Piston Engines and the First Fifty Years of Powered Flight

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The following paper illustrates the first 50 years of aviation history, which were significantly influenced and driven by constant technological developments in the area of piston engines. The period covered starts with Alberto Santos-Dumont's first powered flight without ground assistance in his "14bis" aircraft in 1906 and ends with the 1956 maiden flight of what was probably the most technologically advanced piston-powered airliner - the Lockheed L-1649 “Starliner”. Within these five decades, aircraft piston engines evolved from simple in-line configurations to mechanically complex rotary engines, powerful V-types, compact opposed piston engines, and high-performance multi-row radial engines. The history of aircraft performance is thereby inextricably connected to piston engine technology, where increasing speed and manoeuvrability were dependent on growing specific power, and high altitudes could only be reached through innovative concepts like supercharging. The first 50 years in aviation history can therefore be regarded as a showcase for the "piston revolution" and how piston engines helped to make the most spectacular form of transportation possible.

The paper highlights examples of reciprocal technological influences between aircraft design/performance and piston engine development and thereby retraces some key chapters in aviation history as well as prominent contributions of the "piston engine revolution". In doing so, the author identifies the gradual shift from piston engine technology, as an enabler of aviation progress throughout the first decades, to the point where a highly developed piston technology faced physical barriers in a world of ever increasing demand for speed and altitude. This eventually led to the decline of piston power in aviation and its replacement by turbine-based propulsion systems.

KEYWORDS: aviation, history, piston, engine, flight, propeller era

Introduction

The first half of the twentieth century is probably the most revolutionary period in transportation technology to date. In only fifty years, mankind basically developed its transportation capability from horse carriages and steam trains to the early beginnings of space travel. The piston engine, a concept of the nineteenth century, has thereby played an important role in many fields of transportation, one of which is aviation. It was the piston engine that marked the beginnings of powered flight, and it was also the piston engine (in constant technological progress) that fuelled aviation development from the early days of fragile flying machines through times of peace and war to the phenomenon of global mass transportation. Just at the peak of this development, when highly advanced and supercharged piston engines powered intercontinental airliners, they were overtaken by another groundbreaking development in propulsion technology - the jet engine. From this point onwards, the jet engine has taken over the role as the primary propulsion system in aviation whilst piston power has been relegated to the world of small general aviation and training aircraft.

This paper will retrace the history of five decades of piston power in aviation framed by two outstanding aircraft which, amongst others, mark the beginning and the end of this historical period: the *14bis*, built and flown by Alberto Santos-Dumont in 1906 with its 50 hp Antoinette-engine and the Lockheed L-1649 “Starliner” with its four Curtiss-Wright air-cooled, turbo compound, eighteen-cylinder two-row radial engines with 3450 hp each, first flown in 1956. Between these two aircraft lies a period which was shattered by two World Wars yet driven by an enormous technical revolution of which the piston engine is one of the most prominent examples. Whilst the piston engine was unquestionably the key driver for new means of ground transportation (especially the automobile), the rapid development of aviation would also have been completely unthinkable without it. It is this close union between the piston engine and aircraft development that shall be depicted through historical examples on the following pages.

Structurally, the paper follows an arbitrary selection of key engine demands in aviation: thrust, compactness and weight, reliability, speed performance, and altitude performance. The author has tried to subdivide the first fifty years of flight into periods that are characterized by a noteworthy development in aircraft piston engine technology. These periods will each be addressed in chronological order in a section with one or several characteristic aircraft/engine examples, whilst a keyword in the headline of the section will indicate which of the key demands were met by the development. Finally, it shall be noted that the cited technological examples are an individual selection of the author and do not claim to be exhaustive in any respect.

Thrust: Dumont and the first powered flight without ground assistance

When we think of the beginning of powered flight today, we usually think of the Wright Brothers and their successful flight with engine thrust at Kitty Hawk, North Carolina in 1903. Whilst the authenticity of data reported from their initial flights remains a disputed piece of aviation history, they certainly deserve taking credit as prominent inventors of powered flight. Technically, however, their outstanding engineering accomplishment has one imperfection that yields another pioneering breakthrough of powered flight to others - the first powered flight without ground assistance. It shall thereby be noted that the Wright Brothers used a rail to launch their flying machines in a controlled manner. The first to launch his powered aeroplane without any ground infrastructure is often claimed to be the Romanian aviator Traian Vuia, quickly followed by his more famous contemporary Alberto Santos-Dumont. Despite Vuia being almost half a year ahead of Santos-Dumont, the Brazilian usually makes the headlines in history books, which is probably due to his continuous contributions to the development of aviation up to the year 1910, when he fell seriously ill. The paper also looks at Santos-Dumont and his two most famous record-breaking airplanes, as their milestone character is strongly linked to the success story of their engine - the Levavasseur V8 Antoinette engine, the first of its kind in aviation.[1]

Its history goes back to 1902, when the French engineer Léon Levavasseur patented the first V-type eight-cylinder engine, specifically designed for use in aeroplanes. His technical target figures comprised a weight of 100 kg and a power output of 80 hp, which could not be attained by the design. When the engine was built in 1904 it was named the "Antoinette Engine" and only had an output of 24 hp. However, one year later, Levavasseur presented an improved version of the V8 "Antoinette" which already produced 50 hp.[2] The initial 24 hp engine was used one year later by Alberto Santos-Dumont for his famous "14bis" aircraft, Figure 1, which owes its name to the fact that its first test flights were performed with the assistance of Santos-Dumont's airship No.14 to which the fixed wing aircraft was an "appendix".

Once flown as an independent aircraft, the "14bis" crashed after an underpowered seven metre long “flight”. Santos-Dumont thereupon replaced the weak engine by the enhanced 50hp "Antoinette" and thus made "14bis" the first flying machine to receive a certification of accomplishment by the newly founded (1905) "Fédération Aéronautique Internationale" (FAI) for the first controlled and sustained powered flight without ground assistance, performed in front of an "expert audience" in Paris. One year later, Santos-Dumont completed a monoplane called the “Demoiselle”, a further development based on "14bis". The "Demoiselle" was built between 1907 and 1909 and can be considered the first light aircraft in the world. It also used the 50 hp "Antoinette" engine and was such a great success that it was repeatedly copied in Europe and the United States.[3]

Compactness and Weight: World War I rotary engines as a dead-end in aviation engine history

World War I was in many ways the first "industrial" war that sometimes oddly combined traditional fighting techniques and equipment (like horses and carriages)

Figure.1. Dumont’s famous “14bis” aircraft in flight.

with modern technology such as aircraft, for instance. It can undoubtedly be said that the onset of World War I triggered the first real mass production of aircraft, as civil aviation had not really developed up to that date. Thus, aircraft design became an industrial task rather than the work of small-series producers and inventors, and proven technology spread more quickly than before. The aircraft engine development that was triggered by aviation demands of World War I produced an engine configuration that is almost synonymous with WWI aviation, namely, the rotary engine (an engine using pistons, not to be confused with the "Wankel" rotary engine which uses a rotor).

Before going into further detail about the reasons for the temporary success of this engine type, it should be mentioned that the rotary engine is particularly noteworthy from a historical point of view as it was a real success for a while, before disappearing almost completely. This differs strongly from most other development patterns in aviation engine history where technological innovation has oftentimes built upon an earlier evolution (see "turbocharging" in a later paragraph, for instance) but rarely ended as a dead end.[4] The basic concept of the rotary engine can be described as a set of cylinders (usually an odd number per row) in a radial arrangement where the crankshaft remains stationary, being attached to the aircraft fuselage, for instance, whilst the entire block of cylinders rotates around it.

The development of the rotary engine configuration primarily followed aviation's need for lightweight engines that are also compact enough to fit in small and agile fighter planes. Moreover, a key demand for aircraft engines was (and has been ever since) the need to suppress vibrations which at that time appeared difficult to achieve with in-line engines. In addition to that, the radiator and cooling system required for liquid-cooled engines had to be avoided for the sake of reasonable power-to-weight ratios. Thus a configuration was needed that provided sufficient air-cooling by its geometry and a vibration free motion. Both the demand for smooth operations and air-cooling could be achieved by the rotary engine design, as all reciprocating movements of the engine were radially opposed and therefore balanced in terms of momentum whilst the engine shape provided a large surface for cooling, which was even further helped by the rotational movement of the cylinder block. Of course, the design had its critical shortcomings - especially for aviation - which after World War I clearly led to its demise followed by the triumph of radial engines. These flaws were mainly the particularly high fuel consumption as well as the gyroscopic effect of the engine's rotation. The latter could seriously impede aircraft manoeuvrability. The usual turn direction of the cylinder block created a certain resistance of the aircraft to left turns combined with a nose-up tendency, whilst also causing abrupt right-turns with a strong nose-down reaction which could endanger pilots when performed at low altitudes.[5]

Another issue was the lubrication of the rotary components. It required oils that were insoluble in gasoline as the injection of the gasoline-air mixture through the crankcase could otherwise cause the dilution of the lubricating oil. A good and therefore commonly used insoluble lubricant was castor oil which, however, could not be fully contained in the rotating cylinders (due to centrifugal forces) and would spray around during engine runs. In flight, the oil would thereby create toxic fumes that often caused strong nausea with pilots and hence represented another shortcoming of the rotary engine design.

When searching for a representative engine type for this era one will quickly come across the name "Gnôme", Figure 2. Three French engineers, the Seguin brothers, basically converted a stationary "Gnom" engine from the German "Motorenfabrik Oberursel" to an aircraft engine. Their first version being a radial engine, they quickly turned to rotary concepts to improve cooling. This started a series of very successful aircraft engines, most famous of which are the Gnôme Omega and later on the Gnôme Lambda, which powered the legendary Fokker E.I "Eindecker" (monoplane). The Gnôme name already came to glory in 1909 when a Gnôme-powered aircraft won the Grand Prix by flying a world record distance of 180 km. Ironically, later on during the war, the French designs were again copied by the German "Oberursel" manufacturer and therefore found themselves on opposing aircraft during the war. One other noteworthy chapter in the Gnôme design history is the unique twin-row rotary engine, the fourteen-cylinder 160 hp "Double Lambda" (also copied by Oberursel as U.III).[6]

Looking at the colourful history of rotary engines before and during World War I, it is justified to ask what eventually caused the demise of this mechanical concept in the aviation world. First of all, referring to the aforementioned issues of flight dynamics, it is certainly not desirable to have great masses in rotational movement attached to the aircraft body, which can obviously not be avoided with a rotary engine. It is interesting to note, however, that attempts were made to mitigate this problem by creating counter-rotating arrangements where the

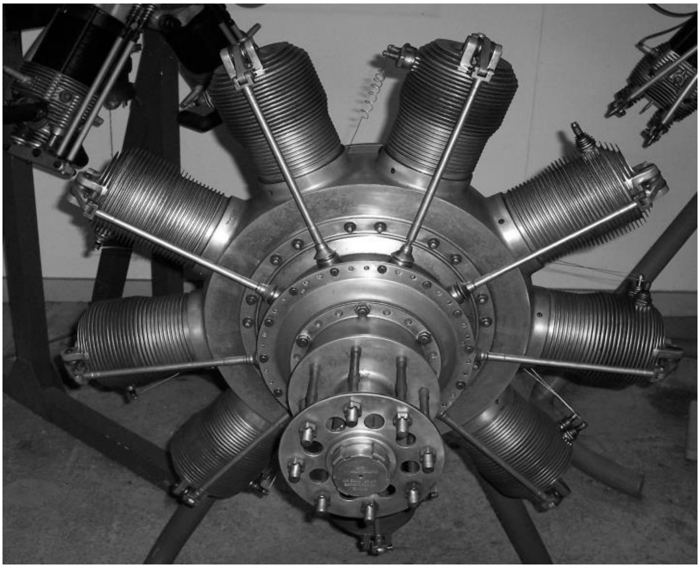

Figure 2. Gnôme 160hp rotary engine.

crankshaft spins in the opposite direction of the cylinder block by means of a gearbox. This allowed the reduction of the angular speed of the main engine mass relative to the fuselage (i.e. reduced angular momentum) and an increase in propeller efficiency. This concept was sometimes referred to as a "reactionless" rotary engine and goes back to pre-war developments by the British engineer Charles Redrup.[7] Probably the most famous example of such an engine, however, is the German 1917 Siemens & Halske Sh.III engine.[8]

Another obvious disadvantage of the rotary engine was its high fuel consumption. This problem became especially critical in post-war civil aviation, which naturally had to be more economically minded than its military counterpart. The fuel inefficiency was combined with a very high oil consumption (sometimes around 25% of the fuel consumption - in fact, in initial developments even more oil than fuel was consumed), which was caused by the loss of lubricants being ejected through the cylinders by centrifugal forces.

As demands for increased power were made, particularly in wartime, rotary engines could not provide increased rotation speed due to the incurred aerodynamic drag, which gave them another clear disadvantage compared to stationary cylinder configurations of any type.

Finally, the fairly coarse and cumbersome power control of rotary engines, which, even with a carburettor, usually had to rely on an ignition toggle to avoid backfire caused by the reed valves, was another reason why the development of the rotary engine came to a dead stop early on in aviation history.[9]

Reliability: the Junkers W33 and its Jumo L5 engine - Junkers' successful establishment as an aircraft engine manufacturer

The period between World War I and II saw a number of aviation records broken as previous military developments entered into civil aviation technology and peacetime caused engineering work to aim more at the original transportation function of the aeroplane rather than its use as a weapon. Moreover, aircraft manufacturers were oftentimes struggling for survival, as they no longer saw wartime demand for their products. This exerted a fair amount of pressure to be innovative. Just like former wartime pilots who suddenly had to "sell" their flying skills in a non-military environment (and invented very entertaining disciplines such as "barnstorming") aircraft manufacturers also had to trim their products to civil needs which mostly revolved around reliability, range, payload and serviceability of the machines.

When we look at the great achievements of flight during the period of the 1920s and 1930s Charles Lindbergh's transoceanic flight in 1927 comes to mind. Paying tribute to our focus on piston engines, we shall this time choose a comparable flying achievement from a less custom-made aeroplane than Lindbergh's "Spirit of St. Louis". This will be examined and leads us to a famous German name in aircraft and aviation engine history: Junkers. The first transatlantic crossing from east to west was performed by a team of three bold men in the remarkable Junkers W33 "Bremen", Figure 3, a single-engine, all-metal, low-wing aircraft originally designed as a cargo aircraft and later on transformed for combined cargo-passenger operations.[10] The entire design proved very rugged and reliable, which led the joint Russian-German airline "Deruluft" to buy the aircraft in 1928 and use it in the remote regions of Siberia under the name "PS-4", where it flew with great success until 1941. In its original versions, and for the record-breaking transatlantic flight of the "Bremen", the Jumo L5 engine was used. It was a six-cylinder in-line engine with a maximum power of 228 kW (310 hp) produced by Junkers. The 1925 Jumo L5 is an enhanced successor engine of the Junkers L2 (1924) and is historically interesting as it represents the successful entry of Junkers Flugzeugwerke into the rank of aircraft engine manufacturers.[11] This was a reaction of the famous professor Hugo Junkers to the growing demand for aircraft engines and led to the foundation of the sister company "Junkers Motorenbau GmbH (Jumo)" in 1923. Earlier Junkers aircraft were mainly powered by BMW engines, but also by those of Daimler, Siemens and Armstrong-Siddley. The Jumo L5 of the Junkers W33 is a great example of Junkers' gradual process of becoming an independent aircraft engine developer, as it was still based upon the BMW IV engine.[12] The L5 had a dry weight of 326kg and thus a maximum specific power of 0.7kW/kg compared to 0.68kW/kg on the 1919 BMW IV.[13] The performance increase was hence very limited (considering the six-year period be-

Figure 3. Junkers W33 “Bremen” after its epic transatlantic crossing.

tween the engines) but the L5 proved so reliable that it became a record-breaking engine.

After a rough start with some nearly disastrous attempts, the W33 established a remarkable 52 h 11 min endurance record before flying the famous transatlantic crossing from Baldonnel, Ireland, to Greenly Island, Newfoundland, in 36.5 hours.[14] The previous endurance record was broken again by the W33 in 1928 with a total 65 h 25 min endurance, where the Junkers test pilots flew a closed circuit route of 5066 km.

To sum up, the Jumo L5 represents a breakthrough in long-range piston engine technology, which was achieved by building on a proven design and using a fairly conservative configuration of a liquid-cooled in-line engine. The same can be said about the Junkers W33 aircraft, as well, which built upon the highly successful Junkers F13 type and together with the successful engine was destined to make aviation history.[15]

It is not surprising that the W33 remained a flying test bed for many other Junkers engines to come. With a total of 199 airframes produced, its long-range success story is crowned when a W33 leaves Berlin-Tempelhof airport on 19 October 1928 to fly a 14250 km journey to Tokyo, Japan, (split up into several legs) in a total flying time of roughly 90 hours.

Speed Performance: blowers against turbines -the turbocharged Allison V-1710 (P38 Lightning) vs. Britain's Merlin (Spitfire) and Germany's DB60X series (Bf109, Bf110)

The vital need for good aircraft engine performance at higher altitudes in preparation for and during World War II led to a dramatic maturing of supercharging technology, which literally gave piston engine development a boost and pushed its performance limits like no other innovation ever since. The implications of supercharging for the usability of piston engines in high performance applications are still visible today and can therefore almost be considered as a “second piston revolution”.

Dealing with the concept of supercharging in aviation inevitably triggers the old debate about the pros and cons of the two main techniques of supercharging: the mechanically driven supercharger (in German literature often ambiguously referred to as "compressor", in Anglo-American literature as "blower") and the turbo-supercharger where a turbine is driven by the engine's exhaust gases, which in turn drives a rotary compressor. The history of those two concepts is deeply rooted in aviation and its constant need to overcome the challenge of low air density at higher altitudes which itself represents a favourable environment for efficient flight due to the reduced aerodynamic drag. Interestingly enough, it was the mechanically driven supercharger that initially led the race during wartime aviation, but was later on beaten by the turbocharger that initially appeared to be restrictively complex in its technical realization whilst being the more economic solution in the long run. To understand reasons for using one or the other, we will have to go into more detail about the supercharging techniques and aviation's requirements during World War II and beyond.

The mechanically driven supercharger subtracts output power from the main engine to provide compressed air to the engine's manifold, thereby increasing the engine's overall performance. This can be fairly well illustrated with the example of the Rolls-Royce Merlin engine, Figure 4, where, in one specific version, the supercharger uses up about 110 kW and the naturally aspirated engine has a power output of 560 kW. With the help of the supercharger, this power output is increased to 750 kW, which equals a net increase of 190 kW, and justifies the use of the supercharger. When looked at separately, the supercharger thereby produces a gross power increase of 300 kW given by the following calculation: 750-560-110 = 300 kW. The reader is reminded that this power increase, of course, comes at the cost of higher fuel consumption and less thermodynamic efficiency. In contrast, the turbocharger has the advantage of using the pressure differences between exhaust gases and ambient pressure, which would normally be unused during the exhaust process. The concept therefore usually increases the engine's overall thermodynamic efficiency. However, it also puts a load on engine gross performance by producing what is called "backpressure" in the engine's exhaust. If this was not the case, turbocharging would be pure efficiency augmentation with better specific fuel consumption, etc. and it would certainly be an integral part of every engine. With the power drain effect of backpressure, the energetic principle is basically the same as with mechanical superchargers: some gross power must be invested to get a net power gain. However, efficiency is much higher in turbocharging compared to mechanical supercharging. On the downside, however, turbocharging requires a more complex arrangement of pressurized pipes and is, generally speaking, more maintenance-intensive. This is due to the fact that the turbine and compressor are mechanically decoupled from the engine (unlike in mechanical superchargers which are usually crankshaft driven) and rotate freely, which needs special lubrication and in the past required specific run-up as well as shutdown procedures to account for critical lubrication temperature changes. The required piping made turbochargers heavy in comparison with mechanical superchargers, which have changed, in modern days, due to better designs and advanced materials. During World War II, the weight issue considerably reduced the specific power output of turbocharged engines compared to their mechanically supercharged counterparts. Moreover, a turbocharger only increases power at higher rotational speeds and thereby creates the so-called "turbo-lag", which is a delayed supply of its power amplification when the engine speed is suddenly increased due to the required pressure build-up in the charger. This problem is not encountered with mechanical superchargers that are directly linked to the engine.[16]

With this technical comparison in mind, it becomes understandable that the most famous turbocharged aircraft engine in World War II, the Allison V-1710, was used to power only the P-38 fighter-bomber. At the time it was conceived the twin engine, twin boom configuration, which housed the turbocharger ducting, was the only way of combining very long range with a speed of over 670kph.[17] For pure fighters like the American P-51 Mustang, the British Spitfire and the German Bf 109 it was logical to use mechanical superchargers to avoid the extra weight and maintain the highest possible manoeuvrability. Thus, both the British Merlin engine (powering the Spitfire and in its licence type Packard V-1650 also in the P-51) as well as the famous German Daimler-Benz DB60X series powering BF109 and BF110 relied on mechanically driven superchargers. One noteworthy detail about the DB605 is that its power transmission from the crankshaft to the supercharger was via a hydraulically operated clutch that was barometrically controlled and therefore adjusted the charger according to flight altitudes.[18] It was greatly superior to the British system which required clutches to take care of the sudden changes in engine speed, which would otherwise have imposed huge stresses on the supercharger gearing. Furthermore, since British engines were geared directly from the engine, at low level, engines were over boosted at full throttle. Engines had to be run on a partially closed throttle, which reduced engine efficiency. As altitude was gained the throttle was opened up more and more, and became fully open at “full throttle height”.

The British designers of the Rolls-Royce Merlin engine eventually recognized the negative implications of a single-speed supercharger, which operates at an optimum for only one particular pressure altitude (full throttle height). Thus, starting regular production of the Merlin XX in 1940, Rolls-Royce introduced a singles-stage supercharger with a two-speed gearbox. Following the decision against a turbocharged version of the Merlin, the engine was further

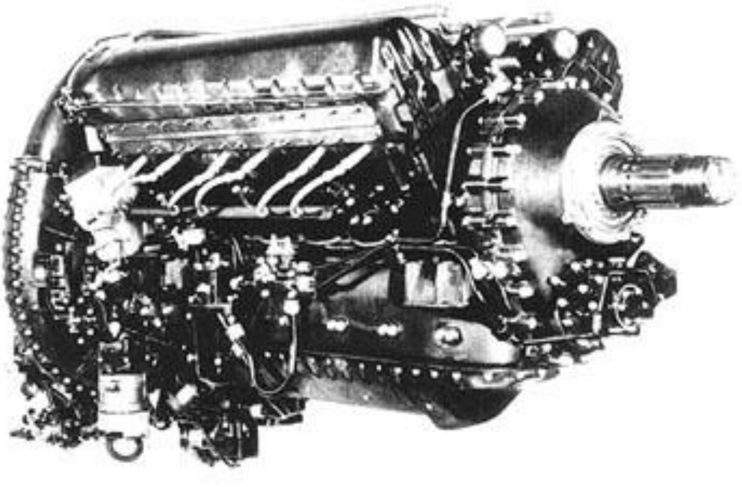

Figure 4. Rolls-Royce Merlin Engine.

enhanced in its 60, 70, and 80 series from 1942 onwards with the help of a two-stage, two-speed supercharger which was a very modern design as it also featured an “intercooler” (really an aftercooler) to avoid overheating by the compressor.[19]

Interestingly enough, the US Army had originally decided to focus their aircraft engine developments on turbocharger technology with the goal to achieve higher performance than their European counterparts.[20] In retrospect, this was a far-sighted strategy, yet the lack of technical maturity of turbocharging made this goal unachievable during the war. Moreover, the Americans had to rely on a single source for research and production of turbochargers, which was General Electric.[21] It can be said that despite the technical obstacles that prevented turbocharging from having a real breakthrough in World War II aviation, the seemingly victorious mechanical superchargers soon became obsolete in post-war developments whilst better designs and materials made turbocharging the way of the future. We will, indeed, see the climax of turbocharger technology (called turbo-compound) in aircraft piston engines again in the following section, which also depicts their close kinship to the turboprop concept.

Altitude Performance: the "Wright 3350 Duplex Cyclone" -high performance piston power at the dawn of the Jet Age

Following the end of World War II and the beginning of political stabilization in Europe in the early 1950s, civil aviation had again reclaimed a large segment of aircraft operations throughout the world. The rapid economic recovery of Western

Europe and Germany, in particular, made flying accessible to a larger public in Europe, whilst the aircraft producing countries, with the United States at the forefront, shifted their efforts from purely military projects towards the development of modern civil aircraft. It must not be forgotten, however, that up to the late 1960s, flying was still a fairly elitist mode of transportation, primarily used by the wealthier and middle aged, upper class. However, technical and operational developments of that time, particularly in the long-haul segment, paved the way for affordable mass transportation by air, culminating in the advent of low-cost operations (even transatlantic) during the 1980s.

An aircraft will be examined that marks the technical apogee of piston-powered long-haul airliners before their decline caused by the "jet age", the Lockheed L.1649A “Starliner”. Figure 5.[22] It is interesting and tragic at the same time, that during the years of its service and despite its technical excellence in almost every detail, this aircraft was nearly ignored as an engineering masterpiece. It was overlooked because of the revolutionary introduction of jet technology in civil aviation, with its promises of "faster, higher, better". The few airlines that bought the aircraft used it as a successor to the widely acclaimed "queen of the prop era", the L.1049 Super Constellation. The “Starliner” was a great improvement over Super Constellation, but was clearly regarded as just an interim solution before the delivery of jet-powered alternatives like the Boeing 707 and Douglas DC-8, for instance. Lufthansa, which alongside TWA and Air France was one of the three first time buyers of the “Starliner”, used the aircraft on passenger services for only nine years. It was then used subsequently as a converted freighter. In comparison, the Boeing 737-300 type has been with Lufthansa since 1986, and remains in service.

The Lockheed L.1649A was powered by four Curtiss-Wright R3350988TC-18EA2 twin-row, turbo-compound, air-cooled radial engines with eighteen-cylinders and 3450 hp (about 2536 kW) each. This engine type, also called the "Wright 3350 Duplex Cyclone", is usually considered as one of the most powerful American radial engines.[23] It featured supercharging technology that is often referred to as a "turbo-compound" design, which is different from the previously described concepts of turbocharging in as much as it uses a so-called "blowdown" or "power-recovery" turbine. There were three downstream turbines, each of which took the output from six cylinders, making use of the kinetic energy in exhaust gases as opposed to the pressure difference. These turbines had a hydraulic connection through to the crankshaft which returned in power to the propeller. The turbo-compound has the great advantage of being a pure power recovery principle without causing power-consuming exhaust gas flow. It therefore does not require additional fuel to provide a power increase but simply enhances the specific fuel consumption and overall engine efficiency by making better use of the kinetic energy released from the engine's combustion process. In addition the engine used a two-speed gear driven, supercharger to improve altitude

Figure 5. Lockheed L-1649A “Starliner”.

performance. Unlike a normal gear driven supercharger, however, any excess pressure in the engine is effectively picked up by the blowdown turbines that return this to the crankshaft and propeller. Hence the efficiency of the engine was close to 40%.

In the case of the Wright 3350 Duplex Cyclone, the three blowdown turbines recover an impressive total of about 550 hp (at maximum continuous power setting).[24] This immediately leads to the question why turbo-compound technology has not been more successful in aviation, as it obviously provides a good way of making use of freely availably energy from a piston engine. Indeed, the only other example of an aircraft engine that made it to the demonstration stage was the British Napier Nomad engine designed in 1949. It was flight tested on the Avro Lincoln bomber (basically a somewhat improved version of the Lancaster using highly boosted Merlins). The answer to this question lies in the complexity of the design and the ensuing reliability issues, as well as the additional weight produced by the mechanical array. Moreover, the turbo compound technology is so close to a conventional turboprop principle that, at least in aviation, a turbo-compound design would have to prove clear advantages to be selected in lieu of a turboprop.

When turbo-compound designs came up in the 1940s and 1950s, it was soon obvious that the power relationship between the main (piston) engine and the power recovery turbines was somewhat odd as the turbines would recover almost as much power as the engine itself would produce as a net output. Thus the transition to a full turbine-based concept such as the turboprop or turbojet engine was an obvious consequence. The use of a turbo-compound design on the Lockheed L.1649A and its Wright 3350 Duplex Cyclone engines is therefore of great historic meaning as it perfectly illustrates the transition from piston to turbo engines in aviation. Turbo-compounding is thus the technological link between these two eras, gracefully represented by the Lockheed “Starliner”, which was sadly outshone in its days by the rapid triumph of the jet engine.

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