



The Impact of Changes in the Landing Gear Structure of Aircraft on Safety Performance

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Abstract. While wings, control surfaces, engine, and flight control make sure the aircraft can fly. The landing gear is the only structure that supports an aircraft's weight on the ground. Landing gear is an essential structure that allows aircraft to take off and land because it integrates tires to keep traction on the ground, oleo shock absorbers to reduce landing impact, brakes to stop the aircraft before running to the end of the runway, and steering hinges to help manoeuvre on the ground. Landing gear was first just an unimportant design on early gliders or bicycle wheels on wooden planes for gentler landings. However, it has become increasingly important to aircraft as they become faster, heavier and require more manoeuvrability on the ground. From the early 20th century wheels connected directly to the fuselage on early experimental planes, to elastic connections, retractable structure, and modern oleo strut, multiple-wheel landing gear on large passenger planes, the design of landing gear has experienced many changes. In addition, the development of material science and electronic control has brought landing gear higher strength and smarter automatic controls.

Keywords: Aircraft Landing Gear, Structural Evolution, Shock Absorption, Flight Safety, Composite Materials.

1 Introduction

According to the 2024 Global Commercial Aviation Safety Report released by the International Air Transport Association (IATA), tail strikes and runway excursions are the two most common types of accidents, which accidents caused casualties among some passengers. Further emphasising the importance of optimising take-off and landing safety measures. The landing gear is an indispensable support system for an aircraft during take-off, landing, taxiing, and ground movement. It is crucial for the safe operation of the aircraft. The primary functions of the landing gear are not only to support the weight of the aircraft but also to effectively absorb impact energy during landing and ensure a smooth touchdown.

Landing gears are mainly divided into fixed and retractable types, with different structures catering to the needs of various aircraft types. At the same time, the

connections between components of landing gears are classified as rigid connections, elastic links, and connections with shock absorbers. Different landing gear structures have been applied in different periods, exerting varying degrees of influence on the flight performance and safety of aircraft. From 1900 to 1940, the manufacturing of landing gears entered the mechanical era. Fixed structures were very popular during this period, but the landing gears at that time only had the function of taxiing and did not significantly enhance the safety performance of aircraft. From 1950 to 1990, the emergence of retractable designs represented the standardisation of hydraulic systems and oil-gas shock absorbers. At this time, landing gears could absorb the majority of landing energy, reducing the impact force on aircraft during take-off acceleration and landing deceleration, and to a certain extent, ensuring the safety performance of aircraft. After 1990, composite materials began to be used in landing gears, and the development of digitalisation also made the control of landing gears more convenient and accurate. Modern landing gear shock absorbers can absorb over 70% of landing energy, which has a decisive impact on enhancing passenger comfort, the safety of the fuselage structure, and the safety of equipment inside the aircraft.

This paper focuses on the development history of landing gear structure technology and analyses the impact of structural innovation on modern aviation safety performance through the study of historical development.

2 Basic Principles and Classification of Landing Gear

2.1 Categorising of aircraft landing gear

The structure of aircraft landing gear can be classified based on 2 aspects: retracting structure and shock-absorbing method. The former one includes fixed landing gear, which is installed under the wings or fuselage as an immovable part, always facing the high-speed airflow during aircraft's cruising state, and retractable landing gear, which can stay in down position during take-off and landing and can be retracted into the wings or fuselage during cruising to reduce parasitic drag. Whereas the latter aspect includes hard-linked, solid spring, and oleo strut. Hard-linked landing gear is usually connected to the aircraft by a straight axis and triangular trusses. Next, solid spring landing gear uses steel leaf/coil spring and rubber disks to reduce the impact force of landing, but does not significantly absorb the energy. Finally, Oleo struts, which are also known as pneumatic shocks, absorb and dissipate shock loads using a combination of oil and gas. Oleo strut has high shock-absorbing efficiency due to its structure.

2.2 Basic mechanisms of modern shock absorbers

As shown in Figure 1, the Oleo strut consists of a piston and a cylinder with 2 chambers, which are filled with air and hydraulic oil. The two chambers are connected by an orifice (a small hole), which allows the hydraulic oil to enter the top chamber. As the aircraft touches down, the piston travels up into the cylinder, forcing hydraulic fluid through the orifice into the upper chamber to create resistance [1]. Gas in the upper chamber, functioning like a spring, is compressed by the hydraulic fluid to absorb the

impact of touchdown as well as bumps during taxiing [1]. The compression of gas and movement of fluid through the orifice generates heat that is transferred via convection and conduction through the strut to the airframe and atmosphere [1]. Typical modern landing gears on passenger planes can absorb over 70% of landing energy.

$$\text{efficiency} = \frac{A}{(L \times S)} \quad (1)$$

Where A is the energy absorbed by the strut during its stroke, L is the maximum load on the strut during the stroke, and S is the maximum stroke resulting from the maximum load [1].

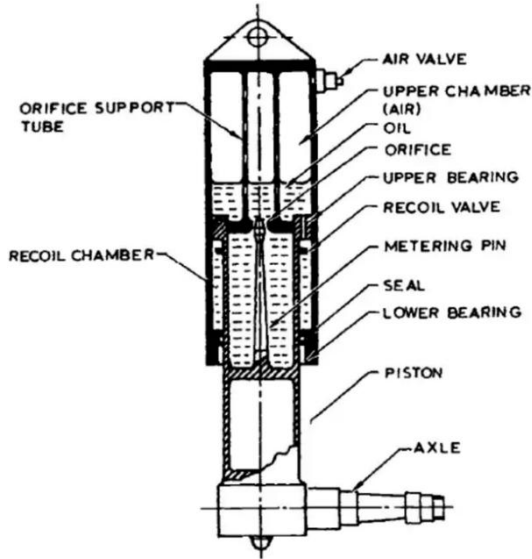


Fig. 1. The structure of a typical oleo strut [2]

2.3 Basic mechanism of retracting structure

As shown in Figure 2, the landing gear struts transmit their load to the airframe through the trunnion mounted on the rear spar of the wing and pivot about the trunnion for stowage within the wing and fuselage [3]. A computer-controlled hydraulic system is used to extend and retract the landing gear automatically. The fluid inside the hydraulic system, pressurised by a pump, can force the piston inside the downlock strut to extend the folded landing gear from the aircraft.

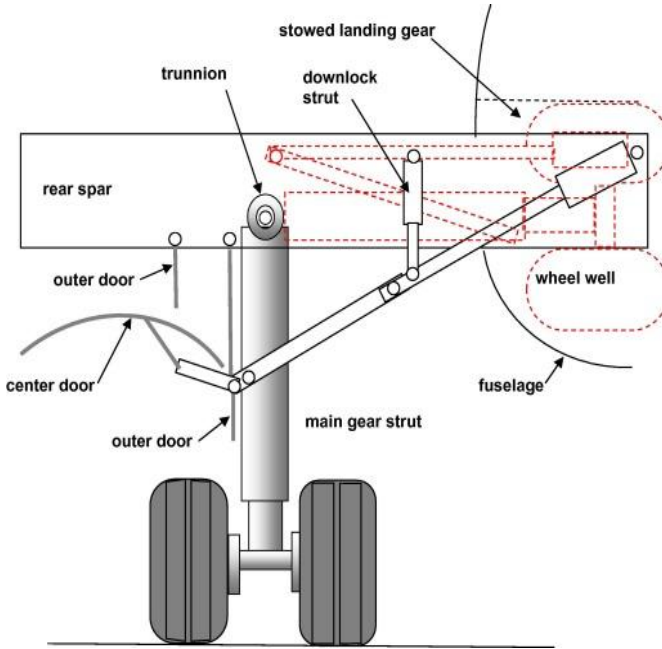


Fig. 2. The structure of the landing gear retracting system [3]

3 Development of landing gear

3.1 Early Aircraft Landing Gear Evolution (1900s-1930s)

In the early 20th century, aircraft relied on rudimentary landing systems. The Wright brothers' 1903 "Flyer I" employed wooden skids for take-off, while Santos-Dumont's 1906 *14-bis* pioneered wheeled gear, enabling smoother ground operations. By World War I, tailwheel configurations became standard, featuring robust struts and elastic cord-based shock absorption to handle rough fields [2].

The P-26's Engineering Leap. As shown in Figure 3, the Boeing P-26 revolutionised landing gear design with a fixed tubular truss structure. This structure balanced strength and weight, supporting short-field take-offs on uneven terrain. Weighing just 1,000 kg, the P-26's landing gear was 30% lighter than contemporary biplanes' rigid struts. Its 600-horsepower engine delivered a 0.18 hp/kg power-to-weight ratio, allowing acceleration to lift-off speed (~110 km/h) within seconds [4].

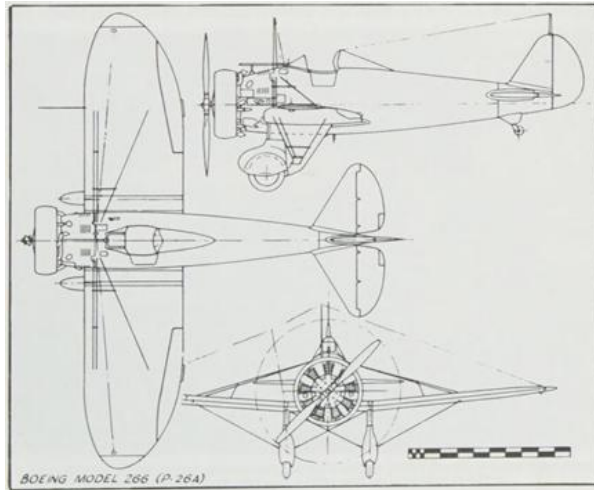


Fig. 3. The structure of the Boeing P-26 [4]

Design Trade-offs and Obsolescence. Dispersing impact across multiple load paths to prevent structural failure. Despite its efficiency, the fixed truss generated excessive drag, limiting maximum speed to 377 km/h. Pre-WWII aircraft often added streamlined fairings to mitigate drag, but these were stopgap solutions. By the 1940s, the truss design was phased out as wartime demands prioritised speed and retractable gear systems. Wind tunnel studies confirmed that exposed structures caused significant aerodynamic interference, accelerating the shift to enclosed designs [5].

3.2 Elastic Connection Era: (1930s-1940s)

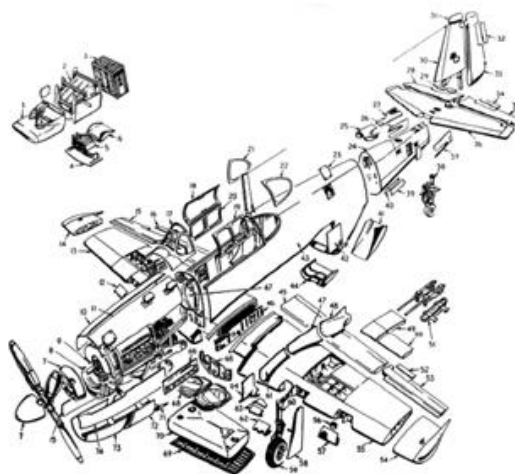


Fig. 4. The structure of P-51[6]

As shown in Figure 4, the leaf Spring is composed of multiple stacked metal layers, absorbing impact forces through bending deformation. It is widely adopted in lightweight or early-model aircraft (e.g., WWII-era fighters). For example, the tailwheel landing gear of the P-51 Mustang utilised a leaf spring design [2]. Typical aviation leaf springs comprised 3–7 layers of metal sheets, each 2–5 mm thick, with a width of 50–100 mm and an overall span of 0.5–1.5 m, depending on landing gear configuration. The selected materials required high yield strength (≥ 1200 MPa) and excellent fatigue resistance ($> 10^5$ cycles) to withstand repeated impact loads [7].

The first phase is to store elastic energy, so that the impact forces bend the leaf spring, converting kinetic energy into elastic potential energy. Absorbs 60–70% of the energy [2]. High-yield-strength materials (e.g., 60Si2MnA spring steel) are critical. The second phase is energy dissipation. Sliding friction between layers (friction coefficient: 0.1–0.3) converts residual energy into heat. Enhanced designs may incorporate friction liners or pre-tightened bolts to optimise damping. The advantage of the leaf spring landing gear is its low maintenance cost due to the spring's simple structure; however, it has the problem of high weight and low damping efficiency. In the late 1940s, with the maturity of hydraulic shock absorption technology, elastic connections were replaced. However, the high elasticity material data and energy dissipation theory accumulated during this stage laid a scientific foundation for subsequent design.

3.3 Application of Hydraulic Shock Absorption Technology (1950s–1990s)

Retractable landing gear design. Due to the influence of factors such as space layout, flight duration, and weight, the landing gear of traditional small aircraft before 1950 was usually in a fixed state. Early aircraft had relatively slow flight speeds, and the requirements for aerodynamic shape were not very strict. Therefore, most aircraft landing gears were designed as fixed type, which had lower requirements for manufacturing technology [8]. This type of landing gear design enables the aircraft to perform sliding actions during take-off and landing. However, it does not enhance the safety performance and efficiency of flight. As the aircraft's flying speed keeps increasing, especially after it crosses the sonic speed, the aerodynamic resistance increases sharply. At this time, the landing gear on the outside of the fuselage has a significant impact on the aerodynamic performance of the aircraft, which restricts the further increase of the flight speed.

The retractable landing gear does not occupy valuable main fuselage space and does not compromise the structural integrity of the fuselage frame. This ensures good reliability of the motion mechanism [7]. The retractable landing gear structure has a significant impact on the aerodynamic shape of the aircraft and will affect the flight resistance and flight duration of the aircraft [9]. The retractable landing gear adds weight and makes the aircraft's structure design and usage more complex. However, it greatly enhances the safety performance and overall efficiency during flight.

Standardisation of Hydraulic Systems and Pneumatic Shock Absorbers. The retraction and extension hydraulic system is an essential component of the landing gear. Its function is to provide hydraulic energy for the retraction, extension and locking of the landing gear, enabling the aircraft to park normally, take off and land smoothly. Failure of the landing gear retraction and extension hydraulic system will significantly increase the flight resistance of the aircraft, potentially causing incidents such as aircraft aborting take-off and running off the runway, and even forcing a belly landing due to the inability of the landing gear to extend, which will seriously endanger flight safety [10].

The general working principle of the retraction and extension hydraulic system is as follows: The shock absorber and the load-bearing strut are combined into one unit. The wheels are directly fixed on the piston rod of the shock absorber. The hydraulic system drives the piston to move and controls the retraction and extension of the landing gear. For example, the Boeing 707 adopted a strut-type landing gear and a hydraulic retraction and extension landing gear. It was widely used from 1973 to 1980. Meanwhile, based on a complete hydraulic system, using an oil-gas type shock absorber can absorb approximately 80%-90% of the landing impact energy.

The oil-gas type shock absorber is a widely adopted shock absorption device in aircraft landing gears. Its structure has evolved from the mixed oil-gas type to the separated oil-gas type, and from the single air chamber type to the double air chamber type, achieving good performance. According to the momentum theorem, the longer the time of the aircraft's impact on the ground during landing, the smaller the impact force. The function of the oil-gas type shock absorber is to increase the time of the aircraft's impact on the ground, thereby reducing the impact force, reducing the jolting and bouncing of the aircraft, and enhancing passenger comfort. With the continuous improvement of aircraft performance, shock absorbers have also gone through different development stages, namely: rubber shock absorbers, spring shock absorbers, oil-impregnated rubber shock absorbers, oil-impregnated spring shock absorbers, oil-gas shock absorbers, and oil shock absorbers. However, their traditional design principles have not been improved as expected, failing to meet the requirements of modern design and calculation technologies. This has increasingly constrained the improvement, modification, and development of old products as well as the research and development of new ones [11]. For this reason, the continuous development of shock absorbers will become a major design point for enhancing the safety performance of aircraft.

3.4 Composite Materials and Digitalisation (1990s-now)

Telegraphy control system. The telegraphy control system is an electrical signal transmission system that feeds back the aircraft's motion as the controlled parameter into the system to control the aircraft's motion. Its reliability has a direct impact on flight safety [12]. In the 1970s, the fly-by-wire system was introduced. It uses electrical signals sent out, equipment switches and an operation handle to control the aircraft, and to control the aircraft's attitude in the air and its flight trajectory.

With the advancement of electronic technology and the rapid development of the aviation industry, researchers have gradually developed high-performance fly-by-wire

control systems. The principle of the fly-by-wire control system is to convert the manual operation signals of pilots into electrical signals, which are then received by the control and stabilising system and make the landing gear retract or extend and change accordingly. The fly-by-wire control system greatly enhances the safety performance and flight performance of the aircraft's operation system [13].

Composite material. Composite materials enjoy wide applications in various fields such as aerospace, rail transportation and automotive manufacturing due to their superior strength and remarkable weight reduction effect [14]. The weight reduction benefits have brought about the most intuitive and significant changes in the application of composite materials in aircraft structures. Using composite materials in landing gears replaces steel rather than aluminium, providing a greater space for weight reduction. Generally, the reduction rate can reach about 40%. The weight reduction means an increase in flight range and more precise control, which will have considerable positive impacts on the safety performance of aircraft. Moreover, its high strength characteristic is in line with the original intention of landing gear design. The provision of a safe and stable take-off and landing process for the aircraft.

4 Analysis of the Landing Gear'S Safety

Safety is always a key concern for engineers who design landing gear systems. During touchdown, the landing gear has to absorb the entire landing impact energy to maintain control and structural integrity. Therefore, the design of the landing gear is essential to the safety of passengers. For hard-linked and fixed elastic landing gear, the design provides a straightforward and durable option for supporting the aircraft during take-off, landing, and taxiing. It involves fewer moving parts, making it less complex to maintain, therefore reducing the number of unspotted failures [15]. However, the fact that they have poor shock-absorbing efficiency makes them prone to creating instability of the aircraft during touchdown due to the rebound, which drastically alters the position of the centre of mass and can lead to loss of control, especially for heavy high-speed planes.

The introduction of pneumatic shock absorbers improves the safety of landing. The design requirement is to dissipate all the impact energy without causing the aircraft to rebound [16]. Therefore, the chance of losing traction from the ground can be greatly reduced to improve safety. In addition, the impact experienced by the fuselage and wings is greatly reduced, thus reducing metal fatigue and failures. Fly-by-wire technology also improves aircraft's safety by automatically releasing or retracting the landing gear based on sensor data. This reduces the chance of accidents caused by improper operation of the retracting system. By using advanced material in landing gear structure, for instance, Carbon/Kevlar fibre composite, and titanium alloy, the tensile strength and fatigue resistance can be further improved, reducing the chance of landing gear failure. Other than this, the weight of the aircraft can be saved by using lighter material, therefore, during touchdown, the landing gear receives less impact.

5 Conclusion

The evolution of aircraft landing gear systems has undergone significant transformations, driven by continuous demands for enhanced safety, efficiency, and aerodynamic performance. Early designs like the Wright brothers' fixed skid landing gear laid the foundation for more complex systems. In the 1930s, Boeing's P-26 was designed with a fixed tubular truss structure, ideal for short-field operations. However, its high drag characteristics led to replacement by retractable landing gear in the 1940s as speed became a critical design factor. The era of elastic connections utilised flexible metals that absorbed impact energy through bending deformation and friction damping. While simple and low maintenance, these systems proved heavier and less efficient than emerging hydraulic alternatives.

The advent of hydraulic damping technology marked a turning point. Retractable landing gear significantly reduced aerodynamic drag, while oleo-pneumatic shock absorbers improved energy dissipation, enhancing both passenger comfort and aircraft stability. Standardised hydraulic systems ensure operational reliability, though continuous improvements remain necessary. Finally, revolutionary applications of composite materials and digitalisation, such as fly-by-wire systems, have transformed landing gear design through weight reduction, strength enhancement, and telegraphy control. These innovations have substantially improved flight safety, operational efficiency, and adaptability to high-speed aviation requirements.

Authors contribution

All the authors contributed equally, and their names were listed in alphabetical order.

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