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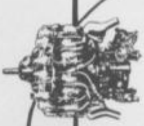


Wright TURBO COMPOUND

OCTOBER 1956

FIELD ENGINEERING DEPARTMENT
CURTISS-WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION
WOOD-RIDGE, NEW JERSEY, U. S. A.

FOREWORD

The Turbo Compound introduced new concepts of engine economy and performance to the aircraft engine operator. Higher powers are now available without substantial change in cylinder working conditions. With the compound engine these powers have proved practical, and they are achieved with lower specific fuel consumption and without danger of detonation or increased cylinder stress. Furthermore, they are available without complication of additional controls or instrumentation.

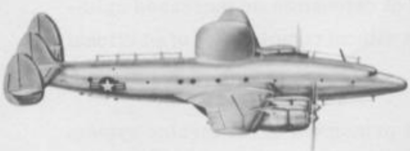
The purpose of this book is to explain the principles of the turbine system which make these advantages possible. Discussion will include how the Turbo Compound differs from other conventional reciprocating engines, how and why the power recovery system works, what experience has been accumulated with compound engines, and the effect that compounding has on the operation of the engine.

DOUGLAS DC-7C

LOCKHEED 1649A

CANADAIR CL-28

THE TURBO COMPOUND IN SERVICE



LOCKHEED C-121

LOCKHEED P2V-7

MARTIN P5M-2

FAIRCHILD C-119

HISTORY

A study of the various methods of power recovery was first started at Wright Aeronautical Division in 1942, culminating in a final design sponsored by the Bureau of Aeronautics U. S. Navy in the summer of 1946. The blow-down system of recovery was chosen because:

1. It offered a direct increase in engine power and economy over the complete operating range without introducing additional basic engine development problems.
2. Its simplicity eliminated the necessity of additional pilot or flight engineer attention at any time.
3. The blow-down system could be designed for a weight to power ratio of .9 lbs/BHP recovered, whereas the exhaust pressure turbine system considered required 1.3 lbs/BHP recovered.
4. Compounding by a blow-down turbine appeared ideal for future development, since a turbo-supercharger or even an additional pressure system power recovery unit could be added at some later date.

Initial testing was done using a single turbine attached to a Cyclone nine cylinder engine. Soon after this, the first full scale compound 18 cylinder engine was built. This engine used six power recovery units. It was soon found that over 200 lbs. saving in weight could be made without loss of power recovery by siamesing exhaust pipes, and reducing the number of turbines to three.

In 1948 the first order for the Turbo Compound was received from the Navy. Following flight tests in the nose of a B-17 in 1949, the engine passed its model test and went into quantity production early in 1950. As of May 1, 1956 approximately 9000 Turbo Compounds have been produced, more than 20% of these being for commercial use.

The initial rating of the engine was 3250 BHP Dry and 3500 BHP Wet. Turbo Compound engines are now in production rated at 3400 BHP Dry and 3700 BHP Wet.

Wright

TURBO COMPOUND

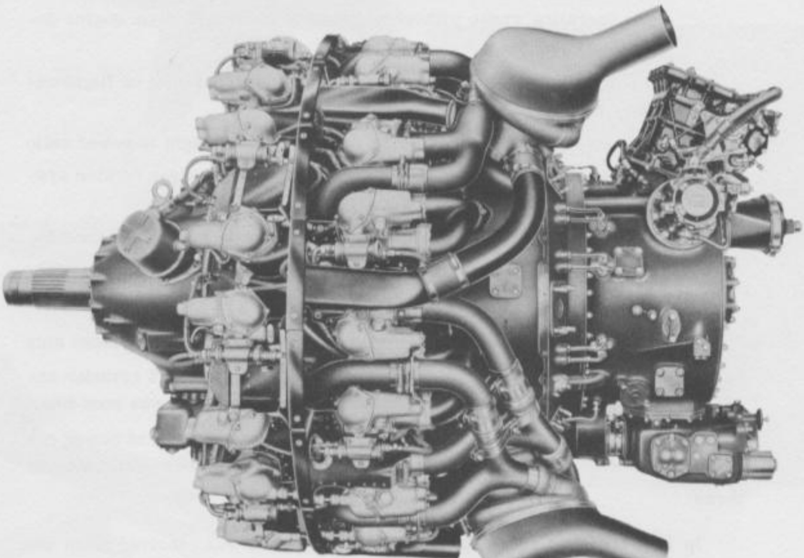


FIGURE 2

HISTORY (Continued)

The Lockheed P2V-4 Navy Patrol airplane was the first airplane to use the Turbo Compound. An earlier model of this airplane, using a non-compounded Wright engine, established a world record for a non-stop flight without refueling. The present P2V airplanes using the Turbo Compound have an even greater potential range. Thus, the Turbo Compound is now the primary long range patrol aircraft engine of the Navy. Similar types of patrol applications are the Lockheed WV-2, RC-121D and the Canadair CL-28.

Additional service experience has been gained with the Turbo Compound in the Martin P5M Flying Boat, and the Fairchild C-119 Cargo airplane. The transport version of the Turbo Compound has been and still is being procured in large quantities by both military and commercial operators for use in the Lockheed Super-Constellation and Douglas DC-7 aircraft.

Thus the engine that developed from an idea in 1942 to a proposal in 1946, and a production engine in 1950, is now accepted as a proven aircraft power plant. There stands behind it an accumulation of over 7.5 million flight hours and more than 25,000 hours of experimental test stand experience.

POWER RECOVERY SYSTEMS

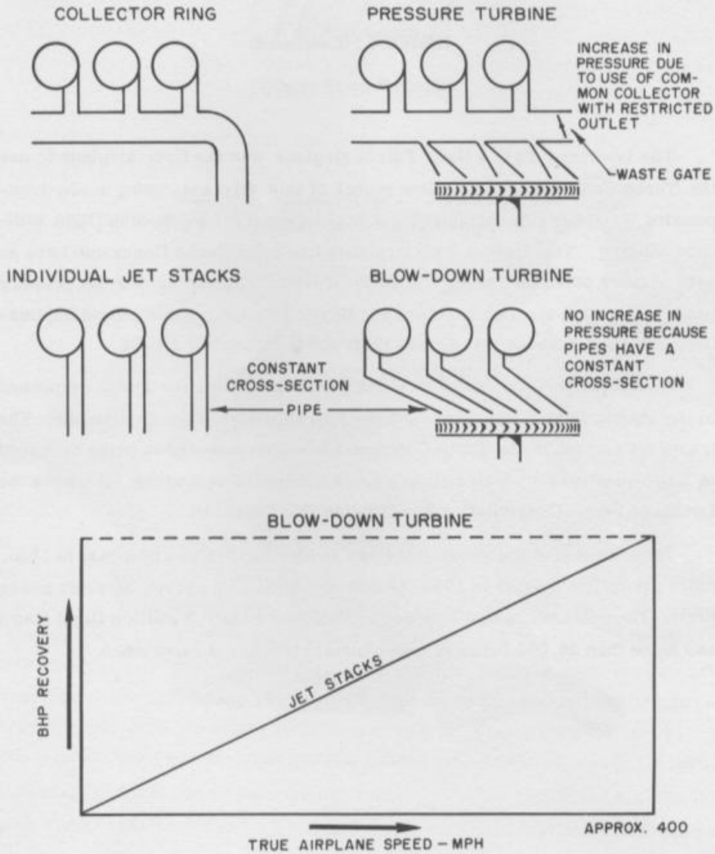


FIGURE 3

EXPLANATION OF COMPOUNDING

In an engine sense, compounding is the combining of two or more power producing units in a single power plant. This idea is not new, having been used for years industrially to raise the efficiency of steam power plants in which steam, exhausted at relatively high pressure from one cylinder, is used in a second cylinder to absorb more of the heat energy.

In the case of the Turbo Compound, the highly developed and dependable basic 18 cylinder Cyclone engine has been supplemented with a second power producer, consisting of three interchangeable "blow-down" turbines. These turbines are geared to the crankshaft and utilize the velocity energy of the exhaust gas, which is normally wasted. The use of these gases by blow-down turbines does not reflect appreciably on the power output of the normal reciprocating engine cycle.

BLOW-DOWN TURBINE PRINCIPLE

"Blow-down" describes any process whereby gas at high pressure is allowed to expand through a valve to lower pressure without doing work during the process. The "blow-off" valves of steam boilers do this; so do the valves of any reciprocating engine. Normally, since no work is accomplished in the blow-down, all the energy of the steam or gas is wasted. However, in the process of blowing down from a pressure of about 200 psi inside the Cyclone cylinder at valve opening to the nearly atmospheric pressure of an exhaust pipe, the gases leave the cylinder at sonic velocity, or approximately 2200 ft/sec. at average exhaust gas temperature. The Turbo Compound uses this high velocity gas to drive an impulse turbine wheel which does work by absorbing some of the velocity energy of the gas without imposing back pressure on the cylinders. The cylinders are relatively unaware of the existence of the turbines and act as if the gases are being discharged to jet stacks. The turbines are called blow-down turbines since the high velocity of the gases they use comes from the gas blowing down across the exhaust valve. The gases are not sent to a common collector, as in the case of the turbo-supercharger, but are conveyed to the turbine wheel through separate siamesed pipes. Figure 3 illustrates the four most common exhaust systems.

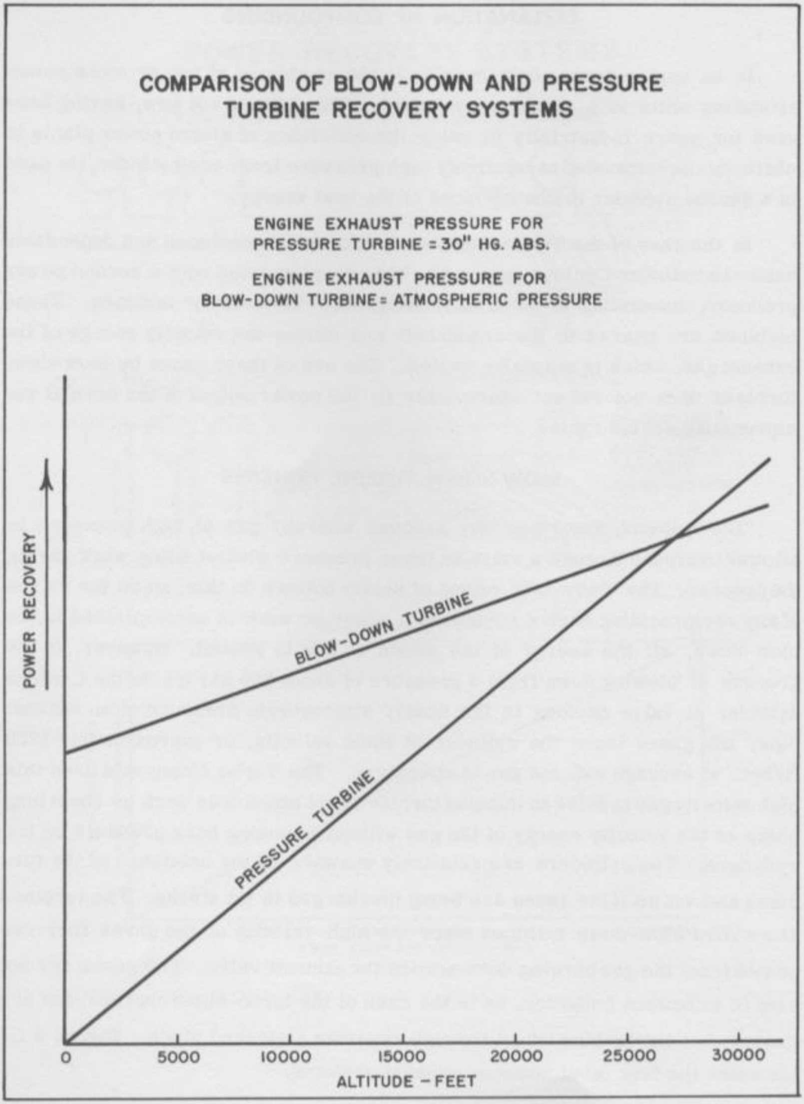

COMPARISON OF BLOW-DOWN AND PRESSURE
TURBINE RECOVERY SYSTEMS
ENGINE EXHAUST PRESSURE FOR
PRESSURE TURBINE = 30" HG. ABS.
ENGINE EXHAUST PRESSURE FOR
BLOW-DOWN TURBINE = ATMOSPHERIC PRESSURE
POWER RECOVERY
BLOW-DOWN TURBINE
PRESSURE TURBINE
0
5000
10000
15000
20000
25000
30000
ALTITUDE – FEET

FIGURE 4

TURBO-SUPERCHARGER PRINCIPLE

The turbo-supercharger, like the blow-down turbine, is an exhaust power recovery device. However, it has a different purpose--that of allowing the engine to develop sea level power at high altitude. Therefore, it utilizes a different method of performing this duty.

In a turbo-supercharger installation, all cylinders exhaust into a common collector with two exit paths; one through a variable opening waste-gate, and the other through nozzles aimed at a turbine wheel. With the waste-gate fully open, there is no restriction, and collector pressure is nearly atmospheric. However, as the waste-gate is closed, pressure builds up in the collector. The gas is forced through the nozzles, turning a turbine, which drives a supercharger. No power recovery is possible in such a system unless the collector is above existing atmospheric pressure.

The turbo-supercharger, therefore, utilizes a "pressure" turbine. It is basically different from a blow-down turbine since it converts blow-down velocity energy into pressure energy in a manifold collector. This conversion to pressure energy reflects on the scavenging ability of the cylinders.

The use of a pressure turbine to recover exhaust energy is quite inefficient for take-off and low altitude operation. This is due to loss of basic engine power which accompanies the increase in exhaust system pressure. The increase of exhaust pressure also has an adverse effect on engine cooling and detonation margin.

With increase in altitude, however, it is possible to maintain sea level exhaust pressure while existing atmospheric pressure decreases. This results in pressure differential, which allows for increase of power recovery with increase of altitude. Figure 4 compares pressure turbine recovery and blow-down power recovery with variation in altitude. As indicated by this curve, the blow-down turbine is more efficient for all power ranges and altitudes normally encountered within current pressure cabin limitations. The pressure turbine becomes more useful only at the very high altitudes.

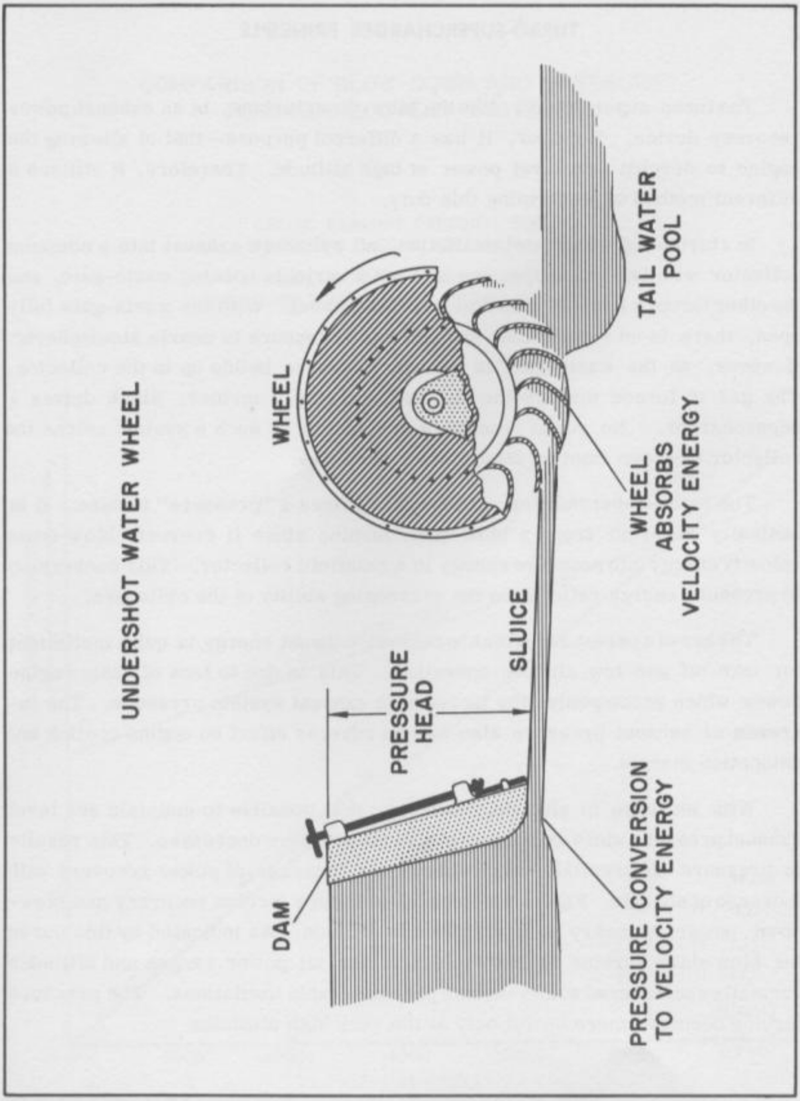

UNDERSHOT WATER WHEEL
WHEEL
TAIL WATER POOL
WHEEL ABSORBS VELOCITY ENERGY
SLUICE
PRESSURE HEAD
DAM
PRESSURE CONVERSION TO VELOCITY ENERGY

FIGURE 5

WATER WHEEL ANALOGY

A simple explanation of the blow-down turbine principle may be made by comparing it to the undershot water wheel. Figure 5 is a diagram of this device. The water, retained by the dam, is released through a slot across its base. It flows swiftly along a sluice and hits the vanes of a water wheel. The vanes are so designed that the water enters at a very low angle, flows up the curved surface of the vanes, and, as the wheel turns, falls back practically without forward velocity into a tail-water pool.

In this case of the dam and water wheel, it can be seen that the pressure head is converted into velocity energy at the dam. There is very little drop in water level from the base of the dam to the water wheel, and no appreciable change in level across the wheel. Any work done by the wheel is therefore attributable to the velocity energy of the water and not pressure energy.

This system is analogous to the blow-down turbine, where pressure stored in the cylinder is converted to velocity energy at the exhaust valve, runs along constant area exhaust pipes to the turbine, and loses its energy by a loss of velocity as it goes through the turbine wheel.

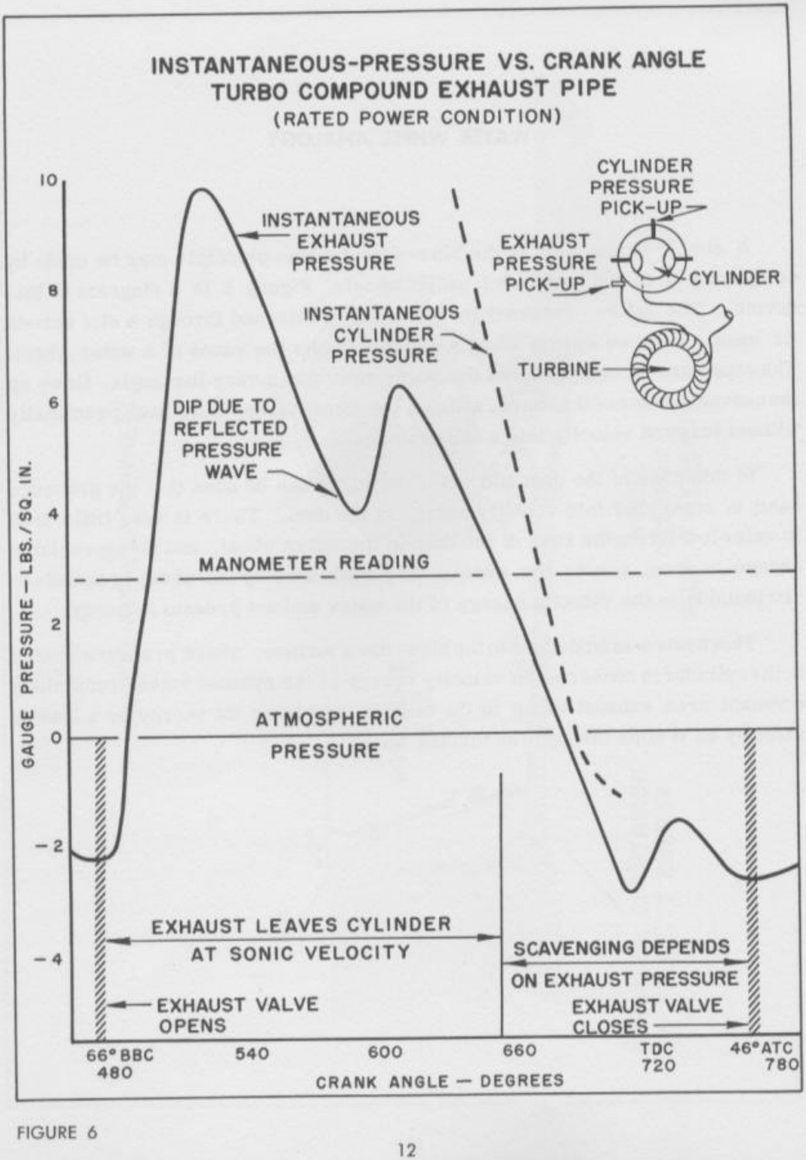

INSTANTANEOUS-PRESSURE VS. CRANK ANGLE
TURBO COMPOUND EXHAUST PIPE
(RATED POWER CONDITION)
CYLINDER PRESSURE PICK-UP
EXHAUST PRESSURE PICK-UP
CYLINDER
TURBINE
INSTANTANEOUS EXHAUST PRESSURE
INSTANTANEOUS CYLINDER PRESSURE
DIP DUE TO REFLECTED PRESSURE WAVE
MANOMETER READING
ATMOSPHERIC PRESSURE
EXHAUST LEAVES CYLINDER AT SONIC VELOCITY
SCAVENGING DEPENDS ON EXHAUST PRESSURE
EXHAUST VALVE OPENS
EXHAUST VALVE CLOSES
GAUGE PRESSURE — LBS./SQ. IN.
10
8
6
4
2
0
-2
-4
66° BBC 480
540
600
660
TDC 720
46° ATC 780
CRANK ANGLE — DEGREES

FIGURE 6

BACK PRESSURE

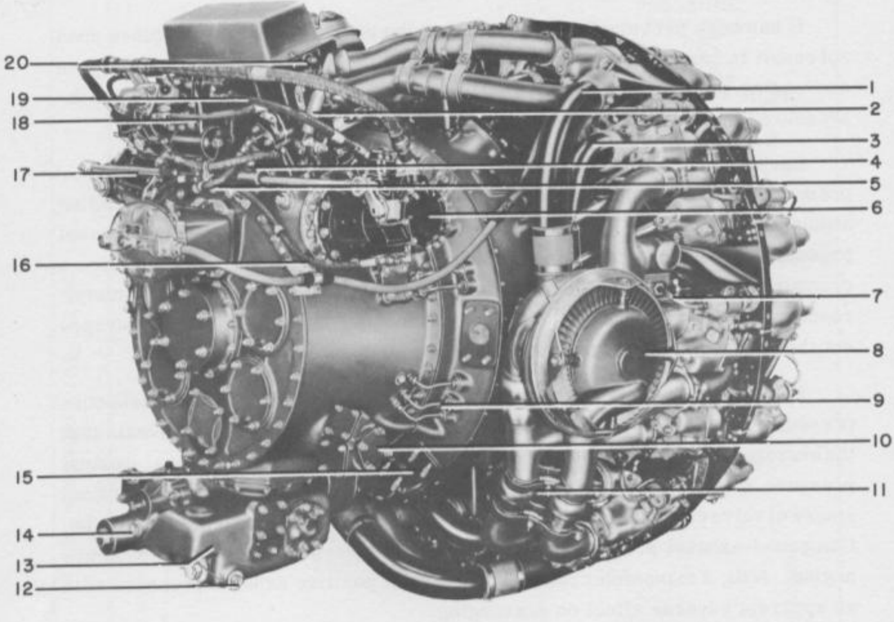
It has been previously mentioned that the use of blow-down turbines does not result in harmful "back-pressure", while a pressure turbine does impede scavenging by imposing back pressure on the engine. What then is "back-pressure"?

Back pressure might be described as the average pressure differential (or pressure read on a manometer) between the exhaust system and the existing atmosphere. However, this pressure might better be termed "average exhaust pressure" rather than "back pressure". The term "back pressure" implies a pressure in the exhaust which impedes scavenging of the cylinder. A manometer reading of pressure in the exhaust system cannot indicate this, since it averages out the pressures occurring during the complete cycle.

Figure 6 shows a typical Turbo Compound exhaust stroke instantaneous-pressure diagram at rated power. Examination of this figure reveals that the average pressure as read on a manometer is greater than the actual exhaust pressure during the closing of the valve. It is the pressure during the final stages of valve closing which affects scavenging. As the curve shows, Turbo Compound exhaust pressure drops below atmospheric and thereby aids scavenging. Still, a manometer reading indicates a positive exhaust pressure with an apparent adverse effect on scavenging.

The instantaneous-pressure diagram for the Turbo Compound is similar to the diagram that would be obtained with a well designed jet stack system. It is, therefore, apparent that the complete compound exhaust system is equivalent to a jet stack installation insofar as it affects engine operation.

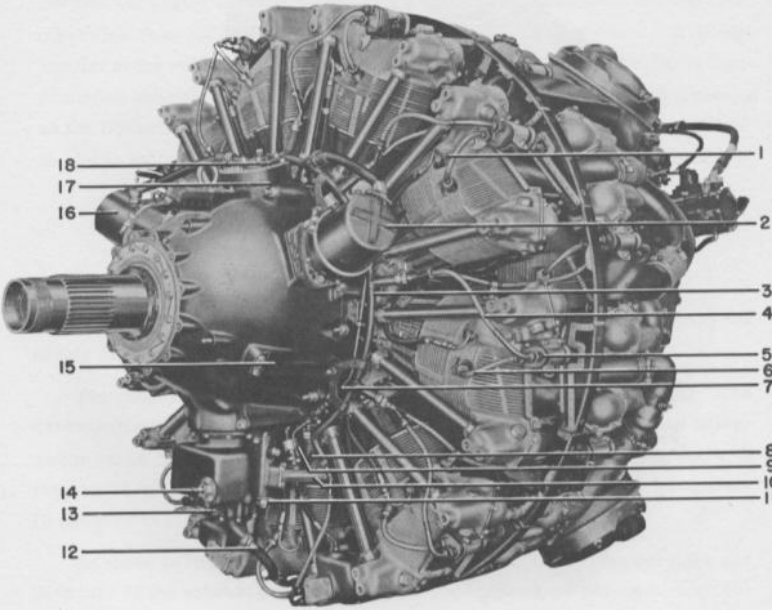
TURBO COMPOUND
REAR RIGHT VIEW



1. Turbine cooling air tube
2. Throttle balance assembly
3. Dual cylinder intake pipe
4. AFS 24 volt receptacle
5. AFS supply tubes
6. Right fuel injection pump
7. Rear spark plug high tension lead
8. Power recovery turbine assembly
9. Fuel injection tubes
10. RH fuel pump substitution cover
11. Exhaust pipe clamp
12. Magnetic drain plug
13. Rear oil pump and sump
14. Oil pressure relief valve
15. Engine mount boss
16. Master control to fuel pump venturi suction tube
17. Synchronizing bar
18. Priming fuel tube
19. Fuel pump to master control vapor return tube
20. Master control

FIGURE 7

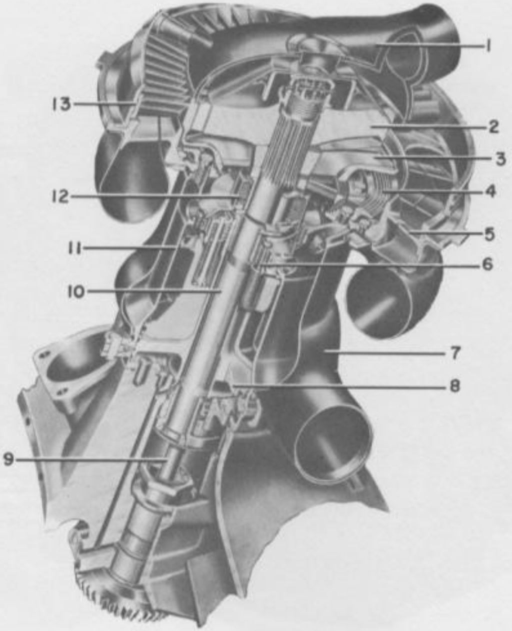
TURBO COMPOUND
LEFT FRONT VIEW



1. Fuel injection nozzle
2. Left distributor
3. Ignition cable manifold
4. Ignition cable manifold to ignition coil low tension lead
5. Ignition coil
6. Ignition coil to spark plug high tension lead
7. Rocker box cover and sump upper vent tube
8. Rocker box cover and sump lower left vent tube
9. Rocker box cover and sump lower right vent tube
10. External oil inlet tube
11. Front oil pump pressure control valve
12. Rocker box drain manifold to scavenge pump tube
13. Front oil pump and sump magnetic drain plug
14. Front oil pump and sump strainer
15. Torquemeter oil external tube connector substituting flange
16. Right distributor
17. Governor drive and torquemeter booster pump
18. Governor substituting cover

FIGURE 8

TURBINE CUTAWAY



1. Cooling air aspirator
2. Turbine wheel
3. Cooling air impeller and inducer assembly
4. Labyrinth seal of air deflector
5. Nozzle guide vane
6. Lateral vibration damper
7. Cooling air shield
8. Turbine shaft support
9. Quill shaft
10. Turbine drive shaft
11. Nozzle support
12. Bellows oil seal
13. Guard ring

FIGURE 9

GENERAL

Figures 7 and 8 are views of the Wright Turbo Compound. The engine shown is the commercial version, or 988TC18EA engine. In the commercial version the engine is equipped with fuel injection for additional economy, but otherwise it is quite similar to other military Turbo Compounds. It is also similar to the non-compounded Cyclone 18CB engine. In fact, the Turbo Compound has substantially the same nose section, power section, and rear section as the Cyclone CB. The major difference is the three turbines "sandwiched" in eleven extra inches of length between the power and supercharger sections.

NOZZLE

A cutaway view of one of the three power recovery turbines showing the nozzle assembly is presented in Figure 9.

The purpose of the nozzle is to direct exhaust gases into the turbine. The gases enter through the exhaust scroll to the nozzle itself which has fifteen stator vanes to guide the gases so they leave at an angle of 15 degrees with the path of the turbine wheel. The low angle results in maximum turbine efficiency.

As there is little reduction in exhaust passage area, the temperature and pressure of the exhaust gas is practically unchanged as it passes through the nozzle. Each of the three siamesed exhaust pipes feeds a 120 degree inlet sector, thus, there are individual discharge areas for each siamesed pair of cylinders.

The nozzle inlet pipes are fabricated from sheet stock and the detachable four piece nozzle is a casting to which the three nozzle inlet pipes are bolted. Both the detachable four piece nozzle assembly and the inlet pipes are made from N-155 which is a high strength, high temperature material having an iron base plus a high content of nickel, chromium, and cobalt. At overhaul, these pieces normally require only minor repair.

TURBINE WHEEL

FIGURE 10

TURBINE DRIVE SYSTEM

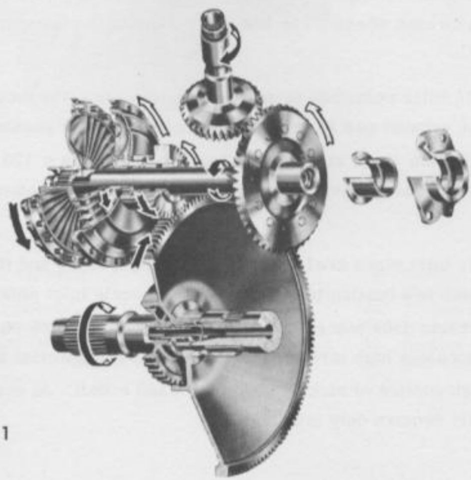


FIGURE 11

TURBINE WHEEL

The turbine wheel is shown in Figure 10. It consists of a special alloy steel hub with 58 cast alloy buckets welded around the outside diameter. The material used in the buckets is known as Stellite -31, which has excellent strength at the exhaust temperatures normally encountered. The diameter of the assembly is 11.45 inches, and the length of the bucket blades is 1-3/8 inches from tip to root. All three turbines turn clockwise when viewed from their outer end. Turbine speed is under 16,000 RPM at cruise, and 19,000 RPM at take-off.

Each turbine wheel is whirl-tested up to 27,500 RPM. After the whirl-test four holes are drilled in the buckets 90 degrees apart on the turbine wheel. These four holes trigger the buckets in the event of overspeeding. The pre-determined point of triggering is approximately 24,000 RPM. This is above the turbine operating range, and in conjunction with the guard rings provides protection in the event of a turbine failure by containing the buckets within the flight hoods until they are discharged through the exhaust outlet with little or no energy. The guard rings are integral with the aircraft exhaust hood and have been tested on full scale engines.

TURBINE DRIVE SYSTEM

A view of the turbine drive system is shown in Figure 11. The power generated by each turbine is transmitted through shafting to bevel gears. The gears reduce the turbine speed, and transmit the power through a fluid coupling to a pinion which drives the crankshaft drive gear. The over-all gear reduction is 6.52 to 1 on all commercial and military engines having the drilled wheels.

FLUID COUPLINGS

Intermittent exhaust pulses impinging on the turbine buckets tend to set up torsional (twisting) vibration in the turbine drive system. Fluid couplings are used to absorb this vibration and prevent it from being transmitted to the crankshaft. At the same time the couplings prevent crankshaft vibration from being transmitted to the turbines, and help absorb the inertia loads during speed changes. The turbo compound fluid coupling utilizes a vortex principle which clears the couplings of sludge by swirl action.

The design size of the coupling limits normal slippage to between one and two percent. Figure 11 includes a cutaway view of one of these couplings.

LATERAL VIBRATION DAMPER

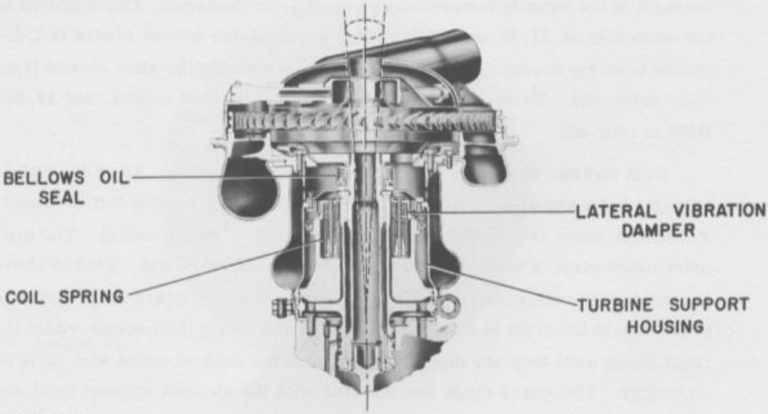


FIGURE 12

TURBINE COOLING SYSTEM

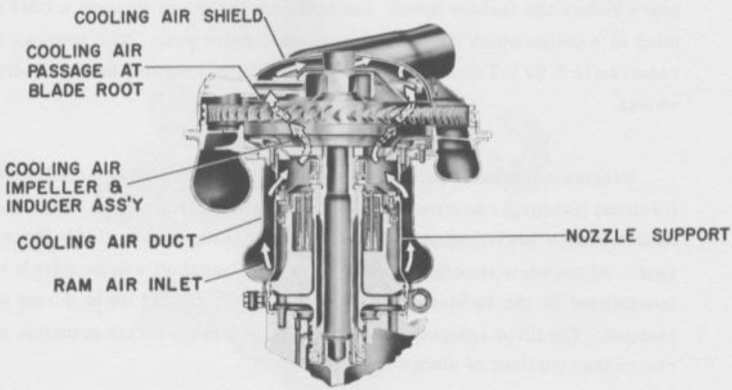


FIGURE 13

FLUID COUPLINGS (Continued)

Each of the three couplings is supplied with oil from the main engine oil supply through an oil pressure regulating valve located in the supercharger front housing. The pressure is set at 50 psi at the factory or overhaul activity. No fluid coupling pressure gage is used in the aircraft.

When the engine is shut down, the oil gradually drains from the couplings so they are momentarily disconnected on a cold engine start until oil pressure is obtained. Because of this, engine starting takes no more power than with a non-compounded engine.

LATERAL VIBRATION DAMPER

The off-center intermittent loading of the turbine wheel by exhaust gas pulsations, which alternately enter from each of the three entry sectors, causes a condition of whirl as well as torsional vibration. This means that there is a tendency for the shaft to wobble around its axis, as is shown in an exaggerated manner in Figure 12. To overcome this tendency, a lateral vibration damper has been installed at the outer support of the turbine drive shaft. The damper consists of a number of plates attached to the outer bearing journal which are sandwiched between discs anchored to the turbine support housing; the assembly is clamped together by a series of coil springs. This assembly restricts tendency of the turbine wheel to wobble and absorbs lateral vibration. A solid support would restrain all outer bearing movement, causing high bearing loads and shaft bending stresses.

TURBINE COOLING

A complete cooling system is built into each turbine unit. A schematic view of the system is shown in Figure 13. Ram air is picked up by a duct at the cowl seal and is delivered to each turbine assembly. A seven inch diameter impeller forces this air through holes at the base of each turbine blade into a cooling cap, where it passes into the exhaust through an aspirator pipe. This system of cooling keeps the hub of the turbine below 700° F, materially lengthening the service life of the turbine wheel. For comparison, turbine hub temperatures on modern gas turbine engines are running about 900° F.

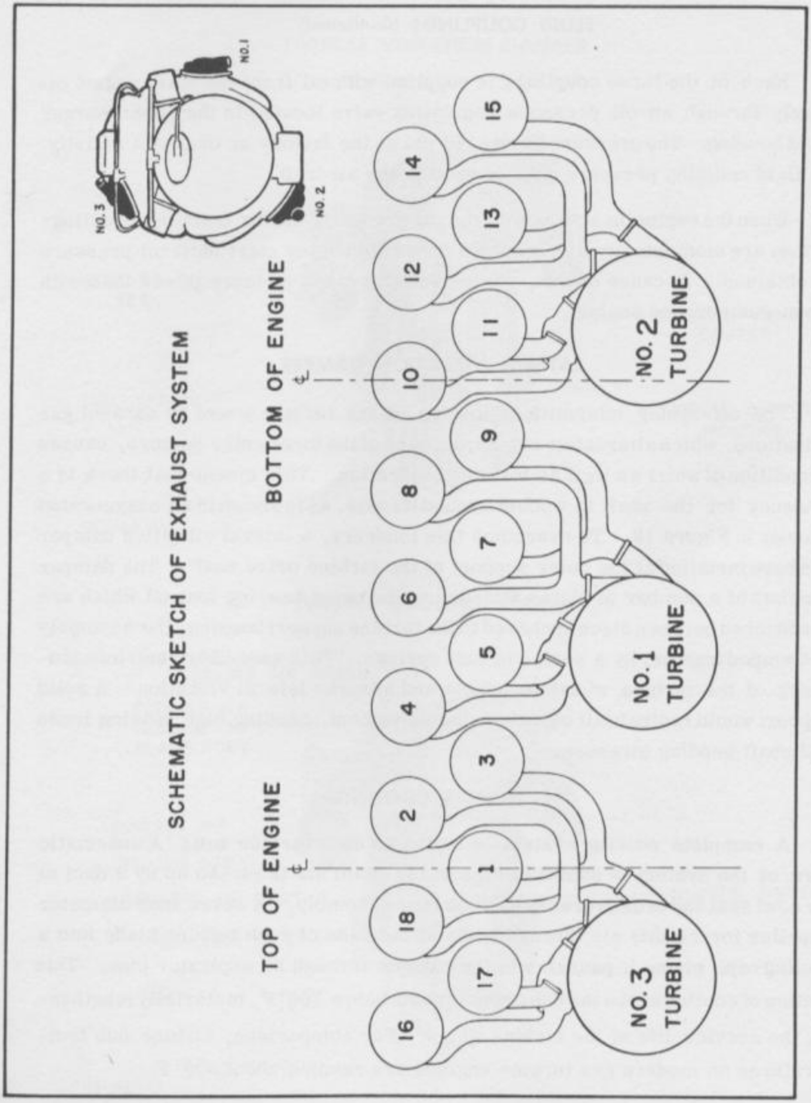

SCHEMATIC SKETCH OF EXHAUST SYSTEM
TOP OF ENGINE
BOTTOM OF ENGINE
NO. 3
NO. 2
NO. 1
16
17
18
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
NO. 3 TURBINE
NO. 1 TURBINE
NO. 2 TURBINE

FIGURE 14

EXHAUST PIPE ARRANGEMENT

The exhaust system feeding the turbines is an integral part of the engine. Each turbine is fed by three siamesed exhaust pipes. The arrangement is shown schematically in Figure 14.

The only arrangements for siamesing so there would not be valve overlap were impractical since they would require very long and intricate exhaust pipes. Therefore, a more practical system is used, which allows one case of valve overlap for each turbine. In these cases the scavenging problem has been remedied by the use of an aspirator, in which the rear row cylinder pipe extends into an expanded portion of the pipe from the front row cylinder. Using this system, the rear row cylinder gases aid the scavenging of the front row cylinder.

CONTROLS

One of the design requirements set up from the inception of the compound engine was that there should be no additional controls. This requirement was one of the numerous reasons why a blow-down system of power recovery has been utilized. Turbine speed is controlled by engine speed, since crankshaft and turbine are directly geared together except for the minor "slip" in the coupling. It is therefore apparent that the engine may be operated with only those controls and instruments used with an uncompounded engine. The significant difference to pilot or flight engineer is the increase in observed BMEP that he may use throughout the flight range. Because the torquemeter reads the sum of "cylinder" and "turbine" torque, "BMEP" no longer is a measure of cylinder output, but is an indication of combined output of cylinders and turbines. The operation of the engine is discussed in a later section.

ENGINE COMPARISON CHART

	TC18DA3 and 4	TC18EA1, 2 and 3	C18CB
Displacement Cubic Inches	3350	3350	3350
Cylinders	18	18	18
Bore/Stroke - Inches	6.125/6.312	6.125/6.312	6.125/6.312
Compression Ratio	6.7:1	6.7:1	6.7:1
Propeller Shaft Ratio	.4375	EA1, EA3-.4375 EA2-.355	.4375
Grade Fuel	115/145	115/145	115/145
Take-Off Power, BHP/RPM	3250/2900	3400/2900	2800/2900
Normal Rated BHP/RPM	2700/2600	2800/2600	2400/2600
Max. Low Blower Cruise	1840-1910/2400	1840-1910/2400	1600/2400
Max. High Blower Cruise	1750-1800/2400	1750-1800/2400	1500/2400
BMEP Constant	236	236	236
Torque Constant	142	EA1, EA3-142 EA2-201	142
Gage Constant	1.66	EA1, EA3-1.66 EA2-1.17	1.66
Supercharger Impeller Dia. Low Blower Ratio High Blower Ratio	13.5 in. 6.46:1 8.67:1	13.5 in. 6.46:1 8.67:1	13.5 in. 6.46:1 8.67:1
Turbine Drive Ratio	6.52:1	6.52:1	None
Turbine Bucket Material	Stellite-31	Stellite-31	None
Metering	Fuel Injection	Fuel Injection	Fuel Injection
Fuel Injection Lines	Internal thru rear section. External Flexible forward of Fireseal.	Internal thru rear section. External Flexible forward of Fireseal.	Steel External behind Fireseal. External Flexible forward of Fireseal.
Water Injection	None	981EA1 only	None
Ignition	Low Tension	Low Tension	Low Tension
Ignition Timing	25° BTC at Take-Off 30° BTC at Cruise	25° BTC at Take-Off 30° BTC at Cruise	25° BTC at Take-Off and NRP 35° BTC at Cruise
Valve Timing	Open / Close	Open / Close	Open / Close
Front Intake	45° BTC / 56° ABC	45° BTC / 56° ABC	45° BTC / 56° ABC
Rear Intake	55° BTC / 56° ABC	55° BTC / 56° ABC	55° BTC / 56° ABC
Front Exhaust	70° BBC / 45° ATC	70° BBC / 45° ATC	70° BBC / 45° ATC
Rear Exhaust	70° BBC / 55° ATC	70° BBC / 55° ATC	70° BBC / 55° ATC
Injection Pump Timing End of Injection	25° ATC Left Pump 15° ATC Right Pump	25° ATC Left Pump 15° ATC Right Pump	65° ATC

Note: The above is for general reference only and may change from model to model. For current information refer to Specification or Engine Data Plate.

FIGURE 15

ENGINE COMPARISON

The comparisons of Figure 15 are presented to show the differences between the non-compounded commercial C18CB engine, the TC18DA3 and 4, and the TC18EA1, 2, and 3.

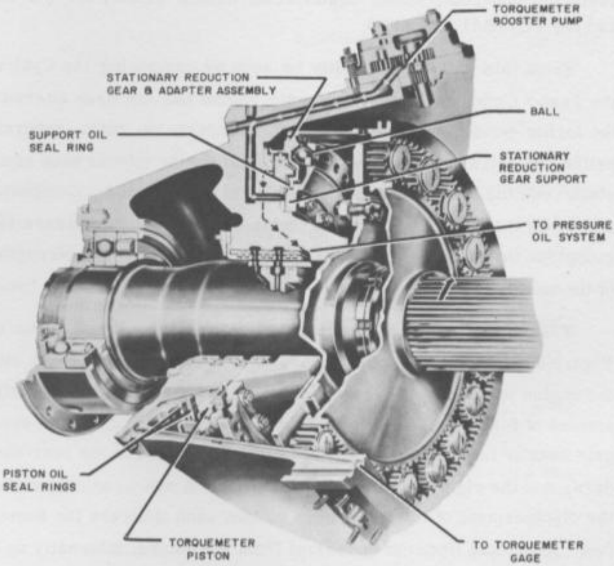
From this list it can readily be seen by comparing the Cyclone CB1 and the Turbo Compounds, that the basic engine has not been altered to produce the higher power. The displacement, compression ratio, supercharger impeller and drive ratios, valve timing, and engine speeds have remained constant. All the increase in power is due to the turbines. Comparing the DA3 and 4 with the EA1, 2, and 3 show that these turbo compounds are very similar except for the increased EA ratings which were achieved by strengthening some of the internal parts.

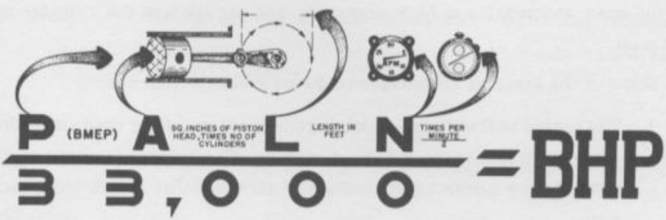
The fuel injection system is used on all commercial turbo compounds. Figure 8 shows the two cylindrical fuel injection pumps, one on either side of the engine just below the master control. These pumps accurately divide the amount of fuel metered to them by the master control so that every cylinder gets exactly its share. The left pump supplies fuel to the rear bank of cylinders, and the right pump to the front bank. A synchronizing rod coordinates the displacement of the two pumps so that each delivers the same quantity of fuel. Individual lines carry the fuel from the pumps, internally up to the fireseal, then externally to each cylinder head. The fuel is forced through the injection lines and nozzles at high pressure, and sprays into the cylinder in a fine mist.

Some of the inherent advantages of direct fuel injection are:

1. The engine is free from backfiring under all operating conditions since there is no fuel in the induction system. The master control benefits from this by never experiencing the stresses that result from backfiring.
2. The mixture may be manually controlled during cruise for maximum economy.
3. Cylinder to cylinder fuel distribution is more accurate.
4. Cylinder cooling is more uniform, resulting in more uniform service life of the combustion parts.

TURBO COMPOUND TORQUEMETER





FOR THE TURBO COMPOUND

$N = \frac{RPM}{2}$ $\quad A = 29.5 \times 18$ SQ.IN. $\quad L = \frac{6.312}{12}$ FT.

$$BHP = \frac{BMEP \times 29.5 \times 18 \times \frac{6.312}{12} \times \frac{RPM}{2}}{33000} = \frac{BMEP \times RPM}{236}$$

FIGURE 16

OPERATION

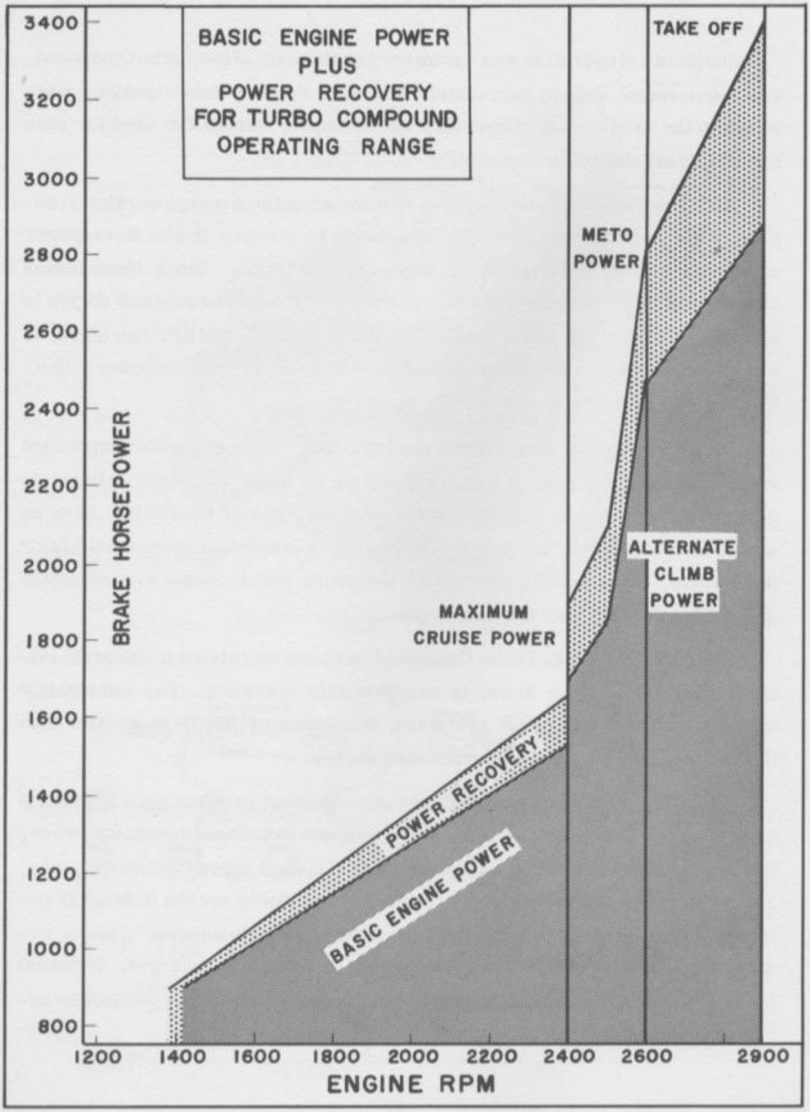
Simplicity of operation was a primary requirement of the Turbo Compound. The requirement was so successfully achieved that the three turbines were added to the conventional air-cooled radial engine without the need for even one additional control or instrument.

BMEP or "Brake Mean Effective Pressure" is the average working pressure in the cylinder that would be necessary to produce Brake Horsepower without accounting for friction and supercharger losses. Since these losses always exist, the average cylinder pressure of a non-compounded engine is always higher than the brake mean effective pressure. BMEP, therefore, is a hypothetical figure generally accepted as a measure of cylinder power output. The derivation of BMEP is shown in Figure 16.

BMEP is directly proportional to crankshaft torque in a non-compounded engine. Because of this, a torquemeter may be used, by proper calibration of its indicator dial, to indicate BMEP. For purposes of simplicity, when an engine is compounded, the same relationship of crankshaft torque and BMEP is assumed. This results in a BMEP indication that includes a combination of cylinder "BMEP" and turbine torque.

The operation of the Turbo Compound has been calculated to maintain cylinder BMEP at a figure known to result in safe operation. The total BMEP includes turbine torque, and therefore, the indicated BMEP is greater than that encountered with a non-compounded engine.

In setting engine power the Wright Aeronautical Division uses the BMEP gage as the primary control. Manifold pressure is not used in setting power, but is utilized as a limit both as to maximum value and spread between engines. Except for manual leaning during climb, the acceptable spread in MAP is two inches after allowance is made for engine differences in accessory power requirements, such as cabin supercharger vs. no cabin supercharger. If manual leaning is used in either cruise power climb or alternate power climb, the acceptable spread in MAP is reduced to one inch.


BASIC ENGINE POWER
PLUS
POWER RECOVERY
FOR TURBO COMPOUND
OPERATING RANGE
TAKE OFF
METO
POWER
ALTERNATE
CLIMB
POWER
MAXIMUM
CRUISE POWER
POWER RECOVERY
BASIC ENGINE POWER
BRAKE HORSEPOWER
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
1200
1400
1600
1800
2000
2200
2400
2600
2900
ENGINE RPM

The take-off BMEP rating for the Turbo Compound of 277 BMEP is obtained with a cylinder BMEP of only 234. The additional 43 BMEP read on the indicator is supplied by the turbine recovery, without effect on cylinder pressure. The operator must, therefore, become accustomed to BMEP figures which would mean certain detonation and engine damage on non-compounded engines.

Allowable BMEP readings further increase with altitude because there is an increase in turbine recovery with altitude. Thus, the cylinders are maintained at a constant power output, while the power from the turbines increases, and the sum of the two readings, read on a torquemeter indicator, likewise increases. In spite of this increase of power with altitude, fuel flow remains constant, and the engine therefore becomes more efficient with increasing altitude.

The increase in turbine recovery with altitude is due primarily to the increased amount of blow-down. The pressure in the cylinder at constant power at start of blow-down is constant while the existing atmospheric pressure is less; therefore, the duration of the exhaust impulse increases, and there is an improvement in exhaust recovery.

Figure 17 is presented to show more clearly the increase in power that is possible due to power recovery on the Turbo Compound throughout the operating range. For simplicity, no mention is made of the variation in power recovery with altitude. The purpose of the chart is merely to give the reader an idea of the amount of power recovery that is gained by the use of the blow-down turbines on the Turbo Compound, as compared with the basic engine power. For actual flight, the aircraft flight manual covers correct power settings that should be used with the Turbo Compound.

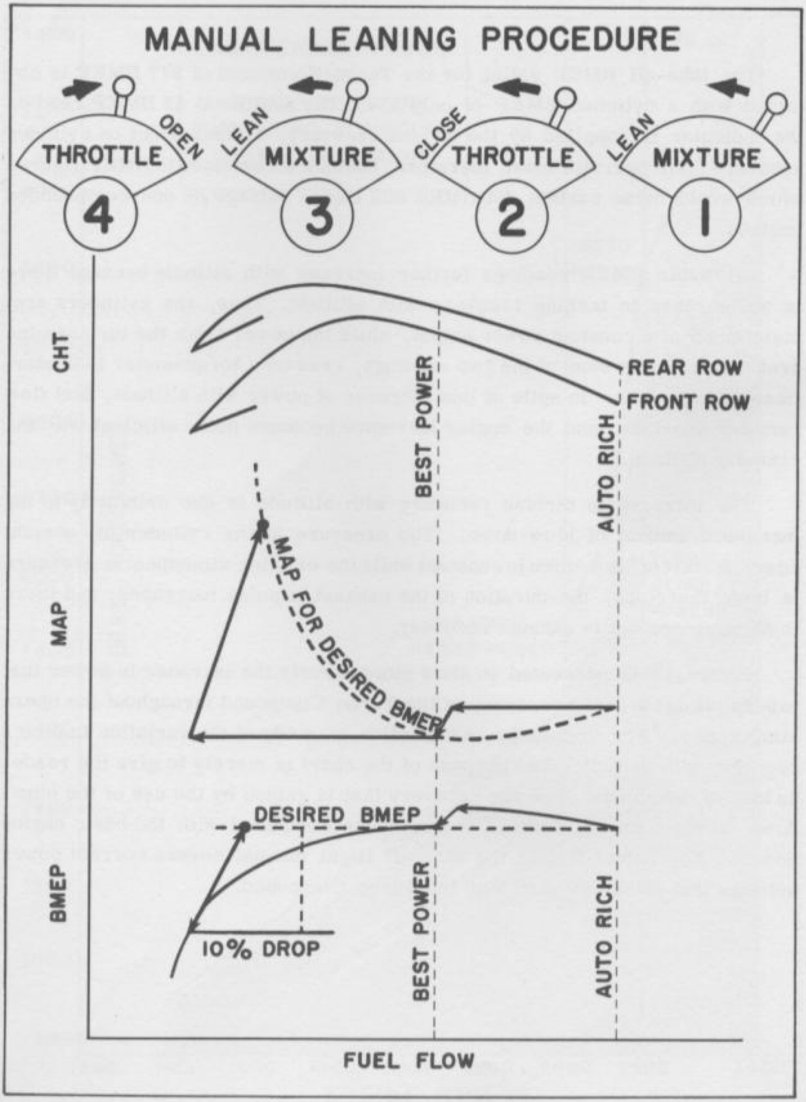

MANUAL LEANING PROCEDURE
THROTTLE
OPEN
4
LEAN
MIXTURE
3
CLOSE
THROTTLE
2
LEAN
MIXTURE
1
CHT
REAR ROW
FRONT ROW
MAP
MAP FOR DESIRED BMEP
BMEP
DESIRED BMEP
10% DROP
BEST POWER
AUTO RICH
FUEL FLOW

FIGURE 18

MANUAL LEANING

The commercial Turbo Compound is similar to other Wright fuel injection engines with regard to the use of the mixture control for manual leaning during cruise (Figure 18). For those not familiar with fuel injection engines, a review of the purpose of manual leaning is presented.

Manual leaning is a definite aid in establishing economical cruise mixtures without respect to position of automatic mixture detents of the master control. Due to a number of causes, ranging from atmospheric effects to a malfunctioning master control, automatic mixture positions often provide mixture strengths which vary considerably from that desired. It was, therefore, established that for cruise control, the operator should manually lean according to the procedures set forth in WAD Operating Instructions. This provides for manually leaning to a 10% BMEP drop from best power, resulting in operation at approximately best economy mixtures. Leaning beyond 10% power drop does very little to improve the fuel economy and results in an unnecessary loss of critical altitude. Also, leaning less than 10% drop is not desirable, since higher exhaust gas temperatures result from mixtures between best power and best economy.

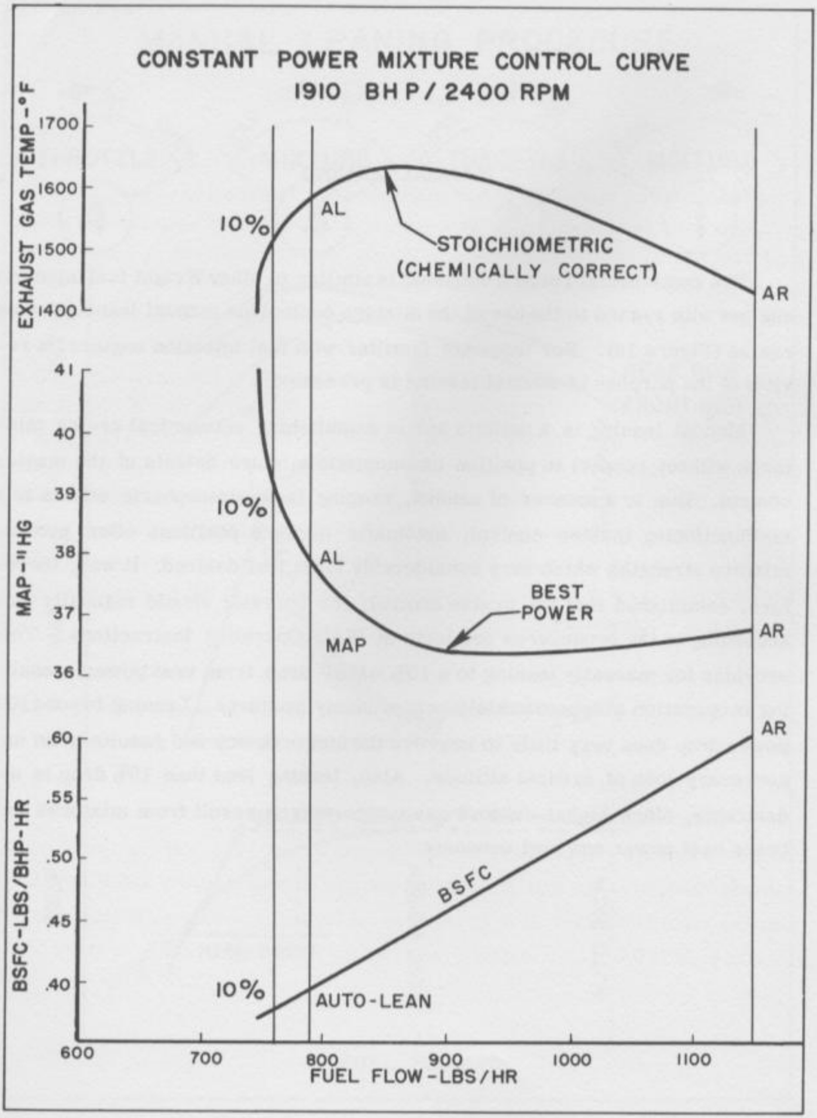

CONSTANT POWER MIXTURE CONTROL CURVE
1910 BHP/2400 RPM
EXHAUST GAS TEMP-°F
1700
1600
1500
1400
10%
AL
STOICHIOMETRIC
(CHEMICALLY CORRECT)
AR
MAP-" HG
41
40
39
38
37
36
10%
AL
BEST
POWER
MAP
AR
BSFC-LBS/BHP-HR
.60
.55
.50
.45
.40
AR
BSFC
10%
AUTO-LEAN
600
700
800
900
1000
1100
FUEL FLOW-LBS/HR

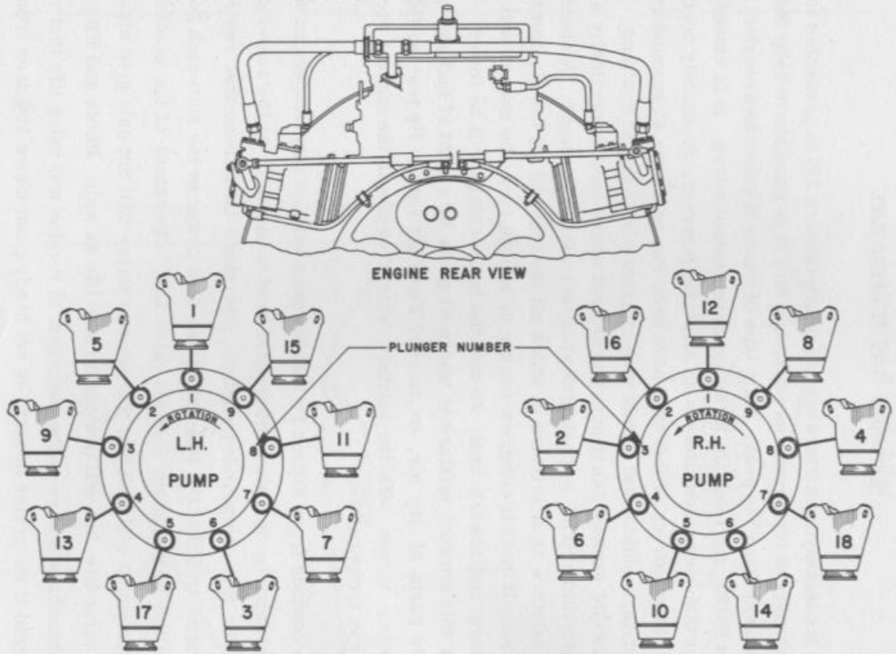
FIGURE 19

EXHAUST GAS TEMPERATURE

The accompanying mixture control curve (Figure 19) is presented to show where exhaust gas temperatures peak, and how it is possible to keep the temperature away from the peak. This type of curve is known as a constant power (constant BMEP and constant RPM) mixture control curve. It is rather difficult to run this curve accurately in an airplane; however, accurately controlled constant power curves of this type have been run on Turbo Compound engines on Wright Aeronautical test stands with instrumented exhaust systems. These tests show that exhaust gas temperatures peak where they theoretically should, at the "stoichiometric" or chemically correct mixture strength. A chemically correct mixture is a mixture in which all the fuel and all the air combine in combustion. If there is either excess air or excess fuel, the excess will dilute the mixture and absorb heat, so that the temperature will be lower. Theoretically this correct mixture is where 67 parts by weight of fuel are burned with 1000 parts of dry air, or an .067 Fuel/Air ratio. By test we find that this mixture agrees with the mixture which results in the highest recorded exhaust gas temperature.

It is obvious from Figure 19 that the peak exhaust gas temperatures may best be avoided by operating either near best economy or at the auto-rich position. For non-compounded engines, operators have found that restricting the operation to either the 10% drop from best power or the auto-rich position has resulted in maximum exhaust valve life. Operators of the commercial Turbo Compound will find that the same practice will not only give maximum exhaust valve life, but will prolong turbine life as well. Pilots and Flight Engineers should be aware of the reduction of turbine and valve life that will be encountered if the cruise mixture is set at any point above 10% drop from best power.

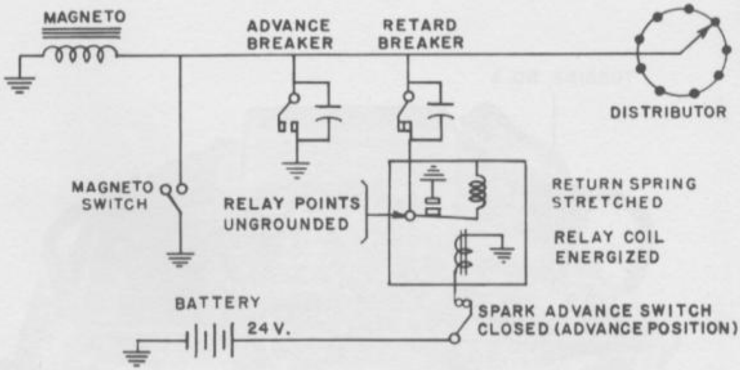
FUEL INJECTION PUMP INJECTING ORDER



CYLINDER INJECTION ORDER - 1 - 5 - 9 - 13 - 17 - 3 - 7 - 11 - 15
LEFT PUMP - REAR BANK

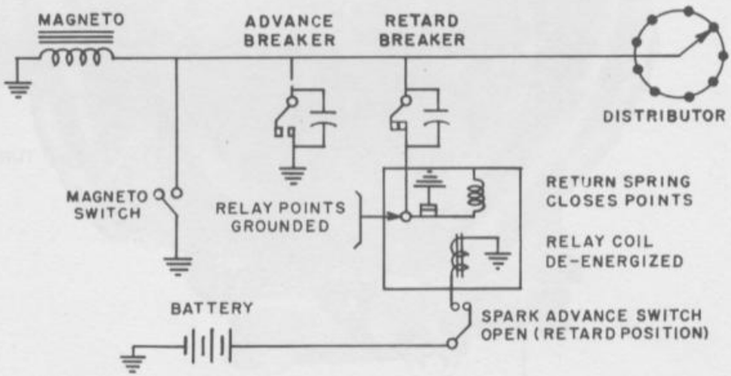
CYLINDER INJECTION ORDER - 12 - 16 - 2 - 6 - 10 - 14 - 18 - 4 - 8
RIGHT PUMP - FRONT BANK

MANUAL SPARK ADVANCE SYSTEM



ADVANCE TIMING — RELAY ENERGIZED

RELAY POINTS ARE UNGROUNDED. SPARK OCCURS WHEN ADVANCE BREAKER POINTS OPEN AT 30° B.T.C.



RETARD TIMING — RELAY DE-ENERGIZED

RELAY POINTS ARE GROUNDED. NO SPARK OCCURS WHEN ADVANCE BREAKER POINTS OPEN BECAUSE RETARD BREAKER POINTS ARE GROUNDED. SPARK OCCURS AS RETARD BREAKER POINTS OPEN AT 25° B. T. C.

TURBO COMPOUND
REAR VIEW

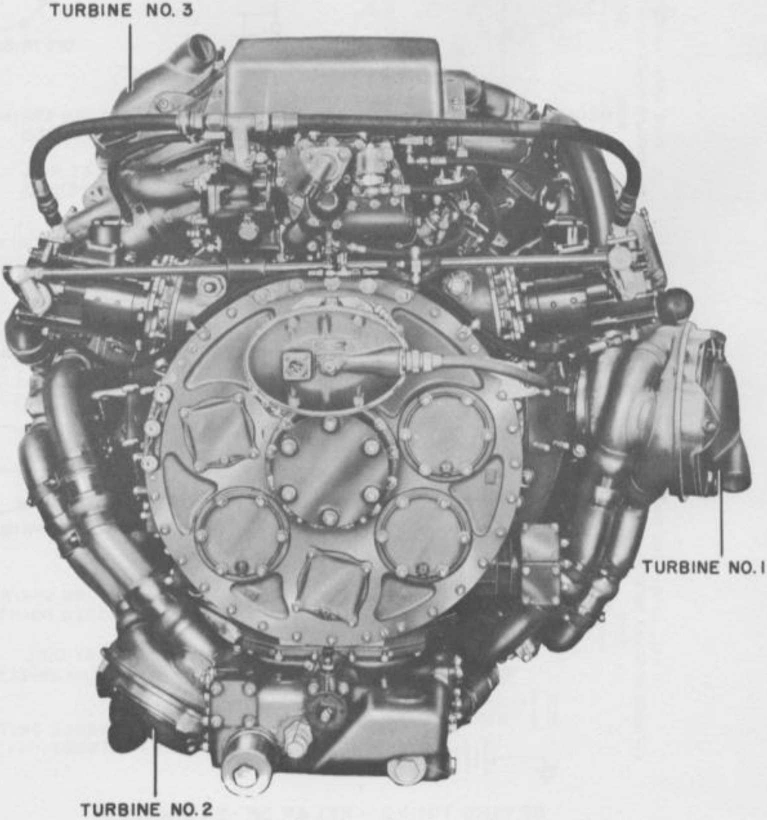


FIGURE 20

WRIGHT AERONAUTICAL DIVISION

CURTISS-WRIGHT

CORPORATION • WOOD-RIDGE, N. J.