POWER PLANT

DO YOU KNOW YOUR POWER PLANT?

The supercharged power plant of the modern airplane is indeed a complex machine. With automatic devices such as constant speed propellers, electronic supercharger controls, and carburetors for controlling fuel-air mixtures, it is a far cry from the aircraft engine of 20 years ago.

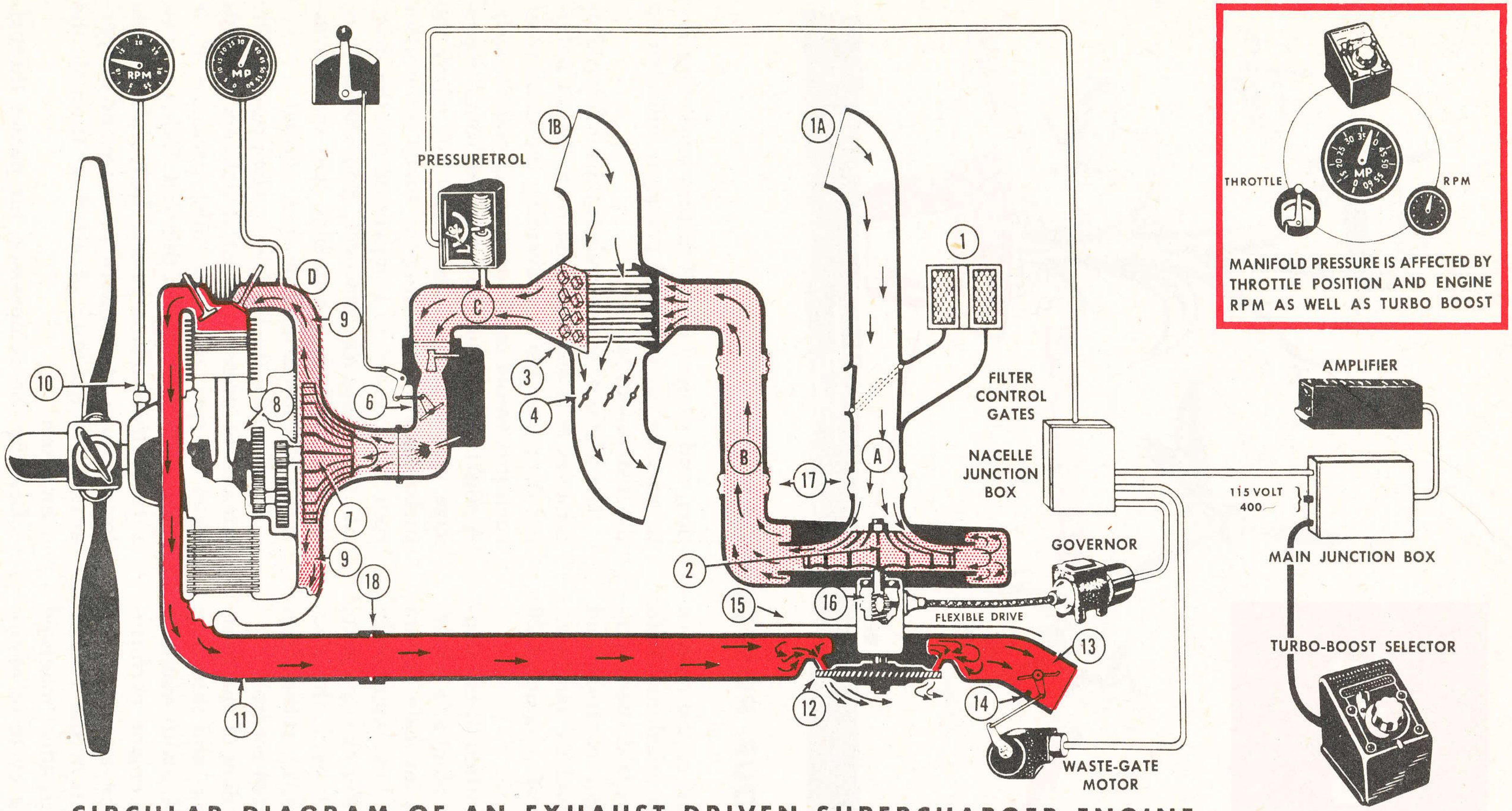
In this discussion of its operation, it is essential first to consider the power plant as a whole, since when one factor in the intricate system changes, other factors—even those apparently remote—may also be affected. For clarity's sake, the discussion will deal chiefly with the electronic turbo-supercharger control, rather than the early type with oil regulated control.

To gain a better understanding of the operation of a supercharged engine, and thus help clear up the existing confusion about manifold pressure and its influence on engine performance, let us first consider the accompanying diagram. It shows the location of the various parts of the power plant which affect manifold pressure during the complete cycle of operation, and shows how all factors work together to produce the manifold pressure indicated on the instrument panel.

The first unit in the cycle is the air filter. This removes dust and fine sand from the air entering the power plant, preventing the rapid wear such grit would cause on moving engine parts. A slight drop in pressure results from the passage of air through the filter, but when the turbo control is working the turbo compressor rpm is increased to compensate for the drop. At high altitudes, however, you should turn the filters off, or the turbine will reach overspeed at a lower altitude than normal.

Next is the turbo-driven compressor. The amount of pressure boost it delivers depends upon its rpm and upon inlet pressure. Four factors affect the rpm of this unit: Exhaust pressure in the turbine nozzle box; exhaust gas temperature; atmospheric pressure and temperature, and quantity of air flow through the compressor.

Leaving the compressor, air passes through



MANIFOLD PRESSURE IS AFFECTED BY THROTTLE POSITION AND ENGINE RPM AS WELL AS TURBO BOOST

CIRCULAR DIAGRAM OF AN EXHAUST DRIVEN SUPERCHARGER ENGINE

1 AIR FILTER
1A CARBURETOR AIR SCOOP
1B INTERCOOLER AIR SCOOP
2 TURBO COMPRESSOR
3 INTERCOOLER
4 INTERCOOLER SHUTTERS
5 CARBURETOR
6 THROTTLE
7 INTERNAL BLOWER
8 GEAR DRIVE FOR INTERNAL BLOWER
9 INTAKE MANIFOLD
10 PROPELLER GOVERNOR
11 EXHAUST DUCT
12 TURBINE WHEEL
13 WASTE GATE
14 WASTE GATE STOP
15 HEAT BAFFLE
16 WORM GEAR DRIVE
17 FLEXIBLE COUPLINGS
18 EXPANSION JOINT
A INCOMING AIR PRESSURE
B TURBO OUTPUT PRESSURE
C CARBURETOR INLET PRESSURE
D MANIFOLD PRESSURE

☐ ATMOSPHERIC AIR
▨ COMPRESSED AIR
🟥 EXHAUST GASES

the intercooler. Since this is an integral part of the induction system, a pressure drop occurs here whether the intercooler shutters are open or not. For full power conditions, this drop amounts to approximately 1″ Hg.

The regulator sensing unit, or Pressuretrol, is connected to the induction system between the intercooler and the carburetor. It reacts to the carburetor inlet pressure (CIP), or upper deck pressure. This **not the manifold pressure,** is the pressure the pilot selects with the turbo boost selector (TBS), which operates through the Pressuretrol to control the waste gate position and produce the required CIP. (On the old type oil regulated turbos, there is no Pressuretrol, and the CIP has no effect on waste gate setting.)

Since the regulator reacts to the CIP, it is important that the ducts and joints of the entire system be tight. Remember that altitude increases the pressure difference between the inside and outside of the system; a leak that is not apparent during ground operation or at low altitude will cause a greater pressure loss at altitude. Leaks will cause excessive "droop" and unstable power, and will make the turbo overspeed control cut in below the normal altitude.

The next unit in the system is the carburetor, where the position of the throttle controls the manifold pressure. When the throttle is at its optimum position (offering minimum resistance to air flow), the manifold pressure will be at a maximum if other factors do not change. The optimum position of the throttle butterfly is not wide open, but several degrees from this point. Opening it beyond the optimum position may cause an instability and loss of manifold pressure. If the open-throttle stops are set so that the throttle cannot open to the optimum position, an excessive pressure drop will exist across the carburetor. In order to obtain take-off power, the regulator would have to be re-calibrated to give a higher induction pressure. (The regulator should not be re-calibrated to offset incorrectly adjusted throttle stops, however.) This condition will exist at all altitudes and will cause the turbine to overspeed at a lower altitude.

Another function of the carburetor is to regulate the mixture of fuel and air, maintaining the weight ratio constant in the normal operating range. Manual mixture adjustment is provided for high and low power conditions. Changing from automatic rich to automatic lean doesn't affect manifold pressure appreciably, but excessive carburetor inlet pressure affects the mixture. Carburetors on B-24 airplanes are designed to maintain a constant fuel-air ratio for variable inlet pressures up to 31″ Hg. Above this pressure the mixture becomes lean; if carried too high, this causes detonation and high cylinder-head temperatures.

The next unit in the system is the internal blower. Since this blower is driven directly by the engine, any change in engine rpm causes the blower speed to change. This causes a change in the boost added to the lower carburetor deck pressure to give the indicated manifold pressure.

At higher engine speeds with wide open throttle, the boost from this blower is a large part of the total manifold pressure, and a small change in engine rpm, resulting from a sluggish propeller governor, will bring a noticeable change in manifold pressure. (This effect is common in low temperatures, which cause the oil in the propeller dome to congeal and slow the rate of change in prop pitch. You can correct this by working the prop governor back and forth a few times to send warm engine oil through the dome.)

If the engine rpm is reduced excessively, the turbine will have insufficient gases to operate on and a complete collapse of the cycle may occur. This gives the impression of improper turbo-supercharger regulation. When it occurs, the engine rpm should be increased.

The next part of the system is the intake manifold, which obviously must be leak-proof if you are to get stable pressures. The engine itself comes next. Since manifold pressure depends upon a uniform flow of exhaust gas to drive the turbine, it follows that any flaw in engine operation—faulty valve action, faulty ignition, or changes in rpm—will alter the manifold pressure by causing fluctuations in exhaust pressure. Ignition is a common cause of unstable manifold pressure at altitude, because decreased atmospheric pressure leads to increased leakage throughout the electrical system. The ignition system must be in perfect condition to offset this tendency at altitude.

The exhaust duct, turbine, and waste gate complete the supercharger system proper. The position of the waste gate controls the speed of the turbine by determining the amount of exhaust back pressure and, consequently, the amount of exhaust flow through the turbine wheel. The TBS knob and the Pressuretrol, as already explained, act upon the waste gate motor to control the position of the waste gate by reference to CIP. A further control of turbine speed is exercised by the overspeed control feature of the governor.

The parts of the regulating mechanism which can cause hunts in manifold pressure are the governor and the Pressuretrol. Improper functioning of these units will be evident at all altitudes whenever boost is being used.

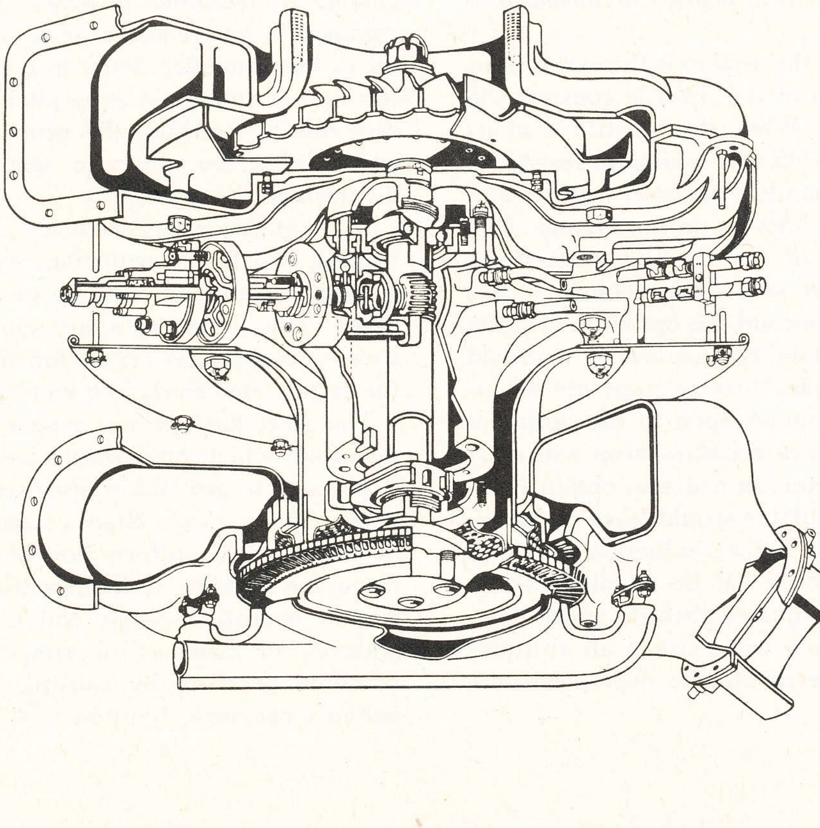
To prevent turbine speed from overshooting its limit during power changes at altitude, the overspeed control opens the waste gate rapidly to relieve exhaust back pressure, and then closes it at a slower rate to establish the limiting turbo speed. Since turbine speed, instead of pressure, is controlled, a slight instability in manifold pressure will exist at higher powers. The fluctuation warns you when the overspeed control takes effect.

Note: Manifold pressure should be reduced slightly whenever the overspeed control goes into operation. The device is designed to work when the turbine reaches maximum rated speed plus 10%. This overspeed rating should be limited to 5 minutes, as continued operation would greatly shorten the life of the turbine wheel. Reduce the turbine rpm about 10% by reducing manifold pressure approximately 1.5" Hg, and continue to reduce it by 1.5" for each 1000 feet you climb above that point.

The foregoing discussion is a general explanation of how your engine works. The material which follows deals in greater detail with the individual parts of the power plant.

Turbo-superchargers

The turbo-superchargers are installed behind the mount support of each engine, below the



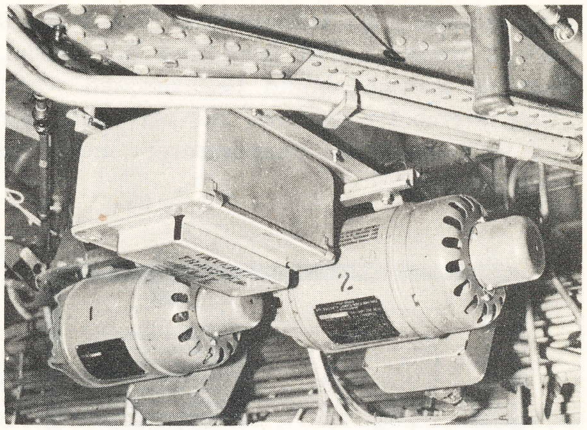
wing's lower surface. On early series B-24's, type B-2 turbos are used, while late B-24's have type B-22 turbos. The two types are almost identical in appearance, but differ in their limitations.

The B-22 has a higher maximum rpm, and therefore a higher critical altitude, than the B-2. At normal rated power—2550 rpm and 46″ Hg.—the B-22 has a maximum wheel speed of 24,000 rpm, compared to 21,300 rpm for the B-2. At military power—2700 rpm and 49″—these speeds rise to 26,400 for the B-22 and 22,400 for the B-2, but use of this power is limited to 5 minutes. Because of the greater wheel speed, the B-22 turbo has a critical altitude of 30,000 feet, as against 27,000 feet for the B-2 turbo.

When you reach the critical altitude of the type of turbo you are using (or when the overspeed control takes effect on the B-22 type, producing fluctuations in manifold pressure), reduce manifold pressure 1.5″ for every additional 1000 feet you climb at maximum manifold pressure. If you are climbing at less than the maximum pressure, you can raise the critical altitude 1000 feet for each 1.5″ that your manifold pressure is below the maximum. Thus, if the critical altitude is 30,000 feet at 46″, it will be 32,000 feet at 43″, etc.

Controls: The superchargers are regulated either through the engine oil pressure system or by electronic control. With the oil-regulated system, used on early B-24's, the pilot regulates the turbos by means of 4 levers on the left side of the pedestal. The levers control the operation of the waste gates on the 4 engines through the oil type regulators.

The electronic control is used on all late B-24's and is replacing the oil-regulated type on most early aircraft. In this system, the TBS knob is the manual control unit. It is mounted on the pilot's pedestal in the space formerly occupied by the 4 turbo levers. The TBS unit contains 4 small calibrated potentiometers which require adjustments only to compensate for small differences in engine or turbo performance. Once the calibrators are set, the pilot controls the turbo boost on all 4 engines simultaneously by turning the control knob.

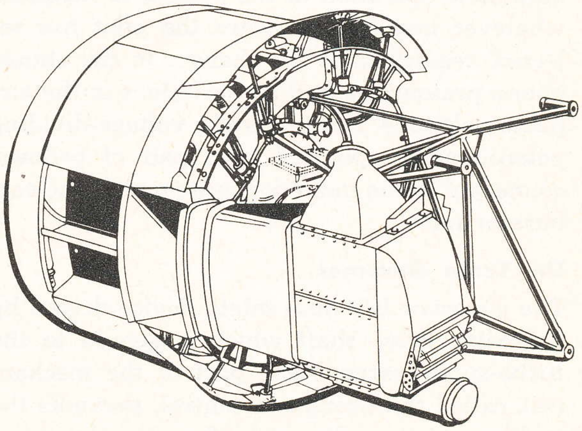


Electric Energy

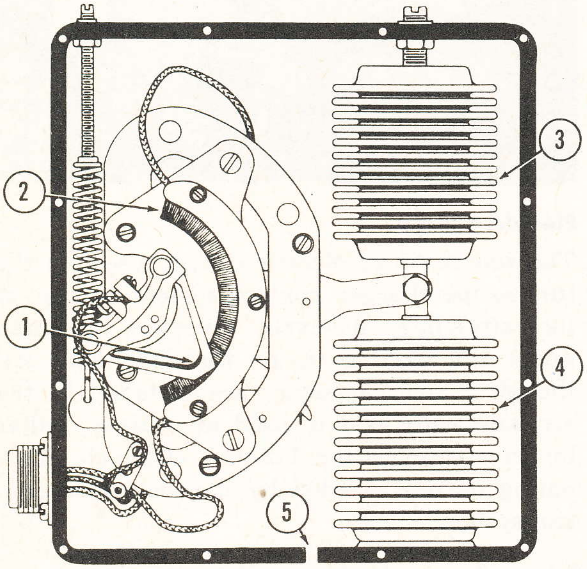
The source of all electric energy used by the turbo-supercharger control system is one of the airplane's 400-cycle inverters mounted under the flight deck, on the right side. Although 2 such inverters are installed in the airplane, only one is used at a time. Either inverter supplies the 115-volt, 400-cycle alternating current needed by the electronic control system.

Intercoolers

Heat from compression of the air by the turbo-superchargers must be dissipated before it reaches the engine; otherwise, the normal carburetor intake temperature limits will be exceeded. This is accomplished by intercoolers or radiators in the air intake duct between the turbo-supercharger and the carburetor. Shutters on the intercoolers are provided to regulate



the carburetor air temperature. The shutters have 2 positions—full open and full closed. Extreme caution should be exercised when using intercooler shutters, and carburetor air and cylinder-head temperatures must be watched closely.



1. Wiper
2. Potentiometer
3. Reference Bellows
4. Operating Bellows
5. Vent and Drain

The Pressuretrol

Control of the pressure in the induction system is accomplished automatically by the Pressuretrol. This unit measures electrically the pressure of the air supplied by the turbo-supercharger to the carburetor, and controls the automatic operation of the system to maintain whatever manifold pressure the pilot has selected, regardless of the changes in the atmospheric pressure caused by variations in the airplane's altitude. It consists of a voltage-dividing potentiometer operated by a pair of bellows, connected to the induction system near the carburetor inlet.

The Turbo Governor

The governor is a dual safety device driven by a flexible drive shaft which is geared to the turbo-supercharger. One part of the mechanism, called the overspeed control, prevents the turbo from exceeding its safe operating speed limit. The other part, the accelerometer, anticipates the pressure increase from turbo acceleration and provides a signal to start opening the waste gate in time to prevent the overshooting of manifold pressure.

The Amplifier

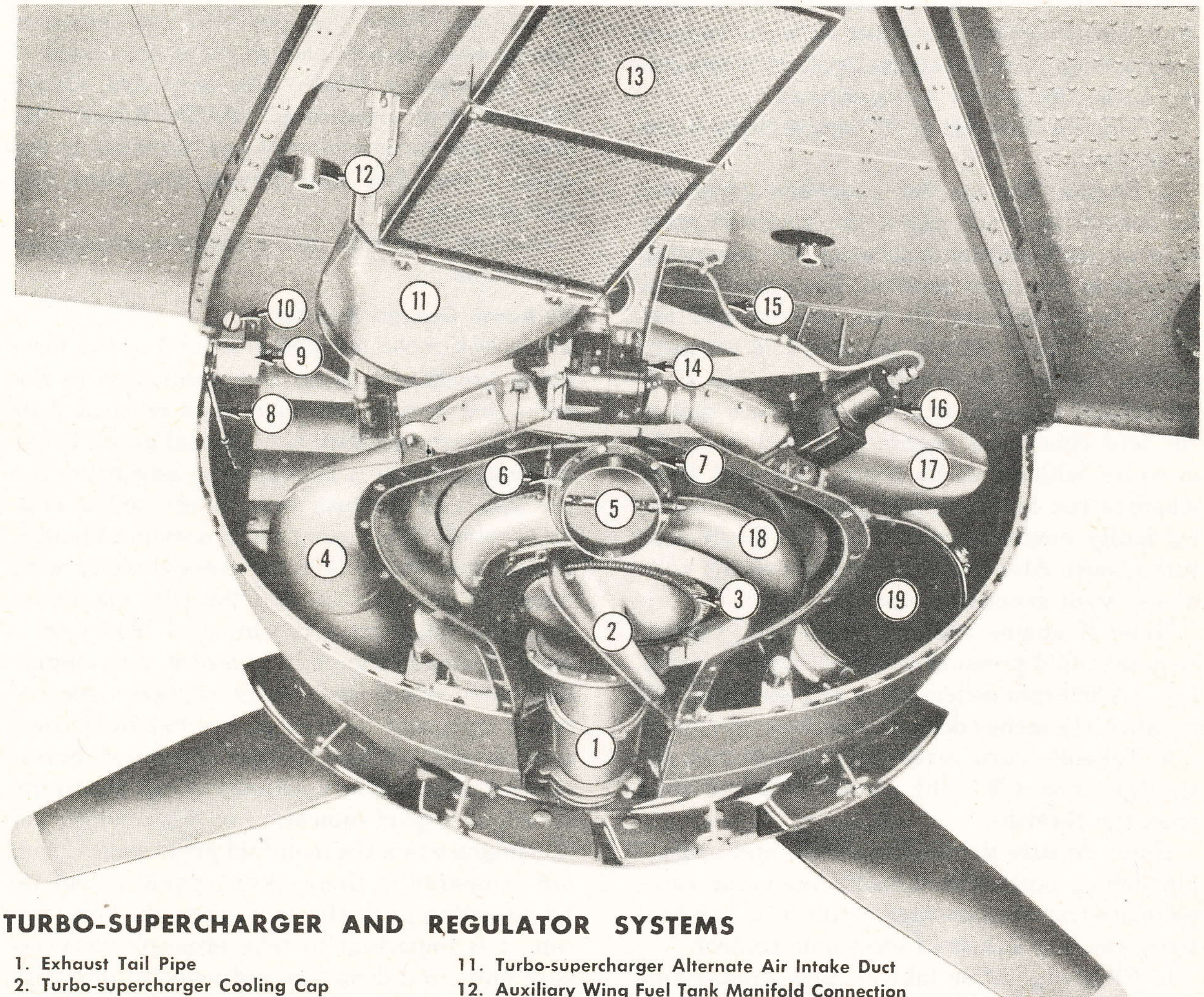
The amplifier is an intermediate unit between the control units and the waste gate motor. It receives two kinds of signals from the other control units. One kind calls for rotation of the waste gate motor to close the gate; the other, for rotation to open it. After amplifying the signal, the amplifier determines the direction of movement called for and controls the power delivered to the waste gate motor accordingly.

If the amplifier of any one of the 4 turbos fails, the waste gate remains fixed in the position it held when the amplifier went out. It is possible, however, to adjust all 4 turbos to any desired manifold pressure even if only one of the 4 amplifiers, or the spare, is working. To do so, it is necessary to disconnect the cannon plugs from the amplifiers (accessible from the

bomb bay). Then remove the dead amplifier for the turbo you wish to set up, and replace it with the good amplifier, reconnecting the cannon plug. (The pilot must be on the alert for any turbo fluctuations, keeping his hand on the throttle to control sudden changes, until the amplifier warms up.) From that point on, the procedure is normal, except that when the turbo is properly set up, the cannon plug is again disconnected, freezing the waste gate in the desired position. This procedure can be used in flight or, if necessary, to set up desired power for takeoff.

The Waste Gate Motor

When the waste gate motor operates the waste gate in response to the control signals, it also operates a balancing potentiometer which produces a signal opposed to the original control signal. When the rotation of the motor is enough to make the 2 signals exactly neutralize



TURBO-SUPERCHARGER AND REGULATOR SYSTEMS

1. Exhaust Tail Pipe
2. Turbo-supercharger Cooling Cap
3. Turbo-supercharger Bucket Wheel
4. Air Duct from Supercharger to Intercooler
5. Exhaust Waste Gate
6. Waste Gate Control Linkage
7. Exhaust Tail Pipe Outlet
8. Intercooler Shutter Control Linkage
9. Intercooler Motor Control Box
10. Intercooler Motor
11. Turbo-supercharger Alternate Air Intake Duct
12. Auxiliary Wing Fuel Tank Manifold Connection
13. Alternate Air Intake Filter Box
14. Waste Gate Control Motor
15. Electric Cable
16. Turbo Regulator Governor
17. Turbo-supercharger Air Intake Duct
18. Turbo-supercharger
19. Oil Cooler

each other, the power from the amplifier is cut off, and the waste gate motor stops.

Operating Instructions

Electronic Turbo Control

1. Engage the System—After turning on the airplane's battery switches, the main line switch, and one inverter switch, allow 2 minutes for the amplifier to warm up. The control system will then respond to the setting of the turbo boost selector.

2. Before Starting Engines—Set turbo boost selector at "0." Turn on auxiliary power unit. Warning: Never turn inverter off while engines are running, since the control system is dependent on the AC power for operation.

3. Taxiing—Set dial at "0" unless turbo boost is needed.

4. Engine Run-up—Set propeller governors for takeoff rpm and check the manifold pressure on each engine separately by advancing throttle to full open position. Then turn dial of turbo boost selector to the desired position ("8" with Grade 100). If the manifold pressure on any engine fails to come up to within 1" of the takeoff pressure with full rpm, turn dial to "0" and check the engine rpm and manifold pressure without turbo boost. This will show whether the low manifold pressure is caused by faulty engine operation or by insufficient turbo boost. Also check DC voltage on the voltmeter, with generators on.

Note: If engine does not attain full takeoff rpm, manifold pressure will be correspondingly less. (A 100 rpm deficiency in engine speed will produce 1½ inches drop in manifold pressure.)

5. Takeoff—Turn turbo boost selector to desired position ("8" with Grade 100) and then open the throttles.

Note: Be sure generators are on and operating during and after takeoff; otherwise complete electrical failure may result from low batteries causing failure of electronic control.

6. Climbing—After takeoff, turn knob counterclockwise until desired manifold pressure is reached. Decrease rpm to desired value. Re-set manifold pressure with turbo boost selector if necessary. For climbing after cruising, increase rpm first; then advance throttles and increase manifold pressure to the desired value by turning turbo boost selector clockwise.

7. Cruising—Use dial to select manifold pressure. If manifold pressure cannot be lowered sufficiently with the knob, pull back on the throttles. Decrease rpm to desired value, and then, if necessary, re-set the manifold pressure with throttles and dial.

If icing conditions prevail, close intercoolers and operate as close to full throttle as possible. If ice has already formed (indicated by reduced manifold pressure) open throttle and increase power settings until manifold pressure returns to normal. Watch cylinder-head temperatures closely when intercooler shutters are closed.

8. Emergency Power—Use only with Grade 100 fuel. Put mixture in "AUTO-RICH." Increase rpm to maximum. Open throttles to the stops. Press dial stop release and turn dial clockwise to "10."

Caution: Use only under extreme emergency conditions.

No-boost Ground Run-up

The check recommended in Item 4 of the foregoing procedures is an important step in determining engine efficiency, and as such calls for fuller explanation. In a normal ground run-up, engine speed is increased by advancing the throttle, with the prop remaining fixed at minimum pitch. Since prop pitch does not change, engine rpm above 1200 increases directly with manifold pressure. At full throttle, maximum rpm, the boost from the internal blower is a major factor in manifold pressure. Any engine deficiency which reduces horsepower also reduces rpm, and in turn causes manifold pressure to fall off and further decreases horsepower and rpm. The no-boost run-up, therefore, serves as a good indication of the condition of the engine when the manifold pressure and rpm are compared to those of an engine known to be operating properly. In making the comparison, it is important to take atmospheric pressure and wind direction and velocity into consideration. Because of the change in prop loading, a rise in wind velocity from zero to 25 mph may alter engine speed by 50 rpm. In the range of engine speeds above 1400 rpm, rpm may be changed by altering prop pitch, keeping the throttle position fixed.

Overspeeding Turbo-supercharger

This occurs infrequently but usually on takeoff. An overspeeding turbo is evidenced by the manifold pressure quickly going sky-high. A turbo can overspeed during takeoff and then settle down immediately afterward and continue to operate normally.

If you know a turbo is overspeeding during the first third of takeoff, it is best not to take off if you have room in which to stop.

Remedy With Electronic Control

Don't feather with an overspeeding turbo. Reduce manifold pressure with throttle. You can't dial back supercharger setting or you will lose manifold pressure on all 4 engines.

With the electronic supercharger control, a runaway supercharger is usually directly traceable to amplifier failure or insufficient electric power. Amplifier tubes control the opening and closing of the waste gate, and if the tube that controls opening of the waste gate is burned out, the supercharger may overspeed. There is a spare amplifier aboard and it can be changed as soon as you reach a safe altitude.

Caution: Reduce power on the affected engine when changing the amplifier, if circumstances permit, and give it 2 minutes to warm up. Then you can resume power.

Never shut the inverter off for any length of time without reducing power before bringing inverter on again. (Avoid turning inverter off unless in an emergency.)

Remedy With Oil-Regulated Control

On the oil-regulated type turbo, overspeeding usually results from clogging of the regulator balance lines or from congealed oil. The tendency to overspeed will usually be evident when you are setting turbos during run-up.

Don't feather. You are getting power from the engine, and you can use it. For the first step, you have two choices. Either pull back the supercharger control or reduce throttle to the desired manifold pressure. Reducing throttle is better because if the supercharger settles down after takeoff, it is easier to re-set the throttle than the supercharger control.

If the turbo wheel continues to overspeed with throttle retarded, pull back the supercharger control and control power with throttle.

Carburetor and Mixture Controls

The R-1830-43 engine is equipped with the Bendix Stromberg injection carburetor. The R-1830-65 engine has the Chandler-Evans Company (Ceco) carburetor. Metering of the fuel is accomplished by air flow through the carburetor venturis. Four positions of the pilot's mixture control lever can be used in operating the Bendix Stromberg carburetor: "IDLE CUT-OFF," "AUTO-LEAN," "AUTO-RICH," and "FULL (EMERGENCY) RICH." With the Ceco carburetor, only the first three of these positions have any effect; the "FULL RICH" position on the control quadrant does not work. On all mixture control quadrants, however, the "FULL RICH" position is safety-wired off from the other three positions. An explanation of the control positions, and their effects, follows:

Automatic Rich—The usual operating position for mixture control, "AUTO-RICH" maintains the necessary fuel-air ratio for all flight conditions. At high power, the proportion of fuel to air is relatively high, to suppress detonation and assist in cooling. Between normal rated and cruising powers the proportion of fuel is decreased, so that in the cruising range fuel consumption is reduced to the minimum required to prevent detonation and over-heating and to provide good acceleration.

Automatic Lean—"AUTO-LEAN" is an alternate operating position of the mixture control, resulting in leaner fuel-air ratios than automatic rich. During the favorable conditions of stabilized level flight or a cruising descent, automatic lean may be used in the cruising power range when fuel economy is of primary importance and when cooling is adequate. Don't try to use intermediate settings beyond the "AUTO-LEAN" position. You gain nothing by any such attempt at manual leaning of the mixture.

Full Rich—"FULL RICH" setting of the mixture control renders inactive the altitude compensating device built into the carburetor to compensate for changes in the density of the air flowing through the venturis and keep the fuel-air ratio constant. "FULL RICH," in reality, is merely a manually enriched mixture, and should only be used when the automatic mixture control unit gives evidence of faulty operation. Despite its other name of "EMERGENCY RICH," "FULL RICH" actually results in a loss of power whenever it is used. Torquemeter tests show, for example, that at 8500 feet, with 35″ manifold pressure, 2500 rpm, and "AUTO-RICH," an engine develops 935 Hp. With the same settings and "FULL RICH," the engine develops only 775 HP—a loss of 160 Hp.

Idle Cut-Off—Moving the mixture control past automatic lean to the end of its travel will stop all fuel flow, regardless of fuel pressure. "IDLE CUT-OFF" is intended for stopping the engine without the hazard of backfiring.

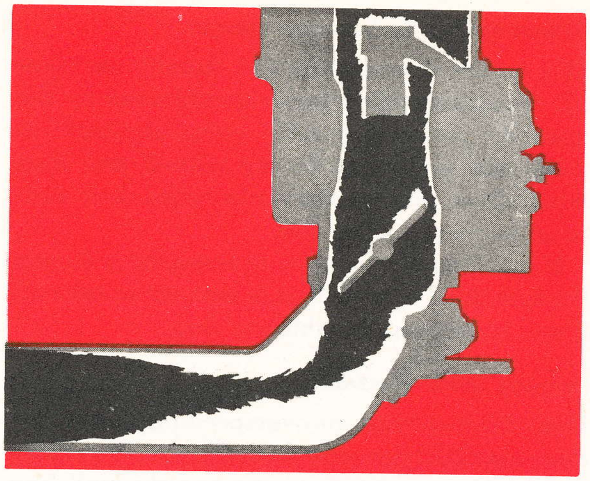
Mixture strength is increased when operating below the cruising power range. This enrichment provides easier starting and the dependable acceleration needed in taxiing and the approach for a landing. Fuel metering in this power range is accomplished largely by throttle opening.

The accelerating pump is operated by, and in proportion to, the momentary changes in air pressure in the manifold entrance. The accelerating pump is not connected with the throttle or throttle controls. Hence, when the engine is not running, no fuel is pumped from the carburetor when the throttle is moved, no matter how rapidly. You can not prime by pumping the throttle.

Carburetor Icing

This is the most talked of and least understood type of icing. It is generally agreed that there is no such thing as a non-icing carburetor. However, carburetor ice and the remedies for it differ with each type of aircraft because of the difference in carburetors. Induction-system ice can occur in the B-24. It is more likely to be refrigerated ice than atmospheric ice.

Atmospheric ice can build up on any surface directly in the path of the intake air, such as the intercooler, carburetor butterfly valve, or the angle of the carburetor adapter (usually in the order named).



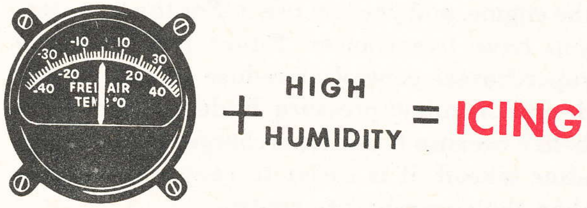
When air is pouring through the induction system, sufficient temperature drop may cause precipitation of moisture. If the temperature is low enough in the system, the moisture will freeze and adhere to the closest surface. Formation of this ice anywhere in the induction system can block off the flow of air to the engine and can cause almost instantaneous engine failure.

Carburetor ice in the B-24 can occur during otherwise ideal flying conditions. It can occur when it is snowing or sleeting. It can occur any time carburetor air temperature is within the icing range. Watch your carburetor air temperature when relative humidity is high.

Know your induction system and what happens to the air pouring through it. Within 3 hours' time your induction system will use air weighing as much as the airplane.

Detection of Carburetor Ice—Icing can progress almost to the point of engine failure before it is indicated on your instruments unless you are alert.

1. Know your carburetor air temperature. If it drops down to 15°C when humidity is high



take measures to bring it back up. Safe range is 15° to 35°C. Above 35°C there is danger of detonation.

2. Note any drop in manifold pressure. A low carburetor air temperature, together with a drop in manifold pressure, suggests carburetor icing. (Do not mistake a drop in manifold pressure caused by change in altitude for carburetor ice.)

3. If you have low carburetor air temperature, plus a sudden drop in manifold pressure, plus a rough-running engine—then, brother, you probably already **have** carburetor ice.

Preventive Measures

If you are flying at cruising power in conditions where there is danger of carburetor icing, close the intercooler shutters and operate as close to full throttle as possible. If ice has already formed (its formation will be indicated by reduced manifold pressure), open the throttles and increase engine power settings until manifold pressure returns to normal.

Caution: Check cylinder-head temperature gages frequently whenever you are operating with the intercooler shutters closed. Excessive cylinder-head temperatures cause detonation.

Function of Intercooler Shutters

When the turbo compresses air, it generates heat in the air. This air is going to the carburetor and would normally be too hot, so it passes through the intercooler. When intercooler shutters are open, cool air, taken in through the air duct in the engine cowl, cools the hot air pouring through the intercoolers. When you close the shutters, the intercooler has no cooling effect so that the blast of hot air from superchargers goes uncooled to the carburetor, melts ice and very rapidly builds up the carburetor air temperature. If this goes too high, you get detonation and engine failure. Closing your intercooler shutters, obviously, will not raise your carburetor air temperature unless turbos are operating.

No Carburetor Air Temperature Gage: If your plane is not equipped with carburetor air temperature gages, you are short the most important instruments for detecting carburetor ice and for observing the effects of intercooler shutters. It becomes even more vital that you know relative humidity of the air through which you are flying. Avoid closing intercooler shutters unless you **know** there is danger of carburetor ice and then close them intermittently for only a few seconds at a time. Leave them open the instant you note a rise in cylinder-head temperatures or a recovery of manifold pressure.

POWER SETTINGS

Grade 91 Fuel—Specification ANF-26

OPERATION	SETTING	MIXTURES	RPM	MP	TIME LIMIT	BMEP	HP
Takeoff	Max.	Auto-rich	2700	42″	5 Minutes	169	1060
Climb	Max.	Auto-rich	2550	38″	1 Hour	160	950
Climb	Desired	Auto-rich	2550	35″	Continuous	147	870
Cruise		Auto-lean	1650-2100*	30″	Continuous	—	—
Local Cruise	Suggested	Auto-lean	2000	30″	Continuous	131	610

*Maximum and minimum rpm in Auto-lean. Do not exceed 30″ manifold pressure.

Grade 100 Fuel—Specification ANF-28

OPERATION	SETTING	MIXTURES	RPM	MP	TIME LIMIT	BMEP	HP
Takeoff	Max.	Auto-rich	2700	49″	5 Minutes	192	1200
Climb (Normal Rated Power)	Max.	Auto-rich	2550	46″	Continuous*	186	1100
Climb	Desired	Auto-rich	2550	41″	Continuous	167	990
Cruise	Max.	Auto-rich	2325	35″	Continuous	152	820
Cruise	Max.	Auto-lean	2200	32″	Continuous	140	715
Cruise	Desired	Auto-lean	2000	30″	Continuous	131	610

*Cyl. head temp. not to exceed 232°C. For temperatures of 232° to 260°, time limit is 1 hour.

DEFINITIONS OF RATINGS

Takeoff Rating: This is the maximum power and engine speed permissible for takeoff and should be maintained only long enough to clear obstructions.

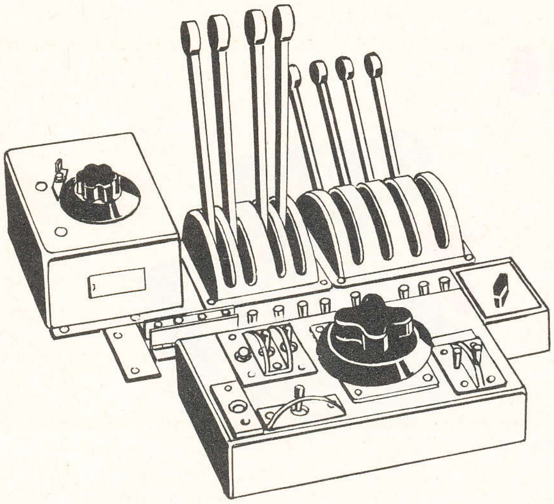
Military Power: This is the maximum power permitted for the military services with less regard for long life of the engine than for immediate tactical needs. Military rating is comparable to takeoff power with manifold pressures modified to suit altitude conditions, and may be used for 5 minutes in any attitude of flight.

Normal Rated Power: This is frequently referred to as a normal maximum rating, or maximum except takeoff power. It is the maximum power at which an engine may be operated continuously for emergency or high performance operation in climb or level flight if cylinder-head temperatures do not exceed 232°C.

Maximum Power and RPM for Cruising: This rating stipulates both the maximum power and maximum rpm permissible for continuous operation with the mixture control in automatic lean. The proper combination of rpm and manifold pressure for the particular horsepower, load and altitude desired can be determined from the cruising control charts.

In takeoff emergencies, you can get 1350 Hp from your engines by using auto-rich, 2700 rpm, and 56″ manifold pressure. These settings give you a BMEP (brake mean effective pressure) of 216. Use this emergency power only if you have to, and then only for the shortest possible time—never more than 5 minutes. Don't go into full (emergency) rich; you sacrifice power if you do.

SEQUENCE OF POWER CHANGES



There are ironclad rules regarding the sequence for increasing or reducing power. Failure to follow the sequence can cause premature firing, excessive pressures, overheating, detonation, and engine failure. Three inter-related elements are involved in any power change, namely: mixture, manifold pressure, and rpm.

Relationship of Mixture and Manifold Pressure

"AUTO-LEAN," for example, automatically reduces the proportion of fuel to air to provide efficient firing with minimum expenditure of fuel. However, as manifold pressure is increased (increasing the pressure in the cylinders), there is a point beyond which the excess pressure will cause hot, hard, and fast firing, with detonation and overheating. If the fuel-air ratio is richer, the same manifold pressure will produce slower, stronger firing, with less heat. That's why richer mixtures must be used at higher power settings.

On the other hand, too rich a mixture interferes with the proper expansion and firing of the gases and results in overloading, torching, and loss of power.

Relationship of Manifold Pressure and RPM

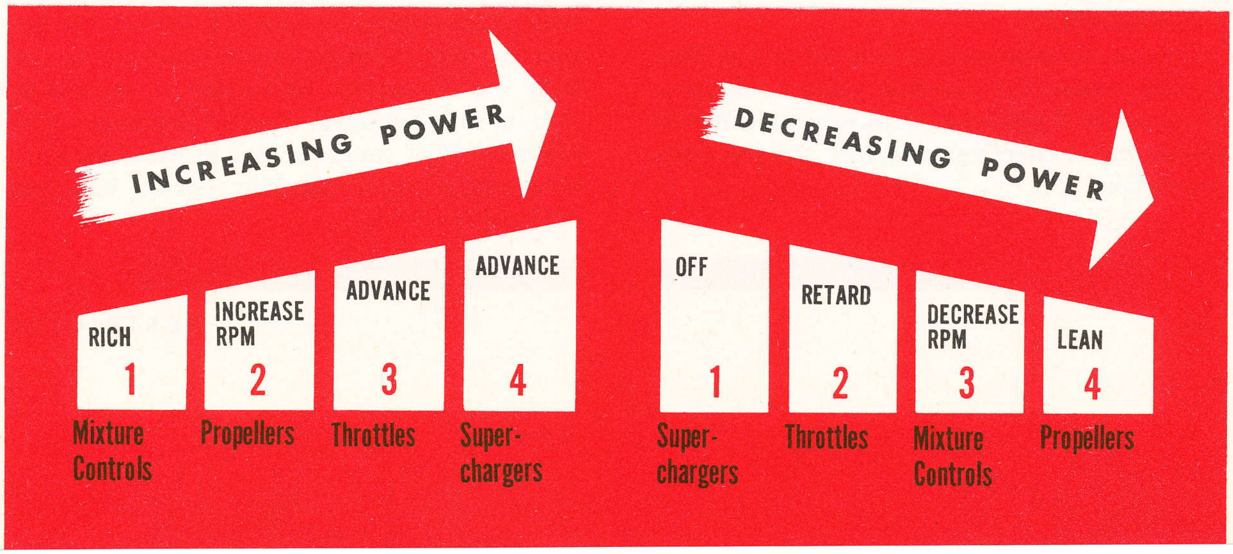
The constant-speed propeller does exactly what its name implies. The propeller governors function so that if propellers are set for a given rpm, governors automatically change the pitch of the propellers to keep them turning at the given rpm. Thus, if a propeller governor is set for 1900 rpm and manifold pressure is increased, the governors increase the pitch of propellers so they take a larger bite and continue to turn at 1900 rpm; this puts a larger load on the power plant and builds up pressure in the cylinders. This is permissible within specified limits, but as pressure increases heat increases. An increase in the speed of propellers gives an outlet for the extra power being produced.

Brake Mean Effective Pressure

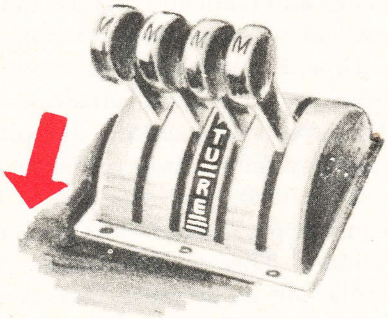
The brake mean effective pressure (BMEP) is the average pressure within the cylinder of an engine during the power stroke of the piston. As the pressure within the cylinder is increased, more heat is developed because of the energy of compression. If the pressure and temperature increase sufficiently, detonation occurs.

The formula for determining BMEP for 1830-43 or 65 P & W engines is:

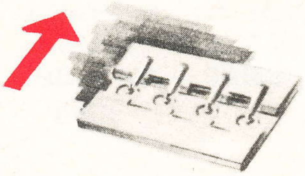
$$BMEP = \frac{433 \times BHP}{RPM}$$



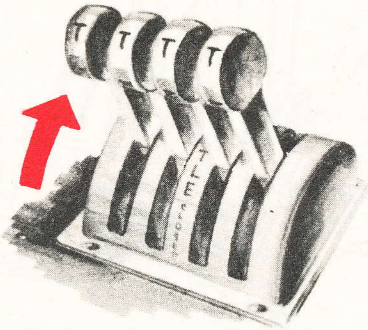
STEPS FOR INCREASING POWER



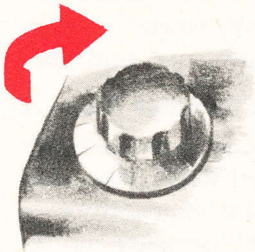
1. **Mixture Controls.**
Copilot sets the mixture controls to "AUTO-RICH" (if necessary) at pilot's signal. Reason: Maximum setting in "AUTO-LEAN" is 32″ manifold pressure and 2200 rpm with Grade 100 fuel, and 30″ and 2100 rpm with Grade 91 fuel. It is obvious that if power is to be increased beyond these maximums the mixture should first be set in "AUTO-RICH."

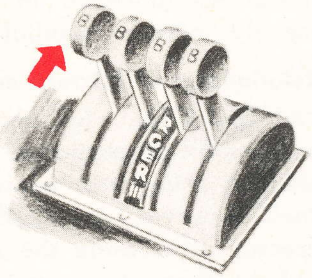


2. **Propellers.**
Copilot increases rpm to desired setting. This should precede the manifold pressure increase to eliminate the danger of an excessive BMEP (brake mean effective pressure) and resultant detonation.



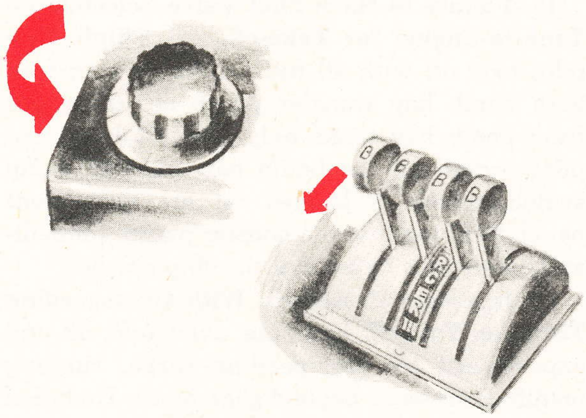
3. **Throttles.**
Pilot advances throttles as the rpm is increased. If more power than full throttle is required, superchargers are advanced.





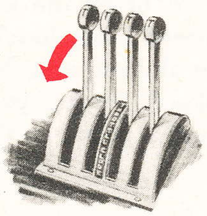
4. **Superchargers**
With electronic control, advance the TBS knob. With oil regulator, the supercharger controls may all be advanced together, but it is advisable to set them one at a time, starting with the dead-engine side if operating with a dead engine. Always use full throttle before applying supercharger boost. Reason: A partially closed throttle will create a back pressure in the induction system resisting turbo pressure. This causes a rise in carburetor air temperature with possible power loss and detonation.

STEPS FOR REDUCING POWER



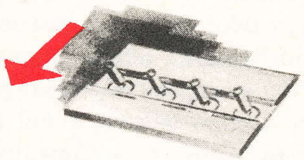
1. Superchargers

To reduce power, pilot first slowly retards supercharger controls—TBS or levers: slowly in order to prevent cracking of the turbo nozzle box by too rapid cooling, superchargers before throttles to prevent back pressure in induction system.



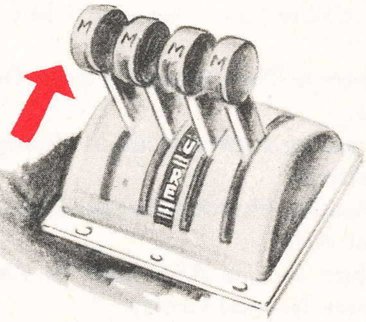
2. Throttles.

Pilot retards throttles before reducing rpm. Reason: Manifold pressures must be reduced before propellers in order to keep BMEP on the low side of safe limits and to prevent detonation.



3. Propellers.

Copilot decreases rpm at command of pilot. This must follow throttles. A sufficiently low rpm permits mixtures to be brought to "AUTO-LEAN."



4. Mixture Controls.

Copilot puts mixture controls in "AUTO-LEAN" if new power setting falls within limits of manifold pressure, rpm and cylinder-head temperatures. Wait until engines are cool before going into "AUTO-LEAN," because a hot engine increases the tendency to detonate.

CAUSES OF ENGINE FAILURE

In considering engine failures, always remember there are three things that make an engine run—fuel, oil, and ignition. Failure of any of these three systems, plus structural failure, are the only things which can cause the loss of an engine.

Structural failure can be mechanical—the result of faulty construction or maintenance—but most of the time it is induced. Accident analyses show that pilot error far outruns mechanical failure in bringing about engine troubles. Here are a few examples of stupid pilot errors which induce engine failure; avoid them.

1. **Failure to Know Gas Consumption.** Example: A pilot flew 5½ hours on a practice bombing mission in "AUTO-RICH" at a high power setting. Airplane crashed and 5 men lost their lives.
2. **Failure to Reduce Manifold Pressure at High Altitude.** This can result in an overspeeding turbo wheel disintegrating. One of the buckets coming your way is just like a .50-cal. bullet.
3. **Failure to Turn Booster Pumps On at High Altitudes.**
4. **Increasing Power Without Changing Propeller Setting.**
5. **Increasing Manifold Pressure Before RPM Instead of After.**
6. **Failure to Use Auto-Rich in Power Settings Above Normal Cruise.**
7. **Stiff-Arming Throttles.**
8. **Failure to Observe Engine Instruments and to Control Excessive Temperatures.**
9. **Failure to Know the Fuel System for Particular Airplane You Are Flying.**
10. **Waiting Too Long to Transfer Fuel.**
11. **Taking Off in Auto-Lean.**
12. **Failure to Turn On Booster Pumps for Takeoff, Causing Collapse of Fuel Lines or Vapor Lock.**
13. **Failure to Observe Carburetor and Free Air Temperature Under Icing Conditions.**
14. **Waiting Until Too Late to Correct for Carburetor Ice.**
15. **Improper Use of Intercooler Shutters Resulting in Excessive Carburetor Heat and Detonation.** Example: One pilot, at high altitude, thought he had an icing condition but failed to observe normal carburetor air temperature. He closed the intercooler shutters, producing high carburetor air and cylinder-head temperatures, followed by the failure of 3 engines. Never let carburetor air temperature get above 35°C, especially when using Grade 91 fuel.
16. **Failure to Have Fuel Valve Selectors on Tank-to-Engine for Take-off and Climb.** One pilot took off with all fuel valves on crossfeed with bomb bay transfer pump on, using gas from bomb bay tanks only. After takeoff, copilot turned off the bomb bay transfer pump switch, which is located on his instrument panel, thinking it was a booster pump. Immediately 4 engines failed and the ship crashed.
17. **Improper Procedure With Overspeeding Turbo on Takeoff.** Example: Pilot took off and experienced an overspeeding turbo, running manifold pressure beyond gage limits. He failed to reduce power and bring the turbo under control. The engine blew 5 cylinders and froze in high rpm. He managed to land, but unnecessarily destroyed an engine.
18. **Immediate Feathering of a Runaway Propeller When the Propeller Could Have Been Brought Under Control With Proper Procedure.** Example: Pilot, during takeoff with a combat load, experienced a runaway propeller. Without trying to bring the propeller under control he feathered immediately. He was unable to maintain altitude and the ship crashed shortly after takeoff. Proper procedure would have given 15 to 50% power on that engine.

DETONATION

Improper firing may be caused by a hot spot within the cylinder, an overheated sparkplug, exhaust valve, carbon deposit, etc. Once this gets started, it becomes progressively worse. The timing of the engines becomes uncontrolled and roughness, and/or detonation, results. The engine becomes overheated and loses power.

Some of the factors over which you have control, and which increase the tendency of the engine to detonate, are: High manifold pressure with low engine speed; too lean a mixture; high inlet temperatures; high cylinder-head temperatures; and improper low-grade fuel.

Under normal conditions, the fuel charge in a cylinder burns quite slowly. When detonation occurs the first part of the charge within the cylinder burns rapidly. This compresses the unburned part of the charge until the pressure and temperature within the cylinder rise so high that the unburned portion of the charge is ignited spontaneously, or detonated.

The pressure of the unburned charge fluctuates at a high frequency. These fluctuations literally hammer the wall of the cylinder and cause the familiar knock.

Even mild detonation will cause overheating, valve, piston, and cylinder-head burning, piston scuffing, and piston ring and valve damage. Severe detonation will cause engine failure in a short time. Complete engine failure can occur because of detonation during the time it takes you to make a takeoff run. The indications of detonation are roughness and overheating.

SOME EXAMPLES OF FAULTY OPERATION

Fault	Flight Reaction	RPM	Manifold Pressure	Cyl. Head Temp.	Oil Temp.	Oil Pressure	Fuel Pressure	Carburetor Air Temps.
Broken Fuel Line	Yaw	*—	Drop if Turbo on	Rapid Drop	Drop	—	Zero	—
Broken Oil Line	—	—	—	Rise	Rise	Drop to Zero	—	—
Breakage of Moving Engine Parts	Possible Violent Vibration	Violent Fluctuation	Unpredictable	Unpredictable	Rise	Variable	Variable	—
Ignition Trouble	Rough Running Engine and Intermittent Yaw	Fluctuation	Fluctuation if Turbo on	Drop	—	—	—	—
Overheating from Closed Intercoolers	—	—	Probable Drop	Rapid Rise	Rise	—	—	Rise
Mixture Too Rich	Torching Turbo or Black Smoke	—	—	Slight Drop	—	—	—	Slight Drop
Failure of Auto-Mixture Feature	Rough Running Engine	Fluctuation	—	Rise or Drop	Rise or Drop	—	—	Rise or Drop
Overspeeding Turbo	—	Possible Overspeeding	Violent Rise	Rapid Rise	Rise	—	—	Rise
Runaway Propeller	Possible Vibration	Rapid Increase	Drop	Variable	Variable	—	—	—
Carburetor Ice	Rough Running Engine	Fluctuation	Drop	—	—	—	—	Drop
Restricted Fuel Flow	Slight Yaw	—	Drop if Turbo on	Drop	—	—	Fluctuation	—

*Sign — (Dash) indicates no apparent change.