The Lockheed XC-35 and Harry Armstrong, M.D.: Development of the First Practical Pressurized Cabin Airplane

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The pressurized cabin ranks as one of the greatest advancements of safety and comfort innovations in aviation. Until the early 1930s, most airplanes had open cockpits that exposed the pilots to the cold air and windblast. If utilized, oxygen masks frequently froze, stopping the flow of oxygen. Enclosed cabin passenger airplanes were of no advantage because they could not fly above the weather. Carrying sufficient oxygen for the passengers was too heavy and oxygen masks too impractical for the public.

U.S. Army Air Corps flight surgeon Capt. Harry G. Armstrong, after a particularly long and cold flight in an open cockpit P-16 fighter, sent a letter to the Air Corps Surgeon and complained about the inadequacy of flight crew equipment. The attention he garnered quickly resulted in him being assigned to Wright Field, OH, in 1934, where he established the Physiological Research Laboratory and began experiments in altitude physiology and high altitude equipment development in a WWI era altitude chamber.[3] Armstrong started developing the physiological specifications for a pressure cabin airplane in 1935. Previous attempts at pressure cabin airplanes had not been successful. The first pressure cabin airplane was the U.S. Army USD-9A, a DH-9 with a pressure capsule that contained three small portholes. On its first flight in 1921 it became over-pressurized, forcing the pilot to land due to severe ear pain and elevated cabin temperature from the compressed air, and it never flew again. The German Junkers Ju-49 in 1931 flew to 30,000 ft utilizing a two-man pressure capsule, but it had very poor visibility, requiring a periscope for the visualization to land.

On 29 April 1935 the U.S. Army Air Corps started a second pressure cabin airplane with Armstrong solely responsible for creating the physiological requirements. Armstrong considered two methods for pressurizing the cabin. The first method was the oxygen-pressure compartment. This was a sealed cabin with oxygen supplementation. Armstrong had considerable experience with high altitude flight and oxygen-pressure compartment cabins from his experience as a physiology consultant and flight surgeon for the Explorer II. This was a National Geographic Society-United States Army Air Corps balloon which, on 11 November 1935, flew to a then-record 72,395 ft and returned its crew safely. The oxygen-pressure compartment had many disadvantages, including the need to carry or produce oxygen, the increased risk of fire from the oxygen enriched environment, and the buildup of carbon dioxide and humidity from exhaled breath. Armstrong adopted a second method, the pressure cabin, which increased the partial pressure of oxygen by regulating (increasing) the pressure in the cabin. He called this the supercharged cabin.

Armstrong developed the physiological requirements for supercharged cabin airplanes from his many altitude chamber experiments. He found that a 5-psi differential between the cabin pressure and the outside atmospheric pressure provided adequate oxygen up to 30,000 ft altitude. This was high enough for current passenger aircraft. For military combat airplanes flying over 30,000 ft, he recommended a 10-psi cabin differential pressure. Armstrong specified that the rate of the pressure change must be controllable to minimize symptoms from barometric changes. He set standards for cabin ventilation to provide enough air exchanges to keep the carbon dioxide concentrations down to comfortable levels and to keep the oxygen replenished. Additionally, he recommended a cabin temperature of 68°F, which at altitude was simply attained by adding heat. Armstrong initially set a humidity comfort goal of 33% maximum, which resulted in condensation and window frosting, and eventually 10% humidity was utilized in practice, which was accomplished through increased ventilation. He also stated that pressurization air sources must be in the front of the engine exhausts to prevent ingestion of carbon monoxide and resultant poisoning. Research by the aeronautical and power plant divisions at Wright Field formed the recommendations for structural, mechanical, air-flow and regulation features of pressure cabin airplanes. Combined, these requirements were released in Air Corps Technical Report 4165 (1935) which formed the contract specifications with Lockheed.[1]

The XC-35 was delivered in May 1937 to Wright Field (**Fig. 1**) and was a heavily modified version of the existing Lockheed 10, which was a small, twin engine cabin airliner that gained fame as being the aircraft Amelia Earhart was flying went she was lost in the Pacific. The XC-35, however, had a completely different fuselage and larger supercharged XR-1340 engines, enabling high altitude flight. It had a circular fuselage with pressure bulkheads at each end, and strong, small windows, which earned the airplane the nickname, "Can't See 35". This system was able to maintain a cabin altitude of 12,000 ft while flying at 30,000 ft. It had two pilots, a flight engineer, and two passenger seats in the pressurized cabin. In a nonpressurized aft section there was one more passenger seat, the exterior entrance, and the lavatory.

Performance testing began in August 1937 when Dr. Armstrong and his laboratory assistant Pvt. Ray Whitney flew many test flights from Wright Field in Ohio. Whitney performed the flight engineer duties, manually controlling cabin pressurization and dealing with problems such as cabin pressure altitude excursions.

From Poquoson, VA.

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Fig. 1. Lockheed XC-35. Note the small cockpit and cabin windows which were easier to build strong enough to withstand cabin pressurization (although the entrance door and easiest to see last two windows are in the non-pressurized aft section of the plane). Additionally, notice the circular-shaped turbosupercharger on the side of the engine that forced more air into the engine, improving high altitude performance and also provided compressed air for cabin pressurization.

Overall, the XC-35 demonstrated outstanding capabilities, attaining a maximum speed of 350 miles per hour and altitudes in excess of 30,000 ft. Contemporary news articles reported "neither oxygen equipment nor heavy clothing was necessary at the highest altitudes." Cabin pressurization successfully eliminated hypoxia, decompression sickness, and allowed ascent and descent rates to be controlled, helping to decrease barotrauma and discomfort in a comfortable, temperature controlled cabin.[4]

Pressurization allowed aircraft to fly above the weather and turbulence, which was a large advancement in passenger safety and comfort. The Air Corps had enough confidence in the XC-35 that it was used as a VIP transport for Louis Johnson, Assistant Secretary of War, and on one famous instance flew above thunderstorms that grounded all civilian airliners.[2] The 1937 Collier Trophy was awarded on 15 September 1938 for "the greatest achievement in aviation whose value has be demonstrated in actual use during the previous year," with the citation reading, "to the United States Army Air Corps for having designed, constructed, and completely equipped the XC-35 Sub-Stratosphere Airplane, the first successful pressure cabin airplane to be flown anywhere in the world." Research using the XC-35 allowed further developments in pressurized aircraft including the development of the Boeing 307, which was the first pressurized cabin airliner (only ten were built), entering service in 1940, and the Boeing B-29 bomber which became the first U.S. cabin pressurized bomber. The Lockheed Constellation in 1943 was the first cabin pressurized passenger airliner in wide service.

The Collier Trophy in 1939 was awarded to Capt. Armstrong, W. Randolph Lovelace II, M.D., and Walter Boothby, M.D., who were awarded the trophy by President Roosevelt for advancements in passenger safety for work relating to oxygen systems. Armstrong went on to author the classic textbook, Principles and Practice of Aviation Medicine[1] and became the Command Flight Surgeon of the 8th Air Force in WWII. He helped pioneer many operational aviation medicine and crew protection advances. In 1949, as a Major General, he became the second Surgeon General of the U.S. Air Force and was later the 23rd President of the Aerospace Medical Association. His research defined the altitude (69,000 ft) at which bodily fluids boil at body temperature and still bears his name as the "Armstrong's Line". He died in 1983 and among his many other honors he was inducted into the Aviation Hall of Fame in 1999.

The Lockheed XC-35, after its testing was completed, was turned over to the National Advisory Committee for Aeronautics and was flown out of Langley Field, Virginia. Ironically, its good high altitude performance and pressurization allowed it to avoid bad weather, and it was utilized to perform basic thunderstorm research in 1941 and 1942 at altitudes of up to 33,000 ft.[5] In 1948 the sole XC-35 was donated to the Smithsonian Institution, where it languishes today, disassembled, unrestored, and out of public view.

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