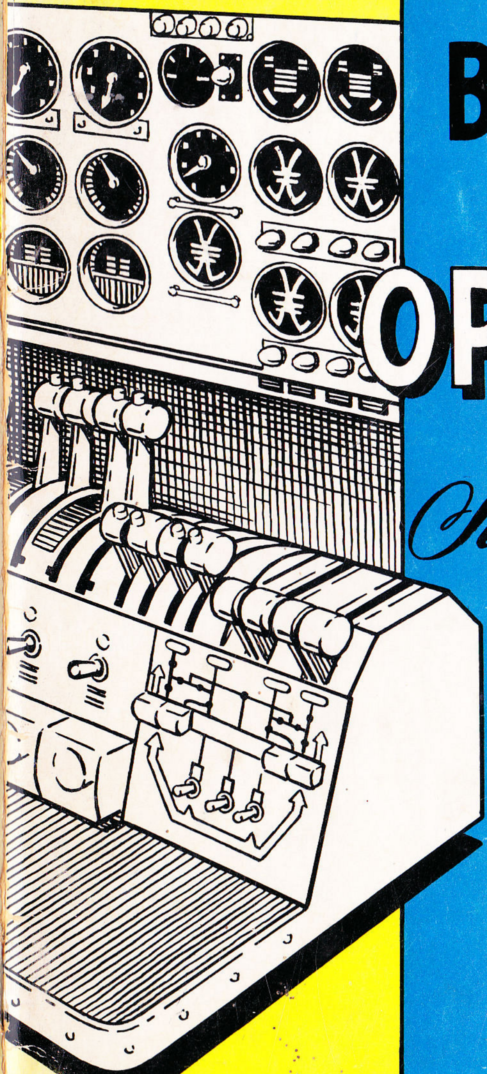
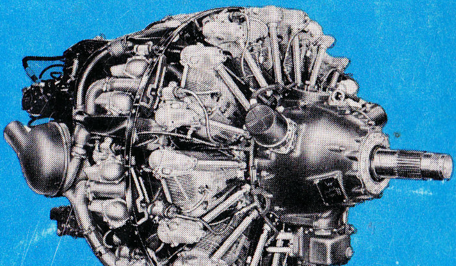
BASIC THEORY OF OPERATION

Turbo Compound ENGINE





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

FIELD ENGINEERING DEPARTMENT

CURTISS-WRIGHT CORPORATION
WRIGHT AERONAUTICAL DIVISION

WOOD-RIDGE, NEW JERSEY, U.S.A.

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CONTENTS

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INTRODUCTION

This booklet is presented to both Flight Crews and Maintenance Personnel, for two reasons:

1. To insure that everyone is provided with the same information, and,
2. In hope of obtaining a better understanding and appreciation of the other fellow's problems.

It includes details of TC18 operating procedures, in-flight trouble-shooting, reporting of in-flight engine malfunctions, analysis of these reports, and several maintenance procedures.

Flight Crews and Maintenance Personnel share the responsibility of obtaining engine dependability. The Flight Crews must:

a. Operate the engine correctly,
b. Identify any engine malfunctioning and accurately report the types of malfunction with accurate and complete details.

Maintenance Personnel must be able to:

a. Interpret the Flight Crew's reports intelligently,
b. Trouble-shoot the engine accordingly, and
c. Fix it.

Each group is important and neither can get along without the other.

When we started to work out the initial operating procedures for the DC-7, the TC18 was a relatively new engine. It had limited commercial and very limited military experience, but had not been operated by any domestic airline. There didn't seem to be much of a problem, as it was only a new, more powerful version of the R-3350 engine, the same engine that has been operated very successfully for many years. We took the Wright Company's recommendations and Operating Instructions, inserted a few other ideas on engine operation, brought you into school, taught you what we knew about the engine, and started flying.

Since that time, a lot has been learned about the mechanical parts in the engine and their operation. You have seen this new knowledge reflected in changes of the operating procedures, manuals and bulletins which have been published since the start of the DC-7 operation.

In this booklet we will tell you what was learned about the engine, explain to you why procedures were changed as we went along, and why we use the procedures currently recommended.

It is not quite correct to talk about these *changes* of procedure. It would be better to refer to them as changes in operating technique, or *development* of new operating techniques. The basic procedures are not too different from those which were previously used from the time of earlier engines.

The throttle must still be advanced to obtain more power, and the mixture control must still be adjusted to obtain a desired mixture strength. We have found it necessary to develop and use new techniques —techniques required because the TC18 engine is much more highly loaded than any of its predecessors. The TC18 engine is much more sensitive to certain operating conditions, such as temperatures and mixture strengths. This trend has been true through the years and is representative of the history of engine development.

It is interesting to compare the power settings and power loadings of the earlier engines with the TC18. For example, the R-1820 had a take-off power of about 1100 *BHP*. The take-off horsepower of the TC18 is 3250 *BHP*. The cruise horsepower of the TC18 is about 1800 *BHP* compared to the cruise horsepower of the R-1820 which is only 600 *BHP*. It is perhaps better to compare engines on the basis of horsepower per cubic inch of displacement. The R-1820 produced .6 of a horsepower at take-off for each cubic inch of displacement. The TC18 produces just under 1 horsepower for each cubic inch of displacement at take-off. This same trend held true in engine development from the R-1820 to the R-2000, which produced .73 horsepower per cubic inch and the R-2800, which produced .86 horsepower per cubic inch.

Each new engine developed requires a little more careful handling than the previous model. (We operate the R-2000 in a manner which would not be satisfactory on the R-2800.) When we first started operating the R-2800 we tried to operate it as an R-2000 and got into trouble. It was found that the engine had to be operated differently—and more carefully. This same situation exists with the TC18 engine.

Engine limitations are always important in any engine. They are even more important in the TC18. In order to fully understand the procedures used on the TC18, it will be to our advantage to review briefly some of the basic engine theory upon which these procedures are founded.

EFFECT OF AIRFLOW ON POWER

An engine, basically, is an air pump. It takes air in the front, pumps it through the engine and out the back. This is a simple and fundamental concept—but a very important one—because the amount of power which the engine produces depends directly upon the amount of air which it pumps. As a matter of fact, the power capacity of an engine is limited by the amount of air which it is capable of pumping.

The engine does not particularly care about the volume of air passing through it, but rather the weight—the number of molecules available for burning. Therefore, when we speak of airflow in our discussions, we refer to mass airflow rather than volumetric airflow.

Many things control mass airflow. There are certain design features in the engine which do this, such as number of cylinders, bore, stroke, valve timing, impeller gear ratios, etc. Since we cannot do anything in the cockpit to change or control these design features, we will ignore them in this discussion. There are several controls, however, which do vary the airflow through the engine. It is interesting to note that the primary engine controls are airflow controls. For example, the throttle, *RPM*, and carburetor heat settings all determine mass airflow. Even cylinder head temperature changes result in a change of airflow. However, for the purpose of simplicity, we will confine this discussion to the two basic controls of airflow—the throttle (Manifold Pressure) and *RPM*.

The following curve demonstrates very simply that horsepower varies directly with the airflow through the engine for a given fuel-air ratio.

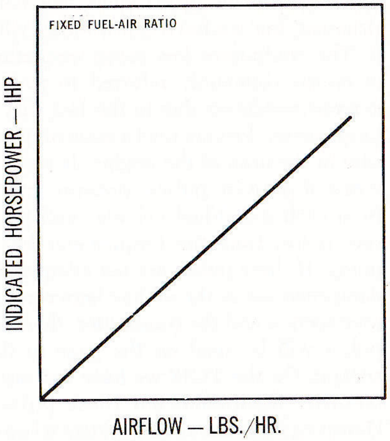

Figure 1—Effect of Airflow on Indicated Horsepower

You will note that as airflow increases, horsepower increases; as airflow decreases, so does horsepower. This is a direct relationship and the curve shows that for any given airflow, that is, any given combination of manifold pressure and *RPM*, a certain horsepower will result, everything else held constant. This is important because it tells us that for a certain airflow—for a certain manifold pressure and *RPM*—we should get a certain horsepower. In other words, control of airflow determines how much power the engine *should* put out. This is important in all engine operation and is the basis of our trouble-shooting procedures in flight. If airflow is set up the same on all four engines (that is, the same manifold pressure and *RPM*), then all four engines should put out the same power—all other factors being constant.

The instrument which tells how much power the engine *actually is* putting out is the torquemeter. The manifold pressure and *RPM* tell only how much air is flowing through the engine, and not how much power the engine is actually putting out. If it were not for the resultant damage to the turbines, this could be demonstrated in flight by turning off the ignition switch. With the ignition switch OFF, neither *MAP, RPM,* nor fuel flow will change. The amount of air and fuel going into the engine remains the same. However, the torquemeter will drop toward 0; the power the engine *is* putting out, of course drops to 0.

The torquemeter on the TC18 engine is considered to be an extremely good instrument, but we have had troubles with it. The continuous low range oscillation in cruise—commonly referred to as the *nervous needle*—is due to the fact that a torquemeter does not read a constant pressure in the nose of the engine. It reads a series of pressure pulses—pressure pulses from each individual cylinder and pressure pulses from the torquemeter boost pump. If these pulses are not adequately dampened out in the oil line between the nose section and the transmitter, then the pulses will be read on the gage in the cockpit. On the TC18 we have not satisfactorily dampened out these pulses. However, a good snubbing system is being developed and may soon be installed on our engines. This should result in a smooth and steady torquemeter reading.

Another comment concerning the TC18 torquemeter is that it fluctuates during take-off—sometimes so much that it is impossible to read. This is not a malfunctioning torquemeter, but rather a malfunctioning engine, which is being shown on the torquemeter. We know that during take-off the spark plugs often cut in and out. Engine power, therefore, oscillates over a large range and quite rapidly. Spark plug fouling is what you see on the torquemeter. The torquemeter is telling you the truth. Anytime the torquemeter reads low, indicating that an engine is not putting out as much power as it should, trouble-shooting should be accomplished on the assumption that the torquemeter is reading correctly and that there is something wrong with the engine, which should be investigated and reported.

EFFECT OF MIXTURE STRENGTH ON POWER

In the previous discussion on airflow, the effect of fuel flow or fuel-air ratio was intentionally not mentioned. You all know that if a given airflow is established to the engine, the amount of power produced by the engine will vary with the fuel-air ratio. Power will change if the mixture is richened or leaned.

In order to obtain a better understanding of the effect of fuel flow on power, let's review briefly the basic process of combustion in the cylinder. Combustion is the rapid combination of oxygen and fuel. Heat is required in order to produce combustion. The heat in the cylinder is initially generated by the firing of the spark plugs. When the spark plug fires, it raises the temperature of the fuel molecules adjacent to it. Their temperature is raised up to the point where they are hot enough to burn. These burning fuel molecules, in turn, radiate heat to the adjacent fuel molecules and their temperature is then raised to the kindling point and they ignite. A flame front progresses across the cylinder with each fuel molecule burning, radiating heat and igniting the adjacent fuel molecules. The result is combustion, expansion, pressure, and power.

With an excessively lean mixture there are very few fuel molecules in the cylinder, and these are widely spaced. The spark plug may initially ignite the fuel molecules adjacent to it, and these fuel molecules may burn, but they are so far away from the adjacent molecules that the fire goes out before the adjacent molecules have had their temperatures raised to the kindling point. There are insufficient fuel molecules in the cylinder and too much air insulating one from the other. The result is no combustion and no power. As the mixture is richened, more fuel is sent into the cylinder and the fuel molecules are more closely spaced. The result is a slow transfer of heat from one fuel molecule to another, but enough to keep the fire burning in the cylinder. The power is relatively low and the flame front moves slowly. When the mixture is richened even further, more fuel is delivered into the cylinder; the fuel molecules are closer together, more power is produced and the flame front moves more rapidly. As the mixture is richened more, the power increases until a peak power is developed. This is known as the "Best Power" mixture strength. At this mixture strength, the most power is being obtained for the given amount of air in the cylinder. The "Best Power" mixture covers a range of fuel-air ratios from about .0725 to .080.

If the mixture is then richened beyond a "Best Power" fuel-air ratio, there is an excess of fuel in the cylinder and the molecules are packed closer together. When the initial combustion takes place at the spark plugs, the burning fuel molecules radiate heat as they did with the lean mixture. The excess fuel now does what the excess air did with the lean mixture. The excess fuel insulates one fuel molecule from the other; it absorbs heat, slows down the flame front, and reduces the power. The mixture can be set so rich that it will not burn. In that case, when the initial combustion takes place at the spark plugs, the excess fuel molecules absorb all the heat. The temperature of all the adjacent fuel molecules is raised slowly and not high enough to ignite the fuel. There is no combustion because of a rich mixture. With rich mixtures, even with combustion, the excess fuel goes out the exhaust system as unburned fuel vapor which can be condensed out of the exhaust gases as raw fuel.

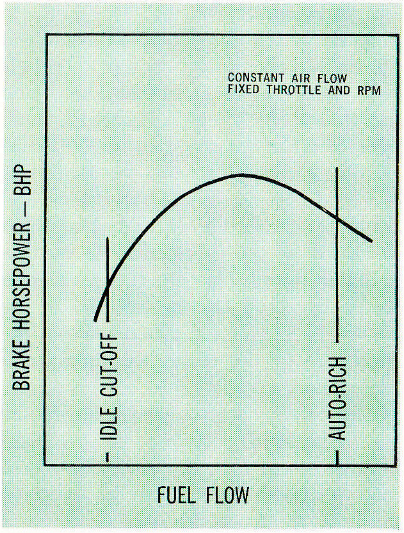

Figure 2—*BHP* Constant Throttle—*RPM* Mixture Control Curve

This relationship of fuel-air ratio to power is shown in Figure 2.

This curve assumes a constant airflow through the engine—that is a fixed throttle and constant RPM. The mixture control is moved from IDLE CUT-OFF (the left side of the curve) slowly through to AUTO-RICH, the extreme right side of the curve. You will note that the power varies as previously discussed. There is no combustion on the lean side, no combustion on the rich side, and the power peaks at the "Best Power" range.

The carburetor automatically meters the fuel along this curve during high power operation in AUTO-RICH. At takeoff the mixture strength is automatically controlled to be excessively rich. This richness (excess fuel) is required to suppress detonation. At rated power the mixture is automatically controlled to be somewhat leaner, but still on the rich side. So, during high power operation, in AUTO-RICH, the carburetor automatically adjusts the mixture to the desired fuel-air ratio. In CRUISE, however, the mixture can be manually controlled and set at AUTO-RICH or any place leaner. In the case of the TC18 engine, the mixture is set at a 10% *BMEP drop* fuel-air ratio.

BMEP drop actually is not a phrase associated with power. *BMEP drop* defines a certain fuel-air ratio. Considering the peak *BMEP* to occur at the "Best Power" mixture, a 3% *BMEP drop* setting would be a fuel-air ratio which results in a *BMEP* 3% below the peak ("Best Power") *BMEP*. A 10% *BMEP drop* setting defines a fuel-air ratio which results in a *BMEP* 10% below the "Best Power" *BMEP*. It is important to remember that *BMEP drop* defines fuel-air ratio mixture strength. Why then do we select a certain *BMEP drop* or mixture strength in Cruise?

EFFECT OF MIXTURE STRENGTH ON ENGINE TEMPERATURES

If the selection of the mixture strength in cruise involved only the considerations shown in Figure 2, it would be a simple matter. We would set the mixture at "Best Power" and get the most power for the set airflow. However, there are other and more important things to be considered: primary among them being the temperature of the engine—cylinder head and exhaust gas temperatures. The relationship of fuel-air ratio to these temperatures is shown on the following curves.

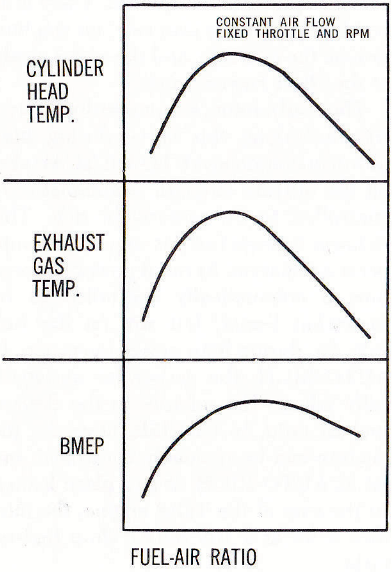

Figure 3—*CHT, EGT,* and *BMEP* Constant Throttle—*RPM* Mixture Control Curves

The bottom curve in this group is a reproduction of the power relationship just discussed. The middle curve shows the relationship of exhaust gas temperature to change in fuel-air ratio, and the upper curve shows cylinder head temperature.

With the excessively lean mixture on the left side of the curve—with a relatively small amount of fuel in the cylinder and with the fuel molecules widely separated—when combustion takes place there is an excess of air which absorbs heat. With the air inside the cylinder absorbing heat, the cylinder walls and the cylinder head remain relatively cool. Therefore, the cylinder head temperatures are relatively low. As the mixture is richened, there is less excess air to absorb heat and, therefore, more power is being developed. Consequently, the cylinder walls and the cylinder begin to run hotter. The peak temperatures occur at an air-to-fuel ratio of about 15 to 1 (15 pounds of air to one pound of fuel). This is known as the chemically correct mixture and occurs at a fuel-air ratio of .067. This cooling effect of excess air can be readily visualized by considering the fact that at the 15 to 1, or chemically correct mixture, all the air is burned and all the fuel is burned. With a leaner mixture, for example an 18 to 1 ratio, there is an excess of air on the order of three parts—the difference between 15 to 1 and 18 to 1. Those three parts of air will not burn. They will not participate in the combustion process. Therefore, the excess air absorbs the heat and the cylinder runs cooler.

As the mixture is richened beyond the 15 to 1 (chemically correct) fuel-air ratio, there is an excess of fuel. This excess fuel then absorbs heat in exactly the same manner as did the excess air with the lean mixture. Consequently, as the mixture is richened, more and more heat is absorbed by the excess fuel and less and less heat absorbed by the cylinder walls and the cylinder head. Therefore, the cylinder again runs cool. On the left side of the curve, the cylinder is air-cooled. On the right side of the curve, the cylinder is fuel-cooled.

The exhaust gas temperatures follow much the same pattern as do the head temperatures. With the excessively lean mixtures (with the excess of air) absorbing heat, the temperature of combustion is less; therefore, the exhaust gas temperature is relatively low. The same applies to the RICH side of the curve where fuel cooling takes place.

Everyone now agrees that lean mixtures will cool the heads. At the start of our DC-7 operation, however, there was a small amount of controversy on that point because of previous experience on other types of engines. In the past when the mixture control was moved from AUTO-RICH to AUTO-LEAN the head temperature did go up, and here is why:

Earlier engines had relatively poor fuel distribution. For example, the R-1820 discharged fuel into the induction system through an injection bar installed directly below the carburetor. The mixing of fuel and air at that point was not good. Consequently, some cylinders received a lot of fuel, others very little. Some cylinders ran rich and others ran lean. Engines with poor fuel distribution had to be operated at a relatively rich mixture because if they were leaned down very much, the leaner running cylinders would begin to cut out, the engine would backfire and run rough. For this reason, on the earlier engines the AUTO-LEAN position of the mixture control was set at about .067—the chemically correct (and hottest) fuel-air ratio. Therefore, when the mixture control was moved from AUTO-RICH to AUTO-LEAN, which was the normal procedure for setting power, the cylinder head temperature went up.

On those engines, if the fuel distribution had been good enough to permit leaning beyond AUTO-LEAN, the engine would have kept running satisfactorily and the head temperature would have gone down, precisely in accordance with this curve. However, the engines wouldn't operate at these mixtures because the fuel distribution was poor.

On other types of engines the fuel is injected into the impeller where it is mixed with the air and vaporized. The fuel distribution on these is much better than on the R-1820; therefore, they can be leaned down more than the earlier engines and will operate satisfactorily at the leaner mixture. In the TC18 engine where the fuel is injected under high pressure directly into the individual cylinders, the engine can be satisfactorily leaned down to an almost unbelievable point. The fuel distribution on the TC18 is excellent. As a matter of fact, the TC18 will remain stable at lean mixtures down to 40 BMEP drop and more. Therefore, we can operate this engine at lower cylinder head and gas temperatures than we could previous engines because we can operate it at leaner mixtures.

The temperature and power relationships shown in Figure 3 apply not only to a TC18 engine—they represent a characteristic of the burning properties of the fuel. These power and temperature relationships will hold true for any engine of this type; 18, 14, or 9 cylinders or even on a single cylinder engine, on which much test work is done. All engines of this type react the same way when the mixture strength is changed.

The curve which we have been discussing up to now is based on *constant airflow.* However, it is not exactly representative of power-fuel flow relationships which occur during the process of setting cruise power and mixture since cruise power and mixture are set on the basis of a *varying airflow.* Throttle and mixture control are manipulated individually in order to hold a *constant power.* Let us look at these same relationships shown on a constant power curve.

Figure 4 shows the relationship between manifold pressure and fuel flow if the mixture strength is changed and the power is held constant. The manifold pressure is plotted on the left and the fuel flow on the bottom. Each point on this curve represents operation at a constant power—let's say 177 *BMEP.* This curve was actually plotted from flight test data on a DC-7 in high blower at about 1800 horsepower. It shows that if the mixture control is placed in AUTO-RICH, it takes about 37″ of manifold pressure to produce 177 *BMEP.* At that manifold

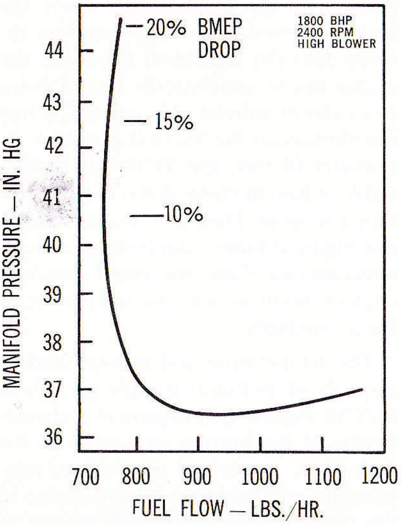

Figure 4—Constant Power Mixture Control Curve

pressure in AUTO-RICH the fuel flow will be about 1170 lbs. per hour. If the mixture is leaned down slightly to about 1000 lbs., the power *(BMEP)* will at first increase a small amount. In order to hold the power constant at 177, it is then necessary to retard the throttle as shown on the curve to about 36½″. As the mixture is leaned still further to 850 lbs., the *BMEP* will then begin to fall. It will, therefore, be necessary to advance the throttle a small amount in order to maintain the *BMEP* constant, at 177. This is shown in that 37″ of manifold pressure is required to obtain the power at 800 lbs. fuel flow. As the mixture is leaned still further, the power drops off rapidly. This effect was seen on the previous curve of constant airflow. When the mixture is leaned, the power drops off rapidly; more and more manifold pressure is required to hold the power constant at 177 as shown on the curve. Points of 10, 15, and 20% *BMEP drop* are shown on the curve; actually the engine can run much leaner than 20%, but the curve has just been stopped at that point.

This curve shows many things which are of interest to us; for one thing, it shows the "Best Power" mixture strength in this way. "Best Power" by definition is the fuel-air ratio at which the most power can be obtained; or conversely, on a constant power basis, "Best Power" is the fuel-air ratio where we can get a given power with the lowest manifold pressure. Therefore, in order to find the "Best Power" fuel-air ratio range, all we need do is draw a horizontal tangent line at the bottom of the curve. Such a line shows the manifold pressure for best power is about 36½″. The fuel flow for best power is about 950 lbs.

Best economy may be defined as the point at which the power is obtained for the lowest fuel flow. Therefore, the best economy fuel-air ratio can be obtained on this curve merely by drawing a vertical tangent line from the bottom of the scale up to the curve. This shows the range at which the power, 177 *BMEP,* is obtained from the lowest fuel flow—a mixture strength of 13% to 14% *BMEP drop.*

When you set cruise power and cruise mixture on every flight, you actually set three points on a curve similar to this one. Start out in AUTO-RICH at constant power—that's the first point. The second point is the "Best Power" point, at which we hold for just a fraction of time during the mixture setting procedure. The third point then is the final point or the 10% *BMEP drop* point.

This curve is very useul in that it provides the only means of determining whether the mixture has been set properly at 10% *BMEP drop.* There is no way, other than the one shown on this curve, for determining that the mixture has been set properly. Fuel flowmeter readings cannot be used to determine if the mixture is at 10%, 15%, or 5% *BMEP drop.* Note on the curve that if the power is set at 177 *BMEP,* for example, the mixture could be at 10%, 15%, 20%, 7%, or 5% and the fuel flow would be just about the same almost within the limits of readability of the flowmeter. There is very little variation of fuel flow with mixture strength once you start leaning below about 3% *BMEP drop.*

One thing is noticeable, though, and that is the difference in manifold pressure between AUTO-RICH and 10% drop. This difference provides the only means of determining whether the mixture has been set properly. Note on this curve, that in AUTO-RICH the manifold pressure required to obtain 177 *BMEP* is 37″. At 10% *BMEP drop* mixture, the manifold pressure required to obtain 177 *BMEP* is about 40″. There is about a 3″ manifold pressure spread between AUTO-RICH and 10% drop. In low blower, the manifold pressure spread is about 2″. Therefore, in order to check yourself, and in order to check that the engine is operating properly, note the manifold pressure in AUTO-RICH when you first start to set power and mixture. At this time, record the manifold pressure in AUTO-RICH and take a complete set of AUTO-RICH readings before setting the mixture at 10% *BMEP drop*. Set the mixture in accordance with standard procedure at 10% *BMEP drop*. Note the *MAP* in AUTO-RICH and the *MAP* at 10% drop. In high blower there should be about a 3″ spread; in low blower about 2″.

This manifold pressure spread can vary according to several factors—primarily the fuel flow that is obtained in AUTO-RICH. Note, that if the AUTO-RICH fuel flow, instead of being 1170, were about 1000 (if the carburetor were metering lean), the manifold pressure spread, instead of being 3″, would be about 3½″. Correspondingly, if the AUTO-RICH fuel flow were very rich, about 1400 lbs., the manifold pressure spread would be about 2½″. The same applies to low blower operation around the 2″ limit. Therefore, these 3″ and 2″ numbers are not limits, but rather general approximate guides to help you determine that the mixture has been set properly—to help you double-check yourself and the engine.

MAP spread is, effectively, *BMEP drop*. This is shown on the following curve.

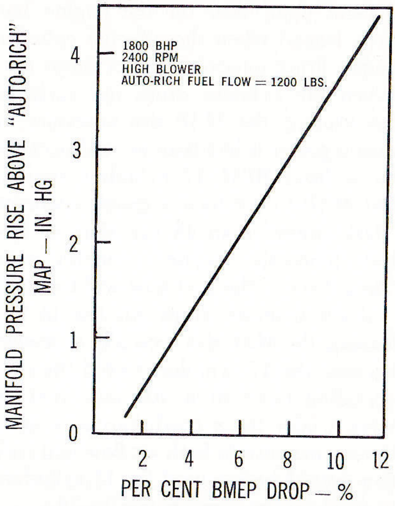

Figure 5—Manifold Pressure Rise Above AUTO-RICH *MAP* Versus *BMEP Drop*

Note, that for a given AUTO-RICH fuel flow (as an example, 1200 lbs/hr) for each *BMEP drop*, each mixture strength, and each fuel-air ratio, there is a certain manifold pressure spread or rise between AUTO-RICH and each leaner mixture. At 6% BMEP drop it is about 2″; at 10% it is a little over 3″; at 12% it is a little over 4″, and so forth. If you had a manifold pressure spread of 5″ between AUTO-RICH and manual lean, you would know that the mixture was much too lean. In that case, it would be about 15% *BMEP drop*.

This type of check protects not only against improperly set mixtures, but also against certain types of engine malfunction. For example, assume that the fuel injection line to one cylinder is leaking. With the mixture control in AUTO-RICH the cylinder, in spite of the leak, might receive enough fuel to fire, and the *MAP* fuel flow-*BMEP* relationships will be normal. However, when you start leaning, the cylinder may begin to fire intermittently or may drop out altogether when the fuel-air ratio to that cylinder becomes excessively lean due to the leak plus the leaning. Engine symptoms which may accompany this condition are roughness at the manual lean point, excessive *MAP* spread and high fuel flow.

The symptoms that are observed will

depend upon how far the engine has been leaned when the affected cylinder begins firing intermittently or drops out. When the cylinder drops out early in the leaning, the *MAP* rise necessary to regain power is less than normal because for a fixed *RPM* 17 cylinders require less *MAP* to produce a given power at "Best Power" than 18 cylinders at 10% lean. Since the engine is running near "Best Power," the fuel flow will be high.

If the cylinder drops out late in the leaning, the *MAP* rise is usually excessive because the 17 cylinders would then be operating close to a 10% lean fuel-air ratio. Under these conditions a proportionate increase in both air flow and fuel flow would be required for 17 cylinders to produce the same power as 18.

The following example will illustrate what may happen if the cylinder drops out entirely in the early stages of leaning:

After "Best Power" is established in accordance with the standard procedure, the mixture control is being moved towards 10% *BMEP drop.* The first 6 *BMEP* decrease occurs due to normal leaning. Further movement of the mixture control causes a sudden drop of 12 *BMEP* (the affected cylinder stopped firing). The result will be that you will have moved the mixture control handle until the *BMEP* dropped 18, which is the normal amount; however, the engine has not been leaned to an actual 10% *BMEP drop.* The engine itself has been leaned to only a 6 *BMEP drop* (a 2% to 3% *BMEP drop*). The remaining 12 *BMEP drop* is due to the cylinder dropping out. The result is you will be operating the engine with 17 cylinders carrying the load of 18. In other words, each of the cylinders is not only overloaded but is also operating at the most unfavorable fuel-air ratio — around 1, 2 or 3% *BMEP drop.* Such a condition may be evidenced by a manifold pressure rise between AUTO-RICH and 10% drop of perhaps 2″ instead of 3″.

However, more frequently the cylinder drops out only when the engine has been leaned to the lower fuel-air ratios. Under these conditions a high *MAP* rise usually results (perhaps 4″ instead of 3″).

The *MAP* spread between engines usually detects both conditions.

Let us look now at the cylinder head temperature and exhaust gas temperature relationship on this constant power type of curve. These are shown in Figure 6.

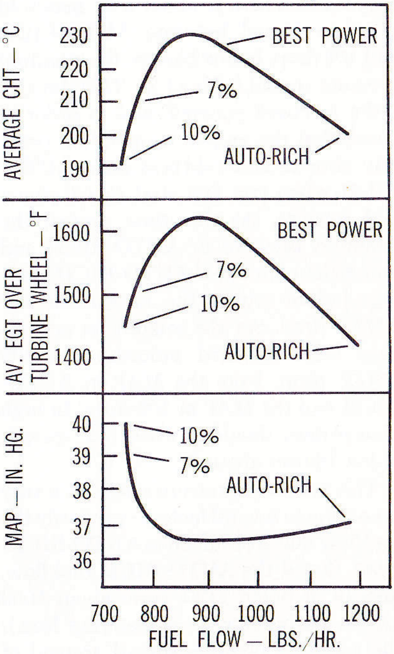

Figure 6—*CHT, EGT,* and *MAP* Constant Power Mixture Control Curves

The bottom of these three curves shows the same manifold pressure fuel flow relationship we were just looking at, but stops at 10% drop. The middle curve shows the *EGT* variation with mixture strength on a constant power basis. The top curve shows the same relationship for the cylinder head temperature.

You will note that the exhaust gas and cylinder head temperature relationships follow about the same trend as they do on the constant airflow curve. They peak at about a 15 to 1 or chemically correct fuel air ratio; they drop off relatively slowly as the mixture is richened. They drop off very rapidly (notice how steep the slope is) when the mixture is leaned. The steep slope on the lean side of the curve is a good indication of the benefits of leaning and the effects of not leaning enough. It doesn't take much difference in fuel flow to change the mixture strength from 10% to 7% to 5% to 3%, with a correspondingly rapid rise in head temperature and exhaust gas temperature. Conversely, a small amount of leaning in excess of 10% gives a very rapid drop in head temperature and exhaust gas temperature.

The cylinder head temperatures can be controlled in two ways: by mixture strength and also by cowl flap position. If there were no airspeed considerations, as far as head temperatures were concerned, the mixtures could be set at the hottest point—even at 15 to 1 fuel-air ratio and the cowl flaps could be opened as required to bring the heads down to the desired temperature.

In the case of the exhaust gas temperatures, however, there is no secondary control. The only means of controlling exhaust gas temperature is fuel air ratio (mixture strength, or *BMEP drop*). It is a good direct control because the temperatures always vary with the mixture strength.

It is interesting to note here the actual temperature in the exhaust system—about 1400° and 1500°F. These temperatures are quite high and must be carefully controlled. The Wright Company want the turbines to be operated well below 1600°F; 10% *BMEP* mixture does that.

The mechanics of this exhaust gas temperature effect can be stated simply as follows: As we move the mixture control from AUTO-RICH to 10% *BMEP drop* we go through a series of mixture strengths from slightly richer than best power to 10% drop fuel-air ratio. Each mixture has different burning characteristics. The fastest burning mixture is about .080 fuel air ratio and is known as best power. Any mixture which is either richer or leaner than best power has a slower flame speed. The "Best Power" mixture develops the most power for any given airflow because of this high flame speed which reduces the total ignition time and utilizes all of the oxygen available. The maximum *CHT* and exhaust gas temperature is reached at approximately 2% *BMEP drop* or a mixture ratio of .067. This mixture is known as *stochiometric* or "chemically correct" mixture because there is exactly the correct proportions of fuel and air for complete combustion, hence we obtain the maximum energy release. The high temperatures encountered at stochiometric mixtures are extremely injurious to both cylinder and turbine life and durability and should be avoided. Leaning beyond 2% *BMEP drop* lowers cylinder and exhaust temperatures as was shown previously. The 10% *BMEP drop* mixture gives sufficient margin from these high temperatures and this is why accurate leaning procedures are stressed. It is essential that the high temperature mixtures be avoided not only because of thermal damage but also because of mechanical damage which may result from detonation. The chemically correct mixture is definitely the most prone to detonation. This combination of high temperature and detonation can lead to engine failure within a very short time so be certain of your leaning procedure.

This curve also answers a question which has been asked many times since we started taking the AUTO-RICH reading at the beginning of cruise. The question was, "Does it not hurt the turbines to operate in AUTO-RICH for the 6, 8 or 10 minutes required to stabilize the head temperatures before recording the data?" The answer is shown on the gas temperature curve. Note that in AUTO-RICH the exhaust gas temperatures actually run cooler than they do at 10% *BMEP drop* mixture. So, as far as the turbine is concerned it would prefer to run at AUTO-RICH. Of course in AUTO-RICH there is a considerable flame coming from the stack, but it is a relatively cool flame and the turbines are not damaged nor are they overheated by the prolonged operation in AUTO-RICH.

So this curve, as does the constant airflow curve, points out the benefits of operating at a 10% *BMEP drop* mixture; primarily, lower exhaust gas and cylinder head temperatures, and secondly a saving in fuel consumption. There is another advantage to be gained from operating at lean mixtures and that is to increase the margin above detonation. It would be well at this point to review briefly just what detonation is and what it does to an engine.

DETONATION AND PRE-IGNITION

Detonation has been the subject of much discussion and research for many years and there have been many theories concerning it. It is now agreed that detonation can take many forms; one type, the worst, is heavy detonation, which will wreck a cylinder and an engine in a matter of seconds. There's another type known as incipient, or very light, detonation. An engine can operate in this type of detonation for long periods of time without being damaged. Of course, there will be some power loss and inefficiency of engine operation, but very light or incipient detonation will not damage an engine for short periods of time. Then, there are varying degrees of detonation between the very light and heavy detonation.

Detonation generally occurs as follows: When the two spark plugs in the cylinder ignite, two flame fronts are set up, which progress towards each other. As they move towards each other, they compress between them the unburned charge of fuel and air. As the unburned charge is compressed, its pressure increases and, therefore, its temperature increases. Normally, the unburned charge will finally be ignited by the flame fronts as they approach each other. All portions of the unburned charge will burn until there is none left. However, if the unburned charge is compressed enough, and if its temperature is raised high enough (by compression) so that it will ignite, then the unburned charge will explode; it will auto-ignite; ignite itself because of its own temperature, a temperature due to pressure. The unburned charge will then explode back into the two flame fronts, set up sonic velocities in the cylinder with resultant extremely high pressures and temperatures. Such a condition, if bad enough, will wreck a cylinder and an engine within two or three seconds.

The TC18 engine is no different, as far as detonation is concerned, than any other engine. It has at least as good a margin above detonation, and in some cases better. The margin above detonation depends basically upon two factors. The first factor is the initial temperature of the unburned charge. The higher the temperature of the unburned charge, the more likely will be the possibility of detonation. Anything that raises the temperature of the unburned charge of fuel and air will decrease the detonation margin. Things that can do this are: increase in carburetor air temperature, increase in cylinder head temperature, shifting from low to high blower (in high blower there is a greater temperature rise across the impeller; therefore, the initial temperature of the unburned charge will be higher). Increase in power will increase the temperature of the unburned charge since more manifold pressure means a greater pressure inside the cylinder and, consequently, a higher temperature. So, any one of these factors which increases the temperature of the air going into the cylinder will decrease the margin from detonation. If the engine is operated within limits, there is a good safe detonation margin even at the peak limits of maximum head temperature, and maximum carburetor air temperature. However, this engine, as any other engine, will not tolerate increasing temperatures and pressures above limits. The detonation margin in such cases is rapidly decreased until none remains. So temperature is the primary control, as far as detonation is concerned.

The second factor which affects the possibility of detonation is the temperature at which the unburned charge will explode. The ease with which the unburned charge will explode depends primarily on two things: the octane rating of the fuel, which is pre-set and over which we have no control in flight; and most important, the mixture strength—the fuel-air ratio. At certain fuel-air ratios there is a greater tendency for the unburned charge to detonate than at other fuel-air ratios. At certain fuel-air ratios the unburned charge will explode at a lower temperature, and detonation will be most likely to occur. These fuel-air ratios are in the range of approximately .065-.070 (approximately 2% BMEP drop) and can be shown on the constant power mixture curve as follows:

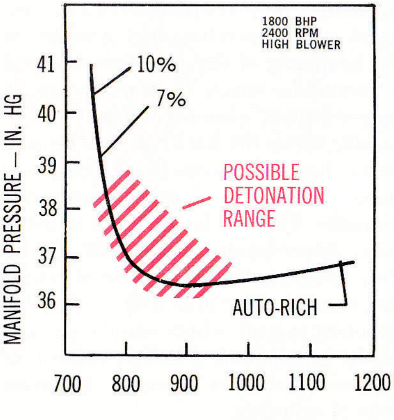

Figure 7—Manifold Pressure Constant Power Mixture Control Curve

It is possible in the TC18 engine at the powers at which we operate to get into a very light detonation in this range of fuel-air ratio. This is only possible under the most adverse conditions—that is, high cylinder head temperature, high carburetor air temperature, high blower, and high power. Under these adverse conditions, if the mixture is improperly set, in the range of "Best Power" to about 2% BMEP drop, there is a possibility of getting very light detonation—not the type of detonation at which operation cannot be tolerated—but the kind where there is some loss in engine efficiency but no damage unless the operation is continued there for a long period of time. As you can see on this curve, we must go through this mixture strength range when setting the cruise power from AUTO-RICH to 10% drop. There isn't any problem because we go through it fast. We don't operate in that range for any long period of time. Chances are that if we did operate in that range we would not get this light detonation, but it is a possibility. You should be aware of it and it is most certainly a range of mixture strength to be avoided. Note, that as the mixture is leaned, we get farther away from this range of light detonation, and if we should richen the mixture above this range of possible light detonation, we also get farther away. Therefore, richening or leaning away from this unfavorable fuel-air ratio increases the detonation margin.

Detonation is something which may or may not be taking place inside the cylinder; but in any case, it's nothing that can be seen by instrumentation or by looking at the engine in time to do anything about it. Severe heavy detonation can be seen by a very rapid rise of cylinder head temperature, rough running engine and white smoke coming out of the exhaust, closely followed by pieces of piston and other primary structural parts. When you see these symptoms, it's too late to do anything about it. Very light detonation—the kind we've been talking about here—is something you would never know you had—it would not show on instrumentation or in engine roughness.

There is a good reason for avoiding this light detonation range even though it may not immediately damage the engine, and that is the fact that pre-ignition goes along with it. Pre-ignition and detonation are phenomena which occur very frequently together. Pre-ignition is early ignition and it occurs when a piece of metal in the cylinder continues to glow and remain ignited after the combustion process has taken place. This piece of metal could be a feathered valve or a granular roughness on the piston head—anything that retains heat and continues to glow. This glow plug sets off the mixture much sooner than it should. Peak pressure in the cylinder is reached as the piston is coming up on the compression stroke; therefore, high pressures and high temperatures are set up inside the cylinder. These high pressures and temperatures will induce detonation. Detonation makes the pre-ignition worse. Each makes the other worse and they occur together. Therefore, operation in very light detonation may eventually, because of pre-ignition, result in heavy detonation and severe engine damage.

SUMMARY OF REASONS FOR USING 10% BMEP DROP

In summary then, there are four reasons for using a 10% *BMEP drop* mixture:

1. Low cylinder head temperatures and correspondingly low cowl flap settings.
2. Low exhaust gas temperatures.
3. Use of the lean 10% drop mixture provides adequate margin from the range of possible light detonation.
4. 10% is a nice round number and it is easy to work with. We would achieve about the same results with 11% or maybe 9%, but 10% seems to work out quite well, and it gives the desired results.

Fuel economy, a second advantage, is a very nice thing to have. If fuel economy were the only thing we were interested in, we wouldn't use the 10% drop mixture—we would use something close to 13% or 14% *BMEP drop.* Of course, we don't like to go too lean as far as the airplane itself is concerned, because the leaner the mixture the lower the critical altitude and the lower the airspeed. Therefore, 10% is a good compromise considering the many factors which are involved.

Actually, as far as the engine itself is concerned, it likes lean mixtures—the leaner the better. The engine would like to operate at 15% or 20% *BMEP drop* mixture. Leaning down to these values, as you can see, would result in a very rapid and substantial drop in cylinder head and exhaust gas temperature. For a while, at the beginning of the operation, we used a procedure which became known as "super-leaning"—leaning below 10% drop, to 14%, 15% or 16% *BMEP drop.* This procedure had to be discontinued, because in many cases engines were not operating normally. This will be discussed in detail later. Super-leaning below 10% *BMEP drop* was discontinued because of certain malfunctions associated with the fuel distribution system which caused damage to the pistons and cylinders because of richness — excessive richness — in certain rows of cylinders.

CARBURETION

Several times it has been mentioned that the carburetor does many things automatically. It gives the proper fuel air ratio in AUTO-RICH during high power operation, compensates for changes in pressure and compensates for

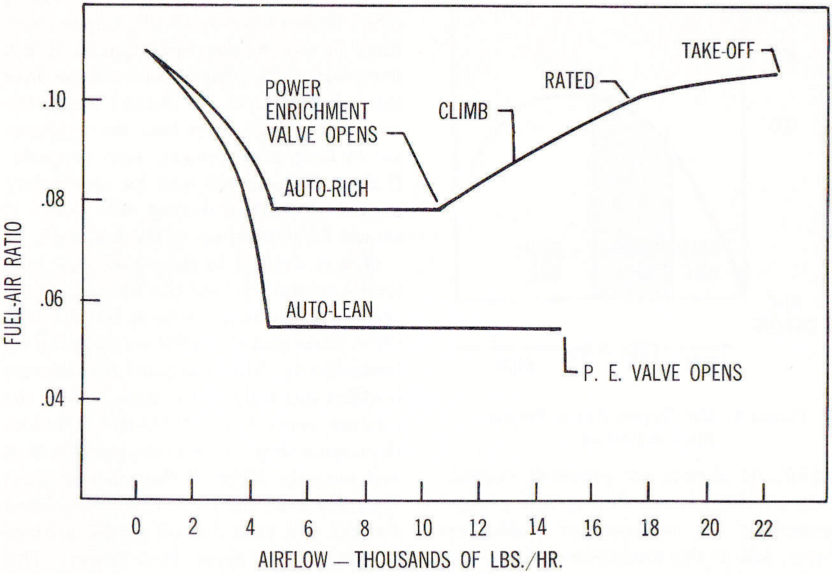

Figure 8—Basic Carburetor Metering Curve

changes in temperature. Let's look at the basic carburetor metering curve — the curve which is used in the carburetor shop for adjusting the carburetor and setting it up to flow within certain limits.

This curve shows what a TC18 carburetor should do during all phases of engine operation. On the bottom scale is shown airflow in thousands of pounds per hour. Airflow is power; increasing the airflow is accomplished by advancing the throttle, increasing the *RPM*, shifting from low to high blower, and decreasing carburetor air temperature. Again, any of the things which affect airflow also affect carburetor metering. The vertical scale shows fuel-air ratio or mixture strength.

Let us consider this curve in several sections—first, the low power portion of the curve, or the idling range.

An engine should idle with the "Best Power" mixture. "Best Power" is obtained at a fuel-air ratio of approximately .080. If the engine idles richer than "Best Power," the spark plugs will load up, an accumulation of soot will be put on the spark plugs and the result will be severe spark plug fouling. The spark plugs on the TC18 engine apparently foul more easily than do the plugs on previous engines. Consequently, on this engine, it is even more important that the idle mixture be set precisely at or slightly leaner than "Best Power." In view of the importance of maintaining properly set idle mixtures, all flight crews should check these idle mixture settings on every engine shut down. This can easily be done and requires no additional manipulation of controls, merely an observation of certain instruments. Following is the familiar curve again showing the effect of mixture strength on power.

This curve is plotted on a fixed throttle basis. The bottom scale is fuel flow and the left hand scale is *RPM*. We can show the left hand scale as *RPM* rather than

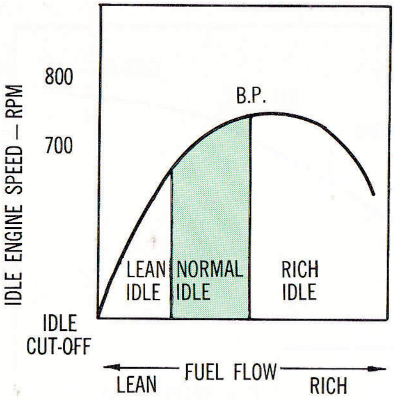

Figure 9—Idle Engine Speed Versus Mixture Setting

BMEP, as shown on previous curves, since on the ground during low power operation, the tachometer indicates power, just as the torquemeter does. On the ground, the propellers are in fixed pitch (low pitch stop) and the *RPM* under these conditions will be a direct indication of power.

If the mixture is properly set, the carburetor in AUTO-RICH will deliver very close to peak power or peak *RPM*.

When the mixture control is placed in IDLE CUT-OFF, with the properly set mixture, the *RPM* will immediately drop; if the mixture is left in IDLE CUT-OFF, the *RPM* will drop to zero.

If the mixture is too rich, then when the mixture control is placed in IDLE CUT-OFF, the power or *RPM* will first rise towards "Best Power" mixture and then fall off. This is the best indication of a mixture which is set too rich. So, every time you shut down the engines, observe the tachometer. If the *RPM* first rises and then falls off, the mixture is too rich and should be so noted in the log book. If the *RPM* falls off directly, then the mixture is either just right, at "Best Power" *or* it is leaner than "Best Power." Lean mixtures are not too serious as far as spark plug fouling is concerned. When Maintenance sets the idle mixtures, they take care to set them at the proper point, just about at "Lean Best Power"; however, when flight crews check idle mixture settings in day to day operation, it is not necessary to be that precise on the lean side of the curve. It doesn't make too much difference how lean the mixtures are as long as the engine runs properly. If the mixture is too lean for satisfactory engine operation during idle, then it should be written up in the log book.

If it is desired to determine just how lean a mixture is, use the following procedure. Place the mixture in IDLE CUT-OFF. Note that the *RPM* starts to fall off immediately. This indicates the mixture is either just right or too lean. Return the mixture control to AUTO-RICH before the engine stops. Toggle the prime switch and note the *RPM*. If the mixture is excessively lean, the *RPM* will rise to "Best Power" and then fall off as the mixture becomes richer than "Best Power." This primer check will give an indication of the extent of leanness, and can be used if an engine is not running properly at IDLE and lean mixtures are suspected. Be sure to make all idle checks with cylinder head temperatures at least at normal idle temperatures (about 140°C). If cylinder head temperatures are too low, then the idle check is worthless.

Returning now to the basic carburetor metering curve, Figure 8, it will be noted that in the idle range as shown previously, the mixture or fuel-air ratio is apparently well above "Best Power," (.080). As a matter of fact, it will be noted that the fuel-air ratio at idle is very close to the fuel-air ratio which the carburetor meters at take-off. How then can the desired "Best Power" mixture be obtained at idle if the carburetor is set at mixtures very much richer than "Best Power." The answer is valve overlap and is explained as follows.

Valve overlap (the period during which both the intake valve and the exhaust valve are open) is one of the most important phases of basic engine design. An engine is required to move great masses of air in very short periods of time. For example, looking at the carburetor metering curve, it will be noted that at take-off the engine must pump 22,000 lbs. of air per hour. At maximum cruise power, the engine must pump 13,000 lbs. of air per hour. This is a great mass of air with a great amount of inertia which must be overcome. In order to obtain maximum volumetric efficiency, a certain amount of valve overlap must be built into the engine. Volumetric efficiency is the ratio of the amount of fresh air which the cylinder actually does take in during the intake stroke compared to the amount of fresh air which the cylinder has the capacity to take in during the intake stroke. In order to obtain optimum engine operation and maximum volumetric efficiency during high *RPM* operation, the pressure of the fresh charge coming into the cylinder is used to help push out the burned exhaust gases. The intake valve opens during the latter part of the exhaust stroke, the fresh air is forced into the cylinder at high manifold pressure and helps to scavange the exhaust gases. During the first part of the intake stroke, the intake valve is open, and the exhaust valve remains open. Therefore, exhaust gases are still being scavenged during the first part of the intake stroke and the fresh charge of air is helping to scavenge these burned gases.

Valve overlap increases engine efficiency at high *RPM* and is absolutely required. However, it has the effect of making the engine extremely inefficient at low power and low *RPM* operation—particularly at idle.

When the throttle is pulled back to the idle position, the manifold pressure is about 25″ Hg. at a sea level airport; the pressure of the fresh charge coming into the cylinder would be about 25″ Hg. and the pressure against which the exhaust gases were attempting to discharge would be about 30″ Hg. During the end of the exhaust stroke and the beginning of the intake stroke—when the fresh charge is trying to come into the cylinder—the intake valve and the exhaust valve are both open due to valve overlap. The fresh charge is coming in at 25″ and the exhaust gases are pushing against 30″ of atmospheric pressure; therefore, part of the exhaust gases will tend to flow back into the cylinder. This flow-back of burned exhaust gases into the cylinder dilutes the charge of fresh air and acts as an additional separator between the combustible air molecules and the fuel. Hence, an excess of fuel must be delivered to the cylinder during idling in order to overcome the diluting effect of the burned gases which are forced back into the cylinder. As shown on the carburetor metering curve, the actual fuel-air ratio delivered to the cylinder during idling is very much richer than cruise "Best Power," but the fuel-air mixture which actually burns inside the cylinder is a "Best Power" mixture.

It is of value now to review the relationship between the throttle and the fuel metering system of the carburetor during idle operation. Basically the carburetor meters on the basis of airflow through it—translated into air pressure. During high power operation a certain amount of air flows through the carburetor and into the engine. This air sets up differential forces within the carburetor which move diaphragms, open fuel valves a certain amount and meter the fuel proportionately. During low power or low airflow operation — (the idling range)—the air forces in the carburetor are not strong enough to permit the carburetor to meter fuel accurately on the basis of air pressure. The carburetor isn't that sensitive. So the fuel metering during idle is done mechanically by means of the idle valve.

In order for the fuel to get through the carburetor and into the engine, it must go through certain valves and jets, through the injection pumps and finally into the engine. The fuel always goes through the idle valve, through at least one jet and through the mixture control plate. Whichever of these openings is the smallest, that opening will provide the metering. If the mixture control plate opening is the smallest in the line, then the fuel will be metered there. If the idle valve is closed down to the point where it is the smallest opening in the line, then the fuel will be metered by the idle valve.

The idle valve in the carburetor is a mechanically controlled valve, rigged directly to the throttle. During idling operation with the throttle pulled back, the idle valve accomplishes the metering of the fuel in the carburetor. Pulling the throttle back closes the idle valve sufficiently so that it is the smallest opening of all the fuel valves and jets in the fuel system of the carburetor. As the throttle is advanced, the idle valve is mechanically opened more and more. At a throttle opening sufficient to give approximately 1200 *RPM*, the idle valve becomes a greater opening than the jets and at this point the jets take over the metering and the idle valve is out of the picture. At powers above 1200 *RPM* the fuel will still have to go through the idle valve in order to get through the carburetor, but the idle valve will be open much more than any of the other restrictions; and, therefore, will have no effect on the actual fuel flow through the carburetor.

This explains the reason for the AUTO-RICH and AUTO-LEAN lines coming together in the idle range on the carburetor metering curve. They are superimposed from airflows equivalent to about 1200 *RPM* down to the minimum obtained with the throttle closed. This means that during idling and at all *RPM's* up to about 1200 it accomplishes nothing to move the mixture control from AUTO-RICH to AUTO-LEAN. Moving from AUTO-RICH to AUTO-LEAN merely cuts out the AUTO-RICH jet, but since the fuel metering at the low *RPM* range is being done by the idle valve and not the jets—cutting out the AUTO-RICH jet has no effect at all on carburetor metering with a properly set carburetor.

The relationship of the throttle and the idle valve also explains the fact that an idle mixture can be properly set under certain conditions and then, under changing conditions, the idle mixture will richen up or lean out. This is explained as follows.

Assume that the idle mixture is being set at a sea level airport at standard temperature. The throttle is pulled back all the way. At this point the throttle valves are open a certain amount, permitting a certain amount of air to flow through the carburetor. Also, with the throttle fixed at the *Full Closed* position the idle valve, mechanically rigged to the throttle, is also fixed at a certain position permitting a certain fixed amount of fuel to flow through the carburetor. This, then, establishes a certain fuel-air ratio in the engine during idle. The airflow is a function of the opening of the throttle valve, and the fuel flow is a function of the opening of the idle valve.

Assume then that the airplane flies and lands at a high altitude airport. An attempt is made to idle the engine by pulling the throttle back and leaving the mixture in AUTO-RICH. With the throttle pulled back, the opening of the throttle valve will be the same as it was at the sea level airport, thus permitting the same volume (cubic feet/hour) of air to flow through the carburetor and into the engine. However, since the pressure of the air at the high altitude airport is less than the pressure of the air at the sea level airport, then the mass (lbs./hour) airflow through the engine will be less. The fuel flow through the engine will be the same with the throttle closed, since the idle valve is still open the same amount, and the amount of fuel flowing through it will be the same. Therefore, with the same amount of fuel but less mass airflow the mixture will be much richer at the high altitude airport. For a fixed altitude, an increase in air temperature would reduce the air density. This would cause a reduction in the mass airflow and the effect would be the same—a richer mixture.

There are several other factors which can produce a similar affect; for example, if the airplane is parked in a tailwind the idle mixture will richen because of reduced mass airflow. When the airplane is parked in a headwind the idle mixture will tend to become leaner. On a humid day the idle mixture tends to become richer because the water vapor displaces dry air and the net result is a reduced mass airflow. Consequently, when checking idle mixtures it is important to consider the effect of these variables. If all four engines seem to be too rich or too lean, the reason can probably be found in a consideration of the effects of temperature, pressure, or humidity. Such a richening or leaning should not be written up in the log book because it's something that can't be helped. If one engine, though, has become very rich or very lean while the other three remain normal, then this is a condition which should be written up in the log book.

Returning to the carburetor metering curve, let us follow the AUTO-RICH line. Note that at an airflow of approximately 3500 lbs/hr (about 1200 RPM) the AUTO-RICH line and the AUTO-LEAN line diverge, indicating that the jets have taken over from the idle valve at that point and do have an effect on fuel-air ratio. The AUTO-RICH line then levels off for a range of airflows up to about 11,000 lbs. per hour. This indicates that if the throttle is advanced from about 5500 to 11,000 lbs. per hour, with the mixture control in AUTO-RICH, the fuel air ratio will remain constant at about "Rich Best Power," .080. Of course, as the throttle is advanced through this range, the fuel flow shown on the flowmeter will increase; the airflow increases as the throttle is advanced and the fuel flow increases. In this range, the airflow and the fuel flow increase at the same rate. Consequently, the fuel-air ratio remains constant.

Examine on Figure 10 the area which is marked "Detonation". This detonation line actually defines an area of moderate or heavy detonation. It shows that at

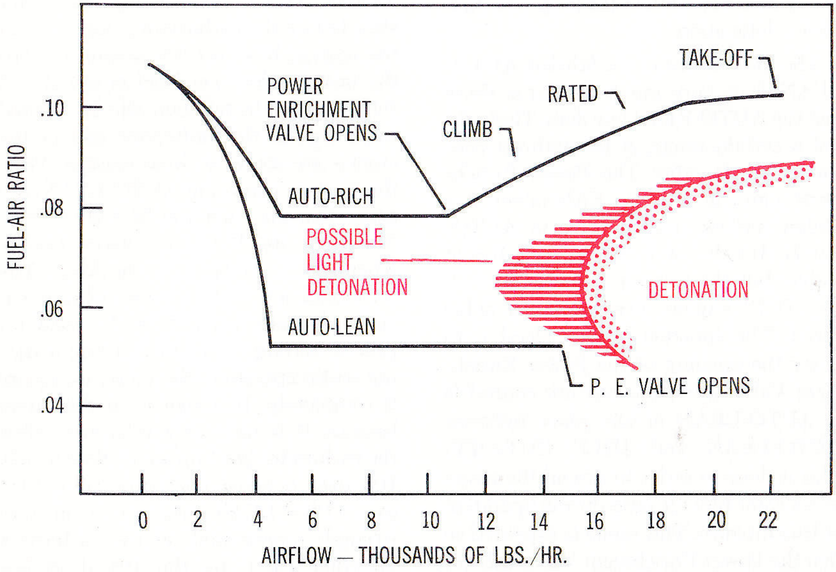

Figure 10—Carburetor Metering Curve Showing the Detonation Area

about 22,000 lbs. of airflow a fuel-air ratio of .09 is required to avoid detonation. It shows that as the airflow is reduced to 20,000 lbs. the fuel-air ratio required to avoid detonation is slightly less, about .088. As airflow is further reduced to 16,000 lbs. a leaner mixture, about .080 will just barely keep the engine out of detonation. This is a range which must be avoided. Anything to the right of this line means trouble from detonation. Note then, going back to the AUTO-RICH line, at an airflow of about 11,000 lbs. per hour, the Power Enrichment Valve in the carburetor opens. Then from this point on, as the throttle is advanced (as the airflow increases) the carburetor delivers a richer fuel-air ratio to the engine. The AUTO-RICH line above the point of opening of the Power Enrichment Valve, runs along just about parallel to the line of detonation, maintaining about the same margin above the detonation line as the power increases. This is the function of the Power Enrichment Valve. As power is increased, the Power Enrichment Valve serves to richen the mixture as required to maintain the proper margin above detonation.

The line on this curve labeled AUTO-LEAN does very much the same thing that the AUTO-RICH line does. Throughout a certain range, it maintains a constant fuel-air ratio. The Power Enrichment Valve in AUTO-LEAN opens at a higher airflow than it does in AUTO-RICH. It's the same Power Enrichment Valve, but the mixture control plates in the TC18 engine incorporates a delay bleed. The function of this bleed is to delay the opening of the Power Enrichment Valve when the mixture control is in AUTO-LEAN or any place between AUTO-LEAN and IDLE CUT-OFF. This is done in order to extend the range of constant fuel-air ratio during operation at lean mixture. This range is extended so that the Power Enrichment Valve will not be in the picture when we are trying to set up the proper mixture for cruise. The Power Enrichment Valve must open early during AUTO-RICH operation in order to provide the necessary rich mixtures which will protect against detonation. This is not required at lean mixtures and the Power Enrichment Valve opening is delayed in order to keep it from interfering with the operation of the carburetor during cruise.

The curve shows an AUTO-LEAN line, which is set on the flow bench at a mixture strength of about 7% *BMEP drop.* Actually, in our operation, there is no such thing as AUTOMATIC LEAN.

The AUTO-RICH position is used for starting, ground operation, and high power operation. The carburetor does its job under these conditions automatically. During cruise operation, which represents about 98% of the time on the engine, it is important that the mixture be set precisely at the correct point. The carburetor cannot do that job automatically.

As shown on Figure 10, AUTOMATIC LEAN is set at about a 7% *BMEP drop* mixture. This is done in the carburetor shop before the carburetor is installed on the engine; however, for several reasons the mixture does not hold at exactly 7% *BMEP drop.* Installation effects, normal tolerances in the carburetor and in the engine are some of these reasons. With the mixture control in AUTO-LEAN, the carburetor may meter at 5% *BMEP drop,* 3%, 7% or 9%. We never know exactly where it is except by checking. The AUTO-LEAN notch on the carburetor is not sufficiently accurate to be used for precise setting of mixture strength during cruise operation; therefore, we ignore it completely. It is shown on this curve because it is used as a reference when the carburetor is set up on the flow bench. However, in actual operation, rather than use AUTO-LEAN, we use a mixture strength represented on the carburetor metering curve by the 10% drop line which sets the mixture to about .053 fuel-air ratio. We know where it is and have control of it. Therefore, AUTO-LEAN is not used.

The Carburetor Metering Curve shows that once a mixture has been set properly to 10% *BMEP drop,* the airflow can be changed (up or down) by moving the throttle, by changing RPM, or by shifting blowers, etc.—and the mixture will hold about constant. In other words, if you set 10% *BMEP drop* mixture, leave the mixture control where it is and then move the throttle (up and down), the BMEP will change, as will the fuel flow, but the fuel-air ratio will remain about the same. It should be noted that present day carburetors are not quiet capable of holding the same fuel-air ratio if the changes in airflow are substantial.

The detonation range which we discussed previously—the range of possible light detonation—is shown on the carburetor metering curve by a shaded area.

This is the range where it may be possible to get light detonation under the most adverse conditions. It represents fuel-air ratios of about .065 to .070. This range, although not a range of moderate or severe detonation, is certainly a range to be avoided, and explains in part the reason for the mixture setting procedure which is used on the TC18 engine—a procedure which appears to be a little bit complicated, but one for which there is a good reason. Let us go through a typical mixture setting procedure, the one which is used all the time on the TC18 engine in cruise, and plot it on the carburetor metering curve.

The first step is to set the *BMEP* (A). Assume operation in high blower, 177 *BMEP,* AUTO-RICH mixture.

The next step is to lean down the mixture control until "Best Power" mixture strength is obtained (B). This is done with the throttle held constant—constant airflow and leaning to a "Best Power" mixture strength of approximately 181 BMEP.

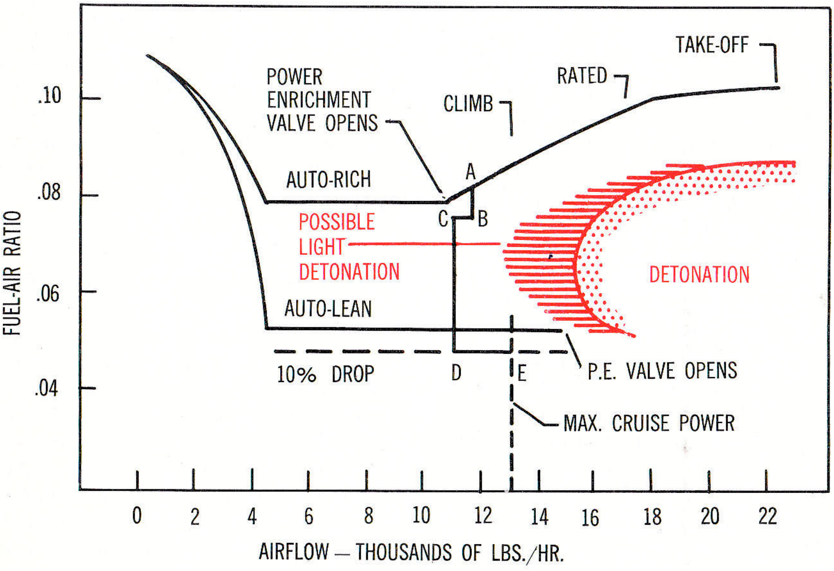

Figure 11—Manual Leaning Procedure Plotted on a Carburetor Metering Curve

The next step is to reduce the throttle to 177 *BMEP* (C), leaving the mixture control at the "Best Power" setting. The mixture remains at "Lean Best Power". The next step then is to lean with the mixture control to 10% *BMEP drop* (D); that is, lean down 18 *BMEP* on the torquemeter. This is done at fixed throttle (constant airflow).

The final step is to advance the throttle to maximum cruise power—back to 177 *BMEP* (E)—leaving the mixture control set to obtain the 10% *BMEP drop* mixture.

This graphically portrays the reason for the mixture control procedure which we use. Note how we back off behind the range of possible light detonation, lean down and then apply power underneath the range, coming back down under it up to 177 *BMEP*. This represents a conservative way of operating the engine, a method which gives the greatest margins from any trouble from detonation or preignition.

It is interesting to note, considering again the line of heavy detonation, that as shown on previous curves if the mixture is richened or leaned beyond certain mixture strengths, the margins from detonation become greater. The curve shows that the engine is most likely to detonate at .065 to .070. Note that in AUTO-LEAN for example, representing a 7% *BMEP drop*, there is a certain margin from heavy detonation. This is shown as the horizontal distance from the maximum cruise power line, where it intersects the AUTO-LEAN line, to the line showing the detonation range. This is the margin from detonation at maximum cruise power with the 7% *BMEP drop* mixture. Because the detonation curve backs off again as the mixture is leaned, the corresponding margin from detonation shown on the 10% *BMEP drop* line is very much greater than at AUTO-LEAN. If a 12% or 15% drop mixture were used, the margin from detonation would be even greater. This is another method of demonstrating the point that if mixtures are richened or leaned from the point of undesirable mixture strength, then the margins from detonation become greater and greater.

The carburetor metering curve also explains the reason for the present procedures concerning the handling of the mixture controls during descent. Our current procedures state that for descent the mixture should be left at 10% *BMEP drop*. The mixture controls normally need not be adjusted during descent. Note, on the carburetor metering curve, that once the mixture has been properly set at 10% *BMEP drop*, it will hold there for a great range of airflow change. This means that if power is pulled back during descent, if *RPM* is changed, or if blowers are shifted, the airflow will change but the fuel-air ratio will hold about constant at 10% drop, *assuming that the automatic mixture control does its job properly.*

We know that the automatic mixture controls do not always compensate exactly for changes in altitude or changes in pressure. The automatic mixture control has a natural tendency to lag; that is, if you start a rapid descent from 20,000 feet the airplane will come down at a certain rate, but the automatic mixture control might come down more slowly. The effect of that would be leaning of the mixture. In such cases the automatic mixture control will eventually catch up with the airplane and the original mixture strength will be restored.

This type of leaning presents no problem. The engine will continue to run satisfactorily although the automatic mixture control may lag considerably and temporarily the mixture is down to 15% or 20% *BMEP drop*. There is no need to adjust the mixture control during descent, with a normal engine. It is not desirable to arbitrarily richen the mixtures—to just inch the mixture controls up towards rich during descent because of a feeling that mixtures are leaning out a little too much. This sort of operation of the mixture control handle is undesirable because it results in a loss of control of the mixture and can very easily result in the engine being operated somewhere between 10% *BMEP drop* and AUTO-RICH—a range of mixture strength which we wish to avoid.

If the mixture is leaned down excessively during descent because of a lagging AMC, and the engine is not quite right, a slight roughness may develop. For example, if an engine has leaking fuel injection lines, a stuck injection nozzle or bad spark plugs—the engine may roughen up a little bit. In such a case, one of two things should be done, either the mixtures should be reset to 10% drop or placed in AUTO-RICH. Either system is desirable and preferable to partially richening the mixture until smooth engine operation is obtained.

EXHAUST SYSTEM

Many questions have been asked concerning the exhaust flame which is observed during various phases of the operation. It would be well to discuss this point at this time.

The exhaust system on the TC18 engine is, in effect, a complete combustion chamber. Four things are required in order to have a complete combustion chamber. One is the container itself, the exhaust pipe. The second requirement is a supply of fuel. You will recall it was brought out previously that mixtures which are excessively rich result in raw unburned fuel being discharged through the exhaust valve and out into the exhaust system. This raw unburned fuel is then a source of fuel in the combustion chamber contained within the exhaust pipe. The third requirement is heat for ignition. Since the exhaust pipes run in the vicinity of 1300 to 1400°F there is sufficient heat to initiate combustion. The fourth requirement is a supply of fresh air. In this respect, the TC18 installation differs from non-compounded engines. The TC18 does have a constant supply of fresh air pumped into the exhaust pipe. This is the cooling air for the turbines which is taken in through a duct which picks up ram air at the front of the engine, pumps it through the turbine, over the turbine wheel for cooling and then exhausts it into the exhaust pipe along with the exhaust gases, just downstream of the turbine. If the fuel-air ratio inside the exhaust pipe is correct for combustion, then burning will take place just downstream of the turbine.

The required fuel-air ratio in the exhaust system follows much the same curve that it does inside the cylinder itself, as shown on the following curve.

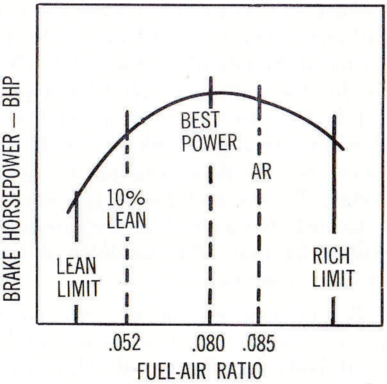

Figure 12—Combustibility Range

If there is too much excess fuel being pumped through the cylinders to the exhaust system, then there will be no combustion. That would represent operation way off the right end of this curve. Such is the case during take-off when the carburetor meters an excessively rich mixture—fresh air is being pumped through the exhaust pipe (turbine cooling air) and there is also raw unburned fuel, but there is so much excess fuel that the mixture inside the exhaust pipe is too rich to burn. When the throttle is retarded to rated power, the carburetor automatically leans down the mixture a small amount. This reduces the amount of excess fuel in the exhaust system, but even at rated power there is still too much fuel in the exhaust system to permit burning. When the throttle is further reduced to climb power, then the carburetor leans the mixture down to the point where the amount of excess fuel going through the cylinders and out into the exhaust system is just about right for combustion and burning in the exhaust pipe. Therefore, during climb you will normally expect to see a flame coming out of the exhaust pipe. This flame represents the burning that takes place in the exhaust system—the burning of the excess fuel mixed with the turbine cooling air.

However, the flame will not always be evident. In the case of an excessively rich carburetor which is metering fuel to the engine at the rate of approximately 1500 lbs/hr., the mixture in the exhaust pipe will be too rich to burn. If in climb you should see an engine with none of the exhaust showing flame you can be quite certain that the fuel flow to that engine is too rich and a check of the flowmeter will verify that. This condition should cause no concern.

It is even more common to see one or two exhaust pipes showing flame and the third showing no flame at all. This condition is not to be considered abnormal either. It is caused by minor differences in fuel and air distribution between cylinders and turbines. Normally, at climb power with a carburetor metering properly, the mixture strength inside the exhaust system is just on the burning edge of the curve; it is just barely lean enough to burn. Therefore, any minor differences in airflow or fuel flow will make the mixture a little bit richer or a little bit leaner. If the mixture in that part of the exhaust system connected to one turbine happens to be very slightly richer than normal, then there will be no flame from the exhaust of that turbine, or the flame may be flickering indicating a marginal condition, with the flame coming in and out. This is to be considered normal. There is no cause for concern if a flame does not appear in any turbine exhaust pipe in climb, if the flame flickers in climb, or if one exhaust pipe shows flame and the others do not. In climb these conditions are normal.

In cruise, however, the exhaust flame can indicate certain types of engine malfunction. When cruise power and mixture have been properly set the flame should always be the same—the characteristic short, straw-colored flame, almost a lack of flame. This should always be the case with a normal engine with cruising mixture set properly at 10% *BMEP drop*. Occasionally, you will see a red streakish flame or orange streaks in the flame. This may indicate oil leaks and will be particularly noticeable in the No. 2 turbine, which is supplied by the lower cylinders.

More frequently, you will see spurts of orange or spurts of red. This indicates certain types of malfunctions and is explained as follows: any type of malfunction inside the engine which causes raw fuel to be passed through the cylinder and into the exhaust pipe during cruise will give the condition which shows up as spurts of flames coming out of the exhaust pipe. Such a condition can result, for example, from two dead spark plugs in one cylinder. In such a case the fuel will go into the cylinder, will not burn because of the dead plugs and will go out into the exhaust system as raw unburned fuel. As soon as it mixes with the turbine cooling air it will burn. You will see that burning in the form of spurts of flame coming out of the exhaust pipe. A similar condition can occur in the case of a leaking fuel injection nozzle. A fuel injection nozzle with a broken spring, for example will leak fuel into the cylinder almost continuously. This will result in a certain amount of raw unburned fuel going through the cylinder and out into the exhaust pipe where it will mix with the turbine cooling air and burn. This will show up not only as spurts of flame but if you go back into the cabin and watch it carefully, and listen, you can hear it pop almost like a machine gun. What you are hearing is the afterburning of the fuel in the exhaust pipe. This represents an engine malfunction and should be written up in the log book. You can help maintenance considerably if you indicate from which turbine the flame was coming. Six cylinders feed each turbine and if you note which turbine it was, then you can pin the trouble down to cylinders feeding that turbine.

THE EFFECT OF SPARK ADVANCE

It is important to know how to use the spark advance switches properly, and is of interest to show what occurs when you advance the spark, and why it is done.

Figure 13 shows crankshaft travel in degrees on the bottom scale through two engine revolutions, 720 degrees. The vertical scale shows relative pressures within the cylinder. The solid line indicates the ideal condition, where the pressure inside the cylinder peaks just after top dead center of the compression stroke. The optimum point pressure of peaking is about 15 degrees after top center. If the pressure peaks too early during the end of the compression stroke, then the pressure peak will occur in the cylinder as the piston is still coming up on compression. This will tend to force the piston down with the maximum pressure which will cause a loss of power and also may damage the engine structurally. If the

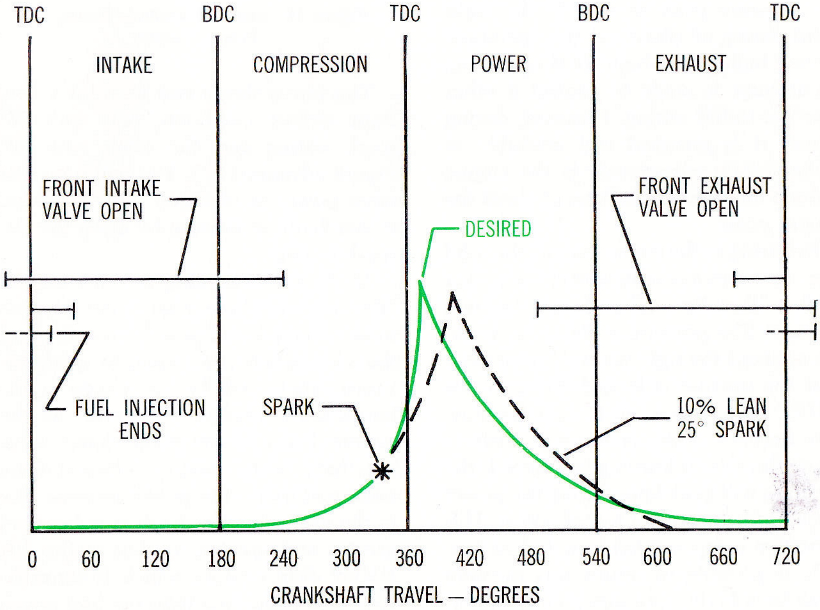

Figure 13—Cylinder Pressure Versus Crankshaft Travel

pressure should peak too late, too much after top center, then by the time the pressure peaks, the volume in the cylinder will be greater since the piston will have moved down further from top center; consequently, the actual pressure will be less. If the pressure peaks late, a certain number of degrees of the power stroke will have been wasted. The net result is a loss of power.

It is very difficult to obtain the optimum peaking of the pressure within the cylinder during all phases of the operation. Many variables are involved; for example, engine *RPM* which determines how much time is available for the mixture to burn. The higher the *RPM*, of course, the less time the mixture has to burn and the later during the power stroke will the pressure peak occur. Another variable is mixture strength. Rich or lean mixtures burn slower and cause the pressure to peak later than the fast burning "Best Power" mixture strength. It is not practical to compensate in the engine for all these variables and obtain the pressure peak at exactly the right point during all phases of the operation. During high power-high *RPM* operation, no attempt is made to control it other than the initial setting. However, during cruise, it is practical and desirable to make certain adjustments in the engine to keep the pressure peaking at about the proper point.

Referring to the curve, assume the solid line represents a condition at cruise power with a "Best Power," or fastest burning mixture. The pressure is shown as peaking at about the right point. Now assume that the mixture is leaned down to 10% *BMEP drop*. When this is done the mixture becomes a slower burning mixture. Since the rate of burning is reduced, the pressure will peak later during the power stroke with a resultant loss of power. This condition is represented by a dashed line.

It is possible to return this pressure peak back to the optimum point by igniting the spark earlier. If the spark is ignited sooner, more time will be made available for the mixture to reach its optimum peak. We advance the spark 5°, and the slower burning mixture resulting from the 10% *BMEP drop* setting will start burning sooner and reach its peak at just the right point.

The gain in horsepower can be shown on the following curve.

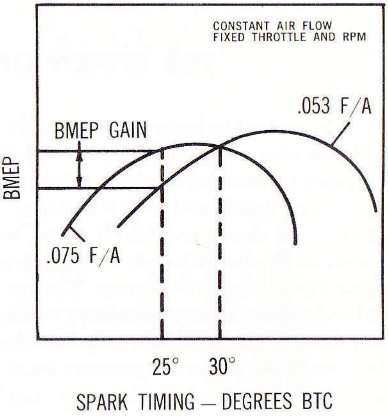

Figure 14—Effect of Ignition Timing on Power Output

This curve shows two lines for a constant airflow condition; one with 25° spark setting and the other with 30° (spark advanced 5°). You will note that more power is obtained with the lean, slower burning mixture by using the 30° spark setting.

At the faster burning mixture, around "Best Power," there is no power increase to be obtained, and power remains about the same when you switch to spark advance. There will be no change in the torquemeter reading. However, as the mixture becomes slower and slower burning; that is, as the mixture is leaned down more and more, the power increase due to the use of the spark advance becomes greater and greater, so that at the 10% *BMEP drop* mixture which is considerably slower burning than the best power mixture, there is a power benefit—a power gain of about 4 *BMEP*. Correspondingly, for the same power, the use of spark advance gives a fuel flow saving of about 10 lbs. per hour, per engine, with the slower burning mixture. So, fuel saving is one of the reasons for using spark advance, although not the main reason.

There is one disadvantage to using spark advance; if the mixture is ignited sooner, then the duration of the combustion period is longer; the burning takes place over a longer period of time inside the combustion chamber; the result is more heat generated inside the cylinder and higher cylinder head temperature. So spark advance requires the use of a little more cowl flap to maintain a given cylinder head temperature. However, since the burning takes place for a longer period of time, inside the cylinder, the resulting exhaust gas temperatures are lower. This is the main reason for using spark advance. Exhaust gas temperatures are reduced, with resulting benefits to turbine and parts in the exhaust system.

CRUISE MIXTURE

One of the procedures which has changed since the beginning of the DC-7 operation was the mixture strength specified for cruise. Initially we started using nothing but a 10% *BMEP drop* mixture strength. Then, in order to gain a little more airplane speed (higher critical altitude) a richer mixture of 7% *BMEP drop* was authorized under certain conditions, on a service test basis. It was shortly thereafter that signs of combustion chamber distress were seen; and since some of it was thought to be attributable to the use of the 7% drop mixture, it was discontinued.

We then tried leaning mixtures below 10% *BMEP drop.* This was known as *super-leaning* and was used as follows: The 10% *BMEP drop* mixture was set. If the engines were not at full throttle, the mixture was then leaned down further and the throttle simultaneously advanced, maintaining cruise *BMEP* until reaching full throttle or the maximum manifold pressure limit of 41 inches—whichever came first. The net result was engines leaned down below 10% *BMEP drop.* The cooler running heads permitted us to close the cowl flaps a little bit more and pick up a small amount of air speed. The exhaust gas temperature and the turbines ran cooler. The engine, as we have discussed previously, likes lean mixtures—the leaner, the better.

However, *super-leaning* was discontinued because of certain malfunctions in the fuel distribution system in the engine. The conditions which developed from these malfunctions are explained as follows.

FUEL DISTRIBUTION

The TC18 engine, as far as fuel distribution is concerned, is really two engines. One consists of the left injection pump for the rear row of cylinders, and the other consists of the right injection pump for the front row of cylinders. Each row of cylinders can be considered as an engine. Both rows, of course, are tied together to the same crankshaft; but as far as fuel distribution is concerned, each row is completely independent.

The basic function of the carburetor (or master control) is to meter fuel to the injection pumps, to determine how much fuel should be sent to the injection pumps and then into the engine. The carburetor on the TC18 engine is identical in operation to the carburetor on any modern spinner injection engine. In the TC18 engine, it's called a master control, but basically it's a carburetor and it works just like a carburetor. When a certain mass airflow is set, that is a certain manifold pressure and *RPM*, the carburetor is set up to meter a certain amount of fuel. It sends this fuel to both injection pumps. The function of the injection pumps is to divide the fuel flow from the carburetor exactly in half and deliver the fuel to the cylinders. The right injection pump sends its supply of the fuel to all the front cylinders, and the left injection pump sends its supply of the fuel to all the rear cylinders.

The carburetor controls the total amount of fuel which flows to the entire engine. Assume a certain airflow through the carburetor, such that the carburetor is set up to meter to the engine a total fuel flow of 800 pounds per hour. This means that each injection pump should take 400 pounds per hour and send that amount to its respective row of cylinders. In such a case, when the injection pumps are doing their job properly, each row of cylinders gets exactly the same amount of fuel.

Consider what happens in each row of cylinders as fuel flow varies, for constant airflow, using the familiar curve showing the effect of mixture strength on power. Fuel flow is plotted on the bottom scale and *BHP* is plotted on the vertical scale. In the case where the carburetor is metering a total of 800 pounds per hour, each pump taking 400 pounds, each row delivers half the power.

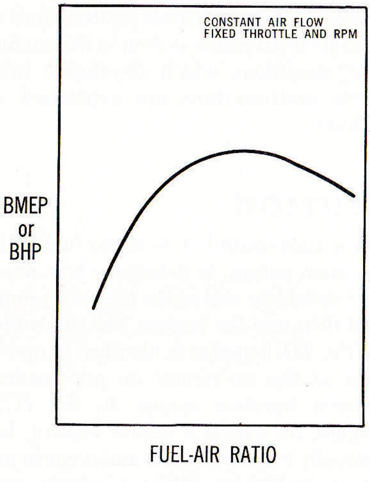

Figure 15—*BMEP* or *BHP* Constant Throttle—*RPM* Mixture Control Curve

With a fuel flow of 400 pounds, and a constant airflow, let us neglect the turbines and say the power produced in each row of cylinders is 900 *BHP*. That is the maximum allowable cruise horsepower per row of cylinders in high blower. Unfortunately, the injection pumps do not always divide the fuel exactly. The fuel injection pumps in the TC18 engine are new type pumps, compared to the injection pumps used in former 3350 engine models. The TC18 pumps are lightweight pumps, and have greater capacity. When they were first put into operation, it was found that some parts of the pump were wearing excessively, causing the pump to lean out. It was found also that another part in the pump was failing occasionally, causing the pumps to go out of balance, resulting in one pump metering too lean and the other too rich. Another factor which makes it possible for one pump to run lean and the other to run rich is poor synchronization. The injection pumps are mechanically connected by a synchronizing bar which is intended to keep the pumps properly synchronized so that each pump will take its full half share of the total fuel flow from the carburetor. However, the pump synchronization is not always precisely correct in which case one pump will run lean and the other will run rich.

If anything happens inside a pump causing it to run lean or rich, or if the synchronization between pumps is not correct, then one pump will always run lean and the other will always run correspondingly rich. Regardless of malfunctions inside the pump or of poor synchronization between pumps, the two pumps must still take the full fuel flow sent to them by the carburetor. In other words, if the carburetor is metering a fuel flow of 800 pounds per hour based on the airflow through it, both pumps must use that total fuel flow of 800 pounds per hour. If one pump only takes 300 pounds the other pump must take 500 pounds; in fact, if one pump were completely plugged, the other pump would be forced to take the total 800 pounds per hour. So if one pump runs lean, the other pump automatically richens up a corresponding amount. There is no such thing as two rich pumps or two lean pumps. The pumps are either matched without any spread between them (in other words, dividing the fuel flow evenly), or if they are not matched, one must run lean and the other must run rich.

Let us consider such a case on the curve previously used. Assume again that with the engine set to 10% *BMEP drop* mixture, the carburetor is metering a total fuel flow of 800 pounds per hour, but now one pump is running lean so that it will take only 300 pounds per hour rather than its normal share of 400. The other pump then will take 500 pounds per hour in order to make up the total of 800. This is shown on the following curve.

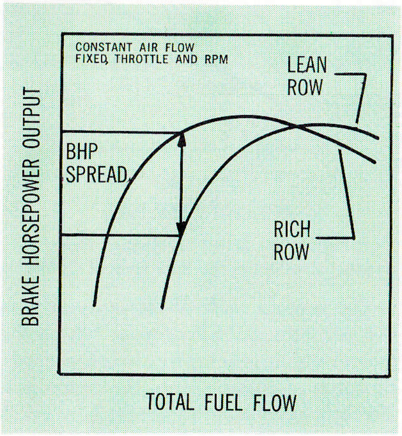

Figure 16—Change in Power Output for Lean and Rich Rows of Cylinders Versus Total Fuel Flow

The pump which is metering only 300 pounds per hour will supply that amount of fuel to its row of cylinders. All cylinders receive exactly the same amount of combustion air, assuming that the air distribution in the engine is even. Therefore, the row of cylinders which is supplied by the lean pump receives less than its normal share of fuel flow and will be low in power. It will fall farther down the slope of the curve. This row of cylinders, let us say, will produce only 700 *BHP* rather than its normal 900 *BHP*. The other pump will be supplying its row of cylinders with 500 pounds of fuel. This row of cylinders will produce more than its normal share of the power since it falls farther up on the curve closer to "Best Power". Since the torquemeter in this case is being set at 177 *BMEP*, or at a total of 1800 *BHP* if the lean running row produces only 700 *BHP*, then the rich row must produce 1100 *BHP*. The lean row likes this condition; it is not being called upon to produce the maximum allowable cruise power. The rich row, however, in this case is overpowered by approximately 200 *BHP*. Such a condition will cause damage to all the rear row cylinders, and this condition has been the major cause of combustion chamber difficulties in our operation of the TC18 engine.

This condition not only causes the rich running row of cylinders to be over-powered, but shows up also on the curve which gives the effect of mixture strength on cylinder head temperature in Fig. 17.

Plotting the same condition on this curve, you will note that the lean running row, in addition to putting out a relatively low power, also is running at relatively low exhaust gas and cylinder head temperatures. This means that the exhaust valves and the interior of the combustion chamber in all the cylinders in the lean running row have low temperature. These cylinders like such a condition—low power and low temperature. However, the rich running row is operating not only at excessively high power, but the cylinders are also operating at excessively high temperatures. Therefore, the condition of excessive spread between injection pumps results in damage to the rich running row of cylinders.

On some engines that have been torn down at the *AA* Maintenance Base at Tulsa it was noted that one row of cylin-

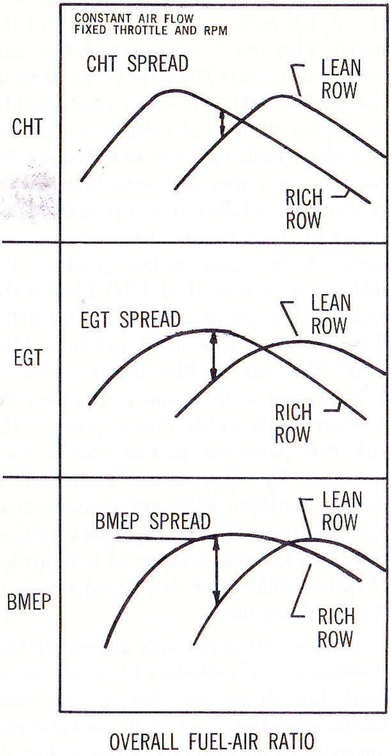

Figure 17—Change in *CHT, EGT,* and *BMEP* for Lean and Rich Rows of Cylinders Versus Engine Fuel-Air Ratio

ders was completely clean and looked very good. It was also noted that the other row of cylinders in the same engine showed indications of over-powering and high temperature. In some cases, all the pistons were burned and piston pin struts were cracked. This was seen time and time again. Tracing back through the records, it was found that such engines had been operated for rather long periods of time with injection pumps having an excessive spread between them.

When this condition exists, the damage to the rich running row becomes worse as the engine is run at leaner and leaner overall mixtures. In other words, if the engine is run for some period of time at a 10% *BMEP drop* mixture and there is an excessive spread between the injection pumps, a certain amount of damage will be done to all the cylinders in the rich row. However, with the same spread between the injection pumps, if the engine were run at a 14% *BMEP drop* mixture instead of 10% drop, the damage to the rich running cylinders would be greater. This is shown on the following curve:

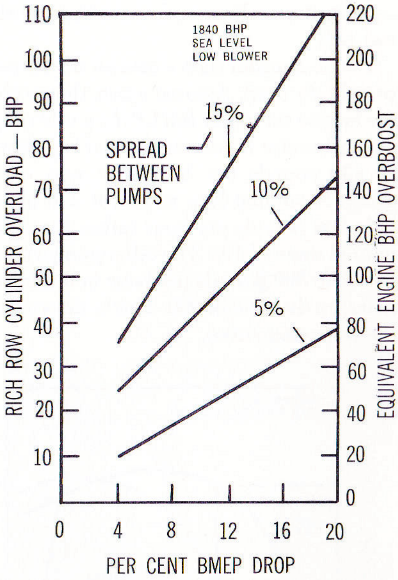

Figure 18—Effect of Injection Pump Synchronization on the Rich Row of Cylinders

The bottom scale of this curve shows the per cent *BMEP drop* at which the overall engine is being run; in other words, the mixture strength set by the flight crew. The left hand scale shows by how much horsepower the rich row is being overloaded. The lines plotted on the curve represent different per cent spread between pumps—spread between pumps being defined as the amount of fuel flow by which the pumps vary. The zero per cent spread, of course, represents the condition where the pumps are dividing the fuel from the carburetor exactly evenly and each pump is flowing the same amount of fuel to its row of cylinders. Assume that the spread between the injection pumps is 15 per cent. The curve says that if the engine is being operated at a 10% *BMEP drop* mixture, with the 15% spread between pumps, the rich row of cylinders will be overloaded by a total of 65 horsepower. If the engine is being operated at a leaner mixture strength, say 16% *BMEP drop,* then the rich row of cylinders will be overloaded by 95 horsepower. In other words, when the injection pumps are not completely balanced and there is a spread between them, the rich row will become more and more overloaded as the mixture is leaned out—as the engine is operated at leaner mixtures. This is the reason and the only reason that *super-leaning* was discontinued. It is emphasized that basically the engine likes lean mixtures—the leaner the better. However, in cases where there is excessive spread between injection pumps, damage to the rich row of cylinders becomes more and more aggravated as the engine is operated at leaner and leaner mixtures. The rich running row suffers. The lean running row in such a case gets along fine. In cases of excessive spread between injection pumps, there has been no evidence of any difficulty in the lean running cylinders. The damage has always been found in the cylinders in the rich running row.

As the bugs are worked out of the injection pumps, and better methods for setting and maintaining synchronization between pumps are developed, it will be possible to hold the spread between the pumps within 4 or 5%. At such a time it may be decided again to operate the engine at mixtures leaner than 10% *BMEP drop.* For the present, however, until the spread between the pumps can be closely controlled, we will continue to operate at cruise power no leaner than 10% drop mixture.

Since this condition is so serious, we should have some way of detecting when the injection pumps are not together. Theoretically, there are several ways in which this could be accomplished. First of all, if it were possible to put a torquemeter on each row of cylinders, it would be easy to note which row was overpowered and which was under-powered. This, of course, is not feasible. It would be considered more practical if a flowmeter could be installed just upstream of each injection pump so that the fuel flow through each injection pump could be measured. This could be done and, in fact, was done for some flight test work conducted by the Douglas Company along with the Wright Company in order to investigate this problem. However, in order to do the job properly, this flowmeter must be extremely sensitive, much more so than the flowmeters which are now installed in the DC-7. Such a flowmeter installation could be made on all our engines, but it would be prohibitively expensive; particularly in view of the fact that there is another way—and a very simple one to determine in flight when the injection pumps have excessive spread. This method is to read the cylinder head temperature of each row of cylinders. If one pump is running lean (at cruise mixture) its row of cylinders will show relatively low head temperatures, whereas the cylinders for the rich running pump will show relatively high cylinder head temperatures. This is the reason that a dual cylinder head temperature gage was installed on the DC-7.

At the time the dual CHT gages were installed, you received a Bulletin which stated that it was not yet known what the normal spread between rear and front indications should be, and that the only way to tell if one row were excessively hot or cool, was to compare the readings of that engine with the readings of the other engines.

Shortly thereafter, it was requested that flight crews record certain cruise data in AUTO-RICH, immediately followed by similar readings with the mixture set at 10% *BMEP drop.* The purpose of this request was threefold. It was intended to accomplish the following: First, it was desired to establish the normal spread between the rear and the front row of cylinders. Secondly, it was desired to determine which injection pumps had excessive spread and to fix them. Third, it was desired to develop maintenance procedures which would be most effective in bringing the injection pumps with excessive spread back into line. Readings accumulated on the flight engineer logs and the application made of this data by maintenance resulted in complete success of the program. We now have good maintenance procedures for bringing injection pumps closer together where an excessive spread exists. We have removed all the bad pumps from the engine, and now have a good idea what the normal spread between cylinder head temperature readings, front and rear should be. This normal spread is shown on the following curve.

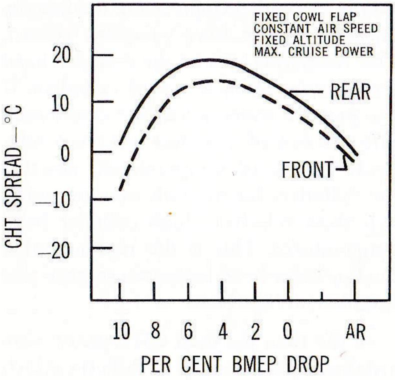

Figure 19—Normal Cylinder Head Temperature Spread Versus *BMEP Drop*

This curve shows on the bottom scale the mixture strength or *BMEP* drop at which the overall engine is set. It shows, on the left scale, the spread in cylinder head temperature between the rear and the front row with a normal engine. Note first, that at all mixture strengths between AUTO-RICH and 10% *BMEP drop* the rear row normally runs hotter than the front row. This is a characteristic of radial engines. The front row of cylinders receives the initial impact of the cooling air, it benefits from the swirling and scrubbing action of the air as it first hits the cylinder and is made turbulent by the propeller. The front row naturally has a tendency to run cooler as is shown on the curve. Note that with the mixture in AUTO-RICH the rear row runs just a few degrees hotter than the front row, and with the mixture set to 10% *BMEP drop* the rear row runs 10° to 15° hotter than the front row. These curves have been drawn up on the basis of hundreds of readings taken from flight engineer logs and are considered quite accurate for the TC18 engine as it is presently set up in our operation.

Let us consider how this curve will change in the event that the injection pumps have excessive spread between them, if the rear row should run rich or if the front row should run rich. Consider first the effect of such a condition on the cylinder head temperature.

In the case where we have a rich left pump the rear row will run the coolest in AUTO-RICH, depending of course on the amount of richness. Normally the rear row runs slightly hotter than the front (equal distribution) because of a slight difference in cooling characteristics between the front and rear rows. If the pump is exceedingly rich to the point where the rear row is running cooler than the front then we can expect trouble when we try to lean. Starting in AUTO-RICH we can imagine both rows as having mixtures which are on the rich side of best power. As the mixture is retarded toward AUTO-LEAN both mixtures approach best power, however; the lean row which in this case is the front row will reach best power first and will lead the rear row all along the mixture strength curve with the end result being that at 10% lean (overall engine) the front row will be much farther away from best power than the rear row on the lean side of the curve.

Basically we can consider each row as a separate and distinct engine and in this case each engine is operating on a different fuel air ratio. From the mixture strength curve we can see that each engine (row) is operating at different power levels and from the fuel-air ratio versus engine temperature curves it is evident that each must also be operating at different temperature levels. This unbalance in power and temperature is very detrimental to engine life and this is why the Wright Corporation believes that basically standardization and good operating techniques in regard to manual leaning and all other operational phases are a large step in the procuring of maximum service from their engines.

The mixture strength relationships which have been presented previously are very basic but are nevertheless sometimes misunderstood. It has been found that relations which at first might seem complicated are sometimes simplified if shown in graphical form and this is why we use graphs so frequently.

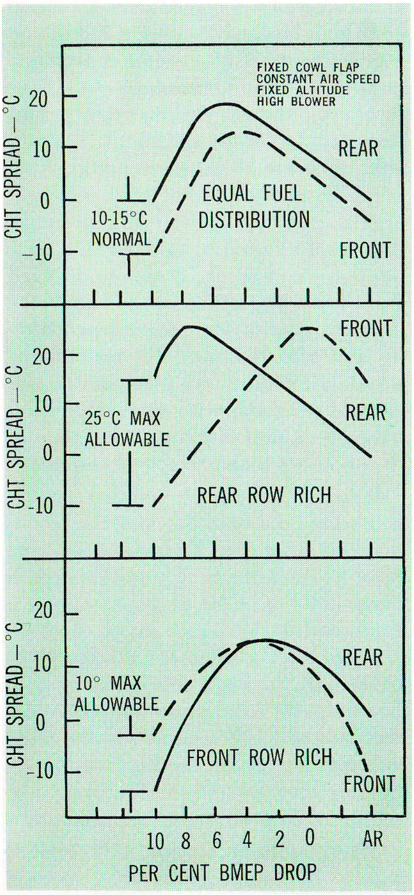

Figure 20—Normal and Allowable Cylinder Head Temperature Spreads Versus *BMEP Drop*

The curves in Figure 20 show spreads between front and rear row for various mixture strengths:

These curves show three conditions. The one on the top is the normal spread between front and rear row with equal fuel distribution. The one in the center shows what the relationship is between front and rear row if the rear row is rich. The curves on the bottom show the relationship if the front row is rich.

Consider the case where the rear row is running rich—note that with the mixture control in AUTO-RICH the rear or rich running row being excessively *fuel-cooled* is the cooler of the two. Whereas, when the mixture is leaned down to 10% *BMEP drop,* then the front or lean running row is the cooler because it is excessively *air-cooled.* Note also, that in such a case where there is excessive spread between pumps there is always a characteristic cross-over of the two lines. It may occur as shown in this particular curve at about a 3% *BMEP drop,* or it may occur richer or leaner. The cross-over point will occur at various mixture strengths depending on how much spread exists between the injection pumps. The point of cross-over is not important. What is important is the fact that the cross-over does occur. When the cross-over does occur, it is an indication of trouble. Note in the bottom curve, which shows front row rich, that the same thing occurs. With the mixtures in AUTO-RICH, the front or rich row is cooler; with the mixtures at 10% drop the rear or lean row is the cooler, and a cross-over occurs.

Some tolerance between injection pumps must be expected due to normal wear and normal tolerances in synchronizing the pumps and setting them up. It is necessary to permit some tolerance, but still establish limits so that the worst offenders can be fixed or removed. Limits have been established and are shown on the previous curve.

The limits which we will use all relate to operation with the engine set at 10% *BMEP drop* in high blower only. There is a difference in *CHT* spread characteristics between low and high blower, and only the limits for high blower are used. As shown on the curve, the normal spread is 10-15° with rear row hot. If the rear row should become rich—in other words, if the left pump should start running rich and the right pump start running lean—then the rear row will become hotter than the front row, by increasing amounts as the pumps go more and more out of spread. At 10% *BMEP drop* the limit shown is 25°C. Anytime a rear row is running more than 25° hotter than the front row with mixtures set at 10% drop, then the engine is out of limits. In the case of the front row rich, only a 10°C spread is permitted. Anytime the front row runs more than 10°C hotter than the rear row with the engine set at 10% drop, then the engine is out of limits.

If this check shows an engine to be out of limits, it should be written up in the log book and maintenance will then take appropriate corrective action. However, the maintenance action is rather lengthy and the first action taken may not cure the trouble. Maintenance has a program consisting of some 10 or 12 different steps. They don't do all the steps initially. This would take too long and would require that the airplane be grounded for a day or so. When an airplane comes into an equipment termination station with such a complaint written up in the log book, maintenance personnel first review the past history by checking through the log book and the flight engineer logs for the past several flights. They then complete the first few steps of their program and release the airplane. They wire ahead to the next terminating station advising them what has been done, and they also wire the Tulsa base, advising their action so that suitable records and checks can be kept. The data is then recorded on the next flight; and if the engine is still out of limits, the complaint is again written up in the log book. At the next equipment termination point maintenance personnel accomplish the next few steps in the procedure, and so on until the complaint has been fixed.

The reason it is permitted to let the engine continue to operate even though it may be out of limits is that the condition is not one which results in a rapid engine failure. The engines which were found to be substantially damaged were not 20, 30 or 40 hour engines; they were 300, 400 or 500 hour engines. The engine can operate quite satisfactorily for short periods of time even though the injection pumps may have excessive spreads. It is desirable, of course, to get the condition fixed as rapidly as possible, but it will not result in engine failure or even serious engine damage if allowed to exist for 3, 4, or 5 days or even a week. Therefore, it is felt that the most practical way to handle the problem, considering engine dependability and also the need for maintaining schedule, is to do it on a progressive maintenance program, with each equipment terminating station doing several steps of the necessary maintenance procedure.

It should be remembered that maintenance has no way of checking this condition on the ground. Cylinder head temperature spreads during ground operation mean nothing as far as this condition is concerned. Maintenance has no checks at all—they rely completely on the data given to them by the flight crews. Therefore, it becomes more and more important that the data which is recorded in the flight engineer log and in the log book be extremely accurate and that the engine be set up to precisely the correct mixture.

When taking readings at AUTO-RICH and 10% *BMEP Drop*, it is most important that certain things be held constant—cowl flap setting, air speed, altitude and power.

With the exception of mixture strength any condition which affects cylinder head temperature should be maintained constant until the 10% drop reading has been taken. What we are trying to obtain is the effect of mixture strength on cylinder head temperature. If either the cowl flap setting, air speed, altitude or power is changed, then a second variable is thrown into the picture and results only in confusion.

It is important also that when the 10% drop mixture is set, it be carefully set to precisely 10% drop. If the mixture is set inadvertently to 6%, for example, then true readings will not be obtained. Assume for a moment that the condition is a rear row rich condition and that the engine actually is out of limits at 10% *BMEP drop;* let us say there is a 30° spread rear row hot at 10% drop. If the engine were set to the wrong mixture—to 6% *BMEP drop*—then because the lines converge with such a condition the head temperature spread might be well within limits, perhaps only 15°, and the engine would be considered normal; however, it would not be a normal engine.

The question has been asked—if the limits pertain only to operation at 10% *BMEP drop,* then why do we need an AUTO-RICH reading? The answer is this: Consider a case where the readings at 10% drop show that the rear row is out of limits, about 30° hotter than the front row. If an AUTO-RICH reading were not taken, such a condition would be reported in the log book and maintenance would proceed with various checks they have to correct excessive spreads between the injection pumps. However, it is entirely possible that such a condition can exist because of reasons other than spread between injection pumps. For example, if an AUTO-RICH reading were taken in such a case and showed up also as rear row hot without the characteristic cross-over, then the trouble could be immediately attributed to the cylinder head temperature indicating system. This is shown in Figure 21.

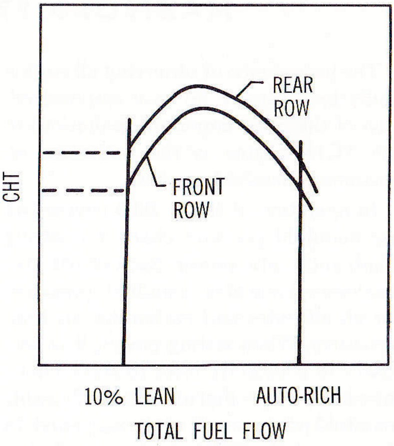

Figure 21—Malfunctioning Thermocouple

Note that the rear row is hot during the entire range of mixture strength, and there is no characteristic cross-over. Maintenance would immediately go into the cylinder head temperature indicating system and get the complaint fixed right away. They would not have to waste time trouble-shooting the injection pumps. Therefore, the AUTO-RICH reading is considered extremely important.

It should be remembered also that excessive spread between head temperature readings can be due to things other than injection pump problems; for example, a loose intake pipe on one of the cylinders on which the thermocouples are attached would give readings outside of limits at 10% *BMEP drop.* Therefore, the problem is not a simple one and sometimes it takes quite some investigation in order to track down the actual trouble. However, maintenance procedures have been well developed and maintenance personnel have all been trained in this important aspect of trouble-shooting and fixing the TC18 engine. If the flight crews also continue to do their part and record data accurately, we are quite confident that combustion chamber problems due to this particular cause will soon be reduced to a minimum.

MANIFOLD PRESSURE LIMITS

The importance of observing all engine limitations cannot be over-emphasized. One of the most important limitations in the TC18 engine is the limitation on maximum manifold pressure.

In operation of the R-2800 engine, we use manifold pressure charts for setting climb and cruise power. Such charts give maximum allowable manifold pressures for all altitudes and carburetor air temperatures. When setting power, it is necessary to constantly refer to these charts in order to assure that maximum allowable manifold pressure will not be exceeded. In the case of the TC18 engine, we do not use such charts. We use instead certain manifold pressure limits for climb and for cruise. The climb limit is 40″ in low blower and 43″ in high blower. The cruise limit is 41″ for both low and high blower. These manifold pressures are not to be exceeded at any altitude or carburetor air temperature, and represent protection against over-boosting the engine. Under many conditions, the standard climb or cruise power can be obtained at manifold pressures very much below the maximum limits, but a check should always be made to assure that maximum allowable manifold pressure is never exceeded.

Another manifold pressure limit, and perhaps an even more important one, is the limit on maximum allowable manifold pressure *spread.* The *AA* DC-7 Operating Manual states that if for the same *BMEP* and *BMEP drop* the manifold pressure of any engine exceeds any other engine by more than 2″, a malfunctioning engine is indicated. In such cases retard the throttle of that engine to a manifold pressure equal to the average of the other engines and leave the mixture set at 10% *BMEP drop.* The malfunctioning engine will thus be operated with its BMEP reading lower than that of the other engines.

This limit is an extremely important one. If all four engines were operating in exactly the same manner and if all instruments were reading correctly, the manifold pressure gages, the *BMEP* gages and the flowmeters of all four engines would read exactly the same with normal climb or cruise power set. With the same manifold pressure set and the same fuel flow or *BMEP drop* set, each engine should put out precisely the same amount of power and, theoretically, all four torquemeters should read exactly the same. If an engine is malfunctioning in any way, it will be low in power; therefore, with the same manifold pressure and fuel flow set on all four engines the malfunctioning engine will indicate a lower *BMEP* output; or if the throttle were advanced on a malfunctioning engine to bring its *BMEP* up to the other engines, then the malfunctioning engine would require more manifold pressure than would the other three engines. If additional manifold pressure is required on any engine to obtain power, everything else being constant, then something is wrong—either instrumentation or engine.

Anytime this condition exists, no matter how small the additional manifold pressure required may be, the flight crew should be alert to the fact that there is a possibility of a malfunctioning engine, and they should monitor the engines very carefully and attempt to trouble-shoot the difficulty as accurately as possible. If an engine requires more than 2″ higher manifold pressure than the other engines, then it is a sure sign that something is seriously wrong, in which case the throttle of that engine should be retarded as previously specified.

Assume a case where two cylinders are inoperative and the total engine power output is the result of the work done by sixteen cylinders instead of eighteen. It would be possible, below critical altitude, to obtain the desired horsepower by advancing the throttle until the BMEP gage read the proper number, but in the case of this engine with two dead cylinders, the horsepower would be developed by only sixteen cylinders, each of which would be over-powered. This type of condition can be avoided by observing the 2″ MAP spread limit. When the throttle of the malfunctioning engine is retarded back to the average of the other engines, then the torquemeter of the malfunctioning engine will read lower than the BMEP gages of the other engines, lower by the amount of the power loss due to the malfunction; but at least each of the operative sixteen cylinders will then be working at their normal limits and not way above them.

Of course, there are many other types of malfunctions which can cause an engine to require additional manifold pressure in order to produce power. Since an engine is basically designed to produce power, any malfunction in the engine will result in a power loss. There are also many types of serious malfunctions which will be within the two inch manifold pressure spread—for example, one dead cylinder. With a dead cylinder it may require only 1″ or 1½″ additional manifold pressure to obtain the power, depending upon the reason the cylinder is dead. If a cylinder is dead because of two fouled spark plugs, and the cylinder is still tight, the engine may require just under 2″ additional manifold pressure to produce the power. A certain amount of power will be required to move the piston of the dead cylinder up on the compression stroke. This cylinder will be contributing no power to the total output of the engine, but will be taking power away because of the friction horsepower required to operate its piston. If the cylinder were dead because of a loss of compression, in the case of a swallowed exhaust valve, then much less power is required to move the piston of the dead cylinder up on the compression stroke. Therefore, the total friction horsepower of the engine will be less and it may require only 1″ or 1½″ additional manifold pressure on that engine to produce the power. In either case the dead cylinder would still result in engine operation with higher manifold pressure required, but still within the 2″ manifold pressure spread limit. Such an engine should be examined very carefully even though it is within the two inch manifold pressure spread limit, and, if the crew is certain that the engine is malfunctioning, then the throttle of that engine should also be retarded to the average of the other engines, or even less.

Anytime an engine is suspected of malfunctioning, even though the malfunction may not be completely obvious, or may be within limits, it is always a good idea to throttle back that engine and operate it at reduced power if schedule and operating conditions permit. In any case the 2″ manifold pressure spread is to be considered as the final protection against over-boosting a malfunctioning engine. It is an extremely important limit and should be carefully observed at all times.

CARBURETOR ICE

The type of icing which you can expect in the TC18 installation is the same as the type of icing expected in the DC-6 or Convair or any installation with a similar type of carburetor. That is, impact tube icing: Icing of the small tubes which control the air metering of the carburetor. Icing of the impact tubes (or icing around the automatic mixture control needle, which can accompany impact tube icing) results in an upset of the air metering forces in the carburetor—an upset in such a direction that the carburetor tends to lean down. The mass airflow through the carburetor and into the engine does not change; the manifold pressure remains the same; however, if the carburetor leans down—if the fuel flow which the carburetor sends to the engine is reduced—and the mass airflow remains the same, there will be a power change. In cruise this will be a power loss. The common symptom of this type of icing is a reduction in fuel flow and a corresponding reduction in *BMEP*. If the icing becomes severe, the torquemeter and the flowmeter may start oscillating; and if the icing is allowed to go too far, the engine may cut out because of lack of fuel.

The TC18 is no more susceptible to this or any other type of icing than is the R-2800, but the TC18 is more *sensitive* to this type of icing—not because of anything peculiar to the construction of the engine or the installation, but only because the TC18 is operated in cruise with leaner mixtures. Refer once again to the familiar curve showing the effect of mixture strength on power.

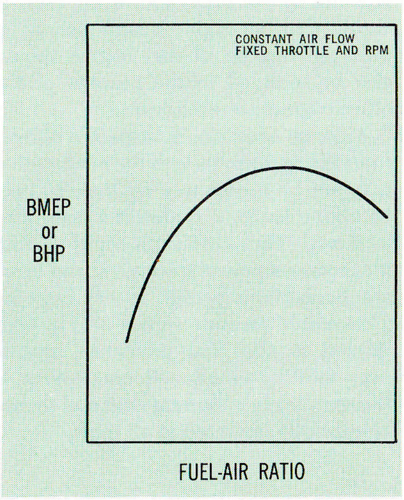

Figure 22—*BMEP* or *BHP* Constant Throttle—*RPM* Mixture Control Curve

Note that if an engine is being operated close to the best power mixture strength, small changes in fuel flow have practically no effect on *BMEP*—the curve is quite flat in the vicinity of one or two *BMEP drop* mixture strength which we have been using in much of our DC-6 operation. Therefore, the engine can tolerate reasonably large amounts of impact tube icing and resulting changes in fuel flow without the condition being noticeable on the *BMEP* gage. The fuel flow may be reduced by icing by 10 or 15 pounds, and the torquemeters will probably not change at all. In the case of the TC18 engine, where we operate at 10% *BMEP drop* on a much steeper portion of the curve, note that very small changes in fuel flow will cause large changes in *BMEP*—as a matter of fact, if the fuel flow on this point of the curve is changed by even 5 pounds—amounts not even readable on our flowmeters—the *BMEP* may change as much as 10 or 15. Therefore, we say that the TC18 engine is much more sensitive to anything which affects fuel flow—for example, impact tube icing. It is more sensitive, not because it's a TC18 engine, but because it's an engine being operated at relatively lean mixtures.

Another characteristic of the TC18 engine, as far as icing is concerned, is that if a TC18 engine is allowed to ice up badly, it may quit suddenly without giving any warning. This is due to the good fuel distribution of the TC18 engine. In the case of a spinner injection engine, if the carburetor should ice up badly, you will get some warning because as the engine leans down to the point of no run, individual cylinders will begin to cut out. All cylinders won't cut out at once because the fuel distribution is not completely even; and as individual cylinders cut out, you will get warning in the form of engine roughness. In the case of the TC18 engine it is quite likely that many cylinders will cut out at the same time in cases of severe icing. In a case of that type the engine will quit suddenly without giving any warning. This condition is usually preceded immediately by a rapidly oscillating flowmeter and *BMEP* gage.

The procedures to be used in the TC18 engine for preventing and removing ice are identical to the procedures used in the R-2800 engine. Carburetor heat is best used as a preventative measure. If carburetor heat is applied in accordance with instructions in the *AA* Operating Manual prior to entering an icing condition, it is unlikely that the carburetor will ice up. If the temperature of the air in the induction system in the vicinity of the carburetor is kept well above the icing level, there is no possibility of ice forming, since there is practically no temperature drop in the induction system between the carburetor and impeller. The most temperature drop which could be expected would be in the order of about 5° which might be the case under a severe condition such as fully closed throttles and high *RPM*, with a large pressure drop across the throttles and a very small temperature drop; but other than that, the temperature in the induction system between the carburetor and the impeller remains substantially the same. Therefore, if the proper *CAT* is maintained, there should be no ice formation any place in the induction system between the pre-heat door and the engine.

If ice does form, of course, pre-heat should be applied as required to remove the ice, up to full pre-heat if necessary. There is no limit on the amount of pre-heat which may be applied in the case of ice which must be removed in emergency. High pre-heat should be applied for as short a period of time as possible, but as much pre-heat may be used as is required.

Before applying pre-heat or before taking heat off, the mixture should normally be placed in AUTO-RICH for a few minutes to permit stabilization of the automatic mixture control. The TC18 engine has, in effect, two automatic mixture controls—the standard pressure compensator similar to the AMC in the R-2800 and a new one, which is a temperature compensator, intended to offset, as much as possible, the effects of rapid temperature changes in the carburetor. This temperature compensator makes the TC18 carburetor less sensitive to these temperatuer changes; but, nevertheless, in order to provide proper stabilization periods for both AMC's the mixture should be placed in AUTO-RICH prior to applying heat. After several minutes have elapsed permitting AMC stabilization, the mixture should be returned to the 10% *BMEP drop* setting if pre-heat is going to be needed for any length of time. Prior to removing the heat, the mixtures should again be placed in AUTO-RICH, the heat controls returned to Full Cold, several minutes allowed for AMC stabilization and then the mixtures reset to the 10% *BMEP drop* value.

In the TC18 engine the pre-heat control should be operated as required to obtain the desired carburetor air temperature—up to full heat if necessary. Under some conditions of operation, for example during flight in heavy wet snow, the desired carburetor air temperature may not be obtained even with the controls in the FULL HOT position. This can be attributed to the cowl flap openings normally used on the TC18. The engine generates a certain amount of heat—part of which is available for use in the carburetor as carburetor pre-heat. If cowl flaps are partially open, much of the engine heat is dissipated through the cowl flaps and, therefore, is not available to the carburetor. Cowl flaps should be closed if necessary to obtain additional pre-heat after the pre-heat control has been moved all the way up to FULL HOT, and under those conditions cowl flaps should be closed as much as required down to the fully closed position.

It has been found that because of electrical lag in the system, occasionally when the automatic cowl flap control is placed in the full closed position, the cowl flaps will not actually fully close. If it should be necessary to fully close the cowl flaps in order to obtain adequate pre-heat, they should be closed with the manual toggle switches. Under all conditions the combination of full pre-heat and cowl flaps full closed should provide adequate carburetor air temperature.

It is permitted—however, as a last resort—and as a last resort only—to slightly richen the mixtures from 10% drop, if still more carburetor heat is needed. This procedure is not desirable because, as you know, mixtures between 10% *BMEP drop* and AUTO-RICH should be avoided. But, our procedures state that if still further heat is needed, the mixtures may be richened from 10% to 7% *BMEP drop.* This will result in a carburetor air temperature increase of only 2° to 4°C. It is practically negligible, and richening of the mixture for this purpose should not be done unless it is absolutely essential that several degrees of additional carburetor heat is obtained. It is emphasized that this is a last resort measure only and will only produce a very small increase in carburetor air temperature.

Of course, we know that additional carburetor heat could be obtained by richening the mixture further to "Best Power". However, this would most certainly damage the engine. With carburetor pre-heat applied the engine is more susceptible to detonation than in any other phase of operation, particularly in high blower. If cruise power were held with carburetor heat in high blower and the mixtures were richened to "Best Power", the engine would be certain to detonate and would be seriously damaged. It is not permitted to operate between 7% drop and AUTO-RICH at any time. The mixture should be even more carefully considered with carburetor heat applied. That is one reason that 7% *BMEP drop* is mentioned as a last resort only.

One of the difficulties of operation with carburetor heat applied is the difficulty of maintaining a stable mixture, and the mixtures may initially be set to a 7% *BMEP drop* but, because of the movement of the AMC's, may drift to richer 5% or 3% mixtures. With pre-heat applied this, of course, is a bad situation. Therefore, any operation between 10% and AUTO-RICH should be avoided if possible.

Normally, however, when carburetor heat is applied, either reset the mixtures to 10% drop or leave the mixtures in AUTO-RICH—either position is satisfactory as far as the engine operation and protection from detonation is concerned. It may be that with excessive amounts of heat the engine will be slightly unstable at 10% drop—in such cases it is permitted and recommended to move the mixture controls to AUTO-RICH and operate in AUTO-RICH until the pre-heat is no longer needed.

Carburetor alcohol in the TC18 engine is considered in the same light as in the R-2800. Carburetor alcohol is a necessary means of de-icing a carburetor. It is not nearly as effective as carburetor heat and should be used only in cases where it is felt that carburetor heat is not doing the job. Some crews have a distrust of the carburetor heat system and a corresponding feeling of confidence in the alcohol system for the following reasons: Take the case of an engine that is normally operated at 10% *BMEP drop.* If impact tube ice should form, the mixture will lean down and the *BMEP* will drop. Carburetor heat will be applied. The application of heat will cause a further power loss for two reasons: First, operation of the preheat door reduces the ram available; and secondly, the increase of temperature decreases the air density. Both of these factors will reduce the power even further. It is felt by the crew member, perhaps, that the reduction of *BMEP* was an indication of further icing or at least an indication that the ice had not been removed, so he applies additional heat with a corresponding further loss of *BMEP*—for the same reasons mentioned above. By this time the ice may have been removed completely and the low *BMEP* may be due only to the ram loss and to the leaning of the mixture. Also, at this time the engine is operating quite lean—way down the lean side of the curve—possibly even to the point of almost cutting out, but in any case, very lean.

At about this point the crew member decides the carburetor heat isn't doing the job for him so he takes off the carburetor heat and applies alcohol. The instant that he touches the alcohol switch, the *BMEP* gage immediately rises a large amount, say 20 *BMEP*. The crew member has visions of a great flood of alcohol washing down the sides of the induction system and taking all the ice with it, clearing out the system completely and removing all the ice. What has actually happened, of course, is this—the ice probably had been removed a long time ago by the application of heat; and when the alcohol was sent into the system, it had the same effect as richening the mixture. It brought the power back up not because of removing ice, but merely because it richened the mixture from a very lean setting to, perhaps, a "Best Power" setting.

Pre-heat should be relied upon as the primary source of ice prevention and ice removal, and alcohol used as a secondary system. One precaution here—alcohol and pre-heat should never be used together. If it is desired to use alcohol, the pre-heat should first be removed; if pre-heat is applied and the alcohol is then sent into the system, the heat will vaporize the alcohol, making it less effective. In addition to that the heat required to vaporize the alcohol will result in a temperature reduction in the pre-heat system. If alcohol and pre-heat are used together, the alcohol will be rendered useless and the carburetor air temperature actually will be lowered a considerable amount. Therefore, any time it is desired to use alcohol, first return the pre-heat control to the FULL COLD position.

IGNITION ANALYZER POLICY WITH ONE DEAD CYLINDER

In past operations of *AA* R-2800 engines there have been many cases where one cylinder has been inoperative and engine operation has been continued with the *BMEP* of the malfunctioning engine indicating lower than the other engines. This condition is usually written up in the log book, but no major action is taken in flight. In the case of the TC18 engine, we have an additional tool which helps us see more of what is going on inside the engine—that is, the ignition analyzer. This tool will show us many cases of cylinder failures of the type which, if allowed to progress, will eventually result in total engine failure.

Our past records of TC18 engines have shown that many engine failures started as cylinder failures; cylinder failures of a type which resulted in or were caused by mechanical failure of certain parts inside the cylinder. For example, if an exhaust valve is swallowed, it will drop into the cylinder and will be broken up into many small pieces by the piston. Eventually the pieces will go out through the exhaust system, through the turbine and out of the engine. During the process of being broken up, however, the valve damages the piston—it will soften the piston, crack it or put a hole through it. The small pieces of valve flying around inside the cylinder usually hit both of the spark plugs peening the electrodes together causing a dead short. Other types of failure which can also peen spark plugs are top ring land failures, top ring failures, edges of the piston chipping off, any type failure which ends up with metal flying around inside the cylinder. Our experience has indicated that perhaps 95% of such types of failure will actually cause peened spark plugs. This condition of peened spark plugs can be seen on the analyzer as a typical secondary short, which, fortunately, is the easiest of the malfunctioning patterns to recognize. The pattern is shown in Figure 23.

When this pattern is seen on both spark plugs in a cylinder and is accompanied by a low *BMEP* gage reading for that engine, you can be quite certain that a mechanical failure has occurred inside the cylinder and will very likely result in a complete engine failure. If the piston is cracked, it will eventually break through,

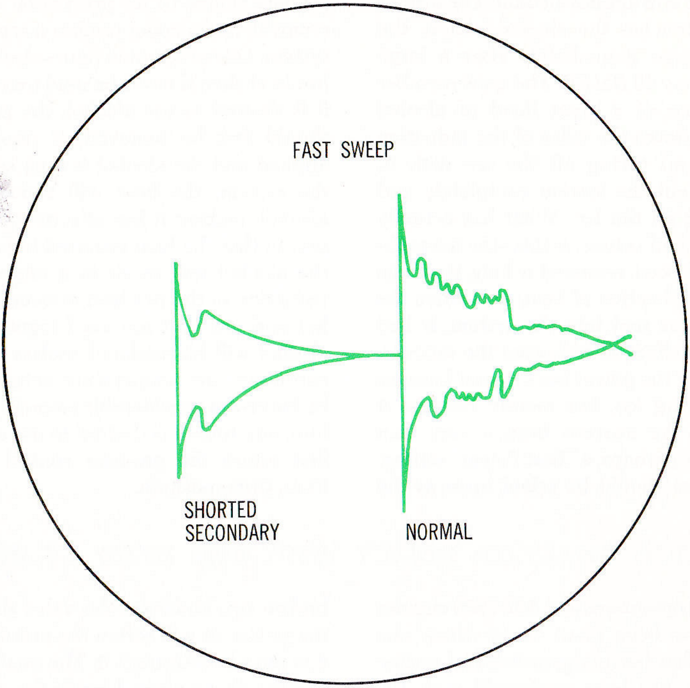

Figure 23—Comparison of Ignition Analyzer Patterns Between Normal Spark Plug and One with a Shorted Secondary—Fast Sweep

pieces will drop down into the engine and wipe out the entire engine. If a malfunction is identified on the analyzer as a shorted secondary pattern on *both* plugs of one or more cylinders, accompanied by a low *BMEP* reading, the engine should be shut down immediately, operating conditions permitting. This type of shut down should be considered operationally in the same light as any other precautionary shut down—for example, a shut down due to high oil consumption. Occasionally operating conditions preclude the possibility of shutting down the engine, or require the use of the engine; but as long as operating conditions permit, the engine in such cases should be shut down. Prior to shutting down the engine it may be advisable to retard the throttle and again check the analyzer. Rarely, but occasionally, the shorted secondary pattern will show up on both spark plugs at high power and the plugs will come back in at low power. If one or both plugs come back in when the throttle is retarded, then engine operation may be continued at the reduced power setting. However, you will find that in the majority of such cases the spark plugs will remain shorted at low power, and in these cases you can also be quite certain that the engine will eventually fail if it is not shut down immediately. This action may mean the difference between a cylinder change or a complete engine overhaul—the most expensive type of overhaul at that.

N. S. Rice

ACKNOWLEDGEMENT

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Approximately one year after American Airlines began operating the Turbo Compound Engine, Mr. Norman Rice, Supervisor of Operating Manuals, gave lectures to Flight Crews and Maintenance Personnel based on material supplied by Wright Aeronautical Division. Wright Aeronautical believes the information put forth in those lectures can be of great value to all operators in training flight and maintenance personnel.

With Mr. Rice's permission, this booklet has been prepared for your benefit.

TC18 TIPS

ENGINE DEPENDABILITY REQUIRES CAREFUL OPERATION

REMEMBER . . .

1. Operate engine within all specified limitations.
2. Reduce power to 20″ *MAP* and 1600 *RPM* prior to shifting to high blower.
3. Maintain cylinder head temperatures as low as practicable.
4. When recording first cruise readings on flight engineer log (AUTO-RICH and 10% *BMEP drop*)—maintain constant airspeed, altitude, cowl flap setting and power.
5. Set cruise mixture precisely to 10% *BMEP drop*. Check manifold pressure spread between AUTO-RICH and 10% drop. Reset mixture if in doubt.
6. Avoid use of mixtures between 10% *BMEP drop* and AUTO-RICH —(except that 7% drop may be used if required for carburetor pre-heat in emergency).
7. Retard throttle if an engine requires more than 2″ MAP above the other engines to obtain cruise power.
8. If analyzer shows two shorted secondaries in one cylinder, and *BMEP* is low, shut down engine immediately (operating conditions permitting).
9. Use of lean mixtures makes the TC18 more sensitive to carburetor icing. Close cowl flaps as required (to full closed) to obtain adequate carburetor pre-heat. Set mixtures at either AUTO-RICH or 10% *BMEP drop*. Use 7% drop only if additional pre-heat is required in emergency.
10. Descend with mixture controls in cruise setting.
11. Check idle mixtures by observing tachometer on every engine shut down. When mixture control is placed in IDLE CUT-OFF *RPM* should immediately decrease. If *RPM* increases, mixture is too rich.
12. Write up all log book complaints completely and accurately.

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