Turbo-Supercharger Development

Evolution to First Operational Use

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The turbo-supercharger is a small relatively simple and unimposing device used in conjunction with piston type aircraft engines to boost their power output and/or maintain their power output to high altitudes. Weighing only a couple of hundred pounds, it is essentially nothing more than a pump supplying air under pressure to the engine induction system.

During the war years almost everyone was familiar with the B-17, B-24, B-29, P-47, P-38 and P-51. These were the mainstays of the USAAF war effort, yet all except one were completely dependent upon the turbo-supercharger for their superior high altitude performance and would almost certainly have been dismal failures without this equipment. Alone of this elite group, the P-51 had no turbo, depending on the superb internally supercharged Rolls Royce/Packard Merlin for its oustanding speed and high altitude abilities.

This article proposes to tell the early development history of the turbine-driven supercharger; it is not meant to be a technical discussion of the turbo. However, for the benefit of those with only a vague idea of the subject and as a background for the history to follow, it is desirable to briefly discuss the types and operation of aircraft engine superchargers.

A piston engine, much like the human body, requires large amounts of air to operate. An unsupercharged engine, such as the familiar auto engine, draws air into its cylinders by the low pressure area created by the downward movement of the piston on its intake stroke. If the mass airflow into the engine can be increased, an increase in power is achieved. By installing an air pump to raise the pressure at the engine inlet, and increase the mass airflow, the engine develops more power.

The piston engine, again like the human body, loses efficiency (power) as altitude increases and air density decreases. If sea level air density can be maintained at the engine inlet as the airplane climbs, then power output will remain essentially the same as it was at sea level. This again is done by an air pump, that magical thing called a supercharger.

Throughout aviation history, only one type of supercharger has seen wide usage, and this is the one with the centrifugal impeller, or compressor. (In Europe, superchargers are often called "compressors." Another common semi-slang term for them in the United States is "blower.") An excellent example of a centrifugal impeller, although on a small scale, is the water pump used on many automobile engines.

Branching out from this basic type, there are two major ways of driving the compressor. One method is a gear driven compressor where the unit is driven by power from the engine crankshaft and is usually an internal part of the engine. The other, the turbo-supercharger, utilizes the same kind of compressor but is driven by engine exhaust gases impinging on a turbine wheel--hence the turbo name, meaning turbine driven. Both types have been in common usage for many years, but it should be made clear that all American WW II combat aircraft equipped with a turbo also had an internal, gear-driven supercharger, and in effect, had two superchargers per engine. The turbo's function was to maintain sea level pressure at the engine inlet as the airplane climbed, and the internal supercharger then compressed the air further before delivery to the engine cylinders.

As indicated, the turbo-supercharger is a simple device consisting of a compressor pumping air and being driven by a gas turbine attached to the other end of the compressor shaft. Yet, the development of this seemingly basic equipment covered a span of over 20 years before it became a really successful accessory to aircraft engines.

By the magic of hindsight we can detect WW II's pattern of high altitude combat way back in the skies of France 25 years before when German observation types, such as the Albatross C-3, carried out their duties above 20,000 feet. Since this was near, or beyond, the capabilities of many allied fighters, they presented a very difficult problem. So, the lesson was there to be learned. During the interwar years, most of the world's military aircraft were essentially medium altitude machines. In the United States, however, there were people who had learned the lesson, and when WW II started the seed of high altitude capability was available.

In delving into the history of any mechanical device an author is always on thin ice when he attempts to pin its origin down to any one place or date. In the case of the turbo-supercharger, however, most sources agree that A. J. Buchi, a Swiss, developed the first workable exhaust-driven supercharger between the years 1909 and 1912. Buchi's unit was for use on diesels and had no aviation application. The first real progress took place in two countries which never made any significant use of this equipment.

Early in WW I, probably about 1915, work on a turbine driven "engine booster" began in France under the direction of Professor Auguste C. E. Rateau, the designer of a widely used steam turbine. Little information has come to light on the early development work, but by the end of WW I it had reached the flight test stage. First installed on an A.R. and then a Spad (type unknown), the installation was not satisfactory and no useful results were obtained. Next applied to a Brequet 14-A2, the "engine booster" showed promising results, and tests continued for about eight months. The best performance achieved with this aircraft was a ceiling of 22,960 feet at which it reached a maximum speed of 105 mph (5 mph faster than an unblown Brequet at its service ceiling of 16,400 feet).

With the completion of the test program on the 12-A2 a number (total not known) of Brequet type 14-B2s were equipped with the Rateau device, and two of these were assigned to the test program. One of the two B2s reached well over 26,000 feet, after which a 10 hour endurance run on the ground was attempted. The endurance run ended abruptly after three and a half hours when the turbine failed, and testing did not resume.

The French turbo program did not end with this failure, however. A report from the U. S. Air Attache in Paris dated 1924 indicates that the French were operating two observation squadrons of turbo equipped aircraft. The type is not specified, but possibly it was the Brequet type 14-B2. These 16 observation craft seem to have

been the sum of the French use of this type of supercharger, no further interest being shown.

In England, too, the advantages of the supercharged aircraft engine were well known, and development work had begun in 1915 at the Royal Aircraft Factory at Farnborough. In charge of the project was Mr. James Ellor, who was to be responsible for all supercharger work at Farnborough until 1927 when he went to Rolls Royce to take over their supercharger development on the current 12-cylinder Kestrel.

Initial development in 1915 involved all the accepted types of air compressors, including the piston or reciprocating type, the Rootes blower and the high speed centrifugal. It became apparent almost from the beginning that only the latter was suitable for aircraft engines. By January of 1916 a B.E.2C (RAF serial #2015) was flying with a gear-driven blower, and by the end of 1916 it had flown successfully for about ten hours.

There was, however, difficulty with the gear drive mechanism, and it was probably because of this that Ellor became interested in driving the compressor with an exhaust turbine. Sometime in 1917 work began on a turbo-compressor in collaboration with Metropolitan Vickers Ltd. A fair amount of preliminary design work had been carried out when Ellor became aware of the French Rateau, which was already running on the bench and was considerably advanced over British work. By January 1918 agreement had been reached between Professor Rateau and the British Air Board, and Dr. A. H. Gibson of the Royal Aircraft Factory's engine department took the installation drawings to Paris on the 16th of January, where he discussed them with Professor Rateau.

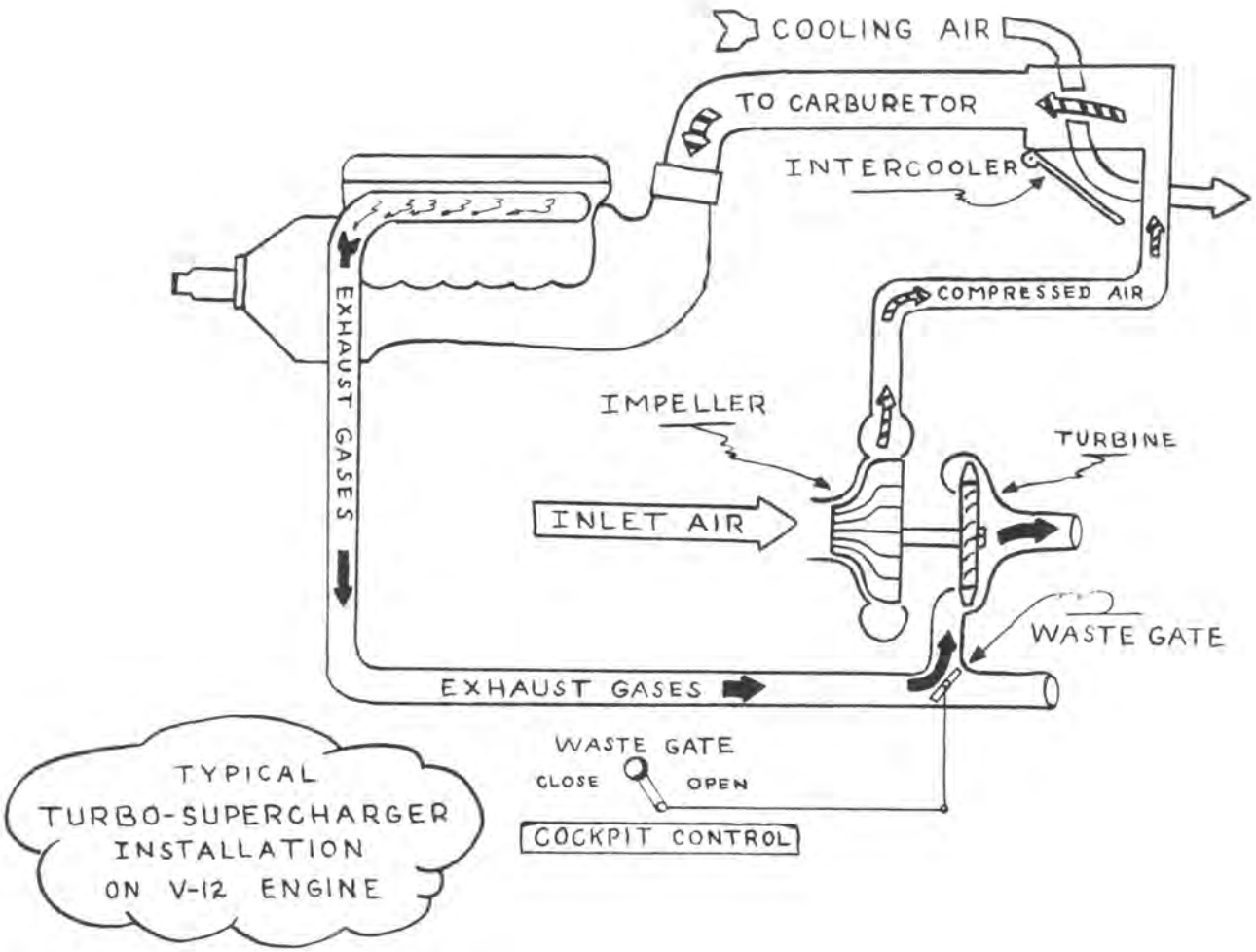
Although the original agreement between Rateau and the Air Board called for all flight testing to be carried out in France, Professor Rateau now agreed to the testing being done at Farnborough provided he was kept well informed.

The French unit was, therefore, brought to England where it was installed on an R.E.8 (RAF serial B738) with an RAF 4D engine. The advantages of a variable pitch propeller were well understood, and such a propeller was available, having been flight-tested on a B.E.2C.

The first flight with the turbo-compressor and variable pitch four-bladed propeller probably took place in March of 1918. It has not been possible to determine the crew identity for this test program; a Lt Harold Elliott is said to have been the observer, but today neither the RAE, British Army Records Center or the RAF can find any record of such a man. It is likely that James Ellor would have ridden the observer's pit to check on the performance of the unit. The first flight in March was not a success, due to engine overheating caused by high air charge temperature, in turn caused by compression through the compressor disc. (About a year later, the first flight of the supercharged LePere at McCook Field would end abruptly for the same reason.)

The remedy adopted for the R.E.8 was simple and direct. A large air scoop was fitted over the engine to provide increased cooling air flow.

A total of nine flights were made but only two with the big variable pitch propeller, which did not prove satisfactory. Even though there were considerable air



leaks in the ducting between the supercharger and the engine, it was found possible to maintain sea level pressure to the carburetor up to about 12,000 feet. On the 4th of May 1918, during its ninth flight, the turbine failed, destroying the Rateau turbo-compressor and ending this series of experiments.

The failure of the turbine, which was running at over 16,000 revolutions per minute, graphically illustrates one of the major problems to be overcome with a turbine driven supercharger, and this was a metalurgical problem. The compressor, or impeller, may be pumping air at high altitudes with a temperature of minus 40 or 50 degrees F, while the turbine on the other end of a one or two foot shaft is operating in the direct blast of the exhaust gases which may far exceed 1,000 degrees F. Add to this the very high rotational speeds required (20,000 RPM and above) by the centrifugal impeller, and it becomes apparent why evolution of this equipment covered so many years.

After the war the RAE (Royal Aircraft Establishment, so renamed to avoid confusion with the newly formed Royal Air Force) continued its research on turbine driven superchargers, and both Napier and Rolls Royce supplied engines for the test program.

However, by 1925 favor had swung away from the turbo for several reasons--lack of reliable controllable pitch propellers, serious troubles with turbine blades, bearings and exhaust manifolds, and heat distortion of the turbine casing.

All British effort over the ensuing years was devoted to the gear driven type, although some of the results were applicable to turbos also. One such was the development, at the RAE, of rotating guide vanes (or inducers) to improve the flow of air into the compressor. One of the most important steps in supercharger development, it is still in use today on almost all centrifugal superchargers.

In the United States the story of the turbo-supercharger finally found a successful conclusion. Despite a late start, development was carried out over a period of 30 years, and the turbo-supercharger was a major item on many U. S. high altitude aircraft for another 20 years.

Evolution in the U. S. began in the last year and a half of WW I and was embodied in two separate programs, one by Mr. E. H. Sherbondy and the other by Dr. Sanford Moss and the General Electric Company. Both of these turbos appear to have depended on the French Rateau, yet all three differed in major details. Whether a Rateau turbo-compressor was available in the United States is unknown, but it seems likely that at least a set of drawings and specifications were.

Sherbondy entered the field first when in June 1917 he was delegated (apparently by the Army) to make full investigation into the potentialities of the aircraft supercharger. Initially he concentrated on the gear driven type but soon settled on the turbine driven configuration. By May of 1918 preliminary testing was begun at the DeLaval Steam Turbine Co. of Trenton, New Jersey. On these tests the unit was not connected to an engine in any way but used steam to drive the turbine. Late in June a slightly different version was tested with steam.

The next month both versions were taken to McCook Field where they were installed on a wind tunnel-mounted Liberty engine. Running of the Sherbondy device continued under these conditions for the remainder of 1918 with a third version being tested in December. However, the unit seldom ran well, and there were continual troubles with the "hot section" (the turbine and nozzle box--the nozzle box being a circular, or semi-circular section containing stationary vanes which direct the flow of exhaust gases onto the turbine buckets).

On December the 16th an endurance run was attempted but had to be abandoned after two and three-quarters hours, as vibration had loosened some oil lines. Soon after shutdown the rear turbine shaft bearing melted again, a common trouble throughout the tests.

Although it is doubtful if the Sherbondy supercharger was assigned a model number at the time, reports in later years referred to it as "type A-1". Flight tests had been planned for the Sherbondy unit but were never carried out. The war was over now, Air Service funds were limited, and by this time the Moss supercharger had demonstrated its superiority. No further effort was expended on the Sherbondy turbo-supercharger.

The name of Sanford Moss has been mentioned previously, and although it would be unjust to others to give him full credit for turbo development in the U. S., nevertheless, his position as father of the turbo in this country is secure.

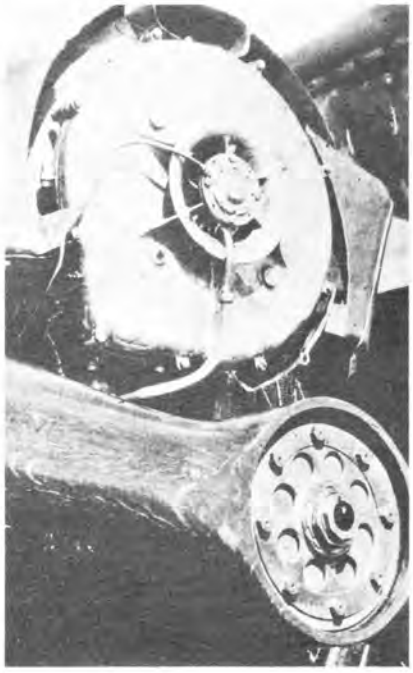
Born in San Francisco August 23, 1872, Sanford Alexander Moss became an apprentice machinist at 16 and later became a draftsman. He then entered the University of California where he studied engineering, receiving his degree in 1896 and his Master's in 1900. For his Doctorate, he went to Cornell, and it was here that he became interested in, and wrote his thesis on the gas turbine. After graduation in 1903 he went to work for General Electric at West Lynn, Massachusetts and carried his enthusiasm for the gas turbine with him. Fourteen years later, when the United States entered WW I, GE had built up a large business in industrial air compressors, and Moss had set up the turbine research department at GE's Lynn steam turbine plant.

When Moss first thought of applying the gas turbine to an aircraft supercharger is not known, but it was probably not until the Fall of 1917 when Doctor Durand (who had known him at Cornell) of the newly-formed NACA asked GE to develop the Rateau "engine booster" for the Liberty engine.

Probably because of GE's extensive turbine and compressor business, Moss had the first experimental unit running in a short time. By February of 1918 it had been steam tested at Lynn and active experimental work was underway at McCook Field. By August it had been run extensively on a Liberty and was satisfactory enough to warrant continued testing at high altitude. This phase of the program was to be carried out atop 14,000 foot Pike's Peak. It would not be the first time that the Peak was used for this purpose as crews from McCook had been there in 1917 to run high altitude tests on the 8-cylinder Liberty engine. For the turbo tests, a complete truck-mounted dynamometer equipped with a 12-cylinder Liberty engine and all necessary equipment was built. After the turbo was installed four engine runs to check functioning were made before leaving Ohio, and

The turbo-supercharger test truck arriving at the Rock Island Rail Yards, Colorado Springs. (Air Force Museum)

1941



The truck mounted dynamometer atop 14,000 foot Pikes Peak early in October 1918 with the turbo-supercharged Liberty running its four hour endurance test. Right, a close-up of the Pikes Peak test turbo. (Air Force Museum)

then the unit was taken by rail to Colorado Springs early in September 1918. It was run once more in the rail yards, before being driven up Pike's Peak.

Appropriately enough, this first GE turbo was designated as Air Service type A, although this designation was probably not applied until later types came along.

It has not been possible to find out the identity of the men on the Army crew or who was in command. Apparently Mr. W. A. Reeves was present as a GE representative, and it is entirely possible that Dr. Moss was there part of the time. Since there were no living quarters on the peak, the crew had to live in Colorado Springs, an inconvience that cost a lot of time (but was probably appreciated by the crew because of the miserable weather conditions on the Peak).

A total of 23 test runs were made on the Peak, five of them without the turbo operating. The best of these five runs indicated a maximum horsepower output of 251 at 1800 RPM. The remaining 18 test runs were all made with the turbo in operation, but with all exhaust gases going to the turbine it was found impossible to run the engine at full throttle because of cylinder pre-ignition due to the high temperature of the air going to the carburetor. This was the result of the heat rise through the supercharger due to compression. Nevertheless, on one run the Liberty produced 356 hp, about six more than it produced at sea level.

The last run made, on October 7th, was an endurance test which lasted 4 hours, 22 minutes. Tests were then discontinued because of the difficulty of refueling the unit while the engine was running--the tank held only 50 gallons. Access to Pike's Peak was much more difficult then than it is now, and it was a problem to transport sufficient fuel to the peak. Throughout the tests there had been no problem with overheating of the supercharger. This trouble would crop up later.

The results of the Pike's Peak tests were highly promising, and with the Sherbondy device out of contention Moss and General Electric had the field to themselves--a situation they maintained until the gas turbine engine made the gas turbine supercharger obsolete. The obvious next step in the evolution was to undertake flight trials, and after some slight changes at Lynn and more steam tests work began on the critical flight phase.

The Supercharger

General Electric turbo-supercharger installed on 12-cylinder Liberty engine. (U. S. Air Force)

Original plans were to use a DH-4 for flight testing, but Major George E. A. Hallett, Chief of the Power Plant Section, vetoed the DH-4 and picked one of the 30 Packard-LePere LUSAC-11 two place biplanes which had been developed too late for combat. Major Hallett's reasoning was that the LePere was a much stronger aircraft and would not be so likely to break up in event of a long fall from high altitude or violent pullouts--a situation he foresaw and which did occur later. The LePere was serial number A.S. 40015, and its McCook Field number was P-53. It was powered by the standard 12-cylinder Liberty engine of about 400 hp, and the turbo was installed on the front of the engine above the propeller shaft with the compressor section and air inlet exposed to the prop blast. The "hot section", consisting of the nozzle box and turbine wheel,were aft, the same position used on all ground tests up to this time. Although the location had been satisfactory, it was to cause trouble very soon.

Most of the work on the project ceased after the Armistice in November 1918 but was resumed in the early months of 1919 when installation and final ground runs were made. Probably it was touch and go whether work would resume. The war was over now, and money for Army aviation had been drastically reduced. There were, however, a number of determined men, both at GE and among the Army people, who were convinced of the turbo-supercharger's future and made every effort to keep the project instated.

Prominent among these was Major Hallett, a pioneer aviation mechanic. As a boy, he had been thrilled by the news of the Wright flights and had by 1910 become involved with a number of California flyers.

When Glenn Curtiss brought his early hydroplane to North Island at San Diego, Hallett had been employed as a mechanic. He remained a part of the Curtiss organization until December 1914 and took part in much of the Curtiss exhibition program including a lengthy trip to Europe in 1912-13. Also noteworthy was his participation in the development of early Curtiss aircraft, such as the ambitious "America" flying boat (a trans-Atlantic project that did not come off because of the war) and the later model N, predecessor of the famous JN series. At the end of 1914 Hallett left Curtiss to take a better paying job with the Army at North Island serving as an engine consultant and later as an instructor in the mechanics' school.

Late in 1917 he went to Washington, D.C. to organize a series of mechanic schools and in May of 1918 was commissioned a Major in the regular Army, being transferred to Wilbur Wright Field at Fairfield, Ohio. On the 21st of December of that year orders became effective assigning him as Chief of the Power Plant Section at McCook, and he therefore became directly involved in the turbo-supercharger program. Major Hallett remained in this position until December 1922 when he resigned from the Army to take a position with General Motors. Hallett thus was the officer in charge of the project during the early flight testing and development.

Although Moss and General Electric had designed and built the turbo-supercharger, the company at that time had no experience in the aviation field, and the whole enterprise was very much a joint effort with the Army engineers and technicians. Two of the Army employees who played a big part in the endeavor for many years were Mr. Opie Chenowith and Mr. A. L. Berger, both of McCook Field's Power Plant Section.

In the opening years of turbo-supercharged flight the name of Major Rudolph "Shorty" Schroeder looms large indeed. Chief of Flight Test Section at McCook, he had already been in aviation for over ten years. In 1910 he had been a mechanic for pioneer flyer Otto Brodie and had learned to fly at Chicago in that year. His commercial pilot's license was number 7. Like many other early flyers he entered the Army when the United States became a participant in the "great" war. A Lieutenant in 1917, by the summer of 1918 he was a Captain at McCook Field and involved in the test program of the new LePere. During the waning days of the war, he was promoted to Major and became Chief of Flight Test. It was in this capacity that he was to become the first man to fly a turbo-supercharged airplane in the United States.

"Shorty" Schroeder (he was over 6 feet tall) left the service in the early 1920s, and after a short period with the Underwriters Laboratory in Chicago, he joined the Aeronautical Division of the Ford Motor Co. in June of 1925. He was the first man to fly the Ford Tri-motor, and along with another pioneer, S. R. "Sinny" Sinclair, he flew the Detroit-Chicago air mail route in Liberty-powered Ford Stouts. During the late 1920s he was involved in the Guggenheim Foundation Safe Aircraft Competition, served as Chief of Aeronautical Inspection for the Bureau of Air Commerce in the early 1930s and finally joined United Airlines in 1936. He retired in 1941 as vice president for safety due to ill health. "Shorty" Schroeder died four days after Christmas 1952, following a lifetime of service to aviation and to his country.

Through the efforts of those men mentioned, and many others, Major Schroeder became airborne on the first test flight. It has been impossible to determine exactly when this first flight took place, but it was sometime in the spring of 1919. In any case, there must have been quite a number of anxious hearts and crossed fingers among the watchers on the ground. A successful flight was not to be, however, for the engine failed at 18,000 due to a combination of serious problems.

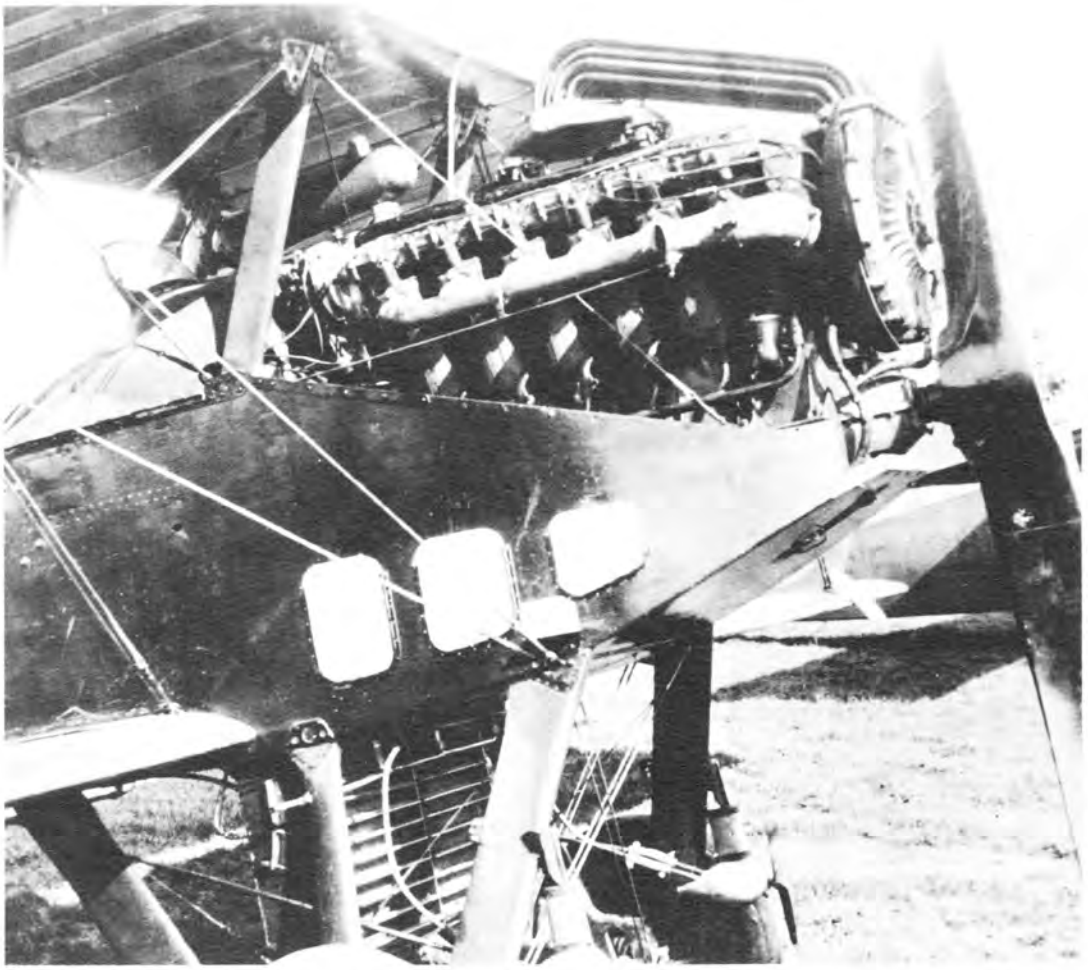
In a report written many years later (1934), by Berger and Chenowith, it is stated that those involved in the evolution of the turbo probably had not realized the magnitude of the job ahead until the unit was actually running on an aircraft. Although the turbo is a simple mechanism, its application affects almost all systems and aspects of a piston engine. Hence, it is not surprising to find that during this flight, resulting in engine failure, we have engine overheating, loss of fuel pressure, extremely high carburetor air temperature and overheating of the turbo nozzle box and turbine. On future flights many other troubles were to appear. The entire engine cooling system had to be redesigned as the upper wing plate-type radiator was inadequate. Since the Liberty engine's normal operating temperature was above boiling at high altitude, a sealed cooling system had to be provided. The final successful radiator installation was suspended below the fuselage with an expansion tank on top of the engine.

The full system also had to be redesigned to overcome the loss of fuel pressure and vapor locking at high altitude.

The high carburetor air temperature was due mainly to the heat rise of the air as it was compressed by the impeller, and an intercooler was designed and installed. The principle of an intercooler is the same as a radiator except that air flow, instead of water, does the cooling, and this unit is normally installed between the supercharger and the carburetor, as it was here. Along with the intercooler, a modified turbo was provided, and this was the type "B" which also had air cooled bearings and expansion joints in the exhaust manifolds.

Probably the most serious problem which manifested itself on this first flight, and the most difficult to solve, was the overheating of the turbine and nozzle box which was running in exhaust gases of 1500 to 1600 degrees F. Most of the difficulty was caused by the position in which the turbo was mounted with its "hot section" aft and sheltered from the prop blast by the compressor section. Although efforts to improve cooling of these vital parts were made by a series of baffles, the problem was not completely solved until the position of the turbo itself was changed.

Like their British counterparts, Army engineers were well aware of the theoretical advantages of a propeller on which the pitch of the blades could be changed at will by the pilot. When the supercharged LePere was being readied for its early flight tests such a propeller was



Early turbo-supercharger installation on LePere LUSAC-11, serial 40015, showing radiator installation below nose, intercooler tubes to carburetor and tubular type exhaust manifold. (USAF)

The first test vehicle and the men: Lt John A. Macready (l), Dr Sanford Moss, Major George E. A. Hallett and General Electric technician Adolph Berger. Different intercooler ducting than on same aircraft above is visible. (Marty Copp)

already tested and available.

The propeller branch at McCook Field had done considerable development and testing work in the first two years of its existence. Approximately 150 propellers had been tested on the destructive whirling rig. The great majority were variations of the common fixed-pitch type, but the Propeller Branch was able to report, in 1919, that "Experimental work is being conducted on variable pitch propellers, one hub for a Liberty 12 and one for a Hispano." Although several types of these propellers were submitted for test in the early post-war years, the Hart propeller seems to have received the most attention and showed considerable promise of success.

The Hart reversible and variable pitch prop was the invention of Mr. Seth Hart of Los Angeles. It was built and test flown successfully in California before Hart brought it to the Army at McCook Field early in 1918.

Tested on the whirling rig it showed no signs of weakness and was installed on a JN-4H (McCook #P-6, Air Service serial 37935). This original Hart propeller was flown for about eight hours and Army engineers were enthusiastic about its performance, especially its reversible feature which reduced landing roll by about two thirds. Ten of the Hart propellers were built for testing on the Liberty 12 and the 150 and 300 hp Hissos.

One of these Hart propellers was used on the supercharged LePere. However, it appears that most of the flight testing with the LePere was done with a fixed pitch wooden propeller.

With most of the major problems solved, except the turbine overheating, the LePere went on to establish a series of world altitude records as part of the high altitude research program. One of the first of these came in early August 1919 when Schroeder, with Lt G.E. Elfrey as observer, attained a speed of 137 mph at 18,400 feet which was claimed as a record at this altitude for a two seater. In October the same crew topped 31,000 feet over Dayton, another two man record.

"Shorty" Shroeder's participation in the program came to an abrupt end on February 27, 1920. Alone this time he topped 38,000 feet, but the crude oxygen equipment and lack of knowledge about the effects of high altitude flight, almost cost him his life. Trouble with the oxygen system caused him to lose consciousness, and the LePere fell out of control for six miles before he regained consciousness and was able to right and then land the plane. A situation such as Hallett had foreseen had occurred, and Schroeder owed his life to the strength of the LePere. With his eyes frozen, and suffering from exposure and exhaustion, he was taken to a hospital where he recovered only after a lengthy stay.

With "Shorty" Schroeder now "off duty" for medical reasons a new pilot was needed for the high altitude turbo project. Although Major Hallett flew the LePere, both as pilot and observer, to check engine/airframe performance, he never did so in a test pilot capacity.

Assigned to the Flight Test Section at that time was a young man who was new to test-flying but had apparently shown considerable promise. Following a month's delay after Schroeder's accident, Lt John A. Macready was chosen to carry on the turbo project, and in the ensuing six years he became one of the most experienced high altitude flyers in the world. During these years, he made over 50 flights to altitudes above 30,000 feet and about ten above 35,000. In the promotionless atmosphere of the post war Army John Macready was unable to progress beyond the rank of First Lieutenant but, nevertheless, he established an enviable record of pioneering in aviation.

His endurance records and first non-stop transcontinental flight (with Lt Oakley Kelly) are his best known achievements. Less well known is his extraordinary photographic survey of the United States, covering 10,000 miles in a DH-4 with that unsung pioneer of aerial photography, Captain A. W. Stevens. In September of 1921 he raised the world altitude record to over 38,000 feet.

Lt John Macready in typical high altitude flight clothing of the 1920s. (U. S. Air Force)

LePere LUSAC-11, 40015, with very early form of turbo and a variable pitch propeller. (Marty Copp Coll.)

The LePere during one of its later flights with Lt Macready waving from the cockpit. (U. S. Air Force)

The purpose of the flight had been primarily to test a longer propeller, turning at 1100 RPM on the ground (normal ground RPM being 1600). The ground takeoff run must have been quite long but Macready set a new record, stating that at 41,200 feet (indicated) the aircraft mushed badly and he had little control over it. Icing of the oxygen tube was again encountered.

Both before and after the record there were endless flights which ended in failure of some part of the engine, airframe or supercharger. On one occasion the propeller flew off at 28,000 feet. On another cold, overcast day over Dayton, above the clouds, the engine caught fire. By diving below the cloud base the fire was extinguished. The observer that day was Roy Langham (another man who regularly risked his life at high altitudes and is practically unknown for it). Misinterpreting Macready's signals, he unfastened his safety belt and started to bail out. Caught at the last second by Macready, he was pulled back in the cockpit and remained with the aircraft for a conventional landing.

Major Hallett's successor as Chief of the Powerplant Section at the end of 1922 was Lt E. T. Jones, who was responsible for one of the most important developments of the turbine supercharger. Overheating of the nose-mounted unit had never been solved and Jones' answer to the problem was to mount the unit on the side of the engine with the "hot section" (turbine and nozzle ring) outermost and exposed to the slipstream. This seemingly simple change was a great success, and all turbos until the advent of the WW II types were so positioned.

By the end of 1921 the LePere had been joined at McCook Field by two other supercharged airplanes, a DH-4B and a Martin MB-2. The DH-4 was McCook number P-131, Air Service serial number 63413. It was powered by a Packard 1237 engine (a V-12 of about 300 hp), and the turbo installation was that designed by Lt Jones. Known as the form F, the supercharger was mounted on the side of the engine (usually right side) with the compressor section buried in the engine compartment and the hot turbine and nozzle box outside and exposed to the prop blast. This proved highly successful, and over 60 hours of flying were done with this airplane with no overheating problems. On one occasion an altitude of 32,160 feet was reached.

The Martin MB-2 was Air Service serial number 64195, McCook Field number P-162, and it was the forerunner of what were planned to be the Army's first turbo-supercharged aircraft in squadron service.

To find the origin of this idea we must go back about a year to June of 1920 when the specification was written for the new Martin MB-2. By this time Major Schroeder had made numerous flights in the LePere, and the Army was sufficiently impressed to include in the MB-2 specifications, under "Powerplant":

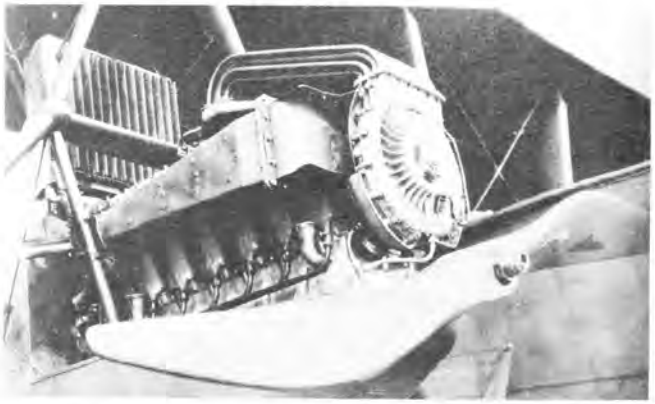
> "Two General Electric type turbo superchargers complete"

It was not to be, however, as 64195 was the only bomber on the Martin contract for 20 on which turbos were installed. The other 19 served out their time as unsupercharged low altitude bombers.

It is probable that the Army did not realize the magnitude of development ahead, or they would not have been optimistic enough to expect the turbo to be ready for installation on production aircraft. Delivered to McCook Field from the Martin plant in December 1920, MB-2, 64195, had difficulty in acquiring its superchargers which were not available until the middle of 1921.

The turbos which finally arrived for the test aircraft were probably of Form "D", the first of a batch of 70 which had been ordered for the Martins and for a dozen DH-4s. Position of the turbos on the MB-2 was similar to that already found unsatisfactory on the LePere--on the front of the engine with the hot section aft. As far as is known no other position was ever tried during the MB-2/NBS-1 program.

Even though the supercharged Martin bomber program was destined to failure, MB-2 64195 performed remarkably



Turbo installation on Martin MB-2 with exhaust manifold leading to turbine, tubes serving as intercoolers. (USAF)

Martin MB-2, 64195, first of supercharged bombers. (USAF)

Same MB-2 held altitude records, let to Curtiss NBS-1. (USAF)

NBS-1 and Maj Reynolds, 2nd Bomb Group C.O. (J. Sloan Coll.)

well during the test program. Early in December 1921 two flights were made at low altitudes to check turbo operation, and then on the 7th an attempt was made to reach the aircraft's ceiling. The pilot during this and later tests was Lt Leigh Wade (now Major General, USAF ret.). Although the creditable altitude of 20,000 feet was attained, the flight was ended due to the observer, Sgt Roy Langham, losing consciousness. No oxygen was carried. Also aboard were Mr. Gregg and Mr. T. Jones of the powerplant branch. Jones is mentioned in several reports of this period, and it is suspected that this is actually Lt Edward T. Jones, who was to take over command of the Powerplant Section from Major Hallett a year later.

With Sgt Langham's experience as a guide oxygen tanks were hurriedly installed, and on the 8th of December another attempt was made to reach the MB-2's ceiling. Again the airplane and turbos performed well, but more trouble was encountered due to the extreme cold in the exposed cockpits. At 25,000 feet temperature in the cockpit was -33 degrees F, and the crude oxygen system gave trouble. It should be mentioned that masks, so familiar to WW II types, were seldom in use, and an oxygen tube was usually held between the teeth. The tubes iced up and blocked the oxygen supply, but even so Wade and Langham reached a true altitude of 25,341 feet above sea level. During 1922 this same aircraft and crew made a number of high altitude flights, during one of which the versatile Capt. A. W. Stevens bailed out at 24,000 feet, the highest parachute jump made up to that time.

There is no record of the final disposition of 64195, but it is probable that it went to one of the service units, minus its turbos, upon completion of the test program. One thing is sure, no other MB-2, or NBS-1, ever climbed so high as did this pioneer, supercharged bomber.

Even though all Martin MB-2s except the one went into service unsupercharged, the desire was still there to make airplanes into high altitude bombers. Consequently, 17 aircraft (and possibly 2 or 3 later) from the Curtiss contract for NBS-1s (MB-2s built by Curtiss) were earmarked for turbo-supercharger installation. Although most of the Curtiss-built NBS-1s were delivered in 1922, the 17 referred to above were not ready for delivery until the spring of 1923.

The 2nd Bomb Group at Langley Field was slated to put these bombers into service, and in April 1923 Leigh Wade was ordered to pick up NBS-1 68508 at the Curtiss plant at Garden City, Long Island. He was then to proceed to Langley Field "for the purpose of instructing and demonstrating, to personnel at Langley Field, on superchargers."

Considerable trouble was encountered with 68508, requiring an engine change and other repairs, but Lt Wade arrived at Langley on the 27th of April to find that the 2nd Group had already decided it did not like supercharged bombers.

Following is a small portion of his report, dated 8 May 1923, to the Chief of Engineering Division at McCook Field.

> Conditions found regarding the superchargers at Langley Field was (sic) as follows; the pilots and other personnel concerned had no confidence in superchargers and did not desire to fly them on Martin bombers, due to fear of fire, increased distance required for takeoff, and poor climb at low altitudes as compared with standard Martin bombers. Also, they were in complete ignorance of what would be required of a Martin bomber equipped with superchargers, e.g. they thought they would have to operate, perhaps, carrying the same bomb loads as a standard Martin bomber, and thought that this was impossible. Also, they had received no instructions on the purpose of the superchargers or their operation. The reasons for their opinions regarding superchargers, as given above, were that the first pilot to ferry one through turned in a very unfavorable report against the superchargers, stating that the climb was very poor, and that it took too much distance to get off the ground, thereby endangering the transfer of airplanes from Mitchel Field to Langley Field. Also, Lt Black, who had a forced landing, completely washed out his airplane near Aberdeen Field, and Lt Cummings had a forced landing near Aberdeen, arriving at Langley Field with the breather pipe on his right engine burned off.

With the cooperation of Major Reynolds, the Group Commander, Lt Wade proposed to fight the supercharger hostility in two ways. Since most of the air and ground crews had only a vague idea of the purpose of the turbo, he assembled all pilots and crew chiefs in the base auditorium on the morning of April 28 for a lecture on the operation and use of the turbo-supercharger. He also explained that the 2nd Bomb Group was to conduct the trial operations of the supercharged bomber.

From the lecture hall they went to the flying field to conduct comparison tests of the standard Martin bomber and the supercharged Curtiss machine.

The tests did not go well from the beginning. The supercharged machine, 68508, required 75 percent more takeoff run, and although it did get off the ground with a 1500-lb bomb load (some of the crews did not believe it would) it climbed slowly, overheated and finally blew a radiator hose on the left engine. It was realized on this flight that the carburetor jets were giving an excessively rich mixture and the turbine adjustments were incorrect. In view of these difficulties it was decided to return to McCook Field where efforts would be made to eliminate the troubles.

Before Lt Wade departed for McCook on May 1, it was decided that the remaining 16 bombers would be flown down to Langley, and this was done during June, July and August by 2nd Group pilots. These 16 airplanes were serial numbers 68512 through 68527, and what happened to them after their delivery is not entirely clear. However, it is probable that they did little flying and were stored awaiting solution of problems which were never solved. It appears that there were two major stumbling blocks which killed the project--one was the poor performance on takeoff and at low altitudes caused largely by the lack of a variable pitch propeller, and the second was the overheating engine problem. The latter was never solved with the front-of-engine installation, although several different radiator locations were tried to improve airflow and cooling.

At least three of these machines were at McCook Field during the test program. These were: 68508, McCook Field number P-293; 68519, number P-316; and 68526, number P-322.

NACA aircraft Number 25 with turbo-supercharger. This DH-4 was also flown with other types of superchargers. (NACA)

Curtiss PW-8, 24-202, was first turbo-supercharged Curtiss pursuit. Tested at McCook Field, 1925-26. (M. Copp)

The Curtiss P-2 was tested with turbo-supercharger at McCook Field as XP-431 in 1928-29. (M. Copp)

Engineering Division TP-1 with front mounted turbo, after crash at McCook Field. (R. Cavanagh Coll.)

TP-1 with side mounted. Type F turbo-supercharger while being tested at McCook Field. (Author)

Most of the 16 aircraft at Langley had their turbos removed and went to the service squadrons, as did 68519 which went to the 20th Squadron of the 2nd Bomb Group. Thus ended the first Army attempt at a high altitude bomber. The next try, 15 years later, would be a brilliant success--the Boeing, B-17 Flying Fortress.

In the years between 1922 and the B-17, development went ahead steadily but always on a small scale. The grand-daddy of all WW II turbo-equipped fighters, and the first single seater so equipped, was an Orenco D, the second of this type built by Curtiss (serial number 63282, McCook Field number P-161). One of the 50 ordered from Curtiss, it is perhaps logical that it was fitted with a turbo-supercharger, if for no other reason than that the Air Service did not know what to do with 50 Orencos! Some of these machines were apparently with the 1st Pursuit Group, but little is known of the service life of the 50 Curtiss-built airplanes (plus 4 built by Orenco). Even less is known about the supercharged version. The blower would have been a type C-1 with an altitude rating of 35,000 feet. It was similar to the type "B" for the Liberty with an intercooler, expansion joints in the exhausts and air-cooled bearings. It differed in being adapted for the 300 hp Hisso. Rumor has it that this airplane crashed soon after modification, and the records indicate that it was surveyed on 5-3-22.

By the mid-1920s the Army felt that it had developed the turbine-driven supercharger to a high state. In the annual report of the Chief of Engineering Division for both 1925 and 1926 it was said that most supercharger effort was being expended on the gear-driven type, the turbo having reached a successful state. By 1925 the old front-mounted "B", "C" and "D" types were obsolete, and the side type was standard in the various versions of the F-2 type. For ease of maintenance they now had removable turbine buckets and demountable impeller and turbine.

Although the Engineering Division felt that the turbo was a successful article, considerable activity took place during 1925 with various installations. A PW-8, serial number 24-202, was flown with an F type, and at 20,000 feet indicated the respectable speed of 175 mph. The purpose of the test was "to obtain information on supercharged pursuit aircraft." Its service ceiling was about 33,000 feet.

Also during that year five blown (supercharged) Curtiss P-2s were ordered. Arriving from the Curtiss plant in December, 25-420 went to McCook as the XP-2, and the other four (25-421 thru 424) went to the 1st Pursuit Group at Selfridge. No information has been uncovered on their reception or use at Selfridge, but a little over a year later, their blowers removed, three had been converted to P-1 standards, and a fourth (24-423) became the XP-6.

There were other turbo-equipped airplanes flying in the middle years of the '20s. A DH-4BS was engaged in testing various propellers for high altitude, and the Engineering Division made extensive modifications to their XCO-5. Originally begun as one of the two TP-1s, a 1922 Engineering Division design for a 2-place pursuit, it was completed as a Corps Observation machine (23-1204). Both it and the remaining TP-1 (68578) were eventually equipped with turbos. The TP-1 shows up in photos with both the front-mounted unit (probably type D) and with the later side-mounted type F, and a cleaner nose. It was badly wrecked with the earlier unit installed, so was apparently rebuilt with the new side type, form F.

In 1925/26 the single XCO-5 was highly modified with a set of long span two bay wings, an F type turbo-supercharger and other structural changes. Designed as a high altitude photography machine it performed very well in this mission. Lt Macready set an F.A.I. altitude record of 38,704 feet in this airplane during 1926 and also made his last record attempt before leaving the Army. On the 10th of April he ran out of fuel above 37,000 feet and made one of his many dead-stick landings.

Also tested in 1926 was the XP-4, a Boeing PW-9 with new wings, a type F turbo and a huge four-bladed wooden prop on its Packard engine. A dismal failure, it was

flown only four hours and abandoned.

Under a contract of 14 May 1927, five more Hawks, this time P-1s which became P-5s, were equipped with turbos (undoubtedly F-2 type), cockpit heaters and other modifications. Although one showed a top speed at 25,000 feet of 173 mph and the excellent service ceiling of 31,000, no further procurements were made of P-5s, and like the P-2s, very little information has come to light on their usage.

Since the abortive attempt with the NBS-1s in the early 1920s, no more effort had been made to provide supercharged aircraft in relatively large quantity. The Pursuit Development Board, which met at Wright Field in November 1930, was to provide the seed of the next attempt. This board, after considerable study and discussion, recommended that pursuit development proceed with the following types:

A. Single seater with high speed at sea level.
B. Single seater with high speed at high altitude.
C. Single seater with high maneuverability.
D. A biplace pursuit.

Pursuit development as carried out under these recommendations would no doubt be a story of great interest, but we are concerned here with item B only. This classification produced not only the most beautiful of biplane fighters, the XP-23 (with an F-2 turbo), but also the first supercharged fighter to fully equip an operational U. S. Army pursuit squadron, the Curtiss P-6D.

No attempt will be made here to recount the involved history of the P-6 series as only the P-6D was important in the turbo story. Basically, however, the P-6 airplanes were similar to the P-1 except for the replacement of the 435 hp Curtiss D-12 engine with a 600 hp Curtiss V-1570 Conqueror. Eighteen P-6s were ordered in fiscal year 1929, and eventually 13 of them became P-6Ds with the side type, F-2 turbo superchargers. All of the F-2s from the F-2A thru the F-2H were designed for the V-1570 engine (the F-2G was for left side installation), and it is likely that they were interchangeable, as the changes were minor (cooling fins, air passages).

The first of these aircraft, the XP-6D, was flying at Wright Field in the spring of 1931 with an F-2A. This was serial number 29-260, and it is easily distinguished from later P-6D's by its two-bladed propeller. All other P-6D's had the more efficient three-bladed prop. In 1932 the XP-6D had an F-2E turbo supercharger.

Besides the XP-6D there were 12 other P-6D's with serial numbers as follows: 29-266, 29-269 thru 29-273 and 29-363 thru 29-368. All of these aircraft started life under other designations, but were finally wrecked or surveyed as P-6D's.

Most, if not all, of these were assigned to the 37th Pursuit Squadron of the 8th Pursuit Group at Langley Field. Formed in September 1933, the Squadron was immediately equipped with the P-6D. (One, 29-363, was wrecked the next month near Langley Field.)

Like the NBS-1 the supercharged P-6D was not an overwhelming success. Long before the type went into service, an attempt was made to halt the conversion program. In a letter dated June 1932, Major Hugh Knerr, Chief of Field Service Section, recommended suspension of the program because "difficulties have been encountered with the V-1570 engine resulting in a change of operating conditions of this engine" (due to the supercharger).

Nevertheless, the conversion program was completed and the aircraft entered service with the 37th, even though continual fuel system troubles plagued them and wrecked several. The P-6D had a good turn of speed at altitude, though. In early 1932, Capt Reuban Moffat flew one from Wright Field in Washington, D. C. in 1 hour and 26 minutes, cruising at 25,000 feet, averaging 266 mph.

The P-1 wings were not designed for the increased weight of the P-6D, and there were severe flight restrictions on the type. In light of the above troubles and flight restrictions it is strange that the 37th was chosen to become an attack squadron when the GHQ Air Force was formed in March of 1935. A probable explana-

Boeing XP-4, 25-324, under test as XP-446. This plane was abandoned after only four hours flying time. (USAF)

Curtiss XP-5, converted from P-1, at McCook Field with F-2 turbosupercharger unit installed. (USAF)

Curtiss XP-6D, 29-260, turbo installation. This was only P-6D to have 2-bladed propeller. (R. Cavanagh)

P-6D, 29-366, of 37th Attack Squadron, 8th Pursuit Group at Langley Field with 3-bladed prop. (Marty Copp)

tion is that plans had already been made to provide more suitable airplanes as Curtiss A-8s arrived for the 37th in May 1935. When the last of the P-6Ds left the 37th is not known, but some of the survivors were assigned to Training Command at Chanute Field. As can be seen by the following none survived for long:

AAC serial	29-266	wrecked 8-23-34
	29-269	surveyed 12-3-37
	29-270	wrecked 6-28-35
	29-271	wrecked 5-10-36
	29-272	wrecked 12-9-36
	29-273	wrecked 3-37
	29-363	wrecked 10-17-33
	29-364	surveyed 4-38
	29-365	wrecked 1-22-34
	29-366	wrecked 7-11-35
	29-367	surveyed 11-37
	29-368	surveyed 11-37

Three other P-6s were involved in turbo research, although probably only two actually were so equipped. The first of these was the XP-6F, which was the old XP-6E modified in 1933 with a new engine, an F-2E turbo and a cockpit canopy. Although it had a good turn of speed at altitude, it never was fully tested and played only an incidental part in turbo-supercharger development. Another modified P-6E became the XP-6G, which incorporated the V-1570 engine modified for turbo usage. It probably never had the turbo installed and was of even less significance than the XP-6F.

The third P-6E was actually the last production aircraft, and after very extensive rebuilding in 1932 it became the XP-23, with an F-2G turbo mounted on the left side of the engine, instead of the usual right side position. The end-of-the line turbo-supercharged Curtiss biplane, the XP-23,was unsuccessful but gained one distinction in its short life. It was probably the handsomest of all biplanes in an era where there was stiff competition for that honor.

Of more significance were the two Boeing P-12s with sidetype blowers. Until the advent of the XP-12G (the first P-12B modified) in 1932, all Army turbo installations had been on liquid-cooled engines. The sole purpose of this test machine was to find out if aircooled engines would cool and operate satisfactorily at high altitudes with turbo-superchargers. This machine and, a year later, the XP-12L (a rebuilt P-12E) were the forerunners of all the WW II turbo-supercharged, aircooled, radial-engined aircraft (B-17, B-24, B-29, P-47 and others). The XP-12L is reported to have overheated badly. Since its supercharger was a type F-7 designed for engines of 600 to 800 hp, the overheating is not difficult to understand (the P-12's Wasp engine developed about 500 hp).

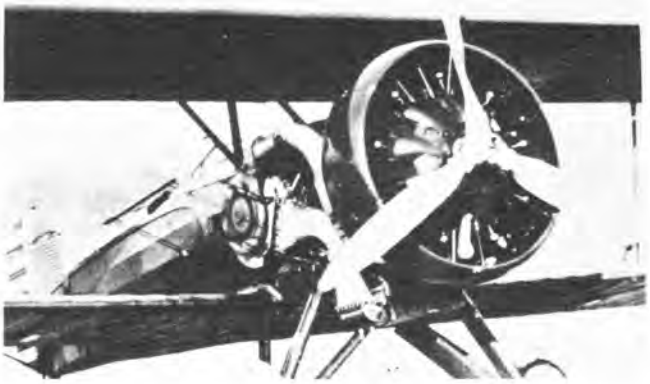
The year 1932 also saw the beginnings of the first successful application of the turbine-driven supercharger to operational military aircraft. The unit had long since been proven a practical device, but its effect on engine systems and the lack of a reliable controllable pitch propeller had doomed all efforts to failure.

The beginnings of success go back to the YIP-24 two seat monoplane fighter, and its immediate successor, the YIP-25. Consolidated received funds for the latter in March 1932 and delivered the airplane to Wright Field in December. Equipped with a V-1570-27 engine and the usual side-mounted turbo, it demonstrated a remarkable performance before crashing in mid-January 1933. Because of its promise, four more were ordered as P-30s (with F-2G) and a later order was for 50 more as P-30A's (with F-2H). Soon after P-30A delivery in 1936, all were designated as PB-2 (P-30) or PB-2A (P-30A).

The first of the PB-2A's, serial number 35-1, arrived at Wright Field in January 1936 and underwent considerable test flying throughout the spring. Equipped with the dash 61 engine and an F-2H turbo it received generally favorable reports from its tests pilots. Lt Donald Putt, who had flown it for 26 hours by mid-April, reported a top speed of 274.5 mph at 25,000 feet and excellent

Wright Field based Curtiss XP-6F, 29-374, was modified XP-6E with F-2 turbo-supercharger. (E. C. Haney)

Last of the turbo-supercharged biplane fighters was the sleek and beautiful Curtiss XP-23. (Jefferies Coll)



First air cooled engine pursuit to be equipped with turbo-supercharger was Boeing XP-12G. (USAF)

First Consolidated PB-2A, 35-1. It was destroyed in crash, May 1936, killing Major Hez McCellan. (Author)

controllability at all speeds. The engine tended to run rough at heights above 28,000, and no tests were conducted above this pending solution of the problem.

Although it fulfilled one of the recommendations of the 1930 Pursuit Board, the operational fallacy of the two-seat fighter was already clear to Lt Putt. Under "Field of Fire" he commented: "Probably small for rear gunner." Although the observer's flexible Browning was installed, no armament trials were conducted. An earlier test pilot on the P-30 had also reported the rear gunner useless unless the aircraft was flown straight and level. The error in the two-seat fighter theory was to be proven beyonddoubt by the RAF in a few short years. Yet, the PB-2A was a successful high altitude airplane and largely because it was equipped with the long-needed controllable pitch propeller. Strangely enough some PB-2A's show up in photographs equipped with ground adjustable prop only, and the reason for this is unknown. Trouble with the early Curtiss Electric props may have been the reason.

The test aircraft, 35-1, did not survive for long. It was destroyed in a crash late in May 1936. The PB-2 series was operated by only four pursuit squadrons--the 33rd, 35th and 36th of the 8th Pursuit Group at Langley Field, and the 27th Squadron of the 1st Pursuit Group at Selfridge. The 1st Group's 94th Squadron operated all four PB-2 type aircraft but never as their basic equipment.

The 27th Squadron was the first to put the PB-2A in service, receiving its first one in April 1936 and being fully equipped by the summer. The 8th Group did not get its PB-2A's until about a year later and, in fact, took over the 27th Squadron's machines in May-July of 1937 when that squadron began conversion to Seversky P-35s. The 8th Group disposed of its PB-2A's in the spring of 1939 and was completely equipped with Curtiss P-36s. Thus ended the brief operational career of the PB-2 type, although it soldiered on in miscellaneous jobs until the war.

A tactically obsolete design, the PB-2 had not been an outstanding aircraft. Nevertheless, it had been a modest success, and a production, turbo-equipped plane had finally entered squadron service in fairly large numbers. It paved the way for thousands of high altitude military aircraft which began rolling from factories only a short time after the PB-2 passed from the scene.

Against a background of years of technical obstacles, "medium altitude" thinking and budget restrictions, the Army had pressed on, and now Dr Sanford Moss' screaming device was ready to take its part in a vast world conflict. Its position of importance in aviation history was secure.

TURBO-SUPERCHARGER DESIGNATIONS & CHARACTERISTICS

Type A - The Pike's Peak supercharger, for Liberty 12 engine. Rating of 20,000 feet. Air and water cooled white metal bearings. Open Exhaust. Mounted between engine and propeller.
Type A-1 - The Sherbondy supercharger. Abandoned due to failure to pass preliminary tests. Altitude rating of 10,000 ft. Completely enclosed nozzle box and turbine. 360 deg. nozzle diaphragm; valve control of exhaust gases; self contained pressure and fuel control; ring diffuser, self aligning bearings.
Type B - Same as type A except for the following: all bearings air cooled; modified exhaust manifolds with expansion joints; intercooler between compressor and carb; development for "D" type Hispano abandoned.
Type C - Same as Type B except for an altitude rating of 35,000 feet.
Type C-1 - Construction as for above types, but adapted for 300 hp Hispano.
Type F-0 - Production article with all improvements from the above types. One modified with ball and roller bearings.
Type F-1 - Production article.
Type F-1A - Applicable to engines which do not exceed 400 hp.
Type F-1B - Experimental. No other data. October 1928.
Type F-2 - Includes all details from ABCD, F & F-1, and to include 360 deg. nozzle diaphragm, removable turbine buckets, ball & roller bearings, demountable impeller and turbine. Adapted for Liberty 12, Curtiss D-12, Packard 1550, Curtiss 1550 and Packard 2500.
Type F-2A - Designed for use on Curtiss V-1570 engines.
Type F-2B - Designed for use on Curtiss V-1570 engines January 1930.
Type F-2C - Similar to F-2B except for addition of cooling fins.
Type F-2D - Similar to F-2C except modified air passages. July 1931.
Type F-2E - Modified F-2C's and F-2D's. Service tested July 1931.
Type F-2F - Improved F-2E equipped with elliptical nozzle box inlet and improved tinning. Service tested April 1932.
Type F-2G - Similar to F-2F except designed for installation on left side of engine. Service tested April 1932.
Type F-2H - Types F-2F and F-2G converted into F-2H in accordance with changes outlined in contract AC-7484. July 1935.
Type F-7 - Experimental, for engines of 600-800 hp 1932.
Type F-8 - Similar to F-7, except for 800-1000 hp engines.
Type F-9 - Production model of the F-7, simplified. Service tested January 1935.
Type F-10 - Production model of the F-8, simplified. Service tested July 1935.
Type F-10A - As F-10 except for incorporation of automatic pressure lubrication system. Service tested December 1936.
Type F-10B - Identical to F-10A.
Type F-11 - For engines of 1500 hp. Altitude rating 25,000 feet.
Type F-12 - For use with engines of 2000 hp. 25,000 ft. rating.
Type F-13 - Similar to F-10, redesignated later to Type B-3.
Type F-14 - Similar to F-10 but with integral oil pump for R-1820-51 engines.
Type F-15 - Assigned to GE for experimental purposes.
Type F-16 - For 700 hp engines, 25,000 ft rating. With integral oil pump, removable diffusers and means for external adjustment of nozzle box. Redesignated A-1.
NOTE: Sometime in the late 1930s (exact date unknown) the turbo-supercharger designation system was changed --the type letter indicating the horsepower of the applicable engines.
Type A - for engines of 550 to 800 hp.
Type B - for engines of 801 to 1400 hp.
Type C - for engines of 1801 to 2200 hp.
Type D - for engines of 1401 to 1800 hp.
Type E - for engines of 2201 to 3000 hp.
Type F - for engines of 3001 to 4200 hp.
Type G - for engines of 4000 to 5000 hp.
Type H - for engines of 5001 to 6000 hp.

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...And various official performance and test reports from the archives of the Air Force Museum.

ABOUT THE AUTHOR: Merle Olmsted, of 3213 Southwest Dr, Wichita Falls, Texas 76305, retired from the U. S. Air Force several years ago after a long tour of duty which brought him a great deal of experience with various aircraft engines from piston types to jets. This experience included first hand contact with turbo-superchargers. In time this led him to a search for the facts and story of the beginnings of turbo-supercharged aircraft in the U. S. Air Service/Army Air Corps. The culmination of that search is the article appearing on these pages.

Merle is one of a very few Members who has written material for the JOURNAL over nearly its entire period of existence, and his work is always highly prized.