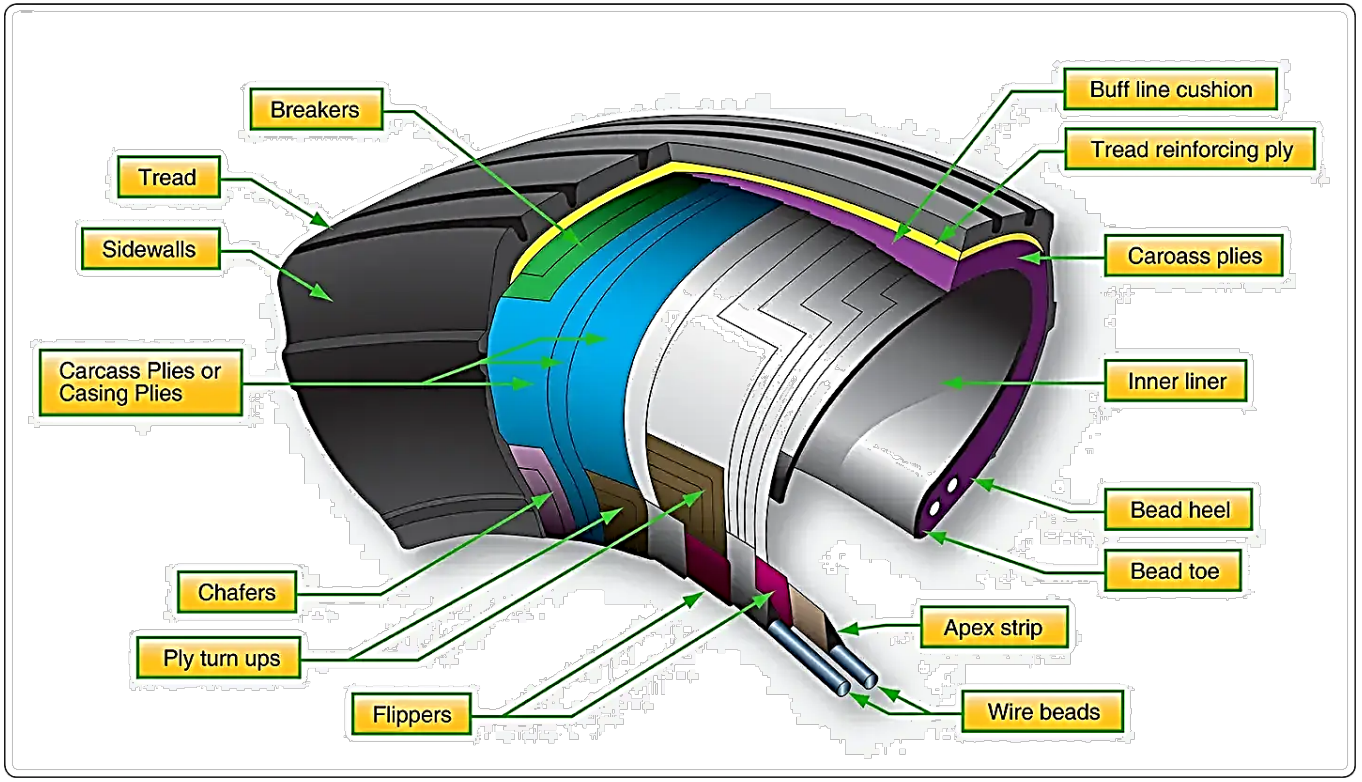
Aircraft tires

- Aircraft tires are one of the strongest and toughest pneumatic tires

- It must withstand high speed, heavy static and dynamic loads
- e.g., the main gear tires of a four engine aircraft need to withstand:
  - the speed up to 250 mph
  - and the dynamic loads could be as high as 33 tons

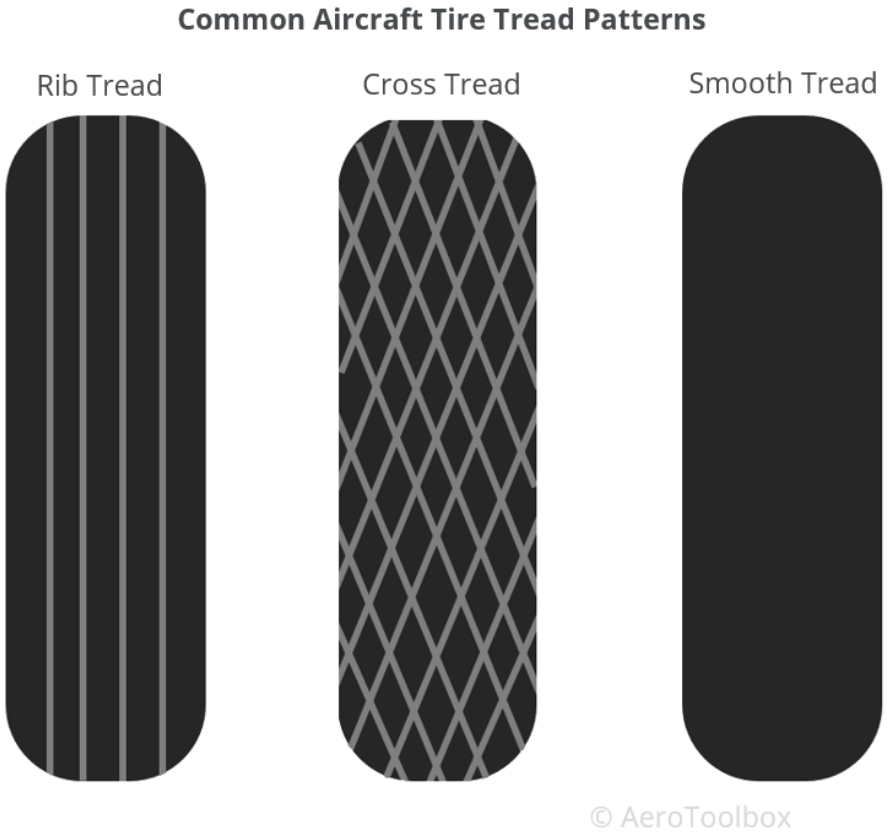
Aircraft tires

- The tire include the parts as:
  - Tread
  - Tread reinforcement
  - Breakers
  - Casing piles
  - Beads
  - Flippers
  - Chafers
  - Bead toe
  - Inner line
  - Sidewall
  - Apex strip, etc



Tread

- Tread refers to the wearable part of the tire that is contact to the ground.
- It should be able to resist frictional wear, cracking, cuts, abrasion, etc., during the landing phase.
- The surface pattern can be featured by:
  - Rib tread tire: assists in cooling the tire and allows water away
  - Cross tread tire: has smaller total contract area to provide less traction
  - Smooth tire (mainly for older aircraft): provides the greatest traction and largest contact area.



Creep marking

- In hard landing with heavy braking, there could be a movement of the tire relative to the wheel rim in the rotation direction. This phenomenon is called the tire creep or tire slip. It can cause the blow-out of the tube valve.
- Tire creeping is detected by painting a single white line crosses the tire and wheel. Any slip can leads to a mismatch of the line.

Aircraft tires: classification

- They are mainly classified according to their:
  - Dimensions: diameter & rim
  - Strength: ply-rating
  - Configuration: tubed or tubeless
- To ensure safety, the tire should be fitted to the particular aircraft in accordance with the operation manual
- Based on the dimension, aircraft tires can be classified following the conventional of the United States Tire and Rim Association.
  - Only types I, III, VII and VIII, i.e., the Three-Part Nomenclature tires, are still in production.

Aircraft tires: classification

- Type III: low-pressure tires for light aircraft. The tires are identified via a two-number system with a "-" separating the numbers.
  - The first number indicates the tire section width in inches
  - The second number indicates the rim diameter in inches
- Type VII: the tires with high performance on jet aircraft. It also involves a two-number system for naming.
  - The first number indicates the nominal overall diameter
  - The second number indicates the section width
- Type VIII: the tires are high-pressure, high speed for large jet aircraft. The naming systems involves the three numbers:
  - The first number indicates the outside diameter
  - The second number indicates the nominal tire width
  - The third number indicates the rim diameter

Aircraft tires: classification

Aircraft Tire Classification

Type III (WW – RD)

6.00 - 6

Tire Width: 6.00 inches

Rim Dia.: 6 inches

Type VII (DD x WW)

24 x 10.00

Tire Dia.: 24 inches

Tire Width: 10 inches

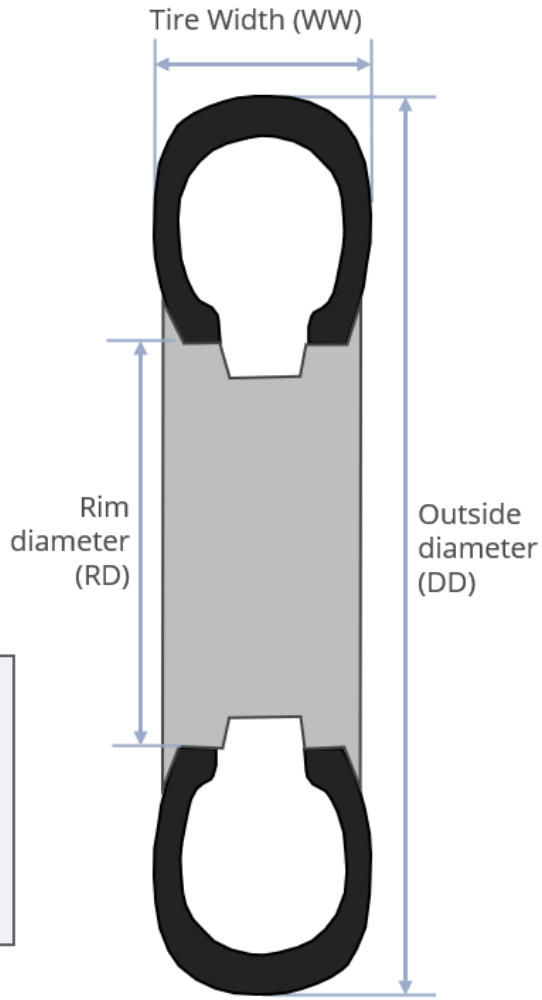
Type VIII (DD x WW - RD)

18 x 4.5 - 10.00

Tire Dia.: 18 inches

Tire Width: 4.5 inches

Rim Dia.: 10 inches



Leading manufacturers

- The aircraft tire manufacturing industry is dominated by a four firm oligopoly that controls 85% of market share
  - Goodyear (US)
  - Michelin (France)
  - Dunlop Aircraft Tyres (UK)
  - Bridgestone (Japan)

- China also has some smaller industry players.

Antiskid system/防滑系統

Antiskid system

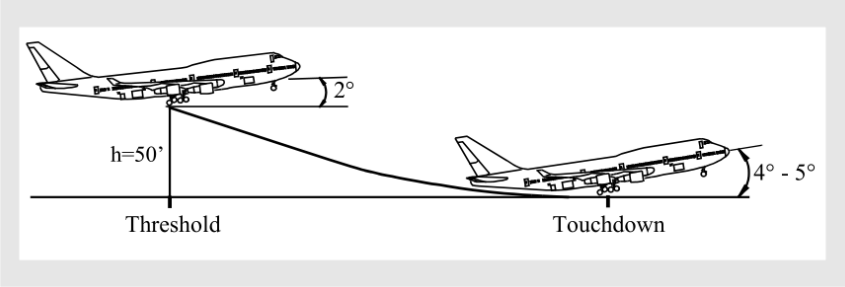
- Antiskid system is a feature in high-performance aircraft braking system. If skid occurs, the braking value is greatly reduced.
- Functions of the antiskid system:
  - Normal skid control
  - Locked wheel skid control
  - Touchdown protection
  - Fail-safe protection

Normal skid control

- In the slow down (but not come to a stop) period, the normal skid control is performed.
  - The wheel sliding has just begun and not reached the full scale slide
  - The skid control valve removes some of the hydraulic pressure to the wheel, permitting the wheel to rotate faster and stop the sliding
  - The skid detection and control of each wheel is completely independent of each other

Locked wheel skid control & Touchdown protection

- Locked wheel skid control:
  - It releases the pressure when the wheels are locked.
  - It is operated if the normal skid control does not prevent the wheel from reaching the full skid.
- The touchdown protection prevents the brakes from being applied during the landing phase even the brake pedals are depressed.
  - It prevents the wheels from being locked in the runway.
  - Two conditions for this application:
    - The squat switch must signal that the weight of the aircraft is on the wheels
    - The wheel generator sense a wheel speed over 15-20 mph



Fail-safe protection

- The fail-safe protection monitors the operation of the anti-skid system. It automatically returns the brake system to full manual in case the system fails, with a warning light.

Autobrake

- Autobrake is a type of automatic wheel-based hydraulic brake system for advanced airplanes during the take-off and landing phases. It is designed to keep the pilot free to perform other tasks.
- Two modes of the autobraking system:
  - Landing
  - Refused take-off (RTO)

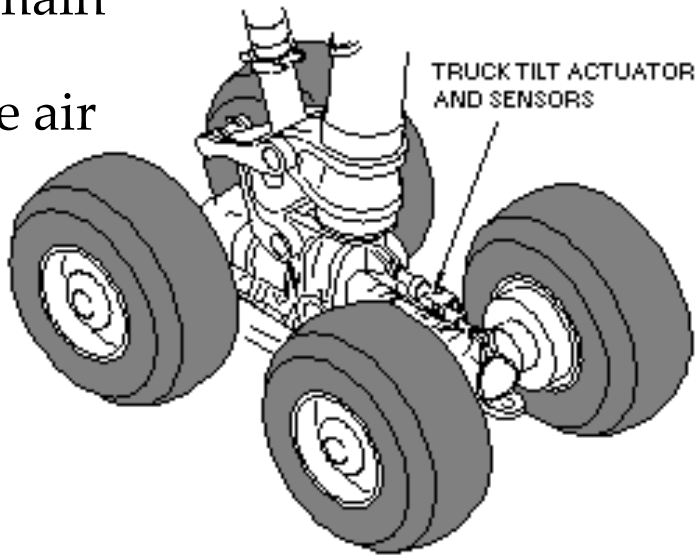
Air/ground sensing system

Air/ground sensing system

- In flight and ground operation, the aircraft is controlled by the air/ground sensing and the nose/ground sensing system.
- The air/ground sensing system is designed to prevent various system from operating inappropriately on the ground. Examples:
  - Truck tilt sensors
  - Nose gear compressed sensors
  - Weight on wheels (WoW) system

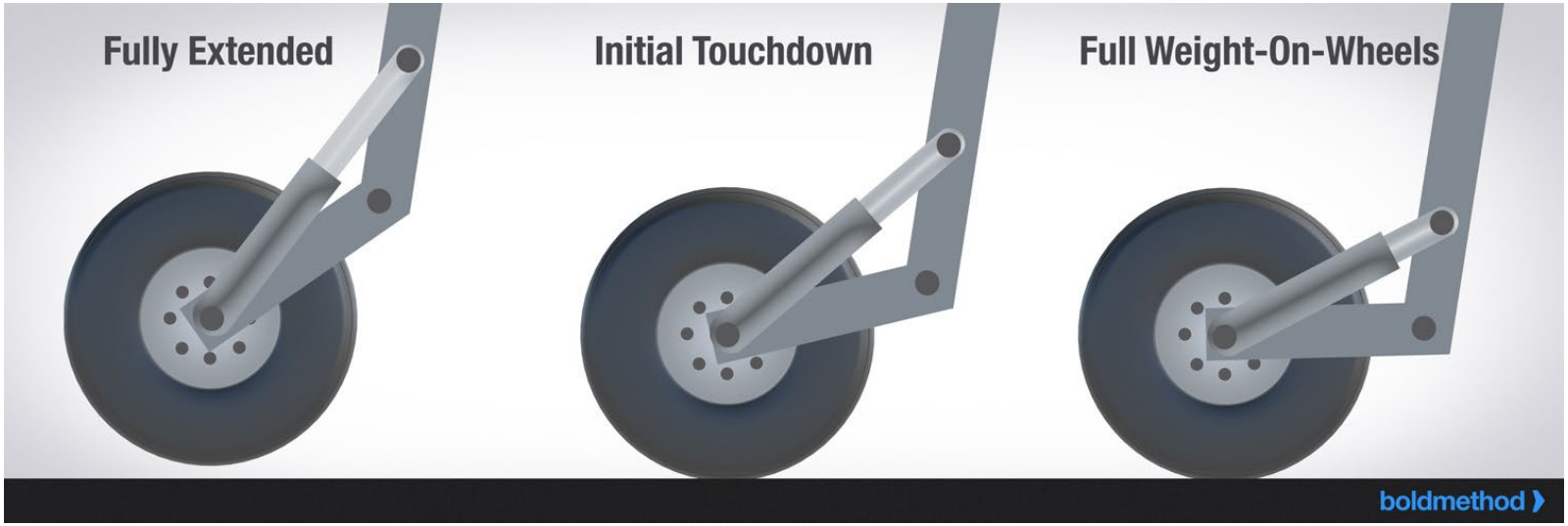
Air/ground sensing system

- Truck tilt sensors: they are located at the main landing gear, and the received signals are used for the aircraft control of appropriate air and ground status in:
  - Land gear lever lock
  - Speed brakes and autobrakes
  - Wing anti-ice, etc.
- Nose gear compressed sensors
  - The sensors are located at the nose gear strut.
  - The signals are used to control the stall warning and other warning systems.



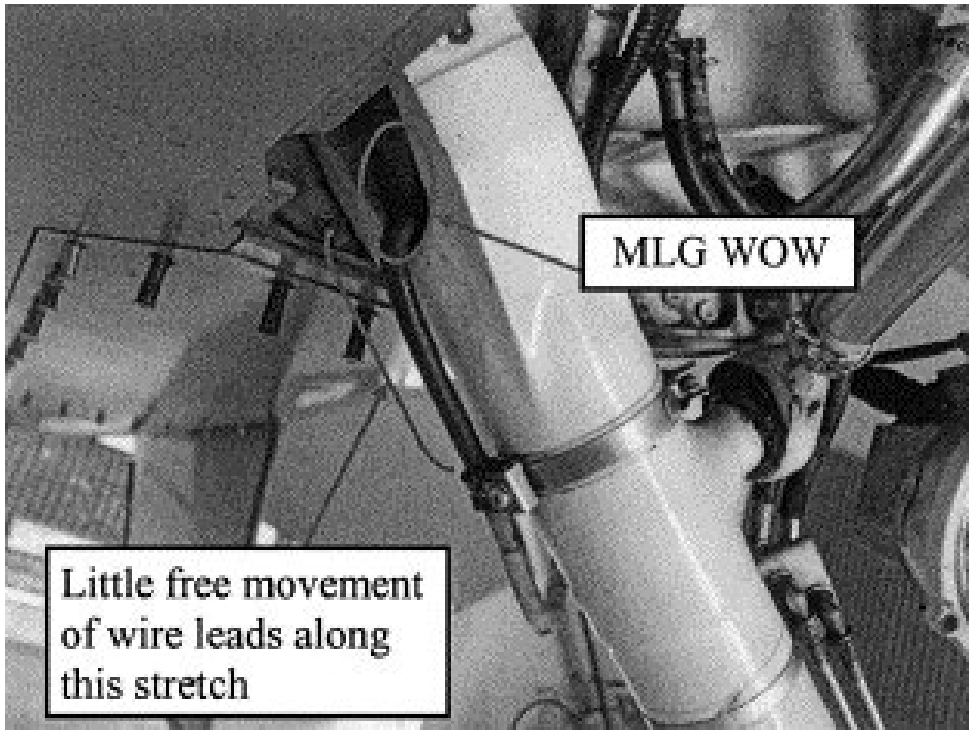
Weight on wheels (WoW) system

- Weight on wheels (WoW) switches indicate whether the weight of an aircraft is resting on its wheels. This information reveals whether the aircraft is airborne or on the ground.



Weight on wheels (WoW) system

- The weight on wheel sensors can be located at different parts of the aircraft and on the landing gear.
- Signals from these sensors are used for the control the systems of:
  - Nose wheel steering, trim system, autopilot, etc.



Summary

Summary

- Components in the aircraft landing gear are introduced
- Principles of the major components such as shock absorber, shock strut, retraction, braking system, etc., are introduced.
- Brief introduction to the classifications of parts of the aircraft landing gear.