This part II report on aircraft engine ignition dynamics, presents comprehensive results of flight tests comparing conventional aircraft magneto ignition to an electronic ignition system that is in popular use in homebuilt aircraft. The reader is encouraged to review Ignition Dynamics I to help interpret these discussions. More detailed results can be found at:

www.cafefoundation.org

THE EIS-1 ELECTROAIR® IGNITION SYSTEM

The EIS-1 ignition system uses high energy, battery-powered ignition coils. It delivers a single, relatively long duration spark whose timing is programmed to vary with RPM and manifold pressure. It is not a capacitive or multiple spark discharge system. The spark plug gap determines the arc voltage and duration. A smaller gap requires lower voltage and produces a longer duration spark, while a larger gap results in a higher voltage, shorter duration spark.

For aircraft engines with two spark plugs per cylinder, the EIS-1 can be installed in two different configurations: 1) as a single electronic unit (“SE”) firing the bottom spark plug in each cylinder (with a standard aircraft magneto firing the top plugs), or,
2) as dual electronic units (“DE”) that replace both aircraft magnetos. In the DE configuration, one unit fires the top spark plugs and the other fires the bottom plugs. This report compares both the SE and DE systems with that of standard dual magnetos (“DM”). The DE system, being entirely dependent on the aircraft battery, requires that a backup battery be installed.

Each EIS-1 system consists of 2 components; a timing unit and the direct ignition unit (DIU). The timing unit mounts like a magneto on the engine accessory case. It consists of an axial shaft onto which is mounted a standard Lycoming magneto drive gear. The shaft has a 60-tooth, iron gear that rotates inside the timing unit’s case past a magnetic pulse generator. This pulse generator is mounted on the perimeter of the case and delivers its triggering signal to the direct ignition unit (DIU). To set the timing to zero degrees (TDC) for starting, the timing unit is inserted into the magneto mounting pad with its shaft rotation locked with a pin after positioning the crankshaft to TDC for cylinder #1.

The EIS-1 modulates timing advance using sensors for both RPM and relative manifold pressure. For research purposes, a switch can be installed to turn on and off the manifold pressure sensor's timing advance function. As manifold pressure drops below 24° Hg., the unit begins to advance the timing by 2° for each inch Hg. of manifold pressure reduction, reaching a maximum of 42° advance at about 16.5° Hg.

The DIU sets and maintains timing at 16° BTDC as soon as the engine reaches 650 RPM after starting. As RPM increases above 1000 RPM, the unit advances the timing in a linear fashion with RPM to reach 25° BTDC timing at 2500 RPM. The typical ignition timing observed at idle is about 16-17° BTDC with the manifold pressure sensor advance turned off and about 35° BTDC with the manifold pressure sensor advance turned on. At takeoff power of 2700 RPM and 29° Hg. manifold pressure, the timing is 25° BTDC, the same as with dual magnetos. The timing settings can be customized by Electroair for different engine applications and can be ground adjusted by the aircraft owner.

A small LCD digital ignition timing indicator is mounted to the aircraft instrument panel to monitor the ignition timing.

Each DIU fires one spark plug for each cylinder and has two high voltage General Motors 'Dual Tower' coils. Each coil 'tower' attaches to its respective cylinder's spark plug wire. The Dual Tower coil actually fires two spark plugs each time it discharges, one in the cylinder that is completing its compression stroke and one in the opposite cylinder that is completing its exhaust stroke. One spark plug fires from barrel to tip electrode and the other, wired in series, fires from tip to barrel. This 'wasted spark' configuration obviates the need for a distributor and its moving parts and only slightly reduces the ignition energy delivered to the plug in the firing cylinder. According to Jeff Rose, "We use high energy GM coils that generate 65,000 volts. The EIS-1 spark discharge is sustained over about 18° of crankshaft rotation when using a 0.030" spark plug electrode gap."

Electroair specifications state that the average electrical current consumption of each electronic ignition unit is 0.75 amps with an instantaneous coil current that is programmed to reach 8.5 amps at the exact point at which a plug must be fired, regardless of RPM.

Each DIU with spark plug harness weighs 4.4 pounds and each timing unit weighs 1.5 pounds. This 5.9 pound total does not include the additional 7 pounds added by a spare 4 a.h. sealed lead-acid motorcycle battery, battery diode isolation device, ignition operation switch panel and attendant wiring. Each Bendix 1200 Series magneto with plug harness weighs about 6.8 pounds. A single EIS-1, if used in place of one Bendix 1200 magneto would result in no significant change in aircraft weight.

The EIS-1 uses special heavy duty automotive 'resistance type' spark plug wires in order to reduce electrical noise, produce less spark plug electrode erosion and to conduct the high voltages involved without arc leakage. Electroair's product brochure claims that the EIS-1 reduces spark plug fouling, can deliver as much as 120 mJ of spark energy and has a timing resolution of 0.5°. Jeff Rose states that there are about 1400 EIS-1 units in operation and that 150 of these are installed in the dual (DE) configuration.

THE TESTBED ENGINE

The experimental IO-360A1B6X engine used in these tests has an 8.7 to one compression ratio. It is a highly modified, experimental version of the 4 cylinder, 200 hp counterweighted Lycoming engine. It has ported, polished and flow-balanced intake and...
exhaust ports, a 4-into-1 tuned exhaust system, as well as a low resistance air-cleaner with good ram recovery. Filtered induction air enters a custom velocity stack mounted on the inlet of the forward-facing Ellison Throttle Body.

The test engine’s modified induction system has small extensions welded onto each of the four individual induction tubes to better equalize their access to the fuel fog emitted by the Ellison Throttle Body. Photos A, B, C. The EGT spread among the four cylinders was reduced to as little as 15–20° F by this technique, when measured at wide open throttle.

The unpressurized Bendix 1200 Series magnetos used in this study are a 'high altitude' model that uses a larger distributor and coil than the smaller Bendix S4LN magnetos. The larger coil affords a higher spark voltage that is better suited for high altitudes and lean mixtures. The larger distributor provides better resistance to internal arc/carbon tracking at these high voltages.

The test engine’s tuned exhaust system provides substantial negative exhaust back pressure, a 4-into-1 tuned exhaust system, and a high resistance air-cleaner to ensure full power, with a 1550’ density altitude. This equated to 127 mph CAS. The aircraft reached 5,000’ density altitude in climb, mixture was leaned from full rich to 15.0 gph (panel). Next, level at 8500’, the RPM was set to 2550 and the cruise speeds were noted at intervals of 0.5 gph fuel flow reductions from very rich to very lean settings. A climb to 12,500’ density altitude was then made, again at 117 mph CAS, w.o.t. and 2600 RPM, leaning as appropriate to remain at least 150° rich of peak EGT. Level at 12,500’ density altitude, the RPM was again set to 2550 and the cruise speeds were noted at intervals of 0.5 gph fuel flow reductions from very rich to very lean settings. Finally, another climb at 117 mph CAS, w.o.t. and 2600 RPM was made to 15,000’ density altitude where the cruise settings were repeated.

Uniform inclusion criteria from stabilized level flight data were used in selecting the comparative results. The criteria were: non-turbulent air, stable OAT, stable altitude and airspeed, on-target RPM and fuel flow, stable fuselage incline angle and no ballistic effects.

Detailed tests of the SE system were conducted at 12,500’ density altitude using the standard settings of w.o.t. and 2550 RPM, cowl flaps open. These included operation at 2 different ignition advance settings, 2 different spark plug gaps, and turning off each ignition unit to collect data while firing either top spark plugs only (Bendix 1200 magneto) or bottom spark plugs only (EIS-1 electronic ignition). Toggling the EIS-1 ignition from standard to advanced ignition timing allowed observation of timing effects on speed, EGT and engine smoothness. The effects of rotating the spark plug electrode gap of the leanest cylinder’s (#4) bottom spark plug were evaluated on three short, consecutive flights on 2/09/02 using the SE ignition with the magneto both on and off.

The data for this report were obtained on different days and are subject to variations in lapse rate, rising or sinking airmass effects, etc. Careful data point selection was used to minimize the influence of these variables. Performance differences that exceed 1.0 mph in TAS and 50 fpm in rate of climb are considered significant and real in this study.
**Mooney N6057Q**

### DE = dual electronic dew point spread ± 18 °F

<table>
<thead>
<tr>
<th>Density</th>
<th>TAS, mph</th>
<th>DE System</th>
</tr>
</thead>
<tbody>
<tr>
<td>15017</td>
<td>147.8</td>
<td>2551</td>
</tr>
<tr>
<td>14989</td>
<td>149.8</td>
<td>2549</td>
</tr>
<tr>
<td>14944</td>
<td>149.4</td>
<td>2532</td>
</tr>
<tr>
<td>14899</td>
<td>148.9</td>
<td>2532</td>
</tr>
<tr>
<td>14844</td>
<td>148.4</td>
<td>2523</td>
</tr>
<tr>
<td>14789</td>
<td>147.8</td>
<td>2523</td>
</tr>
<tr>
<td>14734</td>
<td>147.3</td>
<td>2523</td>
</tr>
<tr>
<td>14679</td>
<td>146.7</td>
<td>2523</td>
</tr>
</tbody>
</table>

### CF open wide

**TAS from careful review of QAT, I.A., stability, video, ballistics**

<table>
<thead>
<tr>
<th>DEM</th>
<th>Alt.</th>
<th>TAS, mph</th>
<th>DE System</th>
</tr>
</thead>
<tbody>
<tr>
<td>82/501 DM</td>
<td>30.99</td>
<td>150.3</td>
<td>1505</td>
</tr>
<tr>
<td>13128</td>
<td>150.7</td>
<td>1505</td>
<td>1505</td>
</tr>
<tr>
<td>13178</td>
<td>150.2</td>
<td>1505</td>
<td>1505</td>
</tr>
<tr>
<td>13228</td>
<td>150.0</td>
<td>1505</td>
<td>1505</td>
</tr>
<tr>
<td>13278</td>
<td>150.0</td>
<td>1505</td>
<td>1505</td>
</tr>
<tr>
<td>13328</td>
<td>150.0</td>
<td>1505</td>
<td>1505</td>
</tr>
</tbody>
</table>

---

**Figure 11a. DE System**

**Figure 11b. DM System**

---

**WARNING TO ALL PILOTS:**

Severe engine damage or engine failure leading to possibly fatal and destructive aircraft accidents can occur when lean mixtures or advanced ignition timing are used inappropriately. The power, ignition timing and mixture settings used by the CAFE program in these experimental flight tests are not safe to be used on all engines or in all flight conditions.

---

**FLIGHT TEST PREPARATION**

Because of the engine cooling challenges of conducting full throttle climbs at best rate of climb airspeed (Vy) in summer air, several FAA climb cooling tests were conducted before taking actual cruise performance data.

With the dual electronic ignition system operating at advanced ignition timing, a significant increase in engine cooling demand was observed. Several changes to the engine cool and induction system were made to assure adequate cooling. Cowl exit area was increased for both cylinder cooling and oil cooler. A large aft-facing air extractor bluff body was installed at the cooler exit, which lowered oil temperatures by 35°F. See Photo D. Baffle exit path openings around the bottom of the cylinder head cooling fins were selectively enlarged. Induction tube geometry was further modified to selectively enrich cylinder #4. Although these induction modifications gave the desired reduction in CHT, they somewhat widened the otherwise narrow EGT spread among cylinders. There was a noticeable loss of aircraft top speed as a result of the increased drag from these cooling system modifications.

An instability of propeller RPM required an overhauling of the propeller.
Mooney N6057Q

<table>
<thead>
<tr>
<th>Density</th>
<th>Altitude</th>
<th>TAS (mp)</th>
<th>RPM</th>
<th>CHT#</th>
<th>CHTF</th>
<th>CHTH</th>
<th>CTHH</th>
<th>CGT</th>
<th>CMT</th>
<th>CGT#</th>
<th>CGM</th>
<th>CGS</th>
<th>CMT#</th>
<th>OHT</th>
<th>GVM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1497</td>
<td>1155</td>
<td>100.4</td>
<td>122</td>
<td>1552</td>
<td>155</td>
<td>105</td>
<td>146</td>
<td>90</td>
<td>119</td>
<td>146</td>
<td>146</td>
<td>146</td>
<td>107</td>
<td>174</td>
<td>223</td>
</tr>
<tr>
<td>1476</td>
<td>1155</td>
<td>101.7</td>
<td>125</td>
<td>1555</td>
<td>105</td>
<td>105</td>
<td>145</td>
<td>90</td>
<td>119</td>
<td>146</td>
<td>146</td>
<td>146</td>
<td>107</td>
<td>174</td>
<td>223</td>
</tr>
</tbody>
</table>

**SE = single electronic**

**dew point spread ≤ 17° F**

**SE on 17/01/01**

**SE on 12/04/01**

**dew point spread ≤ 4° F**

**Note:** 4° x 0.6 arb.

**SE**

**dew point spread ≤ 17° F**

**All data are W.G.T.**

**Target = 2500 RPM**

**TAS from careful review of OAT, I.A. stability, video, ballistic data.**


---

**RESULTS**

The results of the DE, DM, and SE ignition systems tests are presented in spreadsheet form in Figures 11a,b and c, and are graphically shown in Figures 12a and 12b. Temperature data are included along with the true airspeeds to facilitate interpretation of the results.

Figure 12a shows that the DE ignition, when operated at the leanest fuel flows with its ignition timing at 41° BTDC at 15,000' density altitude, performed better than the DM ignition whose timing was set at 25° BTDC. Their respective airspeeds at 6.0 gph are 168.7 mph DE, 168.8 mph SE and 155.5 mph with DM, a more than 13 mph advantage for the electronic ignition. This represents an 8.5% increase in airspeed with the electronic ignition. The 4 channel EGT data at these very lean mixtures (130°-200° F lean of peak) show that the DM system exhibits some lean misfiring at the 6.0 gph setting, accompanied by some engine roughness. When enriched to a fuel flow of 6.5 gph, the DM system gives 170.3 mph at 15,000' and the roughness is eliminated.

In Figure 12b, at 12,500' density altitude, 6.5 gph yields 173.4 mph with DE ignition timing at 36° BTDC and 156.9 mph with the DM system timed at the standard 25° BTDC setting, a 16.5 mph advantage for the electronic ignition. However, the DM system at 6.5 gph again exhibits the rise in EGT that indicates lean misfiring that is not

---

Photo D. Enlarged oil cooler extractor exit.
acceptable for continuous operation. At 7.0 gph, where no misfiring was evident, the DM system shows a TAS of 167.8 mph, 5.6 mph slower than DE system, while using 7.7% more fuel. These figures apply to operation at about 130-200°F lean of peak EGT, i.e., very lean.

By interpolation, at 12,500' density altitude, the dual magneto system would require about 7.2 gph to match the DE’s speed of 173.4 mph on 6.5 gph--a 10.7% fuel savings for the DE system.

The speed advantage of the electronic ignition disappears when operating at less radically lean mixtures. For example, at 15,000', when operating between 50-100° lean of peak EGT at 7.0 gph, all three ignition systems deliver about 179 mph, though the ignition timings are 41° BTDC for the DE/SE and 25° BTDC for the DM at this altitude. At rich mixtures, the DM system showed a slight speed advantage. See 12a.

Figure 12c shows the results of operation at 8,500' density altitude. Here, the DE and SE systems operate with 30° ignition timing while the DM remains fixed at 25° BTDC. The TAS with the DM system essentially equals or surpasses that of the DE/SE at all fuel flows leaner than peak EGT. The differences are small.

Figures 13A, B, C and D show the changes in EGT in the SE configuration during several different modes of operation. The responses of both the leanest (#4) and richest (#2) cylinder’s EGTs are plotted. Depicted are the changes that occur when the timing advance is reduced from 40° to 25° BTDC on the EIS-1 unit while the magneto remains at 25° advance. The effects of extreme leaning, turning off the EIS-1 altogether or of turning off the magneto are also shown.

Figure 14 shows a detailed comparison of the DE and DM systems at 8,500' density altitude, where the electronic ignition timing is 30° BTDC versus 25° BTDC for the magneto.

Figure 15 tabulates the rate of climb test results. At the rich mixtures used in climb tests, the DM performance surpasses that of both the SE and DE systems.

Figure 16 graphically compares the CHT’s and EGT’s of cylinder #4 for the DE, SE, and DM configurations at a density altitude of 15,000 feet.
expected, the CHT is hottest and the EGT is coolest with advanced ignition timing. CHT falls dramatically with all configurations as the mixtures are made very lean. Even during the onset of lean misfire, the EGT remains much cooler than peak EGT.

The DM system reaches its lean misfire limit at significantly richer mixtures than the SE or DE system. The DE system can operate without misfire on slightly leaner mixtures than the SE system.

Four channel EGT and CHT graphs obtained with the DE system at 41° BTDC timing exaggerate the temperature spreads among the four cylinders, showing which are the leanest. In Figure 17a, as the rich mixture is progressively leaned, #4 CHT runs hot early while #2 CHT tends to run hot later in the leaning schedule. The EGT graphs help to explain this CHT behavior. The EGT of cylinder #2, the richest cylinder, is the last to reach peak EGT while EGT #4 is the first to reach peak EGT.

Figure 17b shows that the DM system has a smaller temperature spread among all four cylinders than is found in 17a.

It might be expected that induction tubes #1 and #2, being the forward-most in the induction plenum and therefore closest to the fuel fog emanating from the throat of the Ellison Throttle Body, would exhibit relatively richer mixtures and higher CHT’s than the plenum’s rearmost induction tubes to cylinders #3 and #4, respectively. The CHT curves in Figure 17a tend to support this idea, as does the finding that the EGT rise of lean misfire begins at 6.0 gph for cylinders #3 and #4 but not until 5.5 gph for #1 and #2.

Figure 18 is a table that compares all 3 ignition systems at their minimum tolerable fuel flows. The cool CHTs at these low fuel flows suggest that the cooling system airflow could be reduced substantially to raise the CHT to a more thermodynamically efficient value. The table shows theoretical values for TAS and MPG that might be obtained if the cooling system were sealed up to produce a CHT of 420° F in lean cruise flight on a 100° F day or 400° F on an 80° F day. Such increases in speed require a fully closable cowl air exit that can severely restrict cooling airflow. Such tests were not possible on the testbed aircraft.

Figure 19 reveals the effect of changing the ignition timing or using a large spark plug gap. See its attached explanation.

The oil temperature in all test conditions rarely rose above the Vernatherm setting of 180° F due to the excess of oil cooler airflow in the testbed aircraft.

The engine started reliably and easily with either the electronic or impulse-coupled magneto ignition. It idled smoothly at only 500 RPM with the electronic ignition, much lower than the minimum smooth idle possible with magneto. Electroair recommends powering the DIU’s with a backup battery during starting so that a large sag in main battery voltage during cranking does not upset the functioning of the DIU’s circuitry.

There were no ignition malfunctions during any of these tests. The Electroair ignition units were mounted in the 'cold air' portion of the engine cowl and tolerated heat soaking of up to 175° F inside the cowl after engine shutdown on a 100° day without any subsequent malfunction.

Simultaneously switching both of the DIU’s of the DE system to the backup battery source in flight using a single toggle battery selector switch caused episodes of brief but violent misfiring because of the momentary "off" condition occurring as the switch broke contact in midthrow. A better circuit method would be to power each DIU with a center off, 2 position Mil-spec. 10 amp toggle switch and select the backup battery for each DIU in succession, rather than in one throw.
DISCUSSION

The automotive industry has successfully developed electronically controlled, battery-dependent, high energy ignition systems for many years with excellent reliability. Today’s automobile systems require very low maintenance and yet operate with complex ignition timing control inputs from sensors for manifold pressure, RPM, temperature, throttle position, exhaust oxygen level, engine knock, etc.

EAAsers Jeff Rose and Klaus Savier deserve credit for having led the way in applying such technology to aircraft engines. The results of this study suggest that the EIS-1 ignition system can provide substantial gains in performance during lean mixture operation. It must be emphasized that the results for other electronic ignition systems or for the EIS-1 applied to any other engine may be quite different than those reported here.

Research at Ford Motor Company has shown that improvement in lean operation from multi-spark discharge ignition "is not so large as that obtainable by improving carburetion and continuing to use a standard single-spark ignition system."2 Engine smoothness and reliability also benefit if fuel distribution/atomization deficiencies (common in many aircraft engines) are corrected prior to installing electronic ignition. The EIS-1 system was tested here on a specially modified aircraft engine that may have already achieved much of the performance improvements commonly attributed to adding electronic ignition to otherwise stock aircraft engines.

The DM system's Bendix 1200 mag-
gph. Meanwhile, cylinder #2 shows the more typical cooling in EGT as the mixture is leaned. This contrast in EGT behavior occurs because, on the test engine, cylinder #4 is consistently the leanest while cylinder #2 is the richest.

At point “B”, where the mixture was leaned even further to just 5.8 gph, EGT #4 plummeted due to its having frequent cycles with near total absence of ignition. Here, EGT #2 finally begins to show the characteristic rising EGT of partial misfiring. Not unexpectedly, the engine was running very rough at this point “B”.

At point “C”, the engine was running smoothly at 6.5 gph when the manifold pressure advance was turned off, reducing the EIS-1 timing from 40° BTDC to 25° BTDC, i.e., the same setting as the magneto. This produces a very large rise in EGT on both cylinders #2 and #4 and a commensurate loss of power due to the wasteful late burning of fuel as it exits the exhaust valve.

At point “D” in Figure 13A, the EIS-1 unit was turned off, leaving the Bendix 1200 magneto to fire the top spark plugs only. A major power loss ensues as the EGTs both rise dramatically. Figure 13B expands on these findings.

Point “E” in Figure 13A shows that turning off the Bendix 1200 magneto causes a much more mild rise in EGT and a much less severe loss of power. In other words, even with the slow-burning mixture setting of 6.5 gph, which is the lean misfire limit, the magneto was not contributing much to the ignition process; the major share was being supplied by advanced firings from the EIS-1’s bottom spark plugs.

Figure 13B shows the effect on EGT and TAS of turning off the EIS-1 at various mixtures. With only the top spark plugs firing at their 25° BTDC magneto timing, there is not enough time before the exhaust valve opens (EVO) to fully consume the mixture. In general, the leaner the mixture, the larger the rise in EGT upon turning off the EIS-1 because the leanest, slowest-burning mixtures need the most ‘head start’ at ignition. Note that the EGTs of cylinder #2 (richest) and #4 (leanest) rise different amounts.

In Figure 13B, the TAS drops the most at the leanest setting (point “D”), again reflecting the amount of energy wasted by fuel burning after it exits the exhaust valve. But two effects are occurring simultaneously. One is the influence of firing only the top spark plug in each cylinder. The other is the effect of retarding the timing from 40° BTDC to 25° BTDC.

Figure 13B, point “A” shows a drop in TAS at 11.0 gph when the electronic ignition and its bottom spark plugs are switched off. This TAS loss is partly an indication that ‘bloody rich’ mixtures (200-250°F ROP EGT) do indeed burn more slowly than best power mixtures. The retarding of the timing from 40° to 25° BTDC made it too late, causing the loss of power and airspeed along with the rise in EGT. This timing retarding effect is compounded by initiating ignition at only the top spark plug (magneto) in each chamber, making combustion of the entire mixture take even longer.

At point “B” in Figure 13B, the TAS increased slightly after turning off the electronic EIS-1 ignition at 9.5 gph. This is best power mixture at this RPM, M.P. and altitude. Here, a timing of 25° BTDC on single ignition appears to deliver more power than a setting of 40° BTDC with dual ignitions.

Best power mixtures are the fastest-burning. Running 40° BTDC timing at best power mixture appears to be too advanced—the burning occurs too early. This may impede the piston’s rise near TDC and/or dissipate the peak cylinder pressure too early in the piston’s descent, and thus actually reduce horsepower. The 25° BTDC timing is closer to MBT (maximum brake torque) timing at these particular conditions and the increased power occurs despite the wasted energy evident in
the higher EGT's during single magneto operation. This suggests that the Lycoming engineers who chose a fixed ignition timing of 25° BTDC for this engine made a wise choice.

In Figure 13C, the magneto was turned off while operating at each of 3 different mixture settings.

At point “A”, while running 40° timing advance with the EIS-1 at 11.0 gph (~270° F rich of peak), turning off the magneto with its 25° BTDC timing shows almost no effect on EGT or TAS. This indicates that the magneto's contribution to the ignition process is minimal. Contrast this with point “A” in Figure 13B, where the absence of the EIS-1’s 40° firings has a pronounced effect on EGT and TAS.

At point “B” in Figure 13C, at 8.0 gph (near peak EGT), there is a perceptible rise in EGT when turning off the magneto, but still no significant change in TAS.

At point “C”, at 7.0 gph (~150° F lean of peak EGT), there is a more noticeable rise in EGT and fall in TAS when the magneto is turned off. This again indicates that, in the SE configuration with 40° electronic timing, the magneto only contributes significant ignition at the slowest-burning, leanest mixtures.

See Figure 13C, and point “E” in Figure 13A. Calculation shows that, at 2550 RPM, the advertised spark duration of 1.8 milliseconds for the EIS-1 using 0.030” spark plug gap would provide a continuous spark from 41° BTDC to 13.5° BTDC. With the SE system, this would overlap the 25° BTDC spark delivered by the magneto. Especially with rich mixtures, the flame front that originates at 40° BTDC from the SE top spark plug might be expected to partially engulf the magneto's top spark plug electrodes before they fire their spark. Such circumstances may burden the magneto coil with having to fire its spark into a somewhat increased pressure environment, increasing the possibility of stray arcing in its distributor or coil. Although we saw no evidence of arcing and know of no reports of it thusfar in users of the SE system, it is suggested that the magneto-fired spark plug gaps be kept properly small when using the SE system.

Figure 13D depicts the effects of turning off the manifold pressure-modulated timing advance of the EIS-1. This changes the timing of the bottom spark plugs to 25° BTDC from their advanced setting of 40° BTDC and retains dual ignition operation. The results show a consistent but mild rise in EGT at every fuel flow setting examined, indicating the delay in the burning of the fuel. This is accompanied by the familiar drop in TAS at all except the 8.0 gph (stoichiometric) setting (point “C”), Figure 13D, where the airspeed actually rose by almost 1.0 mph. This rise of TAS demonstrates better power with dual ignition at 25° BTDC at these particular settings than when the bottom plugs were firing at 40° BTDC. i.e., it is closer to the MBT timing. As was shown in Figure 13B, point “B”, the increased power from an optimized timing setting (closer to MBT) more than compensates for the wasted energy of higher EGTs that accompany such retarded timing.

The 'burn speed' of the 8.0 gph stoichiometric mixture is slower than the 9.5 gph best power mixture. The loss of TAS at 9.5 gph (Figure 13D, point “B”), differs from the rise in TAS found at 9.5 gph in Figure 13B, point “B”, where only the top spark plugs were firing. To explain why this situation reverses at 9.5 gph, recognize that flame spread is faster when originated at two spark plugs than when originated at one only. Thus, with both spark plugs firing, 25° BTDC advance is slightly too early for MBT at 9.5 gph (Figure 13D, point “B”), whereas with only the top spark plugs firing, the slower flame spread places 25° timing close to MBT. The MBT setting at 9.5 gph with all spark plugs firing thus would likely be about 20° BTDC. This is true even though the EGT is shown...
Mooney N6057Q at 8,500' density altitude, wide open throttle, 2550 RPM, richest cylinder #2, leanest cylinder #4. Wing Barograph #3 and Vetter DAD records. DE = dual electronic EIS-1 ignition @ 30° BTDC. DM = dual Bendix 1200 magneto @ 25° BTDC.

At 23° Hg. of manifold pressure, the EGTs of the richest cylinder (#2) are not affected by the 4° timing difference from DM to DE while the EGTs of the leanest cylinder (#4) differ significantly. The DE CHT #4 is lower than the DM CHT #4 at all fuel flows. The DE CHT #2 is hotter when LOP and cooler when ROP compared to DM CHT #2. TAS differences are small but indicate that the DE system is fastest using rich mixtures and the DM system is fastest using lean mixtures.

---

**Figure 15.** Electroair EIS-1 ignition versus Bendix 1200 magneto in rate of climb performance.

<table>
<thead>
<tr>
<th>Mooney N6057Q</th>
<th>ROC &gt; Rate of climb</th>
<th>pEGT = peak EGT, est.</th>
<th>ROP = rich of peak</th>
<th>rpm = feet per minute</th>
<th>CHT = cyl. head temp.</th>
<th>EGT = exh. gas temp.</th>
<th>DE= dual electronic</th>
<th>SE=single electronic</th>
<th>DM= dual magneto</th>
<th>w.o.t, 2600 RPM</th>
<th>125 IAS mph, panel</th>
<th>nwp = panel FlowScan</th>
<th>CHTs hottest (cyL #4)</th>
<th>EGT for 100°F day</th>
<th>Dew point spreads:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ign.</td>
<td>Density alt.</td>
<td>gph</td>
<td>Weight, lb.</td>
<td>pEGT, F</td>
<td>EGT, F</td>
<td>ROP, F</td>
<td>CHT, F</td>
<td>OAT, F</td>
<td>Timing, BTDC</td>
<td>ROC, tpm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 2500-3500</td>
<td>18.7</td>
<td>2525</td>
<td>1620</td>
<td>1409</td>
<td>211</td>
<td>399</td>
<td>81</td>
<td>25</td>
<td>1511</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE 3500-4500</td>
<td>17.7</td>
<td>2523</td>
<td>1610</td>
<td>1398</td>
<td>212</td>
<td>407</td>
<td>81</td>
<td>25</td>
<td>988</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE 3500-4500</td>
<td>17.7</td>
<td>2525</td>
<td>1610</td>
<td>1387</td>
<td>223</td>
<td>408</td>
<td>71</td>
<td>25</td>
<td>970</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 3500-4500</td>
<td>17.8</td>
<td>2485</td>
<td>1620</td>
<td>1353</td>
<td>267</td>
<td>402</td>
<td>77</td>
<td>25</td>
<td>1138</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 3500-4500</td>
<td>17.8</td>
<td>2536</td>
<td>1620</td>
<td>1358</td>
<td>262</td>
<td>422</td>
<td>55</td>
<td>25</td>
<td>1029</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 7500-8500</td>
<td>15.0</td>
<td>2514</td>
<td>1600</td>
<td>1408</td>
<td>192</td>
<td>421</td>
<td>64</td>
<td>30</td>
<td>704</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE 7500-8500</td>
<td>15.0</td>
<td>2516</td>
<td>1590</td>
<td>1413</td>
<td>177</td>
<td>436</td>
<td>62</td>
<td>30</td>
<td>701</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 7500-8500</td>
<td>15.0</td>
<td>2480</td>
<td>1605</td>
<td>1388</td>
<td>217</td>
<td>420</td>
<td>70</td>
<td>25</td>
<td>767</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 7500-8500</td>
<td>15.0</td>
<td>2530</td>
<td>1605</td>
<td>1394</td>
<td>211</td>
<td>424</td>
<td>55</td>
<td>25</td>
<td>721</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 10500-11500</td>
<td>13.3</td>
<td>2490</td>
<td>1560</td>
<td>1375</td>
<td>185</td>
<td>430</td>
<td>49</td>
<td>34</td>
<td>557</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE 10500-11500</td>
<td>12.8</td>
<td>2488</td>
<td>1550</td>
<td>1381</td>
<td>169</td>
<td>429</td>
<td>52</td>
<td>34</td>
<td>531</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 10500-11500</td>
<td>13.5</td>
<td>2466</td>
<td>1570</td>
<td>1353</td>
<td>217</td>
<td>402</td>
<td>62</td>
<td>25</td>
<td>579</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE 11500-12500</td>
<td>13.1</td>
<td>2487</td>
<td>1525</td>
<td>1315</td>
<td>210</td>
<td>430</td>
<td>46</td>
<td>35</td>
<td>452</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE 11500-12500</td>
<td>12.7</td>
<td>2485</td>
<td>1515</td>
<td>1360</td>
<td>155</td>
<td>428</td>
<td>47</td>
<td>35</td>
<td>459</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM 11500-12500</td>
<td>13.3</td>
<td>2464</td>
<td>1550</td>
<td>1341</td>
<td>209</td>
<td>402</td>
<td>57</td>
<td>25</td>
<td>508</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DE = 16°F</td>
<td>DE 14000-15000</td>
<td>10.6</td>
<td>2447</td>
<td>1490</td>
<td>1364</td>
<td>126</td>
<td>425</td>
<td>35</td>
<td>40</td>
<td>349</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE = 17°F</td>
<td>SE 14000-15000</td>
<td>10.6</td>
<td>2461</td>
<td>1510</td>
<td>1386</td>
<td>124</td>
<td>439</td>
<td>40</td>
<td>40</td>
<td>345</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM = 15°F</td>
<td>DM 14000-15000</td>
<td>11.0</td>
<td>2444</td>
<td>1530</td>
<td>1380</td>
<td>150</td>
<td>402</td>
<td>48</td>
<td>25</td>
<td>415</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: ROC = Rate of Climb; pEGT = Peak EGT, est.; ROP = Rich of Peak; rpm = Feet per Minute; CHT = Cylinder Head Temp.; EGT = Exhaust Gas Temp.; DE = Dual Electronic; SE = Single Electronic; DM = Dual Magneto; w.o.t. = Wide Open Throttle; IAS = Indicated Air Speed; Panel FlowScan; CHTs hottest = Cylinder Head Temp.; Dew point spreads.
Though firing at the same 41° timing at 15,000' as the DE system, the SE system probably operates as if its ignition were timed later due to the slower burning that results when early firing is initiated only at the SE bottom spark plug. Thus, a slight increase in timing advance relative to the DE system might be expected to help extend the lean misfire limit of the SE system and improve its power output. Figure 19 appears to confirm this idea by showing SE data for both 36° and 40° BTDC timing at 12,500’ altitude. Note here that the airspeed developed with mixtures near the lean limit is slightly better at 40° timing than at 36° timing and that the converse is true at rich mixtures. Also note the expected increase in CHT and decrease in EGT with the 40° timing.

In Figure 19, the 36° timing was too rough running at 6.0 gph to obtain a stable TAS. We estimate that this would have yielded about 15 mph slower than the TAS of the 40° timing at 6.0 gph. The use of a 0.060” electrode gap on the bottom spark plug of cylinder #4 (the leanest cylinder) caused it to prematurely misfire relative to the lean limit found using the standard 0.031” gap. Presumably, the diminished spark duration of the larger gap did not last long enough to reliably ignite the very scarce fuel molecules at the leanest mixtures.

Figures 20a, b and 21 show the results of “clocking” the electrode gap axis of the bottom spark plug in cylinder #4. The results are explained in the accompanying sidebar.

Figure 22 clearly shows the large effect on EGT from advancing the ignition timing. The peak EGT at 15,000’ and 41° BTDC timing is lower and occurs at a leaner mixture than with 25° magneto timing. The fact that the DE and DM EGT’s nearly match at 8,500’ suggests that it is the timing and not the high energy that causes the EGTs of these two systems to differ at 15,000’.

Textron Lycoming’s Flyer newsletter states that they allow "leaning to peak EGT at 75% power and below on our direct drive normally aspirated engines." They also state that "leaning past the peak (EGT) is not recommended".

Wide experience has shown that, when a reasonably even mixture distribution exists, conventional aircraft engines can safely operate continuously lean of peak EGT with the following important stipulations:

1) It must be at less than 70% power. For normally aspirated engines, it is generally at altitudes above 10,000 feet where w.o.t. settings, which are best able to give even mixture distribution, deliver no more than 70% power.

2) It is verified by EGT measurements that all cylinders are at least 25° lean of peak EGT. Ideally, the multi-cylinder EGT/CHT gauge should have an alarm capability such as those built by JPI and KS Avionics.

3) All cylinder’s CHTs’ must be within acceptable limits for continuous operation (generally below 420° F) when measured by an accurate multi-cylinder CHT gauge.

4) There must be no evidence of noticeable roughness.

CONCLUSIONS

1) Advanced ignition timing with the EIS-1 high energy electronic ignition system significantly improved aircraft speed and fuel economy in cruise flight at high altitude during operation with very lean mixtures.
2) These advantages will most benefit aircraft of relatively low span loading that are designed to cruise above 10,000 feet with normally aspirated engines.

3) Before installing electronic ignition on an aircraft:
   a) Its engine induction and mixture distribution should be optimized using high quality, multi-cylinder EGT/CHT gauges to balance the flow to all cylinders.
   b) The adequacy of the engine cooling system should be tested and confirmed as more than adequate.
   c) The engine operator should acquire a thorough understanding of the maintenance and operation of electronic ignition and recognize and accept the risks in its use.

4) The SE system ignition timing appears to optimize at a slightly more advanced setting than the DE system.

5) As the fuel mixture is leaned, the progressive reduction in flame speed can be as much as 50-60%. Programming the ignition to MBT timing during such lean operation requires a closed loop fuel mixture sensor in addition to inputs from absolute manifold pressure and RPM.

6. Lean operation can best be optimized by a properly timed, high energy, long duration spark applied across a large electrode gap that is ideally oriented with respect to local combustion chamber swirl.

Other electronic ignition systems may perform differently than the EIS-I system tested her and may be the subject of future study by the CAFE Foundation.

BIBLIOGRAPHY

1. EPG IV, by Brien Seeley, Ed Vetter and The CAFE Board, Sport Aviation.

3. Klaus Savier, personal communication. 11/08/01.

The CAFE Foundation wishes to thank Jeff Rose at Electroair® for providing the electronic ignition system for this study. His experience, advice and guidance were indispensable in performing this work. The CAFE Foundation has no financial interest in Electroair, LightSpeed Engineering, Unison, Aerospace, Teledyne Technologies, Lycoming, Continental, General Motors or GAMI jectors.

Internet links:
cafefoundation.org
electroair@juno.com (Electroair®)
LightSpeedEngineering.com

Mooney N6057Q: 15,000’ density alt., wide open throttle, 2550 RPM, Vetter DAD records. CHT corrected to 100 °F day. DE = dual electronic EIS-1 ignitions @ 41°BTDC timing. Note cylinder #2 clearly has the richest mixture at any fuel flow.
Figure 17b. DM system: EGT and CHT spreads for all four cylinders.

Figure 18. Cooling drag at lean limit operation—calculated potential TAS and MPG gains with cowl flap fully closed.

<table>
<thead>
<tr>
<th>Mooney N6057Q</th>
<th>Ign.</th>
<th>Dens. alt.</th>
<th>gph</th>
<th>TAS</th>
<th>MPG</th>
<th>LOP EGT, °F</th>
<th>EGT spread, °F</th>
<th>CHT, °F</th>
<th>CHT margin, °F</th>
<th>Cooling excess, %</th>
<th>Drag savings, %</th>
<th>Mph gain</th>
<th>New TAS</th>
<th>New MPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEAN LIMIT operation</td>
<td>DE</td>
<td>8500</td>
<td>8.0</td>
<td>178.8</td>
<td>22.4</td>
<td>159/144/146/18</td>
<td>44</td>
<td>370</td>
<td>50</td>
<td>38%</td>
<td>3.8%</td>
<td>3.4</td>
<td>182.2</td>
<td>22.8</td>
</tr>
<tr>
<td>EIS-1 v. Bendix magneto</td>
<td>SE</td>
<td>8500</td>
<td>8.0</td>
<td>176.4</td>
<td>22.1</td>
<td>174/145/134/16</td>
<td>40</td>
<td>349</td>
<td>71</td>
<td>53%</td>
<td>5.3%</td>
<td>4.9</td>
<td>181.3</td>
<td>22.7</td>
</tr>
<tr>
<td>LOF = lean of peak</td>
<td>DM</td>
<td>8500</td>
<td>8.0</td>
<td>180.3</td>
<td>22.5</td>
<td>169/148/140/18</td>
<td>47</td>
<td>356</td>
<td>64</td>
<td>48%</td>
<td>4.8%</td>
<td>4.5</td>
<td>184.8</td>
<td>23.1</td>
</tr>
<tr>
<td>All CHTs = 100 °F day</td>
<td>DE</td>
<td>12500</td>
<td>6.5</td>
<td>173.4</td>
<td>26.7</td>
<td>189/176/176/19</td>
<td>21</td>
<td>368</td>
<td>52</td>
<td>39%</td>
<td>3.9%</td>
<td>3.5</td>
<td>176.9</td>
<td>27.2</td>
</tr>
<tr>
<td>Potential gains in TAS, MPG</td>
<td>SE</td>
<td>12500</td>
<td>7.0</td>
<td>176.6</td>
<td>25.2</td>
<td>149/110/152/15</td>
<td>47</td>
<td>355</td>
<td>65</td>
<td>49%</td>
<td>4.9%</td>
<td>4.5</td>
<td>181.1</td>
<td>25.9</td>
</tr>
<tr>
<td>Target CHT=420°F</td>
<td>DM</td>
<td>12500</td>
<td>7.0</td>
<td>167.8</td>
<td>24.0</td>
<td>159/157/120/14</td>
<td>39</td>
<td>329</td>
<td>91</td>
<td>68%</td>
<td>6.8%</td>
<td>6.0</td>
<td>173.8</td>
<td>24.8</td>
</tr>
<tr>
<td>TAS with wing cuffs on</td>
<td>DE</td>
<td>15000</td>
<td>6.0</td>
<td>168.7</td>
<td>28.1</td>
<td>215/160/188/22</td>
<td>55</td>
<td>350</td>
<td>70</td>
<td>53%</td>
<td>5.3%</td>
<td>4.6</td>
<td>173.3</td>
<td>28.9</td>
</tr>
<tr>
<td>DE (single electronic)</td>
<td>SE</td>
<td>15000</td>
<td>6.0</td>
<td>168.8</td>
<td>28.1</td>
<td>182/16/129/17</td>
<td>53</td>
<td>346</td>
<td>74</td>
<td>56%</td>
<td>5.6%</td>
<td>4.9</td>
<td>173.7</td>
<td>28.9</td>
</tr>
<tr>
<td>DM (dual magneto)</td>
<td>DM</td>
<td>15000</td>
<td>6.5</td>
<td>170.3</td>
<td>26.2</td>
<td>146/148/90/149</td>
<td>59</td>
<td>331</td>
<td>89</td>
<td>67%</td>
<td>6.7%</td>
<td>6.0</td>
<td>176.3</td>
<td>27.1</td>
</tr>
</tbody>
</table>

Cooling drag excess at lean mixture operation with cowl flaps fully open: A cowl exit that can be almost completely closed would be necessary to achieve these calculated gains in TAS and MPG. All TAS are uncorrected for wing cuff drag and thus are low by 3-5 mph. Assume 0.75% cooling drag reduction per °F rise in CHT, assume cooling drag = 10% of total drag and that induced drag fraction = zero. Source: Lycoming cooling data showing 30% less cooling drag for CHT of 435°F than for CHT of 400°F.
Figure 19. SE ignition: EGT, CHT and TAS, timing and plug gap effects.

The 40° timing produces a hotter CHT than 36° timing. This is a finding consistent with most of the data from other flights in which advancing the timing increases CHT. Likewise, the 40° timed EGTs are generally cooler than when at 36° timing. More of the heat of combustion goes into the cylinder head and less remains in the exhaust gas when using 40° timing than with 36° timing.

The TAS with 40° timing is faster than with 36° timing at their lean misfire limit of 6.5 gph. The TAS with 40° spark advance was slower than with 36° advance when using ROP mixtures. This is presumably because rich mixtures burn faster, calling for less timing advance to optimize power.

When the #4 bottom spark plug gap was set to 0.060", the engine reached its lean misfire limit sooner, with perceptible roughness beginning at 7.0 gph rather than the 6.5 gph limit found on the other flights that used the standard gap of 0.031". The large gap misfired badly at 6.5 gph with a large loss of TAS and major engine roughness.

The 40° timing allowed the engine to continue running without severe roughness at just 6.0 gph. However, at 5.8 gph, the roughness became prominent and uncomfortable as EGT #4 plummeted due to frequent cycles of severe misfire.

Mooney N6057Q: IO-360A1B6X engine. 12,500’ density altitude. ElectroAir EIS-1 firing bottom plugs using 0.031” gap. Bendix 1200 magneto @ 25° BTDC firing top plugs using 0.018” gap. Wide open throttle, 2550 RPM, All CHT’s corr. to 100°F day. Cyl # 4 (leanest) bottom plug gap = 0.060” on 1/10/02 flight only. Aircraft weights: 2472 lb. @ 36°; 2537 lb. @ 40°; 2490 lb. @ 0.060” gap.
Mooney N6057Q; SE ignition at 12,500’ wide open throttle, 2550 RPM, Vetter DAD recordings. EIS-1 fires bottom plugs at 36° BTDC with 0.031” gap. Bendix Magneto @ 25° BTDC fires top plugs with 0.018” gap. Cylinder #4 (leanest) bottom spark plug electrode gap axis tested at 3 different rotations:

- **Flt. #1 = stock = -30°**
- **Flt. #2 = +60°**
- **Flt. #3 = +10°**

See Figures 20b, 21.

**Figure 20a.** EGT cyl #4 at 3 different electrode gap rotations. Three successive flights on 2/09/02.

**Figure 20b.** EGT cyl #2, successive same-day flights with no gap rotation.

Mooney N6057Q at 12,500’ density altitude. SE config., wide open throttle, 2550 RPM, Vetter DAD recordings. EIS-1 fires bottom plugs at 36° BTDC with 0.031” gap. Bendix Magneto @ 25° BTDC fires top plugs with 0.018” gap. Cylinder #2 (richest) has its plug electrode axes remaining at stock rotation on all 3 flights while cylinder #4 has its bottom plug gap rotations set to #1 = -30°, #2 = +60°, #3 = +10°. Figure 20a shows gap rotation effects on EGT.

**Figures 20a and 20b Explanation:**

In Figure 20a, the lowest EGT at each gph setting indicates the most complete combustion before EVO (exhaust valve opening). The blue lines suggest that the +60° spark plug electrode axis gives the most complete combustion at the leanest mixtures short of the misfire limit. The +10° axis (red lines) shows higher EGTs in both the dual and single ignition modes, which implies a slower initiation of the combustion process, causing it to take longer.

Some research suggests that, if the electrode gap is oriented perpendicular to the wind or direction of gas swirl in the combustion chamber at the moment of ignition, a high energy spark can be stretched into a loop shape that better ignites extremely lean mixtures because of the greater surface area of such a looped spark. The blue line in Figure 20a suggests that the +60° gap axis is so oriented. That the +60° axis also demonstrated what both cockpit observers noted as smoother engine operation at 6.5 gph than the other two gap axes tested also implies that, for this particular engine, cylinder, throttle setting and RPM, the +60° axis provides more complete ignition than the others tested.

Figure 20b shows the control values for cylinder #2’s EGT at the exact same second at which the data in Figure 20a was obtained for cylinder #4. There is close agreement in cylinder #2’s EGTs on all three flights. If any difference in fuel flow is apparent between the second flight with +60° gap (blue line on graph) versus the first or third flights, it was that the second flight used a slightly richer mixture at the nominal 7.0 gph setting. For example, if the second flight used 7.05 gph where the other flights used 6.95 gph, the slightly higher (blue) EGT in Figure 20b would be the expected result at the 7.0 gph point.

If indeed the second flight had such a richer mixture, this would be expected to cause higher EGTs for the blue line trace at the 7.0 gph point in Figure 20a. Instead, Figure 20a shows the blue line trace to be lower at the 7.0 gph point. This implies that the observed differences are real and not artifact or noise.

The fact that the dark blue line plunges at the 6.2 gph setting is likely due to the spark being blown out by a ‘wind’ in the combustion chamber that likely blows perpendicularly across the +60° gap axis. ‘Wind’ may be somewhat blocked by the ‘upwind’ electrode with both the -30° and +10° axes, thus their sheltered gap can escape having its spark stretched out to a larger arc length. A stretched spark blow out when the spark energy is no longer sufficient to ionize the scarce (lean) molecules across its longer arc length.

Note that at 8.0 gph, with its easy-to-ignite, faster burning mixture, the gap axis appears to have little or no effect on EGT.
Figure 21. Spark plug electrode axis color corresponds to those in Figure 20a.

REM37-BY spark plug, side view.

Electrode gap axes tested as viewed from top of plug.

-30° +10° +60°

Figure 22. EGT#2, ignition timing advance effects.

Mooney N6057Q. EGT of cylinder #2 (richest) at 8,500' and 15,000' density altitudes. Wide open throttle, 2550 RPM, wing Barograph #3. Cowl flaps fully opened. DM at 25° BTDC. DE at 30° BTDC @ 8,500' and at 41° BTDC @ 15,000'. Vetter DAD records. DM = dual Bendix 1200 magnetos. DE = dual electronic ignition, Electroair EIS-1.