Department of Transportation

FEDERAL AVIATION ADMINISTRATION

VFR PILOT EXAM-O-GRAM* NO. 38

MIXTURE CONTROL--FUEL/AIR RATIO

It is generally conceded by most leading aircraft engine manufacturers that correct use of the mixture control in flight for adjusting the fuel/air ratio (F/A) is one of the most important items in the operation of aircraft engines. This Exam-O-Gram explains some of the related factors which should be considered when leaning the fuel/air mixture. It is hoped that this brief discussion will serve as a stimulus for pilots to study and search for more information on this subject--in aircraft power plant manuals--and especially the engine manual pertinent to the aircraft they are operating. Certain General Aviation Written Examinations contain test items which are concerned with the results of improper use of mixture control.

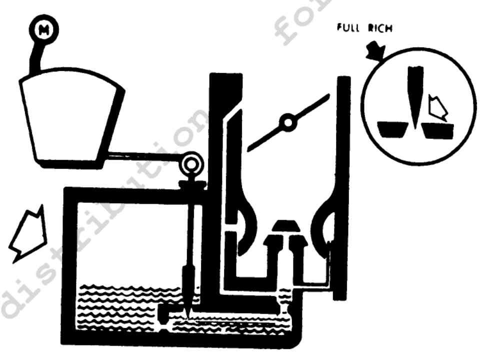
The mixture control knob in an aircraft cockpit is usually RED--an indication that it should be used with "caution." Proper leaning of the mixture provides smoother engine operation, more power for a given power setting, best range and endurance; on the other hand, misuse of the mixture control can soon ruin an aircraft engine.

WHAT DOES FUEL/AIR (F/A) RATIO MEAN? It is the ratio between the weight of the fuel and the weight of the air that goes into the cylinders. In general, gasoline engines require approximately 15 pounds of air in order to completely burn 1 pound of gasoline. However, a theoretically perfect mixture ratio is not essential or desired in all cases. Certain conditions may require the use of mixture either richer or leaner than this average ratio. Usually, the useful mixture ratios are between 1 to 11 and 1 to 16. Fuel and air proportions are expressed on the basis of weight rather than volume. Fuel/air ratios may be given as a direct ratio, such as 1 to 12, but in more common usage, they are designated as decimal fractions such as 0.083. For example: $1 \div 12 = 0.083:1$ (0.083 lb. of fuel to 1 lb. of air).

WHAT IS THE FUNCTION OF THE CARBURETOR? It measures the correct quantity of fuel to be supplied to the engine, ATOMIZING and MIXING the fuel with air in the correct proportion (F/A ratio) before the mixture enters the cylinders. This proportioning must be done correctly regardless of the speed, load, and altitude at which the engine is operating. Gasoline cannot ignite or burn when in the liquid state, it first must be vaporized and mixed with the correct amount of air before it can be ignited and combustion takes place. When compared to other gasoline engines, aircraft engines operate at a greater altitude range and therefore are equipped with manual and/or automatic mixture controls.

HOW ARE CARBURETORS NORMALLY CALIBRATED? They are calibrated for sea-level operation, which means that the correct mixture of fuel and air will be obtained at sea level with the mixture control in the "full rich" position. As we climb to higher altitudes, the air density decreases--that is, a cubic foot of air will not weigh as much as it would at a lower altitude. Therefore, the weight of air entering the carburetor will decrease, although the volume remains the same. The amount of fuel entering the carburetor depends on the volume of air and not the weight of air. As the altitude increases, the amount of fuel entering the carburetor will remain approximately the same for any given throttle setting. Since the same amount (weight) of fuel is entering the carburetor, but a lesser amount (weight) of air, the fuel-air mixture becomes richer as altitude increases.

WHAT DOES THE MIXTURE CONTROL DO? It compensates for the decreased air density by metering the amount of fuel that passes through the main jet in the carburetor. In the less dense air at higher altitudes, a leaner mixture reduces fuel consumption and provides smoother engine operation. The mixture control is used to reduce the amount of fuel flow and maintain the proper F/A ratio--this is also true of engines with fuel injection.



Needle Type Mixture Control System

* Exam-O-Grams are non-directive in nature and are issued solely as an information service to individuals interested in Airman Written Examinations.

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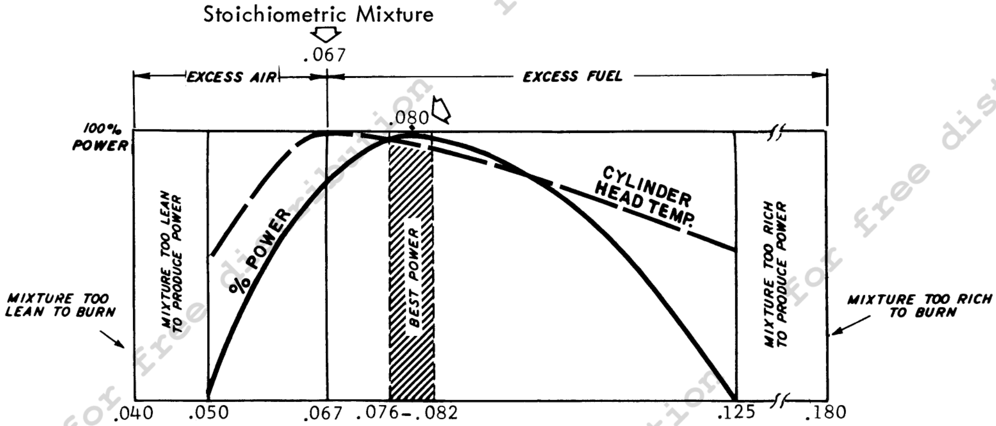
AT WHAT F/A RATIO DO THE HIGHEST CYLINDER TEMPERATURES OCCUR? The greatest heat occurs at a fuel to air ratio of 1 to 15, or .067, and this is known as stoichiometric mixture (pronounced like stoy-key-o-metric), which is the chemically correct mixture where all the air and all the fuel is burned. Even though an F/A ratio of .067 is considered a chemically correct mixture for combustion, it produces peak temperatures and this is generally the mixture which will cause all gasoline engines to run the hottest (see Illustration below).



Fuel-Air Ratios vs Power & Temperature

The mixture of .067 is a theoretical point that can be demonstrated only on a single cylinder engine in a laboratory. In engines with more than one cylinder, the variations in fuel distribution between the cylinders makes it difficult to evaluate the F/A ratio in each cylinder. This matter of distributing equal amounts of fuel and air to the various cylinders is one of the greatest problems facing the aircraft engine manufacturers--or the designer of any gasoline engine for that matter. Because of the unequal Fuel/Air ratio in the various cylinders, the pilot who practices using extremely lean mixture settings without reference to proper instrumentation can experience a situation where all cylinders on his engine are operating at normal temperatures--except for one hot cylinder, where the exhaust valve and seat are red hot.

WHAT IS THE "BEST POWER" MIXTURE? The .080 fuel/air ratio is known as the "Best Power" mixture and it is that ratio at which the most power can be obtained for any given throttle setting. "Best Power" mixture is the fuel/air ratio where we can get a given power with the lowest manifold pressure or throttle setting. (See Illustration above.)

WHAT DOES EXCESS AIR AND EXCESS FUEL MEAN IN THE ILLUSTRATION? The illustration shows "Excess Air" on the left side of the .067 mixture, which means there is more air in the cylinders than is needed for normal combustion, and this excess of air absorbs heat and helps to cool the engine. On the right side of .067 mixture, we have "Excess Fuel" which means that there is more fuel in the cylinders than is needed for normal combustion, and this "Excess Fuel" also absorbs heat and provides additional cooling. Large supercharged engines can operate in the "Excess Air" lean mixture side of the .067 mixture, whereas the carburetor equipped, unsupercharged small aircraft engine should never be leaned to this extent. For example: If the manual mixture control of a supercharged engine is moved toward the lean position, cylinder head temperatures will be greatest when the F/A ratio is .067 and as the mixture is leaned still further, cylinder head temperatures will return to cooler normal values. When cylinder head temperatures climb too high while leaning carburetor equipped, unsupercharged engines, the mixture must be richened in order to return to cooler head temperatures.

WHAT IS MEANT BY UNEVEN MIXTURE DISTRIBUTION? In a carburetor equipped engine, the intake manifolds and induction pipes are used to distribute the fuel and air charge to the various cylinders. Those cylinders which are the farthest from the carburetor often receive a slightly leaner mixture than those cylinders close to the carburetor. When the mixture control is used to lean the mixture, the cylinders which are already receiving a leaner mixture will be the first ones to run hot or misfire.

DOES FUEL INJECTION PROVIDE BETTER FUEL DISTRIBUTION? Yes, the fuel is injected into the intake manifold and it is mixed with air just before entering the cylinders. Theoretically, all of the cylinders of a fuel injection engine are receiving an equal amount of fuel.

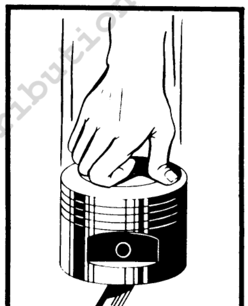
NOTE: Fuel injection engines are equipped with Fuel Flow Gauges to indicate the F/A mixture being supplied to the engine. Some of these instruments also show the percentage of power being used. Proper mixture control and better economy in the operation of a fuel injection engine can be achieved best through the use of an Exhaust Gas Temperature Indicator, a Cylinder Head Temperature Gauge and an Oil Temperature Gauge. The two latter instruments have slow response times but the trend of these basic heat references are very meaningful.

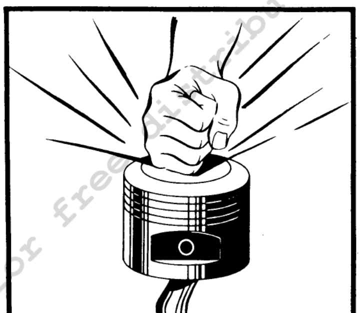
WHAT ARE THE RESULTS OF HAVING THE MIXTURE TOO LEAN? When the mixture is too lean there is too little fuel for the amount of air--in terms of weight. Rough engine operation, sudden "cutting out" or "back firing," detonation, overheating, or an appreciable loss of engine power may occur. Lean mixtures must be avoided when an engine is operating near its maximum output.

AT WHAT ALTITUDE IS LEANING THE MIXTURE NORMALLY EFFECTIVE? Leaning is normally effective above 5,000 feet; however, some aircraft engines may be leaned below 5,000 feet. Always follow the manufacturer's recommendations on leaning the fuel mixture for the particular airplane. By leaning the mixture at too low an altitude or leaning the mixture excessively, you could damage the engine at a high power setting. For example: Suppose that a pilot had been cruising at 8,000 feet with a lean mixture and forgot to move the mixture to full rich before entering the traffic pattern of a low elevation airport. The pilot may experience a rough engine or the engine might "cut out" or even worse if he were to exceed approximately 70% power in the pattern or on a go-around he would be in serious trouble with detonation and engine overheating. In general, lean mixtures must be employed with caution when operating aircraft engines at high power settings.

WHY IS 5,000 FEET CONSIDERED A SAFE ALTITUDE FOR LEANING? Certain aircraft engine manuals state that their engines should not be leaned below 5,000 feet. At 5,000 feet the unsupercharged engine is capable of developing only about 75% of its rated power, and at less than 75% power it is much harder to get into trouble using improper leaning techniques, since the cylinders and other engine parts are operating at lower temperatures.

WHAT IS DETONATION? Detonation is the spontaneous explosion of the unburned charge (in the cylinders) after normal ignition. If the temperature and pressure of the unburned portion of the fuel-air charge reach critical values, combustion will begin spontaneously. The result is a sudden and violent explosion of the charge (detonation) rather than the relatively slow burning of normal combustion.


NORMAL BURNING


DETONATION

Continued operation when detonation is present can result in dished piston heads, collapsed valve heads, broken rings, or eroded portions of valves, pistons, or cylinder heads, and may terminate in sudden and complete engine failure.

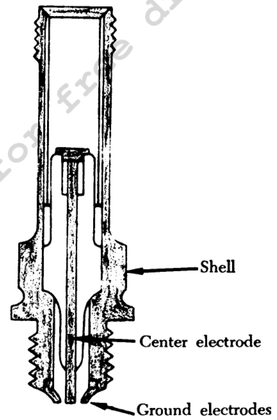
Since it is very important to avoid detonation, it is well to consider the principal factors which contribute to this condition. The antiknock value of the fuel (octane rating-performance no.), cylinder head temperature, incoming mixture temperature, fuel-air ratio, and intake manifold pressure are the most important factors of greatest significance for the pilot.

Usually detonation cannot be recognized from the cockpit through sound or engine roughness; therefore, protection from its possible occurrence must be provided by the design of the engine and adherence to the engine operating limitations.

WHAT IS PRE-IGNITION? Pre-ignition is the uncontrolled firing of the fuel-air charge in advance of normal spark ignition. It is caused by the presence within the combustion chamber of an area which is incandescent (red hot, glowing, luminous, with intense heat) and serves as an ignitor in advance of normal ignition. Pre-ignition may result from a glowing spark plug electrode, exhaust valve, or perhaps a carbon or lead particle heated to incandescence. As with detonation, such operating factors as high intake air temperatures, lean mixtures, high manifold pressures, and improper cooling are likely to set the stage for pre-ignition. Pre-ignition may start detonation, and paradoxically, detonation may start pre-ignition because of the high temperatures involved. Moreover, pre-ignition can be fully as destructive as detonation.

HOW IS ADDITIONAL FUEL PROVIDED FOR COOLING THE ENGINE ON TAKEOFF? At full power on takeoff with the mixture "full rich" you are assured of the best combination of power and cooling. The enrichment of the fuel-air mixture at high-power output is accomplished in actual carburetor design by the incorporation of auxiliary fuel-metering devices. Such devices are variously known as economizers, high speed jets, enrichment jets, power compensators, etc. Regardless of the name applied, all such units serve the same general purpose--that is, when full power is used on takeoff, the enrichment jets or valves cut in and provide additional fuel. This additional fuel helps to cool the engine during maximum power operation.

WHAT ARE THE RESULTS OF USING AN EXCESSIVELY RICH MIXTURE AT HIGH ALTITUDES? Whenever an unsupercharged engine is operated at a high altitude with an excessively rich mixture, the power will be reduced from that which is available at that altitude with proper mixture. Excessive fuel is not required for combustion chamber cooling at high altitudes. The fouling of spark plugs is one of the greatest "bad effects" of operating with an excessively rich mixture. Spark plugs are designed to operate within certain heat ranges in order to function properly and operate without fouling. The excessively rich mixture will cause a below normal temperature of the spark plug center electrode, which, in turn, results in the formation of carbon and lead deposits. These deposits are electrically conductive and when they reach a sufficient depth, the electric current will flow through the deposit rather than "jumping-the-gap" in the spark plug to ignite the fuel air charge. This is what is known as a "fouled" or "shorted out" plug, since the current flows across the deposits on the ceramic insulator and is grounded instead of jumping the gap. Therefore, it is essential to maintain a fuel-air ratio which will provide sufficient heat in the combustion chamber to vaporize any deposits which may form on the ceramic center of the spark plug.



Radio Shielded Spark Plug

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FOLLOW THE MANUFACTURER'S RECOMMENDATIONS ON LEANING THE MIXTURE.