Manifold Pressure

Getting the most from an oft-misunderstood instrument

by KEN GARDNER / AOPA 132319

■■ To the fledgling pilot the term "manifold pressure" and its respective gauge are associated with fast, powerful aircraft that are only flown by high-time pilots. Should he be curious enough to ask about it, most often he is told that it is "of no concern to you at this stage." Terrific. At a time when it might be most easily explained, it isn't.

When this individual eventually reaches check out in an aircraft equipped with a manifold pressure gauge, more often than not it is just that, a check out. The explanation, if any, of manifold pressure is usually brief and insufficient. No wonder the disparities of belief and definition concerning manifold pressure.

The intake, or more properly induction, manifold consists of a series of tubes connecting each engine cylinder to one central source. The induction manifold serves to duct fuel-air mixtures (in the case of fuel injection, only air) from a central source to the engine's cylinders. Near the central source area of the manifold will be a throttle valve. In this application the throttle valve is often referred to as a butterfly valve, or simply a butterfly.

The throttle valve is actuated through

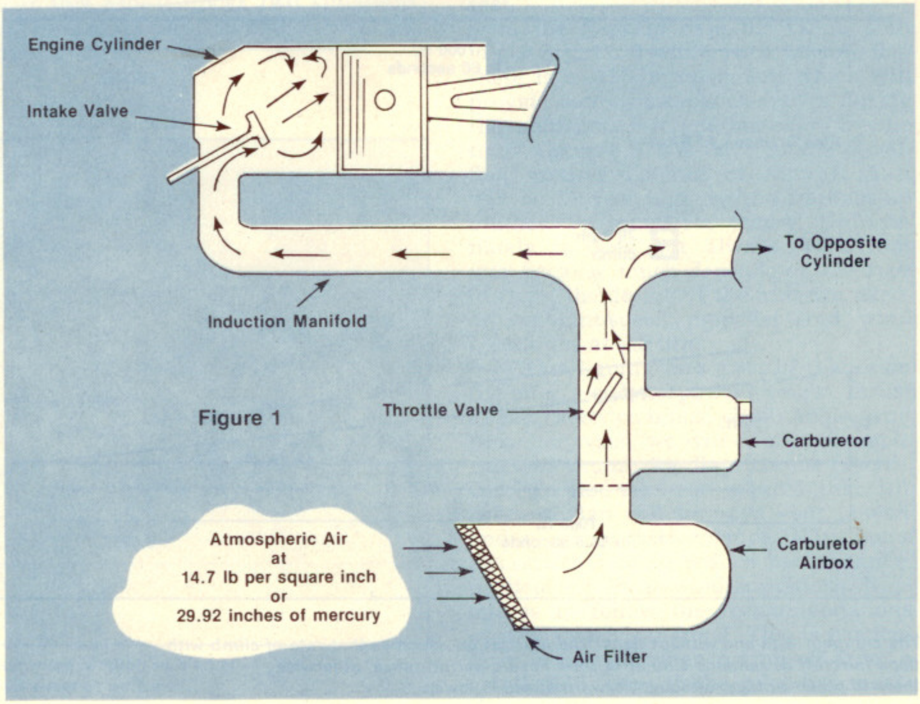

Figure 1

a linkage connected to a control in the cockpit. Figure 1 illustrates a typical arrangement of an induction manifold system. For simplification only one cylinder is shown; however, the arrangement would remain similar if more cylinders were present. The throttle valve always will be located within the carburetor throat if the engine employs a carburetor-type, fuel-metering system. The illustration depicts sea-level conditions and the engine is naturally aspirated (NA). The term naturally aspirated defines an engine that breathes air by means of atmospheric pressure. If the engine were supercharged, it would be defined as mechanically aspirated (MA) or assisted in its breathing by some mechanical means. This distinction is quite important to a basic understanding of manifold pressure, as we will see later on.

When the piston descends within the cylinder bore, it will create a void. This void will experience a reduction in its original air pressure which was atmospheric. Immediately atmospheric pressure from outside the cylinder will attempt to fill this void and restore the pressure within the cylinder to the atmospheric level once again.

The pistons do not suck air into their respective cylinders nor do they create a vacuum. Piston displacement is fixed and therefore cannot change with altitude, throttle position or even engine speed. Only the rate at which displacement occurs can change and that's relative to engine speed. If piston displacement does not change, then what does change to cause a naturally aspirated engine to lose power during ascent? Pressure. Atmospheric pressure — the very force that fills the cylinder with air each time it is displaced. We can also restrict this pressure and thereby control the engine's power output to desired amounts.

In Figure 2 the throttle is almost completely closed as it normally would be at engine idle speed. Displacement of the pistons is creating a continuously recurring void and subsequent reduction in pressure. With the throttle restricting the entrance of atmospheric pressure an equalization of pressure cannot occur. Thus, the throttle is simply a mechanical interference that restricts atmospheric pressure from entering the induction manifold and equalizing the pressure therein.

Now, if we were to install a gauge on the induction manifold, we could determine the actual amount of pressure in the induction manifold at any phase of engine operation. Note that the pick-off point for the manifold pressure gauge is downstream of the throttle, or between the throttle and the cylinders. In actual practice the pick-off point will be located as nearly equidistant from all cylinders as possible. The gauge is fitted with a snubber to damp needle flutter from oscillating pressure waves in the induction manifold.

Actually the manifold pressure gauge is simply an aneroid-type barometer calibrated in inches of mercury (in.Hg). When the engine is at rest the manifold pressure gauge will indicate ambient atmospheric pressure. With the engine operating at idle speed the gauge will read quite low, usually 14 to 16 inches. This will be the lowest reading you will see and represents the maximum differential for that particular engine. Opening the throttle decreases the restriction to atmospheric air entering the manifold and the pressure will rise.

Theoretically the manifold pressure at full throttle should be the same as when the engine was at rest (actual atmospheric pressure), but in reality it will be somewhat less. With full throttle on the ground the manifold pressure on a naturally aspirated engine will be approximately 2 to 3 inches below what the gauge indicated with the engine at rest. This difference is due to air drag across the throttle and through the induction system. In flight, the intake ram effect will reduce this drop to approximately one inch on well-designed systems.

Now for the practical application of the pressure indications obtained from the manifold pressure gauge. First, though, let's review the reason why some airplanes are equipped with manifold gauges and some are not. The difference is whether an airplane has a fixed-pitch or a constant-speed propeller. As previously stated, the throttle valve controls manifold pressure. Aircraft equipped with fixed-pitch propellers have only the throttle for controlling engine power. Since engine speed (rpm) is the better indication of power output with such single-control arrangements, a manifold pressure gauge isn't actually necessary.

The constant-speed propeller provides the means to control engine speed to a desired rpm and maintain it there as well. A separate control is provided with constant-speed propellers to regulate engine speed.

In the low-rpm range power is still controlled entirely by the throttle. However, once engine speed increases to the range where the propeller governor becomes effective (usually from 1,700 to 1,900 rpm) the throttle (manifold pressure) and propeller (rpm) controls become independent of one another. Now precise control of manifold pressure is both possible and practical.

For takeoff the propeller control is placed in the full-rpm position. The throttle is then opened fully and the takeoff roll commenced. At this particular moment the pilot should observe engine speed and manifold pressure indications. Engine speed should reach but not exceed, the maximum rated rpm number. At actual sea-level conditions, the manifold pressure should be approximately two or three inches short of the redline number on the gauge. Remember that the manifold pressure gauge is really a barometer and atmospheric pressure varies from day to day. Consequently you will do well to note the manifold pressure gauge reading before

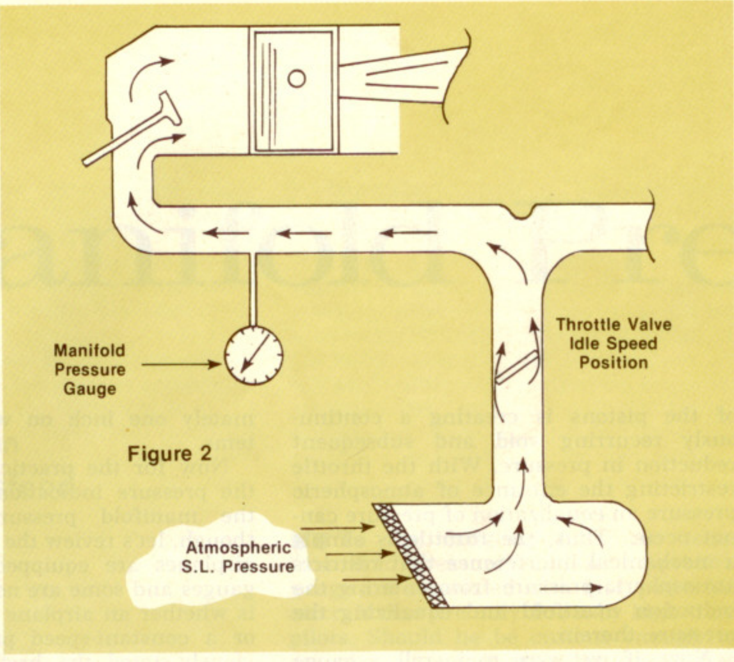

Figure 2

MANIFOLD PRESSURE continued

starting your engine because at that moment it is reading ambient atmospheric pressure; the manifold pressure number you achieve at takeoff should be two or three inches less than that pre-start reading because of induction system air drag mentioned earlier.

After takeoff, power is reduced for climb and the manifold pressure gauge is again utilized. Always reduce the throttle first, and to a manifold pressure reading about one inch less than the recommended climb number. Then reduce engine speed with the propeller control to the recommended climb rpm.

During reduction of engine speed the manifold pressure will increase approximately one inch, and will result in a nearly correct manifold pressure when the rpm is reduced.

This one-inch rise in manifold pressure is the result of the reduction in rate of piston displacement that occurred when engine speed was reduced. Upon the initial throttle reduction the throttle valve was metering air into the manifold at a rate that produced, say, 24 inches with an engine speed of 2,600 rpm. Now with a reduction in engine speed, air will not flow through the engine as rapidly as it did at 2,600 rpm, and yet air is still flowing into the manifold at the same rate it was at 2,600 rpm. Air, entering the manifold at the same rate but not able to get out as fast, simply causes a rise in pressure in the manifold.

During the climb to cruise altitude you will observe a gradual decline in manifold pressure necessitating periodic increases in throttle opening to maintain your original climb power. With a constant engine speed the rate of piston displacement, or air flow, through the engine is also constant. But the pressure outside the engine that is pushing the air into the manifold is decreasing at a rate of approximately .8 inches per 1,000 feet of altitude. At this rate the average naturally aspirated engine will require full throttle somewhere between 7,000 to 8,000 feet density altitude just to attain 75% power.

With the constant-speed propeller various combinations of engine speed and manifold pressure are available for cruise power. Power output is influenced by the amount of air entering the cylinders (mp) and the speed at which this happens (rpm).

The best power setting from a fuel economy standpoint is the lowest engine speed coupled with the highest manifold pressure necessary to obtain the percentage of power you desire.

Moving engine parts encounter friction and the faster these parts move the more often they encounter friction. Fuel must be expended to overcome friction, thus the more friction to overcome the more fuel must be consumed for this purpose alone. Therefore at low engine speeds and high manifold pressures the work is being accomplished at a lesser rate but with a greater force. This approach is defined as operating the engine "oversquare" (i.e. a higher "number" for mp than for rpm, such as a power setting of 25 in. mp and 2,300 rpm).

The concept of oversquare operation will provoke the wrath of many a profound engine lover. They will be quick indeed to say that such practice constitutes an overboost condition which can and will shorten the life of your engine if it doesn't first self-destruct from detonation.

Let's see how that advice stacks up against the facts. Say your engine is continuous-rated for a maximum of 230 hp at 2,600 rpm and 28 inches of manifold pressure. Although not recommended for a steady diet, a continuous rating means that you can operate all day long on that power setting if you choose. But even if we only considered this rating during takeoff, still you would be overboosting your engine if you exceeded 26 inches of manifold pressure. Remember that to be rated at 28 inches the engine had to achieve that number on the test stand. It certainly isn't likely that any engine manufacturer would rate an engine for a manifold pressure that it could not endure.

If these facts are correct how, then, could the maximum attainable or any lesser manifold pressure cause the engine harm? What's more, if the engine is able to cruise safely all day long on 24 inches and 2,400 rpm, why then would it be detrimental to cruise at 24 inches and 2,200 rpm? A manifold pressure of 24 inches is the same at 2,400 rpm as it is at 2,200 rpm. The pressure in the combustion chamber is relative to the amount of air admitted, not how fast it is admitted. You do reach a point in oversquare operation where the engine becomes noticeably rough, but this is due to the "brute bite" effect of getting the power from fewer but mightier pushes on the pistons.

While it is never advisable to operate any engine in a mode that produces roughness, it is acceptable to operate a naturally aspirated engine with an oversquare of two inches of manifold pressure or perhaps even more if the engine operates smoothly. I have heard it stated that engines do not cool properly when operated oversquare. That's interesting considering that engine cooling in flight is dependent upon ram air entering the cowling and not engine speed.

Operation in a square mode (or equal "numbers" such as 24 in. mp and 2,400 rpm), is considered by some to be the best of all three power combinations discussed. Supposedly this particular mode is the most beneficial to engine life. There are no facts or data that I know of to support this belief; however, I readily agree that it is quite acceptable as a satisfactory method for figuring power settings. Certainly one should never have any difficulties or doubts when using this rule for power settings on naturally aspirated engines.

Fortunately, among those expecting long service lives from their engines the undersquare mode (a lower "number" for mp than for rpm, such as 23 in. mp and 2,500 rpm) does not have the greatest following. However, I have encountered some who believe that manifold pressure is more apt to wear out their engines than rpms. This is indeed unfortunate for engines being operated by disciples of this belief. Piston and ring wear is quite relative to piston speed. Many parts of the engine are subjected to unbelieveable centrifugal and reciprocating forces and, although your engine may very well be built to operate continuously at the maximum rpms for which it is rated, it will last longer if it isn't. A power setting that will get you there with the least number of revolutions and do it smoothly will also get the most engine life.

The manifold pressure gauge becomes even more important with supercharged engines. The maximum permissible manifold pressure on most supercharged and/or turbocharged engines can easily be exceeded. This can indeed be disastrous to such an engine, and very quickly. One significant difference between naturally aspirated and mechanically aspirated engines is that the latter engine does develop its own manifold pressure above atmospheric pressure. Therefore you must be careful never to exceed the maximum manifold pressure for which the engine is rated. Another peculiarity of mechanically aspirated engines is that takeoff, climb and cruise manifold pressure settings will always be oversquare. Also, there are no fast, easy rules for power settings on this type of engine; you go strictly by the book.

The manifold pressure gauge can also be a good trouble-shooting instrument if you know how to use it. For example, a mechanically aspirated engine should always achieve its full rated manifold pressure for takeoff. If the manifold pressure needle does not quite make it to the gauge red line at full throttle, you know that all is not well with the engine. Mechanically aspirated engines with gear-driven superchargers will experience maximum readings well in advance of full-open throttle with sea-level conditions. On this type engine the throttle is advanced for takeoff only enough to achieve full rated manifold pressure.

After flying such an engine for awhile you should become familiar with the amount of throttle travel required for full rated manifold pressure on a daily basis. If you begin to notice that more and more throttle is necessary to attain full rated power under similar day-to-day conditions, you can be certain that trouble is developing. Such a situation indicates that more air flow to the manifold is necessary in order to attain the same manifold pressure as previously. Consequently you are losing air somewhere within the engine. This could be a leak in the manifold, burned and leaking exhaust valves, broken piston rings, or something else. Thus, through correlation of throttle position and manifold pressure indications you could detect such troubles in their early stages.

Detection of such troubles on turbocharged engines is equally possible only with slightly different procedures. Many turbocharged engines are equipped with automatic controls to prevent over-boosting during normal operation. Such engines usually require a full-open throttle for take-off power in order to obtain the added fuel flow for internal engine cooling. Nevertheless, these engines are capable, at sea level, of producing considerably more air than they need and, therefore, full-rated manifold pressure will be achieved before the throttles are fully open.

Once you become familiar with the amount of throttle necessary to reach full-rated manifold pressure you will also be aware of any sudden and substantial need for more. Excess airflow with these engines could indicate trouble in the turbocharger and/or its related controls as well as the other troubles previously described. Again, you could detect impending troubles by correlation of manifold pressure readings, and throttle travel.

The manifold pressure gauge can help you detect trouble in naturally aspirated engines as well. For example, an aircraft fitted with a fixed-pitch propeller encounters carburetor icing. Ice building up in the throat of the carburetor and/or induction manifold reduces air flow. The engine will respond to this loss of air by losing power and subsequently rpm. The pilot of such a craft can detect this situation with the tachometer and apply the remedy.

But the procedure will not be the same for an aircraft equipped with a constant-speed propeller. Ice building up in this engine will cause a similar loss of power only the propeller governor will sense it before the pilot does. The governor will reduce the propeller pitch so that the engine will be able to continue turning it at the same speed on less power. Consequently the tachometer will remain steady—but the manifold gauge won't. If engine speed remains the same, so will rate of displacement. If displacement remains unchanged but airflow into the manifold is reduced the manifold pressure will drop, which should make you wary of trouble.

The manifold pressure gauge can also indicate a tired engine that is losing its power. If a power setting of 24 inches and 2,300 rpm previously gave you a true airspeed of 160 mph and lately you can't exceed 150 mph with the same power settings you could be losing power. With the same fuel consumption as previously and if you are certain the TAS is accurate, then you are indeed developing less power from the same settings. Still another reliable indicator of loss of power is consistently higher manifold pressure readings at normal idle speeds.

A good example of misleading manifold pressure indications is the situation that occurs with an engine out in flight on multi-engine aircraft. Should you lose some or even all of the power on one engine the governor will respond by reducing propeller pitch to maintain the rpm for which it is set. As the blades flatten to low pitch they create more frontal drag which increases their ability to windmill the dead engine. The governor will seek whatever pitch is necessary to maintain the original rpm. Under these circumstances piston displacement rate is the same and since you didn't change the throttle, airflow is also the same. Consequently the manifold pressure will be the same as it was. This same situation can occur on mechanically aspirated engines with gear-driven superchargers. A turbocharged engine will definitely experience a loss of manifold pressure with any appreciable power loss.

Here's one extra tip. Naturally you want to be certain that your manifold pressure gauge is accurate, and you can do that quite easily. If you have a sensitive altimeter turn all the hands to zero altitude and read the pressure indicated in the Kollsman window. Compare this reading with the manifold pressure gauge when the engine is at rest. If your altimeter is accurate, and the manifold pressure gauge agrees with the Kollsman window indication the manifold pressure gauge is also correct. Your altimeter should be correct if it correctly indicates field elevation when the station altimeter setting is applied to the Kollsman window. □