



AEROSPACE INFORMATION REPORT

AIR5565™

Issued 2017-07
Reaffirmed 2022-09

Historical Design Information of
Aircraft Landing Gear and Control Actuation Systems

RATIONALE

This SAE Aerospace Information Report (AIR) provides historical design information for various aircraft landing gear and actuation/control systems that may be useful in the design of future systems for similar applications. It presents the basic characteristics, hardware descriptions, functional schematics, and discussions of the actuation mechanisms, controls, and alternate release systems. This AIR is intended as a reference source of information for aircraft actuation system designs. The exclusion or omission of any other appropriate actuation system or subsystem should not limit consideration of its use on future aircraft.

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1. SCOPE

This aerospace information report (AIR) provides historical design information for various aircraft landing gear and actuation/control systems that may be useful in the design of future systems for similar applications. It presents the basic characteristics, hardware descriptions, functional schematics, and discussions of the actuation mechanisms, controls, and alternate release systems.

The report is divided into two basic sections:

1. Landing gear actuation system history from 1876 to the present. This section provides an overview and the defining examples that demonstrate the evolution of landing gear actuation systems to the present day.
2. This section of the report provides an in depth review of various aircraft. A summary table of aircraft detail contained within this section is provided in paragraph 4.1.

The intent is to add new and old aircraft retraction/extension systems to this AIR as the data becomes available.

NOTES

1. For some aircraft, the description is incomplete, due to difficulties in obtaining the data.

2. REFERENCES:

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

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2.2 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5005 Aerospace - Commercial Aircraft Hydraulic Systems

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

AS1290 Aerospace – Graphic Symbols for Aircraft Hydraulic and Pneumatic Systems

SAE Paper # 760920 The Development and Flight Testing of the XC-8A Air Cushion Landing System (ACLS)

2.3 US Government Publications

Copies of these documents are available online at <http://quicksearch.dla.mil>.

MIL-O-5606 Oil, Hydraulic Aircraft, Petroleum Base (31-Jan-1950)

MIL-PRF-5606 (formally MIL-H-5606)Hydraulic Fluid, Petroleum Base, Aircraft, Missile and Ordnance

MIL-PRF-83282 (formally MIL-H-83282) Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base

2.4 General Information

European Patent Search (<http://worldwide.espacenet.com/?locale=en> EP)

The Retractable Landing Gear: its Origin and History (From Curtis to Loening to Grumman 1915 to 1950) Henry E. Prew
Nov 2008 papers

US Patent Office Website (<http://www.uspto.gov/patents/process/search/>)

Website Wikipedia for general information on aircraft

Website <http://www.smartcockpit.com/> for detail information on various aircraft

FAA website Aviation Maintenance Technician Handbook - Airframe
(https://www.faa.gov/regulations_policies/handbooks_manuals/aircraft/amt_airframe_handbook/)

2.5 References per Specific Detailed Aircraft

2.5.1 Spitfire

Spitfire and Polished Metal by Graham Moss and Barry McKee (http://simhardware.org/img/spit_book.pdf)

The Spitfire V Manual (RAF Museum Series) Greenhill Books, London

Spitfire Restoration website (<http://www.spitfirerestoration.com/>)

Spitfires and Polished Metal Restoring the Classic Fighter by Graham Moss and Barry McKee
(http://simhardware.org/img/spit_book.pdf)

2.5.2 Douglas DC-3

The DC-3 Aviation Museum (<http://www.centercomp.com/dc3/>)

Boeing website, DC-3 Commercial Transport (<http://www.boeing.com/history/mdc/dc-3.htm>)

The DC-3 Hangar website (<http://www.douglasdc3.com/>)

Quebecair Inc. Regulations DC-3 Operating Manual, Issued Jan 10, 1957.

Hydraulic Power Systems GTM 13 and Landing Gear and Brakes GTM 14 dated 1-30-05 (www.TheAviatorNetwork.com)

2.5.3 Challenger 300

Patent WO/2006/024145 *Lock Sensor for an Internally Locking Actuator* provided side brace lock group information

H. Zhang, J. Ning, and O. Schmelzer , *Integrated Landing Gear System Retraction/Extension Analysis Using ADAMS* , available at: http://web.mscsoftware.com/support/library/conf/adams/na/16_MessierDowty_landing_gear.pdf

Website RCOCO (<http://www.rcoco.com/sdoc/>)

2.5.4 Eclipse 500

Eclipse Aviation website <http://www.eclipseaviation.com/>

Mecaer website <http://www.mecaer.ca/main/>

2.5.5 Gulfstream G4 and G5

Information provided by Gulfstream

2.5.6 NHI NH90

Information provided by Stork

2.5.7 Vickers-Armstrong Valiant

Information provided by Airbus

2.5.8 Douglas DC-10

Douglas Operating manual

2.5.9 Boeing 737

Information from *The Boeing 737 Technical Site* (<http://www.b737.org.uk/>)

Information from Landing Gear Investigation Hogeschool van Amsterdam Domain Technique Aviation Studies (<http://www.bekirkoncak.com/verslag/proj5/report.pdf>)

2.5.10 Embraer 135/145

ERJ 145 information at Airliners.net. Retrieved April 19, 2010.

2.5.11 Space Shuttle

<http://spaceflight.nasa.gov/shuttle/reference/shutref/orbiter/hyd/>

2.5.12 Airbus A320

Smart Cockpit (<http://www.smartcockpit.com/plane/AIRBUS/A320.html>)

Airlinersnet.com (www.airliners.net/aviation-forums/tech_ops/read.main/216303)

2.5.13 Airbus A340

Smart Cockpit (www.smartcockpit.com/plane/airbus/A340/)

2.5.14 Bombardier Dash-8 400 series

Smart Cockpit (www.smartcockpit.com/plane/BOMBARDIER/DASH-8-400.html)

3. LANDING GEAR ACTUATION SYSTEM HISTORY

Landing gear actuation system history is constantly evolving from the basic beginnings in the early 1900s to the present day with sophisticated self-diagnostic digital systems. This section of the report provides an overview and some detail description of some of the interesting history of the evolution of aircraft landing gear retraction systems. It is not meant to capture every change in the last 100 or so years, but some of the highlights and defining innovations. It is thought that future revisions of the report can include additional key milestones, interesting designs and evolutions. Primary sources used during the writing of this AIR were the US and European Patent Office databases and various restoration websites. Readers are encouraged to access these databases for further detail and information.

This section of the report is divided into these subsections;

- 1876-1903 Prior to First Flight
- 1903-1910 The First Years of Flight
- 1910-1914 Controllable Flight
- 1914-1918 World War I
- 1918-1939 Between the World Wars
- 1939-1945 World War II
- 1945-1980 The Post War Era
- 1980-The Digital Age

Landing gear designs are as unique as the aircraft themselves. The landing gear supports the aircraft when it is not flying, allowing it to take off, land, and taxi without damage. Wheels are typically used, but skids, skis, floats or a combination of these and other elements can be deployed depending both on the surface and on whether the craft only operates vertically or is able to taxi along the surface. Faster aircraft usually have retractable undercarriages, which folds away during flight to reduce air resistance (i.e., drag).

3.1 1876-1903: Prior to First Flight

The first design for retractable landing gear was filed in French patent No. 111,574 in 1876. The design called for the landing gear to be fitted to an amphibious monoplane designed by Frenchmen Alphonse Pénaud and Paul Gauchot. It is interesting to note that powered human flight had not yet been achieved in 1876. It would be another 27 years before the Wright brothers' historic flight on December 17, 1903.

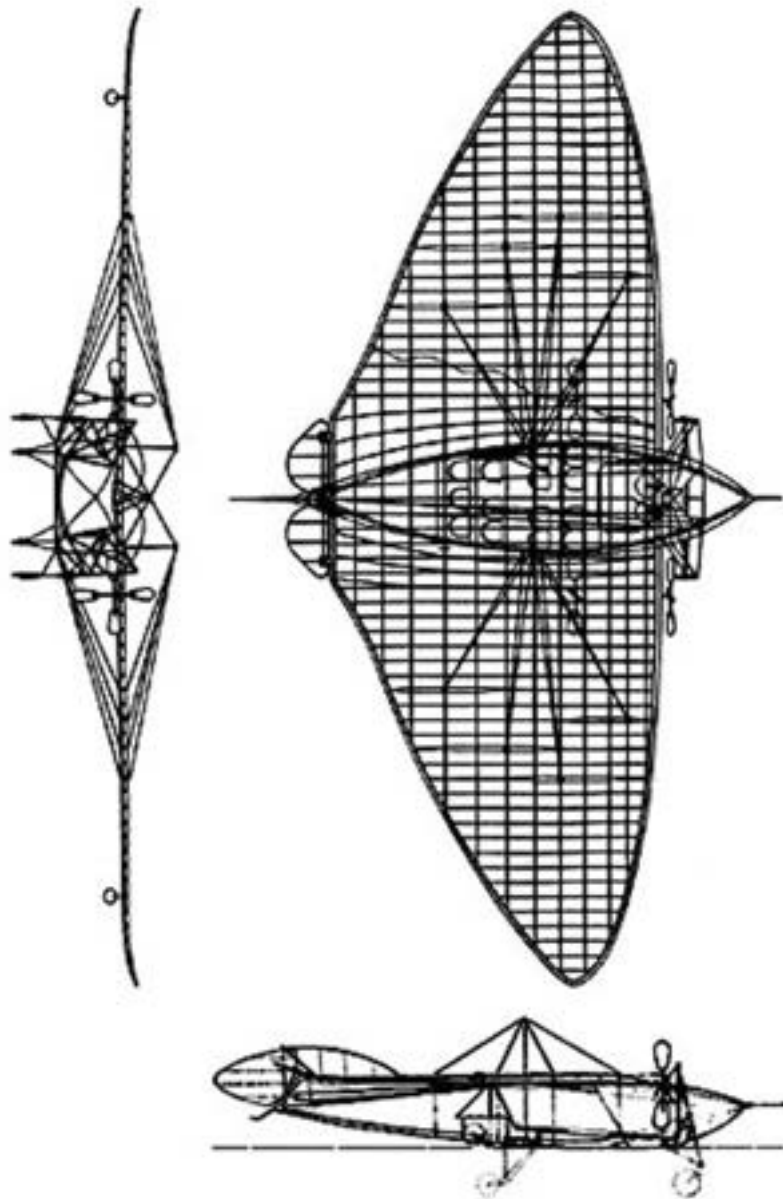


Figure 1 - Alphonse Pénaud and Paul Gauchot Retractable 1876 Landing Gear Design

The years prior to the first powered flight were alive with aviation pioneers exploring basic flight principles. These activities focused on gliders and various ways of controlling the aircraft in flight.

Starting in the 1880s, advances were made in construction that led to the first truly practical gliders. One of the first modern gliders appears to have been built by John J. Montgomery; he claimed to have made a single flight near San Diego on 28 August 1883.

The next 15 or so years focused on solving the problem of aerodynamic instability of the aircraft in flight, which birds compensate for by instant corrections, but which humans would have to address either with stabilizing and control surfaces or by moving the center of gravity of the aircraft.



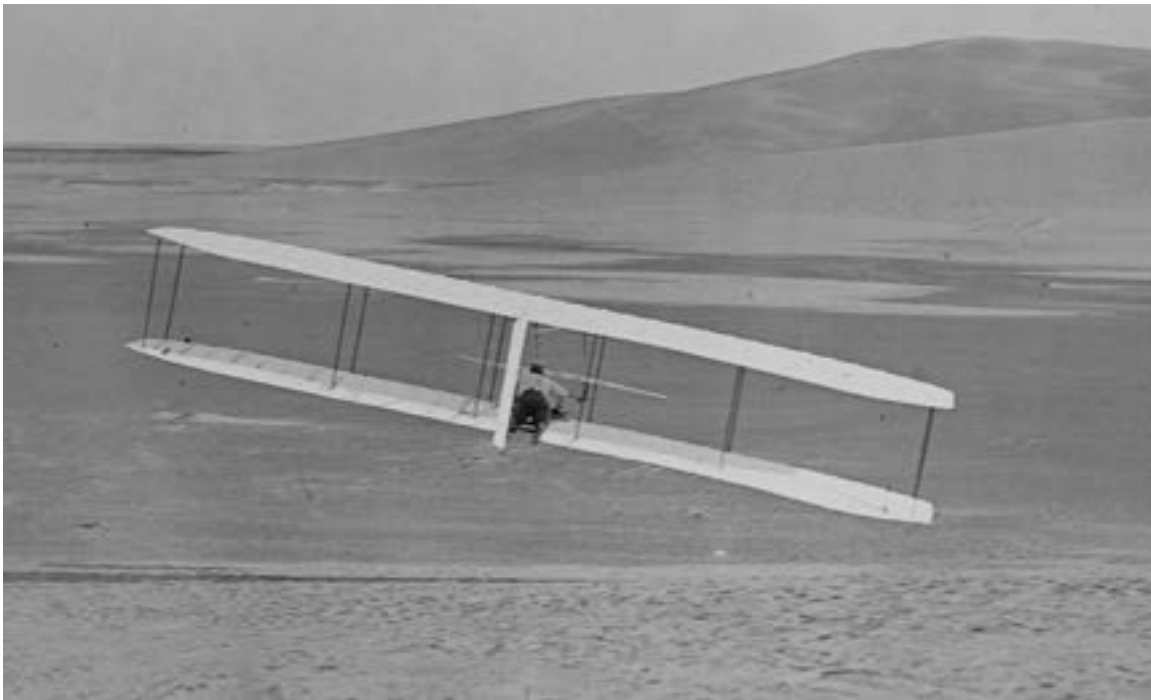
(Source: Dr. Richard Neuhauss 1895 www.lilienthal-museum.de/olma/eba1895.htm)

Figure 2 - Otto Lilienthal's "flight hill", near Berlin, Germany 1895

The Wrights solved both the control and power problems that confronted aeronautical pioneers. They invented roll control using wing warping and combined roll with simultaneous yaw control using a steerable rear rudder.

The Wrights made rigorous wind-tunnel tests of airfoils and flight tests of full-size gliders. They not only built a working powered aircraft, but also significantly advanced the science of aeronautical engineering.

They concentrated on the controllability of unpowered aircraft before attempting to fly a powered design. From 1900 to 1902, they built and flew a series of three gliders. The Wrights constructed their own wind tunnel and lift and drag measuring equipment. The 1902 glider, third in the series, became the first manned heavier than air flying machine that was mechanically controllable in all three axes: pitch, roll and yaw.



(Orville Wright (from Library of Congress)1902)

Figure 3 - Orville Wright making a right turn with the Wright Glider No. 2

Landing gear on these gliders were no more than wooden skids and the wing ribs.

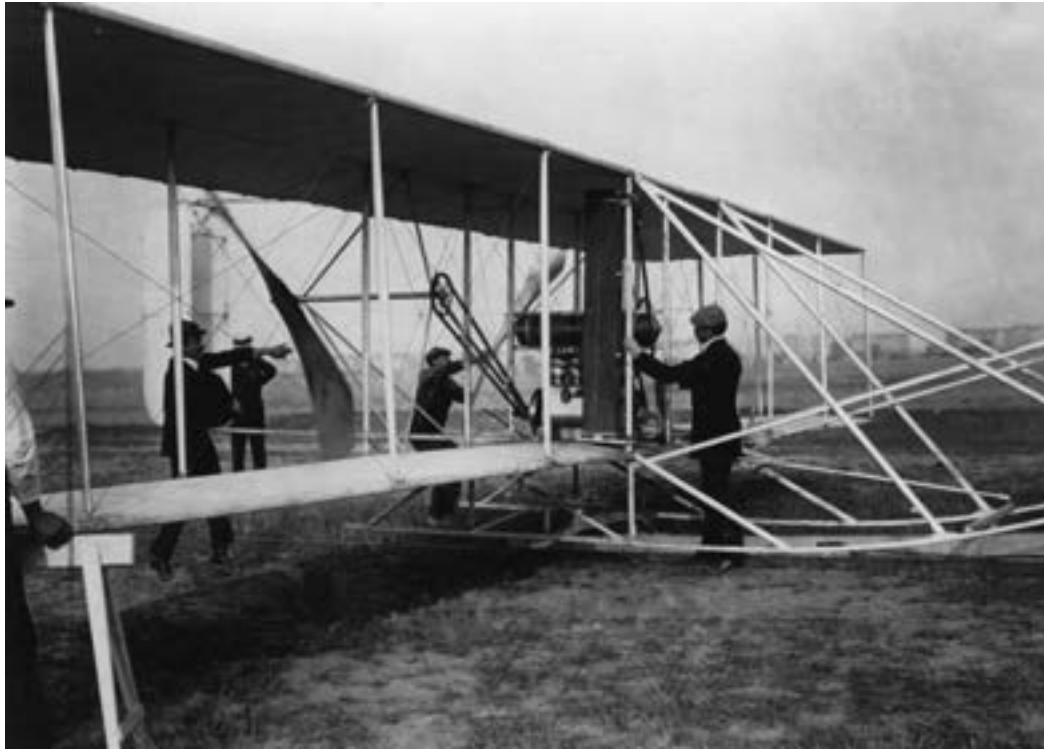
3.2 1900-1910: The First Years of Flight

The landing gear on early aircraft was a simple skid like structure that was fixed to the exterior of the airframe. The Wright Flyer is a famous example of these simple fixed skid-like landing gear structures. It used a level rail system for take-off and the skids were the landing structure.

Using their wind tunnel data, the Wrights designed and carved wooden propellers that were more efficient than any before, enabling them to gain adequate performance from their home built combustion engine. The logical next step was powered flight.

Wilbur Wright made the first attempt at powered flight on December 14, 1903 at Kill Devil Hills just south of Kitty Hawk, North Carolina, but he stalled the aircraft on take-off and damaged the forward section of the machine. Three days were spent making repairs and waiting for the return of good weather. Then, at about 10:35 on the morning of December 17, 1903, Orville made the first successful flight, covering 120 feet (36 meters) through the air in 12 seconds. Wilbur flew 175 feet (53 meters) in 12 seconds on his first attempt, followed by Orville's second effort of 200 feet (60 meters) in 15 seconds. During the final flight of the day, Wilbur flew 852 feet (259 meters) over the sand in 59 seconds. The four flights were witnessed by five local citizens. For the first time in history, a heavier-than-air machine had demonstrated powered and sustained flight under the complete control of the pilot.

On September 16, 1908, Wilbur Wright began a series of flights in France in the course of delivery to a French syndicate, ending the year with a new world record for distance and duration, covering 77.5 miles (124.7 km) in 2:20:23 and winning the Michelin trophy.



(Source Wikipedia: photographer, 1909)

Figure 4 - Orville Wright and Model A Flyer at Tempelhof Field in Berlin 1909

Although full details of the Wright Brothers' system of flight control had been published in *l'Aerophile* in January 1906, the importance of this advance was not recognized by the aviation community. The Wright brothers made no flights at all in 1906 and 1907. They spent the time attempting to persuade the U.S. and European governments that they had invented a successful flying machine. In 1908, after the Wrights' first flights in France, the critics were finally silenced.

Most European aircraft pioneers, from France and England, generally concentrated on attempting to produce inherently stable flying machines. Early work had focused primary on making a craft stable enough to fly but failed to offer full controllability, while the Wrights had sacrificed stability in order to make their Flyer fully controllable. A practical aircraft requires both. Although stability had been achieved by several designs, the principles were not fully understood and progress was erratic. The aileron slowly replaced wing warping for lateral control. Similarly, all-flying tail surfaces gave way to fixed stabilizers with hinged control surfaces attached. The canard pusher configuration of the early Wright Flyers was superseded by tractor propeller aircraft designs.

Glenn Curtiss was a pioneer aviator and leading American manufacturer of aircraft by the time of the United States' entry into World War I. Similar to the Wright Brothers, he began his career in the bicycle business. With his interest in speed, he began to build lightweight internal-combustion engines for motorcycles. Curtiss entered aeronautics in 1904 when he sold a Curtiss motorcycle engine to power the airship *California Arrow*. At the invitation of Alexander Graham Bell, he joined the newly formed Aerial Experiment Association (AEA) in 1907. Flying the AEA June Bug at Hammondsport, N.Y., on July 4, 1908, Curtiss won the Scientific American Trophy for the first public flight of at least 1 km (0.6 mile) with an American airplane.

Another member of the AEA, John A. McCurdy made the first Canadian powered flight in 1909. The aircraft, the Silver Dart, took off from the frozen Bras d'Or Lake at Baddeck Bay, Nova Scotia, Canada. This was the first flight by a British subject anywhere in the British Commonwealth and the first airplane to fly in Canada. The AEA initially consisted of three people: Dr. Alexander Graham Bell, John McCurdy and Frederick (Casey) Baldwin. Glenn Curtiss joined the group after its inception. It was a famous group, as Dr. Bell had invented the telephone, and Baldwin was the first British subject ever to fly (a flight he made in the U.S.A.).



(Source: Photo: RE-12378-22, Canadian Department of National Defence Archives)

Figure 5 - John A. McCurdy and the Silver Dart on the frozen Bras d'Or Lake in February 1909

The aircraft was potentially the first to incorporate a fixed tricycle wheel landing gear arrangement.

3.3 1910-1914: Controllable Flight

The Wright Model B was a pusher biplane designed by the Wright brothers in 1910. It featured a true elevator carried at the tail rather than at the front in a canard configuration. This yielded more longitudinal stability than the Wright's original flying machine. It was the last Wright model to have an open-frame tail. The Model B was a dedicated two-seater with the pilot and a passenger sitting side-by-side on the leading edge of the lower wing. Wheels were added to the fixed landing gear skid.



(Source: Wikipedia: Wright Model B reproduction on display at the Farnborough Airshow 2008 photo by MilborneOne)

Figure 6 - Wright Model B Incorporating Wheel Fixed Landing Gear

By 1910 improvements in aircraft speed drove aircraft designers to start to look at the drag effects of the landing gear on the aircraft. Some attempts were made to streamline the struts and wheels with cowlings and fairings.

Harold D. Boulton Patent No. 17291 issued in 1910 described his patent as "Aerial machines adapted to travel also on land; starting; shock of landing, deadening"-*The undercarriages of aerial machines which carry the wheels, runners, etc. for supporting the machines when running on the ground, are adapted to be drawn up into the bodies of the machines in order to reduce the resistance when in the air. In the form shown, a wheel **A** is carried by pivoted struts (see Fig 1) and links **c**, connected pivotally to slides **d'** on guide-rods **b**. The wheel is maintained in the normal position by stops, such as catches **g**, which can be withdrawn by a foot-press **h** when the wheel and **c**. is to be raised by the winch **j** and cord **k**. The wheel may be sprung by an arrangement of internal or external springs **m** on the struts **c**.*

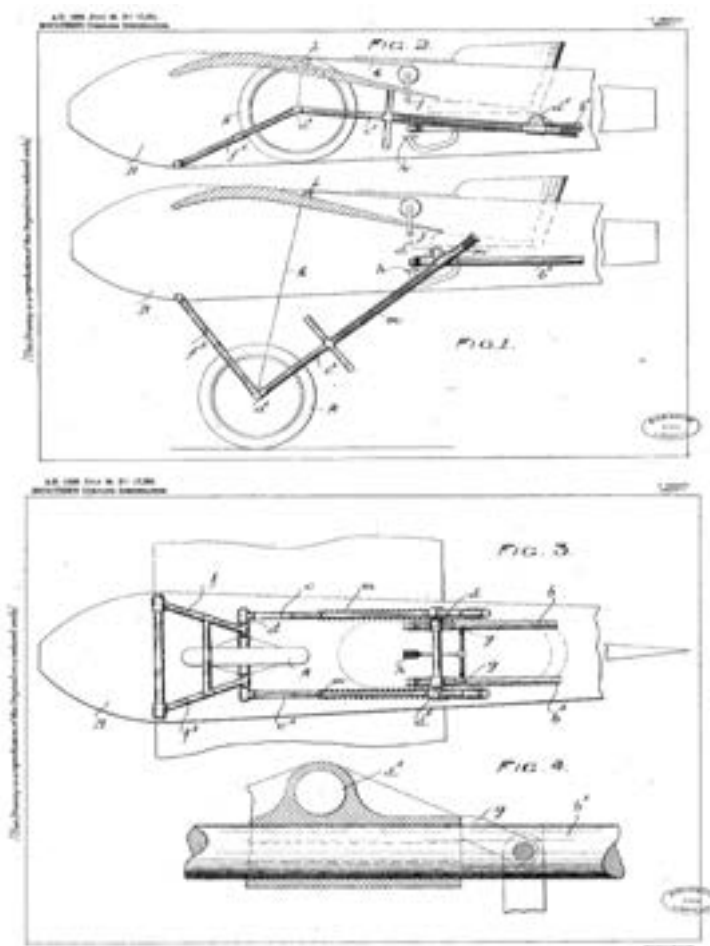


Figure 7 - Harold D. Boulton Great Britain Patent No. 17,291

Harold E. Boulton designed one of the first monoplanes. This was a single-seat, mid-wing monoplane, with a 12 horsepower rotary engine. The wing was constructed of wood and warping was used for lateral control. The landing gear, fitted with long coil springs, was raked well forward. It was to be retractable in flight and was covered by GB patent 17,291 granted in 1909.

The patent followed on to also described how to enclose the fuselage wheels openings in the fuselage with landing gear bay doors as described in patent 17,433. It was stated but not shown that these doors would be driven by the same mechanism.

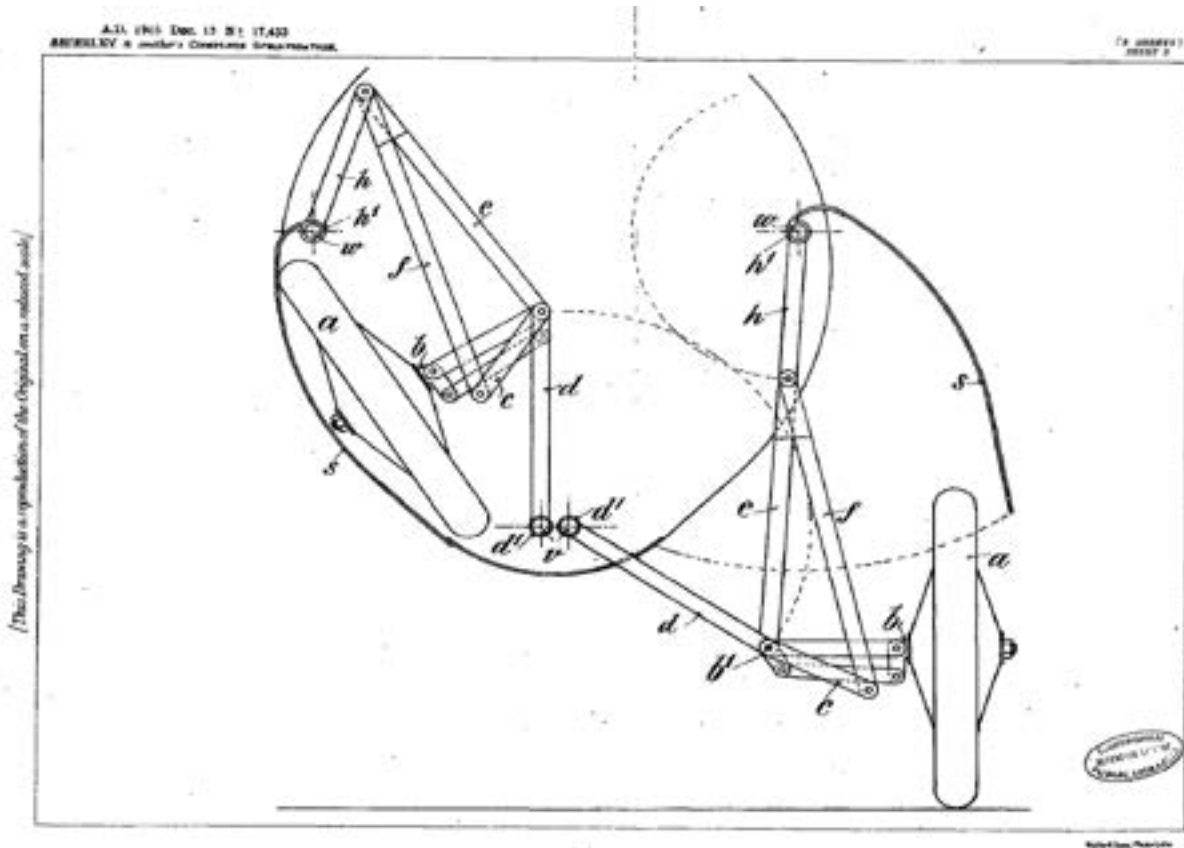


Figure 8 - Great Britain Patent No. 17,433 Harold E. Boulton designed Retractable Landing Gear

Various other flight machine inventors starting filing a series of patents describing retraction mechanisms and landing gears stowing into the body of the aircraft.

Ranfft, Great Britain patent 9,981 of 1909 and Keppel, US patent 1,026,677 described hand-operated screws, cranks, levers, etc., for putting wheels or landing gear up and down.

Ranfft, Great Britain patent # 9,981 of 1909 and Blondin, US patent 989,520 described power operated means for actuating the landing gear.

Various patents filed described the landing gear retracting into a body and/or a wing. They include:

- Boulton, Great Britain patent 17,291 of 1909
- Desvignes & Denhaut French patent 448,585
- Donnet Leveque Great Britain patent 16,776 of 1912.
- Hartly US patent 1,068,652 of 1913
- Francis US patent 1,083,394 of 1914
- McCarroll US patent 1,097,816 of 1915

Weber, French patent 430,670 of 1911 described retractable wheels that are maintained on a transverse arrangement that can swing aftward.

Rumpler, German patent 256,610 of 1911 describes an airplane with a retractable landing gear having wheels, which may be swung upward and aftward upon a folding frame, and which go into holes in the wings of the airplanes.

Walter Brierley patent GB (Great Britain) 17,433 from 1915 described a retractable landing gear mechanism for "aerial machines adapted to travel also on land; shock of landing, deadening. -A landing-chassis for aeroplanes comprises two parts each carrying a landing-wheel and being adapted to be folded up within the fuselage during flight. (Refer to Fig 1 and 2 below) Each wheel **a** is carried by a stud-axle **b** pivoted at **b¹** to a frame **c**, **e**, **f**, which is connected to the fuselage by links **d**, **h** so that the whole may be folded up within the fuselage, as shown at the left-hand side of patent Fig. 1. Elastic cables **x** further connect the axle **b** to the frame **c**. Locking-devices are provided to retain the chassis in either position. When the width of the fuselage is sufficient, the links **h** may be dispensed with, the frame **c**, **e**, **f** being directly pivoted to the fuselage. In a modification, the axle **b** is connected to the frame **c**, **e**, **f** by a parallel-motion linkage. Springs may be introduced in the linkwork, and the axles may be provided with springs to take up horizontal oscillations. The chassis may be adjusted longitudinally of the fuselage."

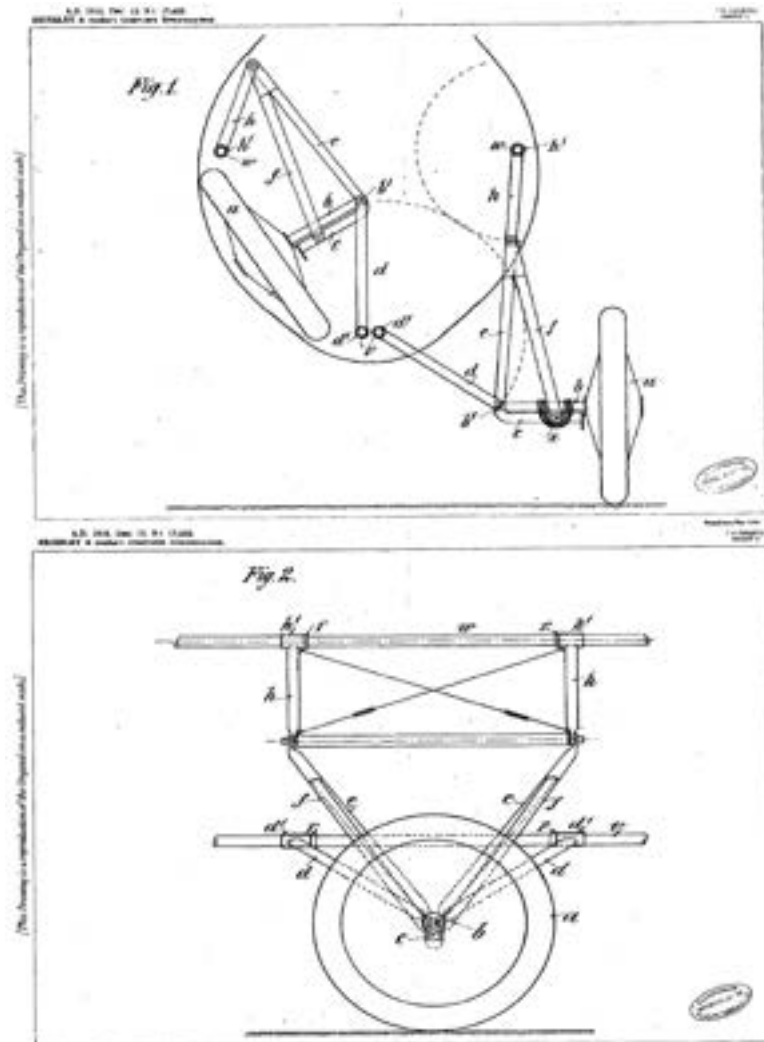


Figure 9 - British Patent 17,433 Retractable Landing Gear, 1915

Frank McCarroll, who said that he got the idea from watching a buzzard draw its legs in during flight, was granted a patent for a retractable aircraft landing gear. The application was filed on Nov. 3, 1911.

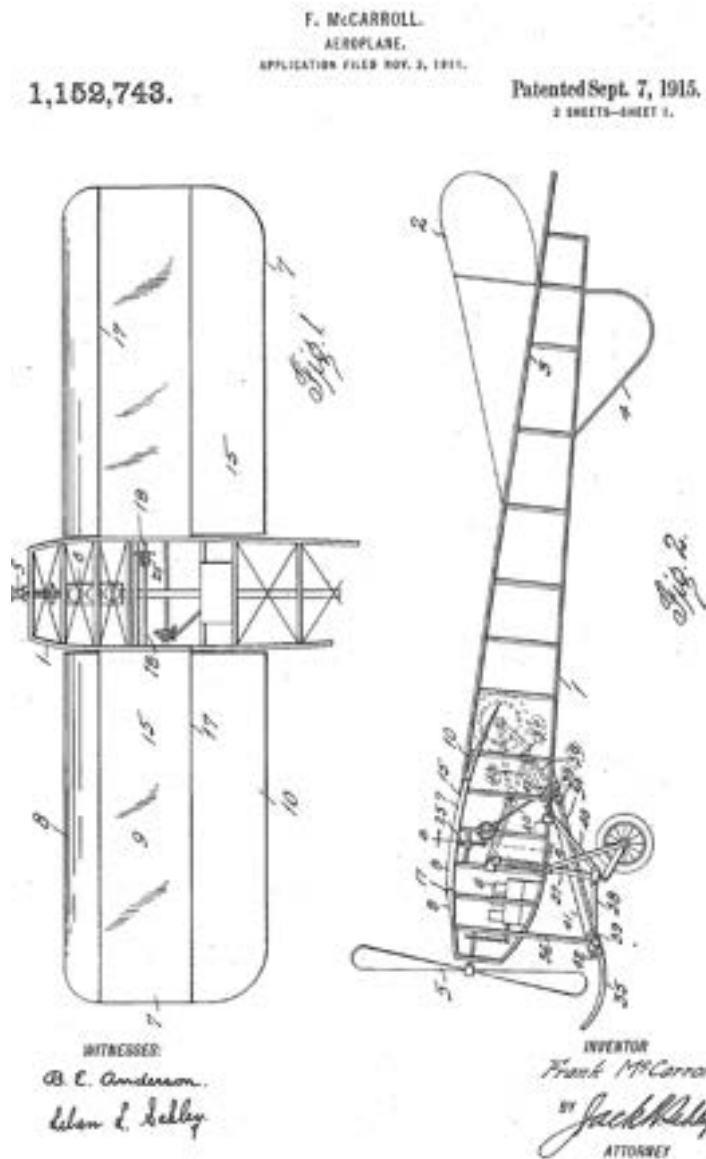
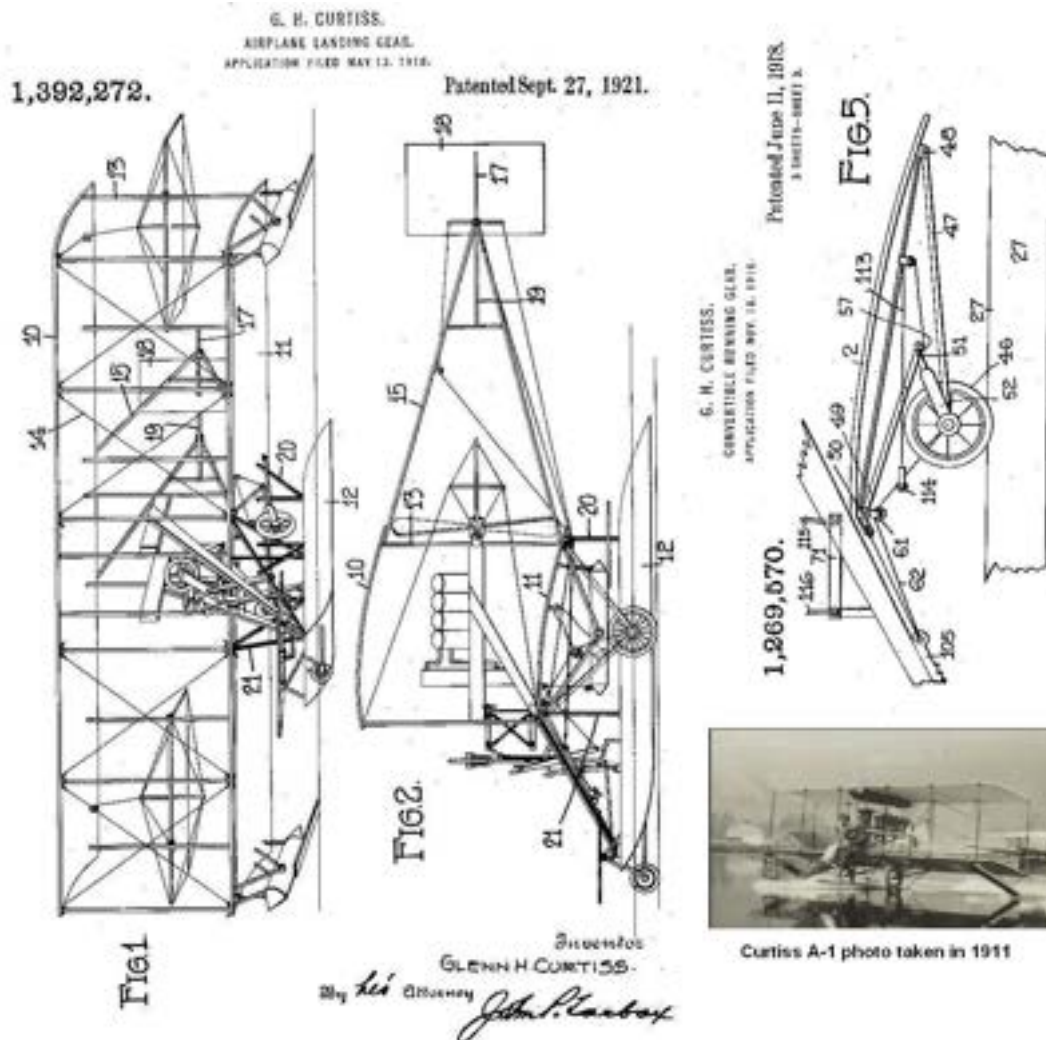


Figure 10 - U.S. Patent 1,152,743 Retractable Landing Gear

Curtiss led the design and manufacture of flying boats in the United States. Curtiss aircraft were the first to make a takeoff (1910) and a landing (1911) from the deck of a warship. With World War I approaching, Curtiss became a major supplier of flying boats to the United States and allied European governments. In 1911, Glenn Curtiss converted his flying boats to amphibians by adding wheels with means to simply lift the wheels out of the water and extend them when required for land operations. He filed various patents on the subject. The landing gear were manually retracted and secured up with a detent. Once released, the gears free fell and locked down automatically.



(Source: unknown photographer 1911)

Figure 11 - Glenn Curtiss Retractable Landing Gear U.S. Patent 1,392,272

Aircraft with at least partially retractable landing gear did not appear until 1911, and it was not until the late 1920s and early 1930s that such aircraft became common. Grover Loening's military aircraft designs were among the first routinely using them for the main landing gear, in a system which was later licensed and used by the Grumman company.

By then, aircraft performance was improved to the point where the aerodynamic advantage of a retractable undercarriage justified the added complexity, weight and interior space penalties.

3.4 1914-1918: World War I

Almost as soon as they were invented, airplanes were used for military purposes. The first country to use them for military purposes was Italy, whose aircraft made reconnaissance, bombing and artillery correction flights in Libya during the Italian-Turkish war (1911–1912). The first mission (a reconnaissance flight) occurred on October 23, 1911. The first bombing mission was flown on November 1, 1911. The first war to see major use of airplanes in offensive, defensive and reconnaissance capabilities was World War I. The Allies and Central Powers both used airplanes and airships extensively.



(Source: 1916 - Library of Congress Collection)

Figure 12 - Aeroplane and Transport, 1st Aero Squadron, Fort Sam Houston Texas 1916

Improved aircraft and engine designs resulted in increased horsepower and increase in speed. However, the landing gear of these early aircraft remained relatively unchanged with most aircraft employing fixed wheel landing gear.

Manfred Albrecht Freiherr von Richthofen (widely known as the Red Baron,) was a German fighter pilot with the Imperial German Army Air Service during the First World War. He is considered the 'ace-of-aces' of the war, being officially credited with 80 air combat victories. Richthofen's famous aircraft was the Fokker Dr. I triplane. This aircraft used solid wheels (versus spoked) and a wing like structure over the axle to cut down aerodynamic drag of the landing gear and provide added lift.



(Source: https://en.wikipedia.org/wiki/Manfred_von_Richthofen#/media/File:Fokker_Dr1_on_the_ground.jpg, circa 1917-18)

Figure 13 - Richthofen's all-red Fokker Dr.I. Triplane

Thijs Postma's watercolor painting depicts what Richthofen's all-red Fokker Dr.I. Triplane would have looked like in the skies in 1917-1918.



(Source: <http://www.thijspostmaaviation.nl/> Thijs Postma's Painting)

Figure 14 - Richthofen's all-red Fokker Dr.I. Triplane - Thijs Postma's Painting

3.5 1918-1939 Between the World Wars

The years between World War I and World War II saw significant improvements in aircraft technology. Airplanes evolved from low-powered, wood and fabric biplanes to aerodynamically refined, high-powered, aluminum monocoque monoplanes.

Aircraft displays and airshows became popular, and air racing drove the design and streamlining of aircraft (as well as increased engine power). As aircraft got faster, drag of the landing gear became a significant performance factor. There were several ways to reduce the drag of the landing gear: retract the landing gear inside the aircraft or redesign a fixed landing gear so that it produced less drag while still protruding below an aircraft.

When designing an aircraft, engineers have always had to address five conflicting requirements. These are: performance, weight, cost, reliability, and maintenance. The best solution to the performance requirement was to retract the landing gear completely inside the aircraft and seal the apertures, presenting a smooth surface that minimised drag. While ideal from a performance standpoint, this approach affected all of the other requirements, as it weighed more, cost more, was less reliable, and required more maintenance.

The Boeing Monomail, which first appeared in 1930, and the Lockheed Orion are generally considered pioneers in the development of a practical retractable landing gear.

However, other designers such as Jack Northrop took a different approach. He was very interested in streamlining aircraft to improve performance and, produced the Northrop Alpha, Beta, and Gamma with fixed landing gear during the 1930s. These aircraft had streamlined fairings that extended down from the fuselage, with the wheels sticking out at the bottom. These were generally referred to as *trouser gears*.

The Lockheed Sirius, which was built for Charles Lindbergh, had streamlined coverings over the wheels. These were referred to as *spats* or *pants* type landing gear. They produced more drag than fully retracted gear, but they were still a substantial improvement over uncovered landing gear. They were still lighter, cheaper, more reliable, and easier to maintain than the retractable gear. During the 1930s, numerous designers embraced retractable gear. They were willing to accept the other drawbacks of retractable landing gear to achieve improved performance.



(Source: <http://zelastchancegaragedu78.blogspot.ca/2009/09/northrop-gamma-2a-sky-chief.html>)

Figure 15 - Northrop Gamma 2 had landing gear with streamlined coverings that extended down from the fuselage with the wheels protruding from the bottom

Numerous ways to retract aircraft landing gear into the fuselage were considered in this period. In some aircraft the landing gear was retracted straight upwards, usually into cowlings behind the engines (such as the DC-3), and often with a portion of the wheels protruding. In other cases, the struts folded inward so that the wheels retracted into the bottom of the fuselage, sometimes covered with a door to further reduce drag. Drive mechanisms varied, and were electric, hydraulic or mechanically actuated.

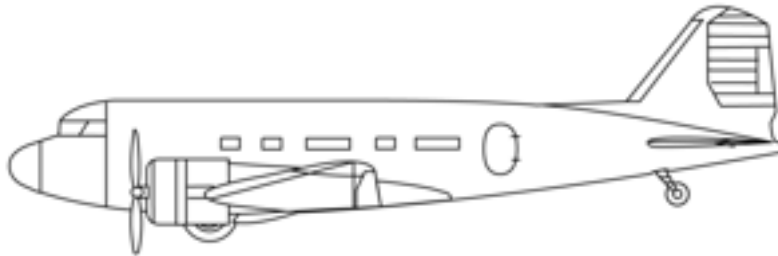


Figure 16 - DC-3 Wheels Partially Protruding When Retracted

The trade-off between extra weight and complexity of the retractable landing gear and the resulting reduced drag was not always evident for aircraft at lower cruise speeds. However, as aircraft began to reach cruise speeds of 200 mph (322 km/h) in the 1930s, the increased weight of retractable gear became less important than reducing drag, and retractable landing gear became commonplace.

Reviewing some specific aircraft and patents illustrates the innovations that took place in aircraft incorporating retractable landing gear in this era.

The Dayton-Wright RB-1 (Rinehart-Bauman model one), also known simply as the Dayton-Wright Racer was a racing aircraft developed in the United States to participate in the 1920 Gordon Bennett Cup air race. The aircraft was a high-wing monoplane with a monocoque fuselage and cantilever wing. The aircraft also featured a retractable undercarriage operated by a hand-crank making it one of the first instances of undercarriage retraction for aerodynamic benefit alone. The aircraft was designed by Orville Wright and Milton Baumann. The unusual design for the time was a tailskid undercarriage with the main units designed to retract into the lower fuselage sides. The landing gear was hand-operated using a chain-and-sprocket system. It could be raised in 10 seconds and lowered in six seconds.

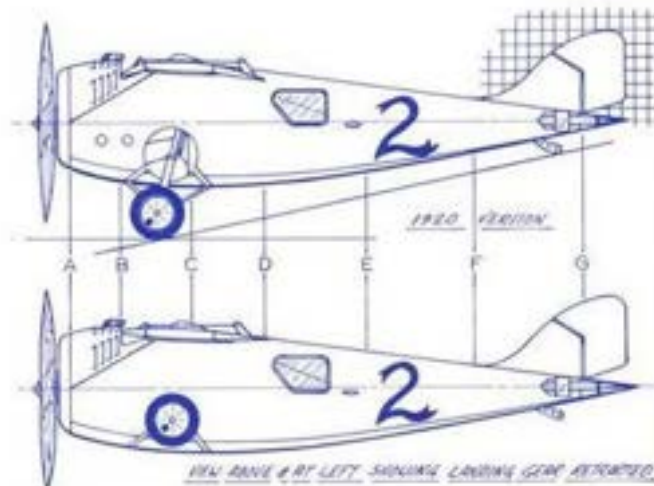


Figure 17 - Dayton-Wright RB-1 1920

Milton Baumann retractable landing gear patent (US 1,718,189) uses a lead screw to retract, extend and lock the landing gear. This concept was employed in many aircraft designs of this era. Typically, a simple ACME thread lead screw was employed coupled to a handle and gearbox of gears and shafts. The pilot would have to wind the gear up and down. The ACME screw system was self-locking. Extra pilot effort/workload during the take-off and landing phases of the flight were required in addition to flying the aircraft.

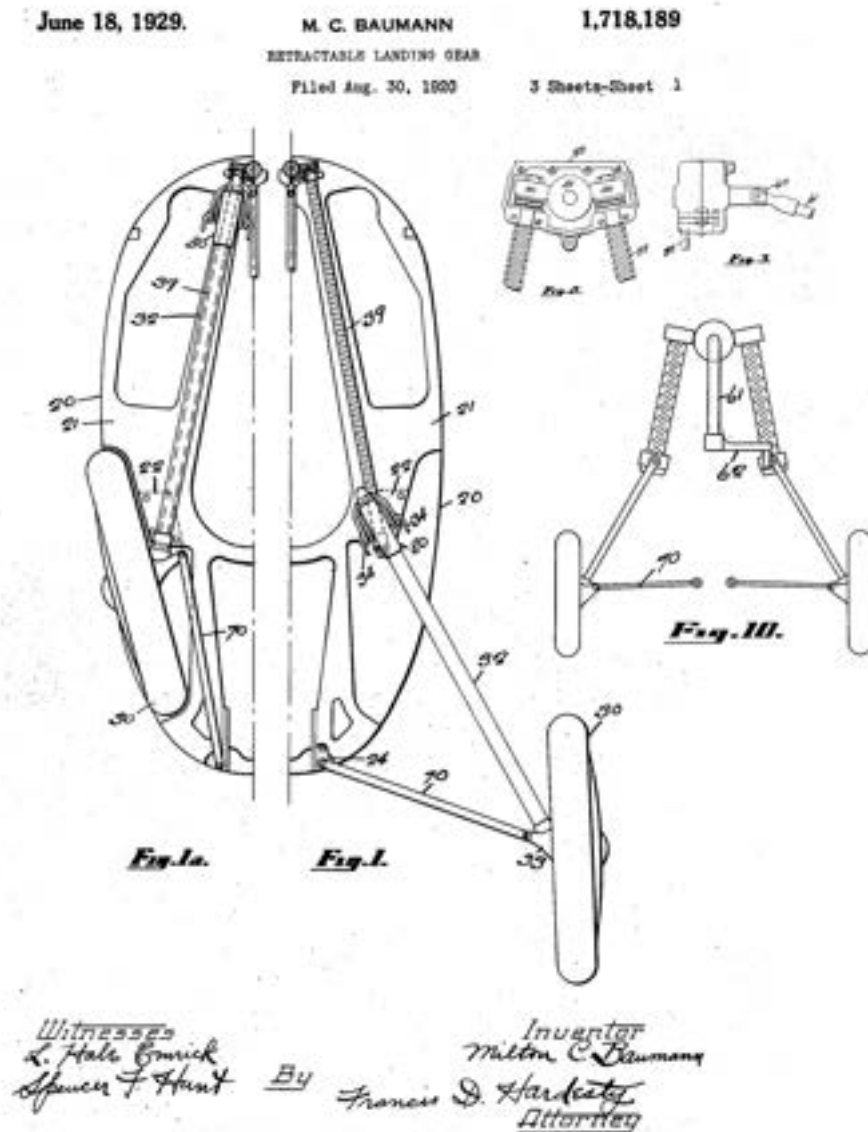


Figure 18 - Milton Baumann Retractable Landing Gear, U.S. Patent 1,718,189

Grover Loening introduced and established the retractable landing gear design in a series of biplane amphibians during the 1920s and 1930s. He employed his own patented design for a body/float amphibian biplane with a semi submerged retractable landing gear which was manually retracted. He help the newly formed Grumman (founded by a number of his former employees) initiate contracts, orders and financing for its first official 1932 US Navy contract for a float plane with retractable landing gear. The Grover Loening company eventually closed in 1933. During World War II, he was chief consultant to the War Production Board, National Advisory Committee for Aeronautics and Grumman.

His patented retractable landing gear design became the basis for essentially identical installations on more than a dozen of Grumman's Navy fighter and other military/commercial designs over the 1940s and 1950s. Other companies copied the design on other aircraft into the 1970s.

Grover Loening's patent (US 1,545,505) shows the use of ACME lead screws and gears to retract the landing gear on an amphibian aircraft. The wheels are completely retracted out of the water during water activities, which greatly reduced the drag during take-off and landings on the water and are deployed during land based activities when required.

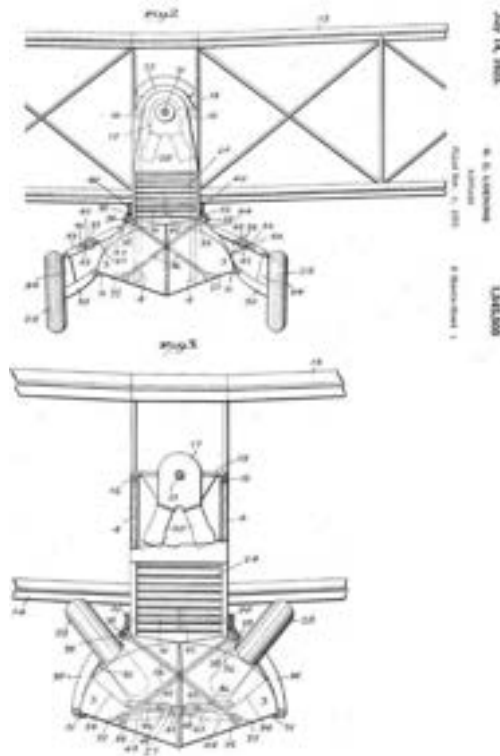


Figure 19 - Grover Loening, U.S. Patent 1,545,505

Flavius Loudy's US patent 1,554,221 offered a unique rotating mechanism as a means to stow the wheel. A series of chain drive sprockets and lead screws would lock the axis of the wheel in the vertical or horizontal position. Side loads would have to be reacted in the mechanism to prevent the wheels from folding over.

Sept. 22, 1925.

1,554,221

F. E. LOUDY
RETRACTABLE LANDING GEAR
Filed April 8, 1924

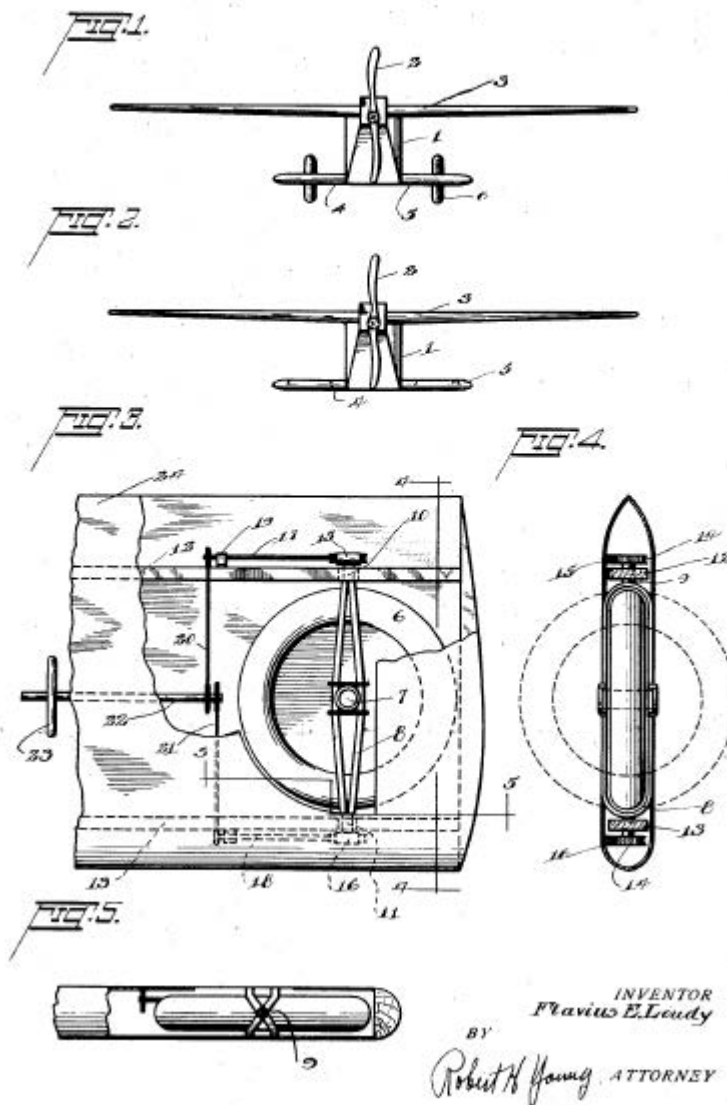


Figure 20 - Flavius Loudy's Retractable Landing Gear, U.S. Patent 1,554,221 (1925)

James Kindelberger's patent (US 1,729,878) introduced the first use of a pneumatic actuator (item # 39 in patent figure below) to retract and extend an amphibian center pontoon which was directly connected to the landing gear for land and water use.

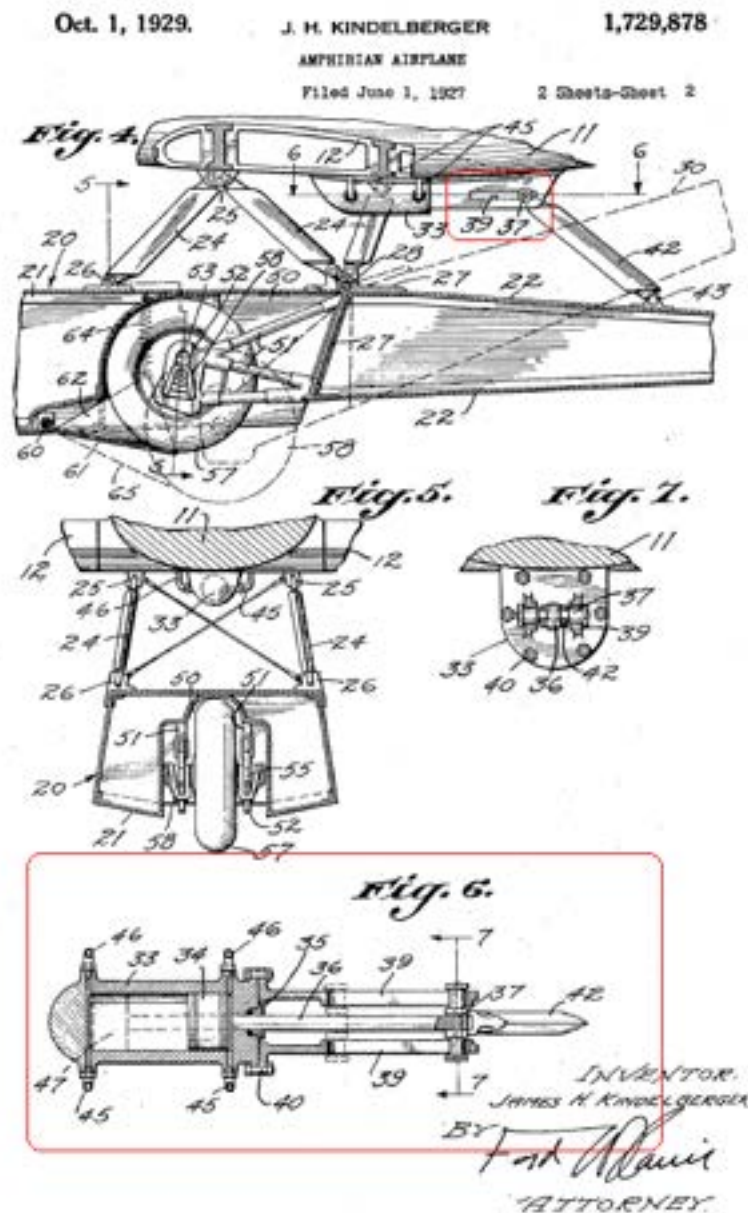


Figure 21 - James Kindelberger, U.S. Patent 1,729,878 (1929)

Isaac Laddon's patent (US 1,768,696) introduced the first use of hydraulics to both retract the landing gear and also provide a landing load damping device. A hand pump was used to provide hydraulic pressure via a control valve to an actuator. A valve was located in the head of the actuator that was set to 1.5g load so it would open and limit the load that the aircraft saw from landing and taxi operations. The pilot had the ability to lower or raise the gear for ground propeller clearance.

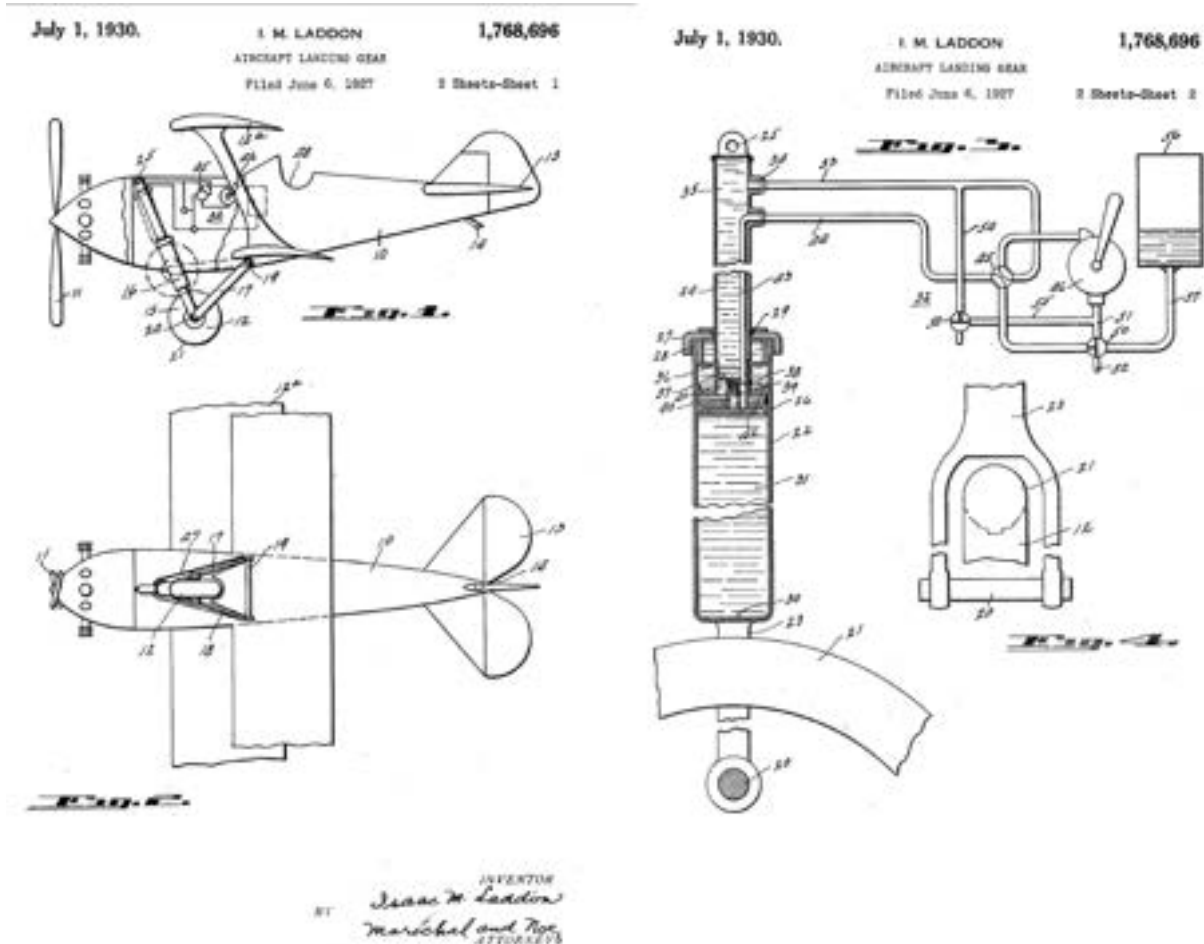


Figure 22 – U.S. Patent 1,768,696 Hydraulic Retraction Actuator (1927)

In the same year, Grover Loening built on his previous patent and introduced an electric reversing motor, that powered a series of gears and jack screws in US patent 1,563,384. The jack screws moved the wheels from a down and locked position to an up position. The motor ran on a 12 V battery. A handle located in the cockpit controlled the motor. A feedback control box was gear timed with the landing gear motion to shut off automatically in the up and down positions. The operation was similar to how a modern day garage door motor drive unit works today.

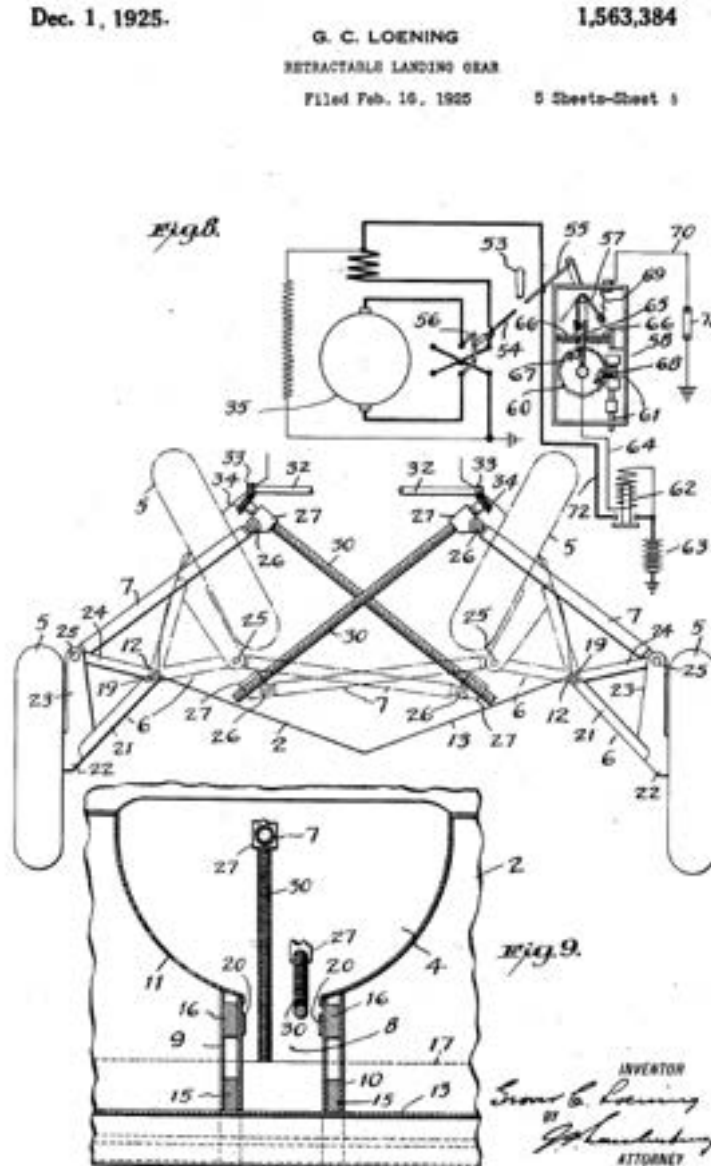


Figure 23 - Grover Loening, U.S. Patent 1,563,384

Leroy Randle "Roy" Grumman was an American aeronautical engineer, test pilot, and industrialist. In 1929, he co-founded Grumman Aeronautical Engineering Co., later renamed Grumman Aerospace Corporation, and now part of Northrop Grumman. In his early years, he worked at Curtiss as a test pilot and later at Loening Aeronautical Engineering Corporation and Keystone Aircraft as a project engineer. In early 1930, Grumman and other ex Loening employees help set up Grumman Aeronautical Engineering Co.

Grumman worked on a design for the US Navy and was awarded US Patent 1,859,624 Retractable Landing Gear for Airplanes in 1932, based on an earlier design that he had developed for the Loening Air Yacht. The manually operated landing gear which progressed from a heavy and unreliable design to a sturdier version helped his company win contracts from the U.S. Navy. When the Grumman Company received its first U.S. Navy production contract for a two-seater biplane fighter, the FF-1, it featured Grumman's trademark "splayed out" landing gear.

By the mid-1930s, he began to design aircraft for the commercial market with the development of the G-21 "Goose" amphibian and the G-22 "Gulfhawk", the civil version of the Grumman F3F carrier-based fighter.

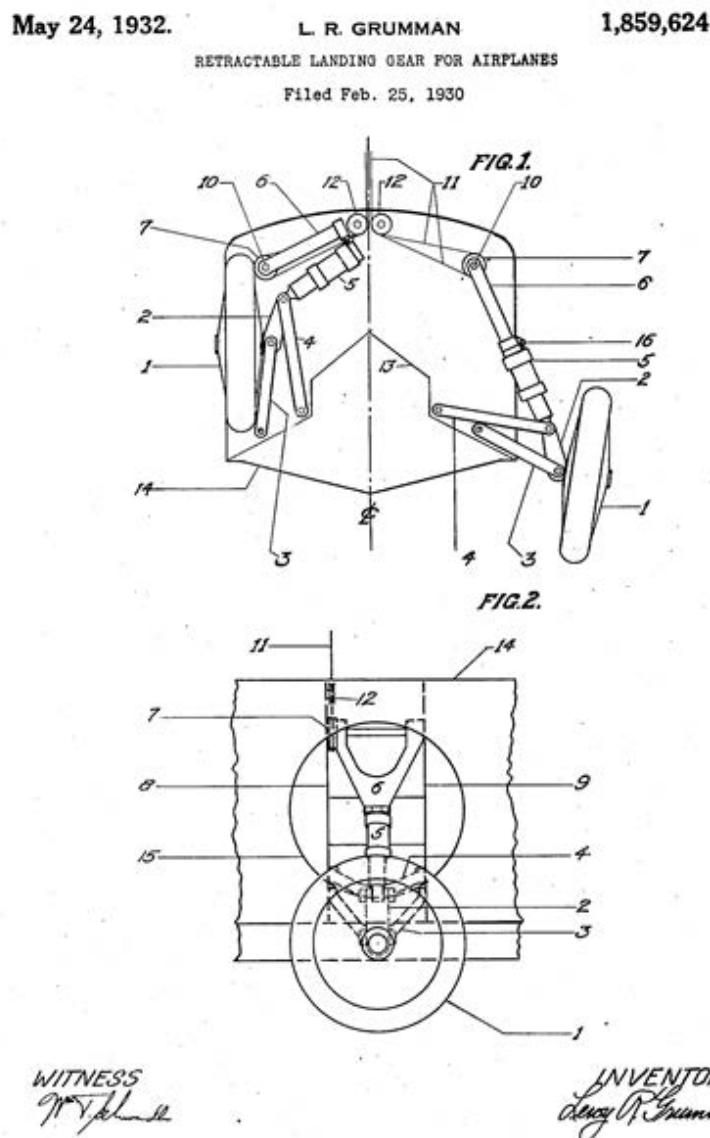


Figure 24 - Grumman, U.S. Patent 1,859,624 (1930)

US Patent 1,919,524 (retractable landing gear) was filed by Robert J. Minshall, who worked for the Boeing company. He introduced a retraction mechanism that incorporated brake control input rods to apply the brakes on retraction in 1933.

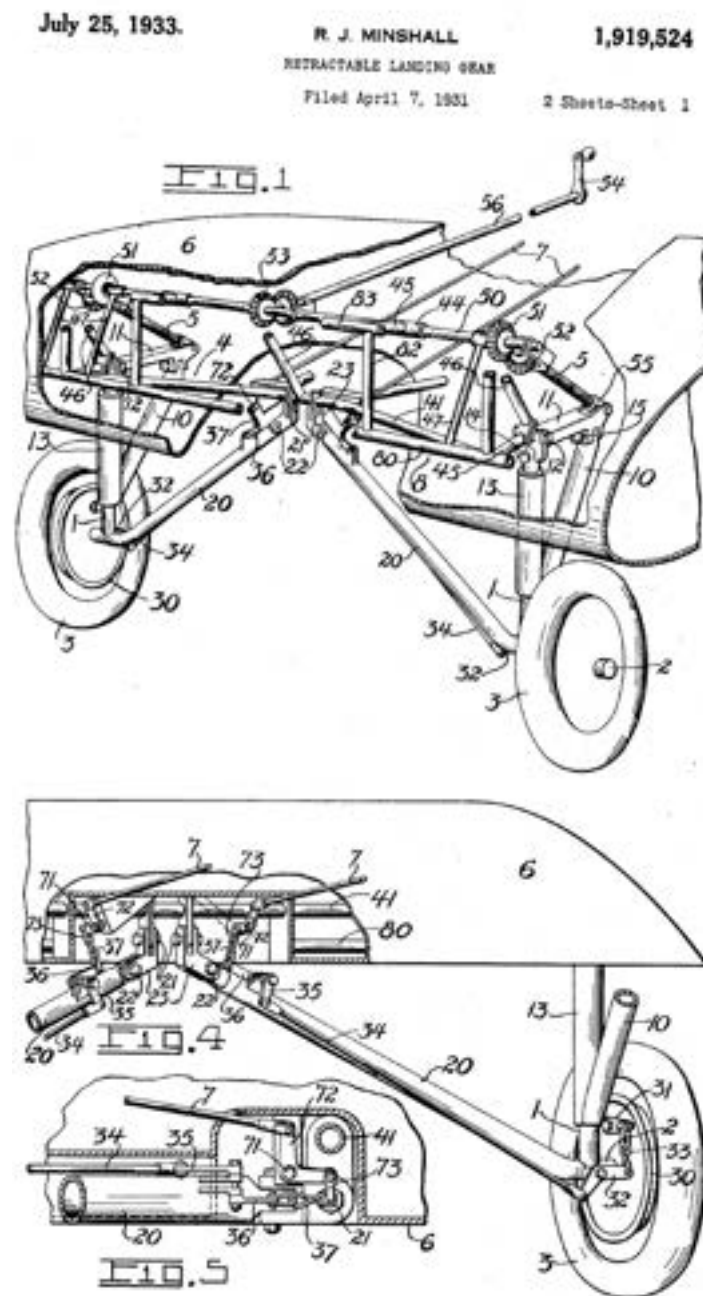


Figure 25 – U.S. Patent 1,919,524 (1933)

Holland Dwell (US patent 1,929,630) used a hand operated crank and transmission shafts and bevel gears to rotate the amphibian floats and fixed wheels through 180° to change from water landings to wheels on land.

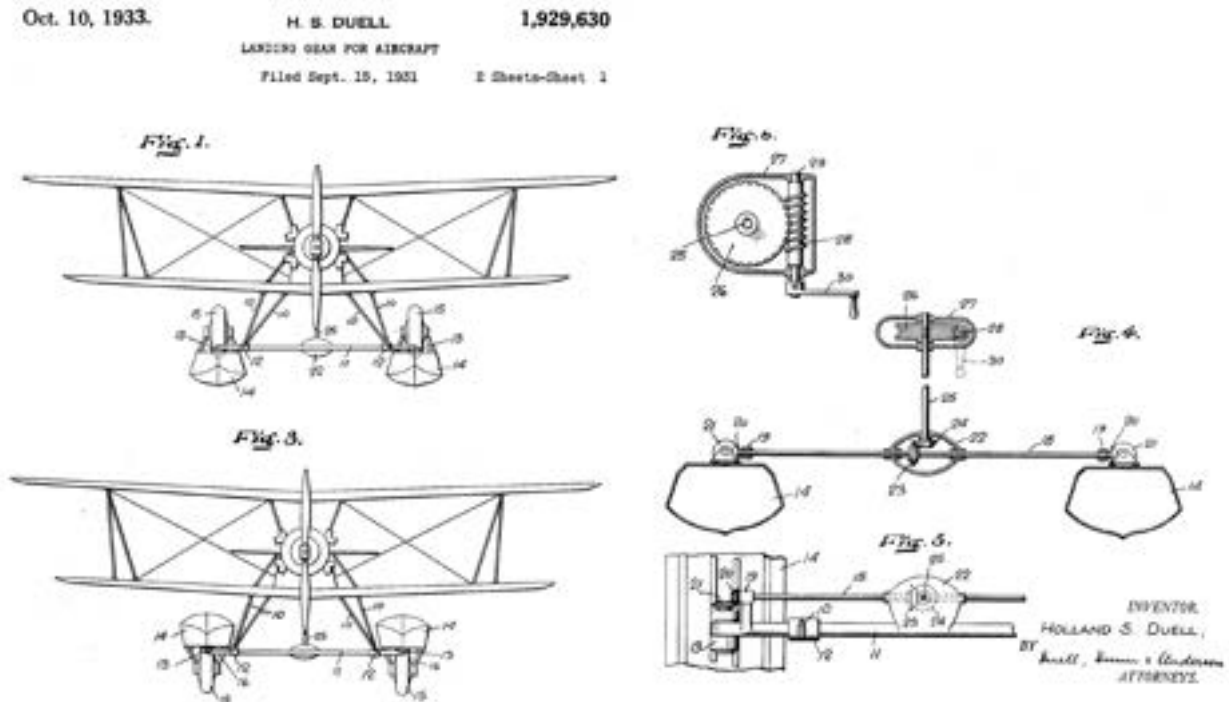


Figure 26 – U.S. Patent No. 1,929,630 (1933)

Francis Brown of London patented a gear down warning device to inform the pilot of the position of the landing gear using both visual and audio warnings. The patent includes an electrical warning device that monitors air speed of the aircraft and gear down position. The aircraft airspeed would create pressure on a diaphragm (item #16 in figure below), which would deflect a relay switch. The pilot would be able to see the state of the gears by lights in the cockpit. If the airspeed was too low and the gear was in any retracted state a horn would also sound. The system could be bypassed on the ground for maintenance purposes.

May 10, 1938.

F. V. BROWN ET AL

2,116,960

WARNING AND INDICATING DEVICE FOR AIRCRAFT

Filed May 4, 1937

2 Sheets-Sheet 1

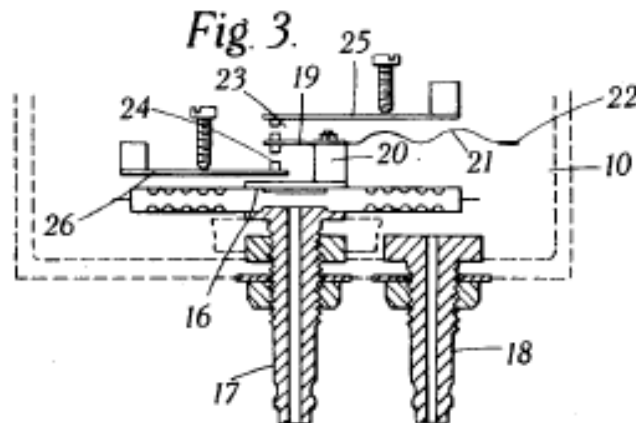
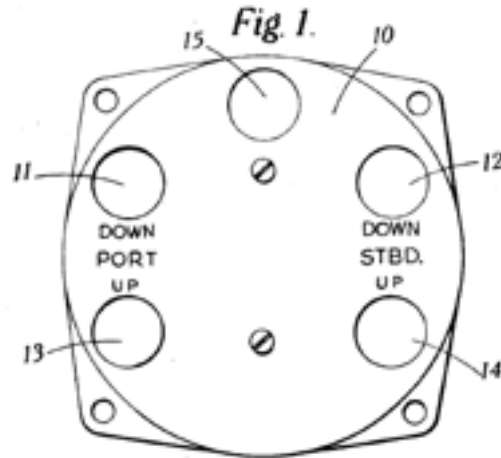


Figure 27 – U.S. Patent 2,116,960 (1938)

Clinton Howard's patent No. 2 128 250 proposed a solution to warn the pilot of a gear up landing by introducing a rudder pedal foot obstruction. He states the existing technology, horns and lights, are not sufficient to warn the pilot.

He writes in his patent, "With the advent of retractable landing gears the Army Air Corps issued exhaustive instructions, supplemented by both audible and visual signaling devices, seeking to safeguard a pilot against the landing of his aircraft with gear retracted. Despite the foregoing precautions, serious accidents continued to reoccur. It became increasingly apparent that power plant noise deadens a pilot's reaction to audible signal and that the great complexity of instrument reading incident to the pilotage of military aircraft equally deadens a pilot's certain reaction to visual signal. It was in the solution of the above problem that the invention came into being and was adopted as an essential part of all military aircraft equipped with retractable landing gears. A particular embodiment of our invention consists in providing the brake and rudder control pedals of an aircraft equipped with retractable landing gear with auxiliary treads adapted to be impelled against the soles of the pilot's feet whenever the power plant of said aircraft is throttled below sustained flight with the landing gear in any degree of retraction."

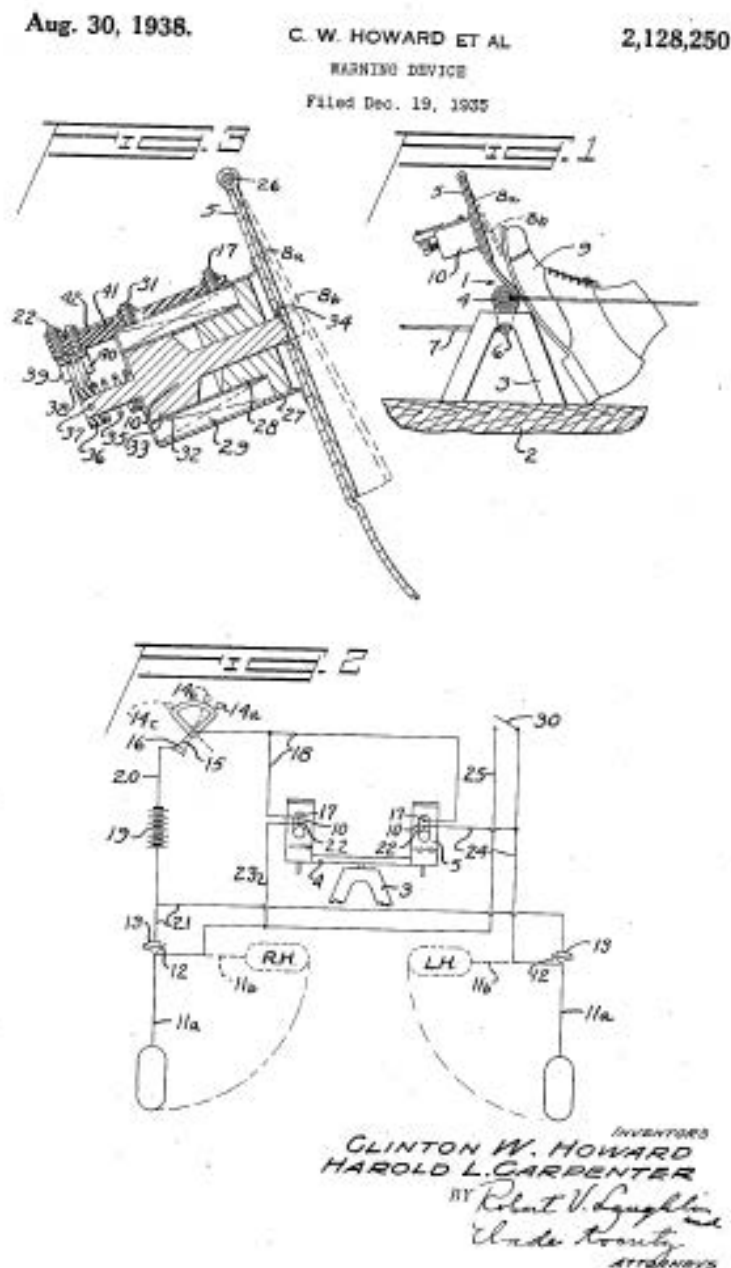


Figure 28 – U.S. Patent No. 2,128,250 (1938)



Documents

Document Sharing Hub

This era saw major advancements in airspeed, stable control flight characteristics and design/manufacturing advancements of aircraft construction as war loomed on the horizon.

3.6 1939-1945 World War II

During World War II, aviation established itself as a critical component of modern warfare.

As with aviation in World War I, military investment during World War II drove aviation forward in leaps and bounds. The streamlined cantilever monoplane quickly proved its worth in almost every role. Engine power and aircraft performance increased steadily, with jet and rocket engines beginning to make their appearance by the end of the war.

The development of civil aviation stagnated until the war ended since most aircraft manufacturers were pressed into military design and manufacturing activities. However, military technologies developed during the war would revolutionize postwar aviation. For example, the widespread construction of airports with serviceable runways would provide the basis for a postwar move of long-range passenger flights from flying boats to landplanes.

The faster speeds required retracting landing gear of conventional configuration with a tailwheel or tailskid. The retracting undercarriage gave landplanes a significant aerodynamic performance advantage over the seaplane, whose floats caused additional drag. However, seaplanes, typically flying boats, had their market niche, and remained in use for long-range maritime operations.

For fighter planes, speed was an important requirement. Consequently, completely stowed landing gear into the wings became the norm. The Mustang, introduced in 1940, incorporated an inward swing cantilevered landing gear with a fixed outer door that formed the bottom of the wing. Inboard doors completed the enclosure of the wheels.



(Source: https://en.wikipedia.org/wiki/North_American_P-51_Mustang#/media/File:MUSTANG_RCAF_9221.jpg, photo by Corsair133693 February 15, 1956)

Figure 29 - P-51D Mustang February 1956 at RCAF Station Calgary, Alberta

The Avro Lancaster is a British four-engined World War II heavy bomber designed and built by Avro for the Royal Air Force (RAF). It first saw active service with RAF Bomber Command in 1942. It was the heavy bomber used by the RAF, the Royal Canadian Air Force (RCAF), and squadrons from other Commonwealth and countries serving within the RAF. The main gear wheel was sized for landing on rough runways. The size and weight of the landing gear required larger forces to power the retraction mechanisms of these aircraft, which drove the need for higher system pressures to keep the component sizes down. After the war some of these aircraft were used in maritime patrol.



(Source: https://en.wikipedia.org/wiki/Avro_Lancaster#/media/File:Lancaster_10MP_405Sqn_RCAF_NAS_Jax_Feb1953.jpg)

Figure 30 - RCAF 405 Squadron Lancaster 10MP Maritime Patrol aircraft Main Landing Gear

The Vought F4U Corsair is an American fighter aircraft that saw service in World War II and the Korean War. The aircraft incorporated the largest engine available at the time: the 2,000 hp (1,500 kW) 18-cylinder Pratt & Whitney R-2800 Double Wasp radial. To extract as much power as possible a relatively large three-blade propeller of 13 feet 4 inches (4.06 m) was used. The wing cord limited the space available for a rearward retracting landing gear that was long enough to provide ground clearance for the large propeller.

The Vought solution was an inverted gull wing, which shortened the required length of the main gear struts. The F4U was the first US Navy aircraft to feature landing gear that retracted into a fully enclosed wheel well. The landing gear shock struts, each with their own fixed door, retracted aftward and rotated through 90° during retraction. A pair of wheel doors acted to seal the remaining aperture. This swiveling, aft-retracting landing gear design was common to the Curtiss P-40 (and its predecessor, the Curtiss P-36) and was adopted for the F4U Corsair's main gear and its former Pacific War counterpart, the Grumman F6F Hellcat.



(Source (left photo): https://en.wikipedia.org/wiki/Vought_F4U_Corsair#/media/File:Corsair_Mk1_Quonset_Point_1943.jpg, Dec 1942 Navy photo, (right photo) https://en.wikipedia.org/wiki/Vought_F4U_Corsair#/media/File:F4U-Corsair_OE-EAS_OTT_2013_04_main_landing_gear.jpg, Julian Herzog 2013,)

Figure 31 - F4U Corsair Main Landing Gear

Some unique speciality aircraft use detachable landing gear to totally eliminate the landing gear drag. Historical examples include the "dolly" using Messerschmitt Me 163 rocket fighter, the Messerschmitt Me 321 Gigant troop glider, and the first eight "trolley" using prototypes of the Arado Ar 234 jet reconnaissance bomber. The main disadvantage to using the takeoff dolly/trolley and landing skid(s) system on German World War II aircraft, was that aircraft would likely be damaged on landing and would be unable to taxi on their own. This could leave them vulnerable to being shot by attacking Allied fighters. A related modern example are the wingtip support wheels "Pogos" on the Lockheed U-2 reconnaissance aircraft, which fall away after take-off and drop to earth; the aircraft then relies on titanium skids on the wingtips for landing.



(Source: Wikipedia; Messerschmitt Me 163 Komert at Canada Aviation Museum, photo by Bzuk 2003)

Figure 32 - Messerschmitt Me 163B Komet with "dolly" detachable landing gear



(Source: https://en.wikipedia.org/wiki/Messerschmitt_Me_163_Komet#/media/File:Me163_Dropping_type_wheel.jpg, photo by baku13, 12 Aug 2005 on display at the Luftwaffenmuseum, Berlin-Gatow Germany)

Figure 33 - Messerschmitt Me 163B's unsprung jettisonable main gear "dolly" unit

Manfred J Johnson's 1940 US patent 2,202,207 introduced what he described a hermetically sealed electric mechanical switch. He stated, *"this invention relates to electric switches, an object of the invention is to provide an improved hermetically sealed electric switching device not affected by external atmospheric or other like conditions. This switching device is of particular use in aviation, in connection with the retractable landing gears of aeroplanes. For safe air travel, it is important that the retractable landing gear mechanism function properly, especially when the aeroplane is taking off or landing. To make the position of the landing gear known to the pilot of the aeroplane at all times, the present improved switch is employed in connection with the signaling device in the cockpit of the aeroplane, the switch being associated with the landing gear to be actuated thereby for indicating whether or not the gear is located properly in extended operative position. The switching device of this invention is not affected by external pressure or water conditions, and no moisture or dirt can enter the switch housing and corrode the contacts or otherwise affect the circuit, or cause the switch to become inoperative. Also, the actuating movement required to operate the switch can be extremely small, so that any, slight movement of the landing gear from its proper position will be immediately indicated in the cockpit of the plane."*

The environmentally sealed electric mechanical switch is used in a very hostile landing gear environment which can include; water, dirt, low/high temperatures, high wind velocities, ice/snow and debris impact from gravel, etc. These switches have been used successfully to indicated the state of the landing gear weight on wheels, lock mechanisms, door positions, steering, truck beam positions, etc. This switch technology was used for the next 40 years, before the introduction of modern proximity sensor technology in the 1980s.

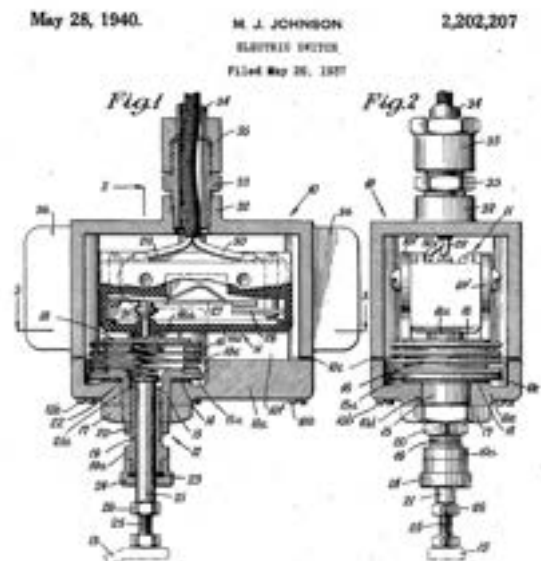


Figure 34 – U.S. Patent 2,202,207 (1940)

3.7 1945-1980 The Post War Era

The war years saw significant advancement in technology and the development of new skills and knowledge level of the people designing and building aircraft. After World War II, commercial aviation grew rapidly, using mostly ex-military aircraft to transport people and cargo. This growth was accelerated by the availability of military airframes that could be converted into commercial aircraft. The DC-3 was a natural at making the transition from military usage to commercial flights.

The first commercial jet airliner to fly was the British de Havilland Comet. By 1952, the British state airline British Overseas Airways Corporation (BOAC) had introduced the Comet into scheduled service. While a technical achievement, the plane suffered a series of highly public failures, as the shape of the windows led to cracks due to metal fatigue. The fatigue was caused by cycles of pressurization and depressurization of the cabin, and eventually led to catastrophic failure of the plane's fuselage. By the time the problems were overcome, other jet airliner designs had already taken to the skies.

USSR's Aeroflot became the second airline to offer regular jet services and the first airline in the world to operate sustained regular jet services on September 15th, 1956 with the Tupolev Tu-104.

The Boeing 707 and DC-8, which established new levels of comfort, safety and passenger expectations, ushered in the age of mass commercial air travel, dubbed the Jet Age (introduction of turbine aircraft engines for commercial aircraft).

The cold war brought new focus on military aircraft like the Convair B-36 Peacemaker, which was a strategic bomber operated solely by the United States Air Force (USAF) from 1949 to 1959. The B-36 was the largest mass-produced piston engine aircraft ever made. It had the longest wingspan of any combat aircraft ever built, at 230 ft (70.1 m). The B-36 was the first bomber capable of delivering any of the nuclear weapons in the U.S. arsenal from inside its four bomb bays without aircraft modifications. With a range of 10,000 mi (16,000 km) and a maximum payload of 87,200 lb (39,600 kg), the B-36 was the world's first manned bomber with an unrefueled intercontinental range. The B-36 took shape as an aircraft of immense proportions. The single main gear wheel was 9 feet tall.

The XB-36 featured a single-wheel main landing gear whose tire was, 9 feet 2 inches (2.79 m) tall, 3 feet (91 cm) wide, and weighing 1,320 pounds (600 kg). The XB-36 was restricted to the Fort Worth airfield and only two other USAF bases due to the runway loading. The single-wheel gear was soon replaced by a four-wheel bogie. At one point, a tank-like tracked landing gear was also tried on the XB-36, but proved heavy and noisy and was abandoned.



(Source: (left photo) https://en.wikipedia.org/wiki/Convair_B-36_Peacemaker#/media/File:Convair_XB-36_main_landing_gear_detail_061128-F-1234S-028.jpg (right photo) United States Air Force, edited by Slashme - Original unedited version from <http://www.nationalmuseum.af.mil/shared/media/photodb/photos/061128-F-1234S-033.jpg>)

Figure 35 - Convair B-36 Peacemaker Main Landing Gear Tire and Prototype track

In October 1947 Chuck Yeager took the rocket-powered Bell X-1 through the sound barrier. This opened up landing gear design to being exposed to higher altitudes and colder temperatures.

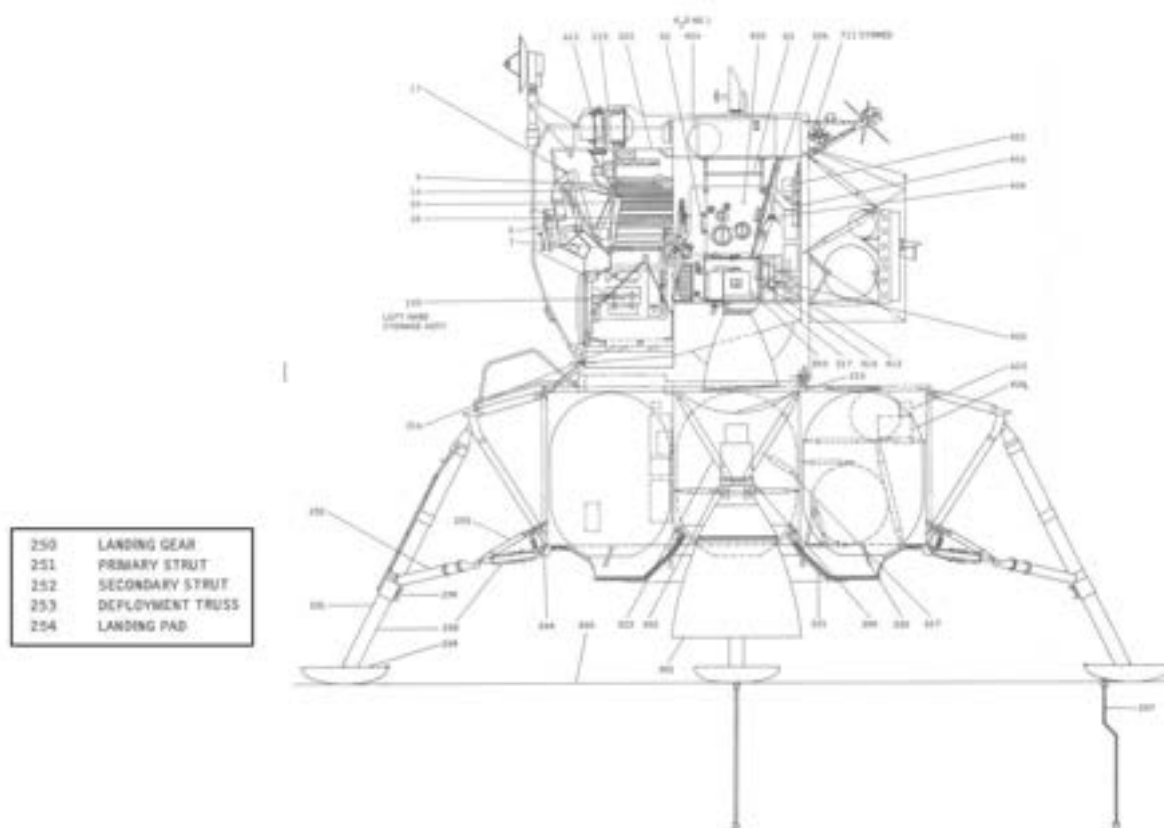
The 1945 invention of nuclear bombs briefly increased the strategic importance of military aircraft in the Cold War between East and West. The Boeing B-52 Stratofortress was put into active service in 1955. The aircraft incorporated four tandem wheel main landing gears mounted to the fuselage and wing tip mounted auxiliary single wheel gears to prevent wing strike.



(Source: USAF - nationalmuseum.af.mil, https://en.wikipedia.org/wiki/Boeing_B-52_Stratofortress#/media/File:Boeing_NB-52A_carrying_X-15.jpg)

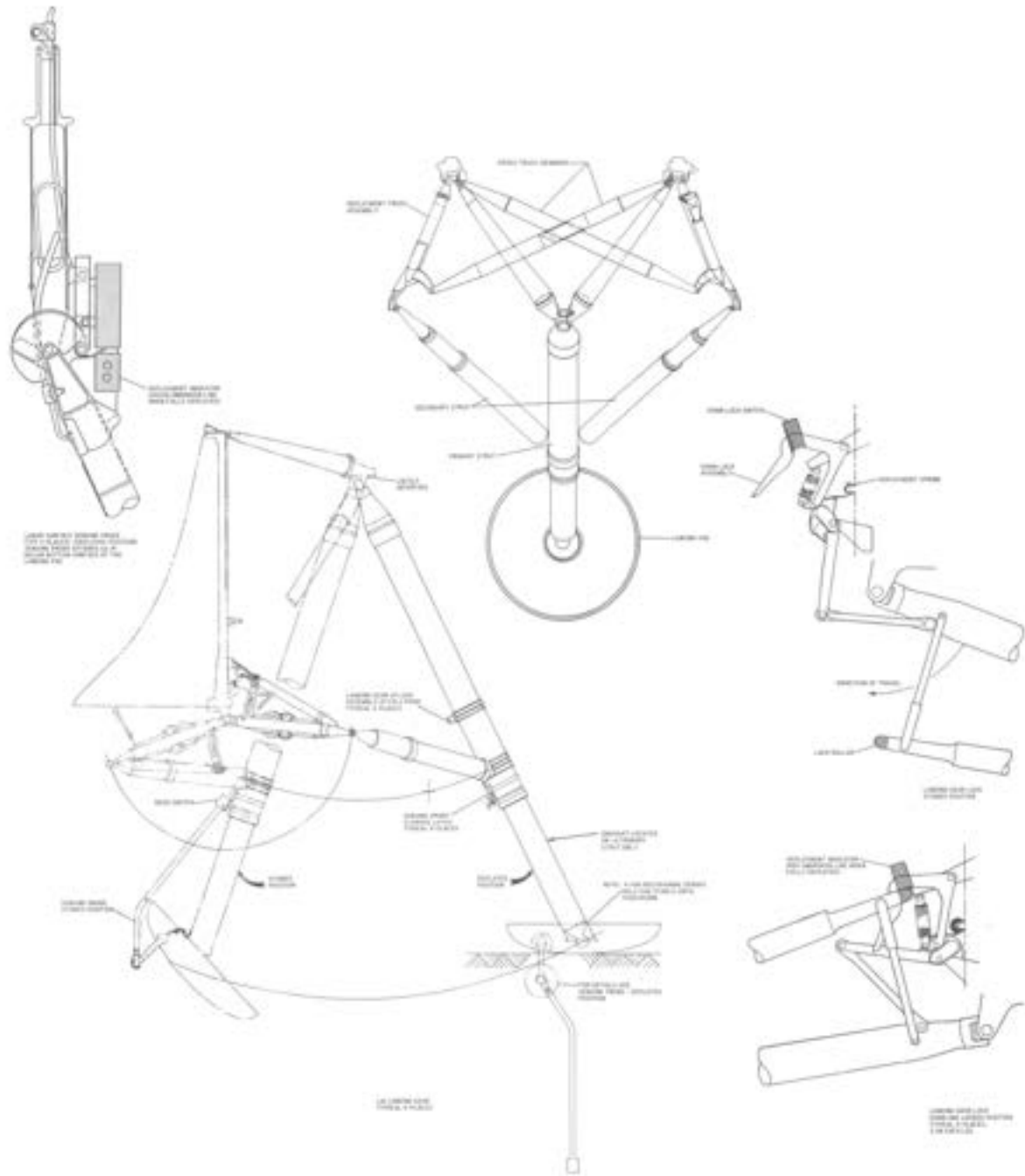
Figure 36 - Boeing NB-52A carrying North American Aviation's Legendary X-15

In the late 1960s landing gear extended to spacecraft designed to land safely on the Moon. The Apollo Lunar Module (LM) was the lander portion of the Apollo spacecraft built for the US Apollo program by Grumman Aircraft to carry a crew of two from lunar orbit to the surface and back. Six such craft successfully landed on the Moon between 1969 and 1972. Once the four landing gear were deployed, 66-inch (1.676 m) long probes extending from three footpads of the lander touched the surface, activating the contact indicator light, which signaled time for descent engine cutoff, allowing the LM to settle on the surface.



(Source: NASA https://en.wikipedia.org/wiki/Apollo_Lunar_Module#/media/File:Lunar_Module_Equipment_Locations_1_of_2.jpg)

Figure 37 - Apollo Lunar Module Landing Gear 1969



(Source: NASA https://en.wikipedia.org/wiki/Apollo_Lunar_Module#/media/File:Lunar_Module_Equipment_Locations_1_of_2.jpg)

Figure 38 - Apollo Lunar Module Landing Gear 1969

The Hawker Siddeley Harrier Jump Jet is a British designed military jet aircraft capable of Vertical/Short Takeoff and Landing (V/STOL) via thrust vectoring. It first flew in 1967. It incorporated one main and nose gear and two wing mounted landing gears. The nose gear hydraulically retracted forward while the main gear retracted aftward. The wing gear retracted aftward and formed part of the outboard edge of the wing in forward flight.



(Source: NASA https://pl.wikipedia.org/wiki/Hawker_P.1127#/media/File:Hawker_P.1127_-_NASA.jpg)

Figure 39 - Hawker-Siddeley P.1127 (Forerunner to Harrier Jump Jet)

In 1965, Lockheed's aircraft design and General Electric's engine design were selected for the new C-5 Galaxy transport, which was the largest military aircraft in the world at the time.

With pressure from the president of Pan American World Airways (Pan Am) to build a passenger aircraft more than twice the size of the 707, Boeing began work on the 747. The aircraft weight and size required four main landing gears (two wing mounted and two body mounted), each with a four-wheel bogie wheel arrangement. The Boeing 747 first flew in January 1970. The aircraft was the largest commercial passenger aircraft ever to fly for many years.



(Source: Clemens Vasters 2009,
https://en.wikipedia.org/wiki/Boeing_747#/media/File:Boeing_747_prototype_main_landing_gear.jpg)

Figure 40 - Boeing 747 Main Landing Gears