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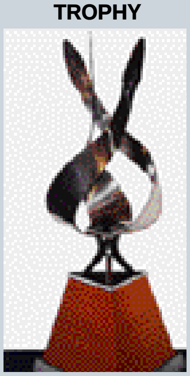


CAFE FOUNDATION
AIRCRAFT PERFORMANCE REPORT

Sponsored and Funded by the Experimental Aircraft Association

# Ignition Dynamics III

## "Timing is everything"

BY BRIEN SEELEY AND THE CAFE BOARD

This part III report on aircraft engine ignition dynamics, presents detailed 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 and II to help interpret these discusssions. More detailed results can be found at:

**www.cafefoundation.org**

RESULTS

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 **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. As 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.

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

### DETAILED EGT ANALYSIS

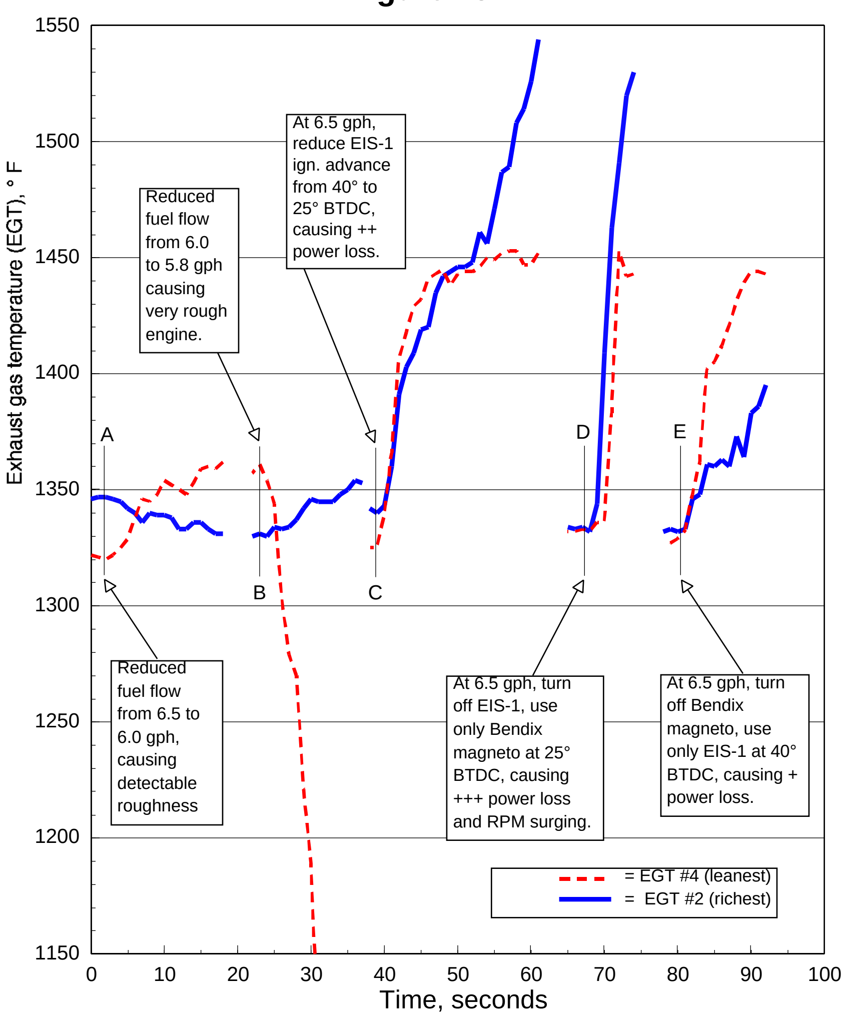
The EGT and TAS performance of the SE ignition system were examined in detail at 12,500' density altitude using wide open throttle and 2550 RPM, cowl flaps fully opened. Figures **13A through D** present the results.

Figure **13A**, point "**A**", shows that the #4 cylinder EGT (red trace) rises and thus begins to show lean misfire as the mixture is leaned from 6.5 to 6.0 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 plummets 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

**Figure 13A.**




Lean misfire limits: Mooney N6057Q, 12/04/01. 12,500' density altitude. One Electroair EIS-1 at 40° ignition timing advance and one Bendix 1200 magneto at 25° timing. EGT4 (red, dotted) = leanest cylinder. EGT2 (blue, solid) = richest cylinder.


COMPARATIVE AIRCRAFT FLIGHT EFFICIENCY, INC.
The CAFE Foundation:
A Non Profit, All Volunteer, Tax-exempt Educational Foundation
4370 Raymond Way, Santa Rosa, CA. 95404.
FAX 707.544.2734
Aircraft Test Facility, Santa Rosa Airport
707.545.CAFE (message)
Dr. Seeley's email: CAFE400@aol.com
website: www.cafefoundation.org


## IMPORTANT NOTICE



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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. Amajor power loss ensues as the EGTs both rise dramatically. Figure **13B** expands on these findings.

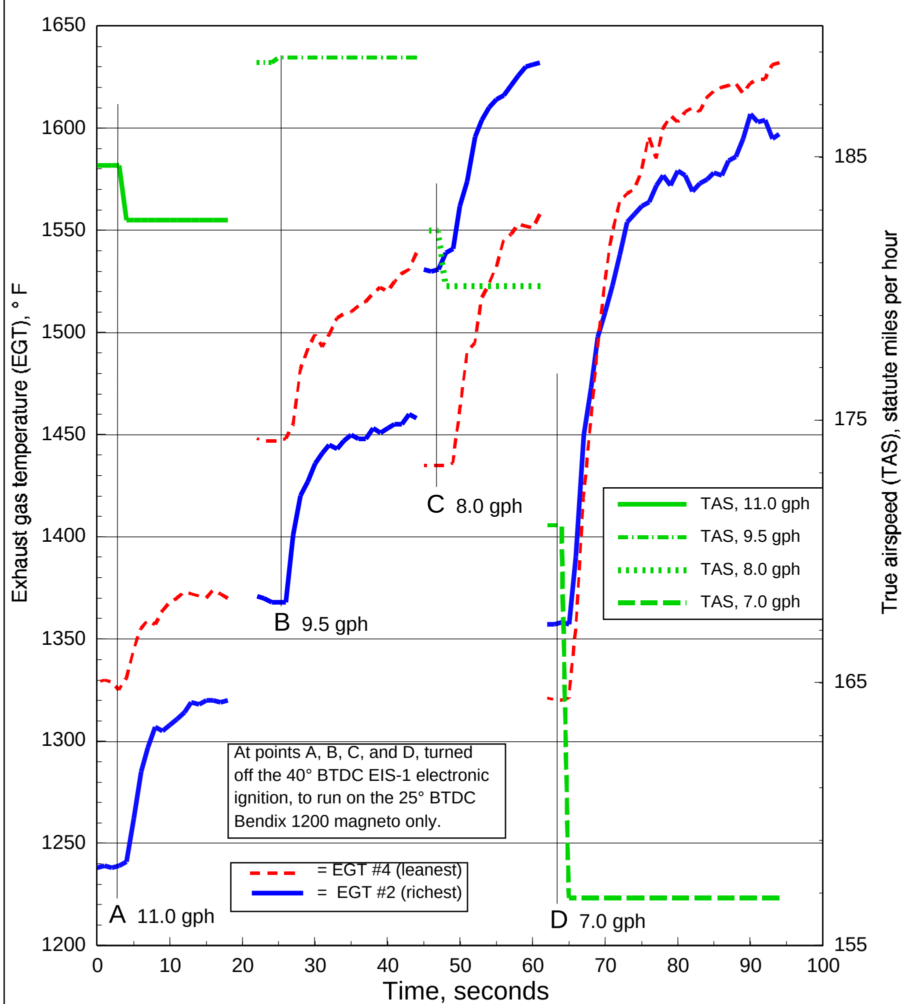
Point "**E**" in Figure **13A** shows that turning off the Bendix 1200 magneto causes a much more mild rise in EGT and a much less severe loss of power. In other words, even with the slow-burning mixture setting of 6.5 gph, which is the lean misfire limit, the magneto was not contributing much to the ignition process; the major share was being supplied by the 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 occuring 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

**Figure 13B.**




Change in EGT and TAS during operation on left magneto only, 4 different fuel mixtures: Mooney N6057Q, 12/15/01. 12,500' density, w.o.t., 2550 RPM. Bottom spark plugs on Electroair EIS-1 at 40° BTDC. Top spark plugs on Bendix 1200 mag @ 25° BTDC timing.

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.

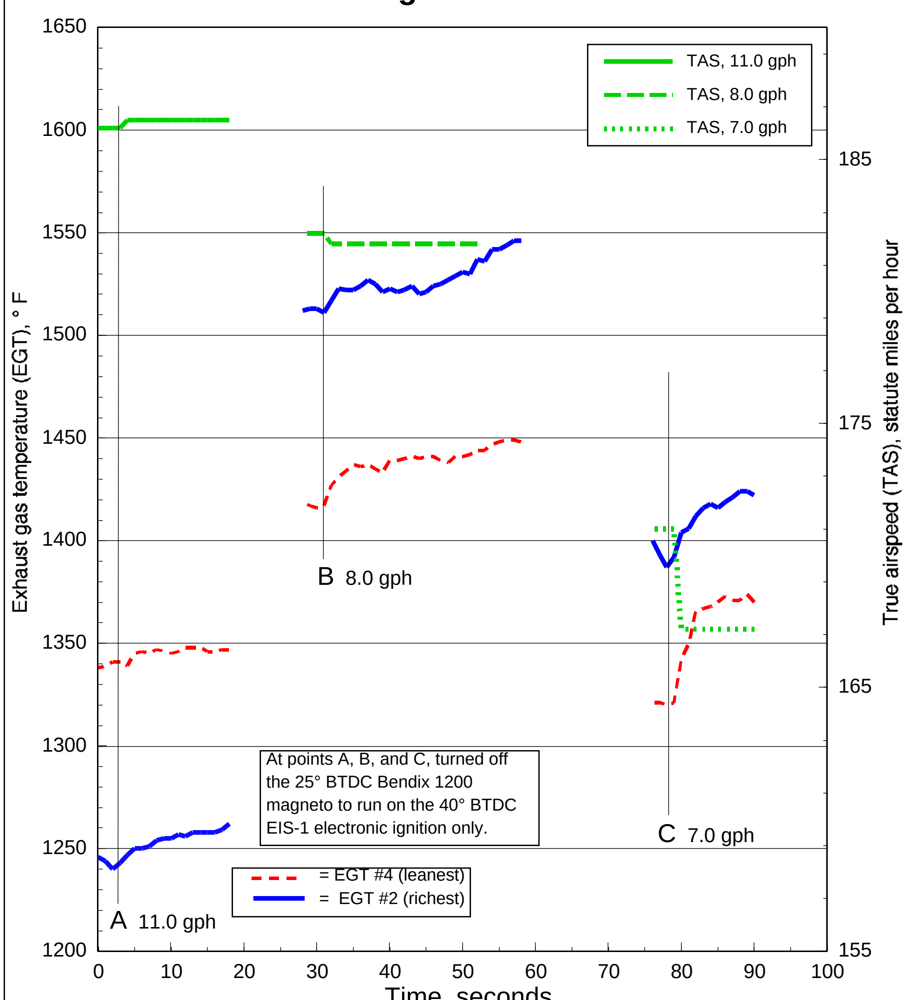
At point "**A**", while running 40° timing advance with the EIS-1 at 11.0 gph (~270° F rich of peak), turning off the magneto with its 25° BTDC timing shows almost no effect on EGT or TAS. This indicates that the magneto's contribution to the ignition process is minimal. Contrast this with point "**A**" 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 bottom 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 13C.**




Change in EGT and TAS during operation on EIS-1 only, 3 different fuel mixtures: Mooney N6057Q, 12/15/01. 12,500' density, w.o.t., 2550 RPM. Bottom spark plugs on Electroair EIS-1 at 40° BTDC. Top spark plugs on Bendix 1200 mag @ 25° BTDC timing.

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 only one. 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 to rise as the 40° BTDC timing is cut to 25°.

Simply modulating ignition timing according to manifold pressure and RPM ignores the direct and profound dependency of MBT timing on the fuel/air mixture. Figure **13** clearly depicts this dependency and suggests the need for a sensor such as an exhaust oxygen sensor to modulate ignition timing with mixture. Although such sensors are purported to be problematic in engines that use leaded fuels, hopefully this technical problem will soon be solved for aircraft engines.

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.

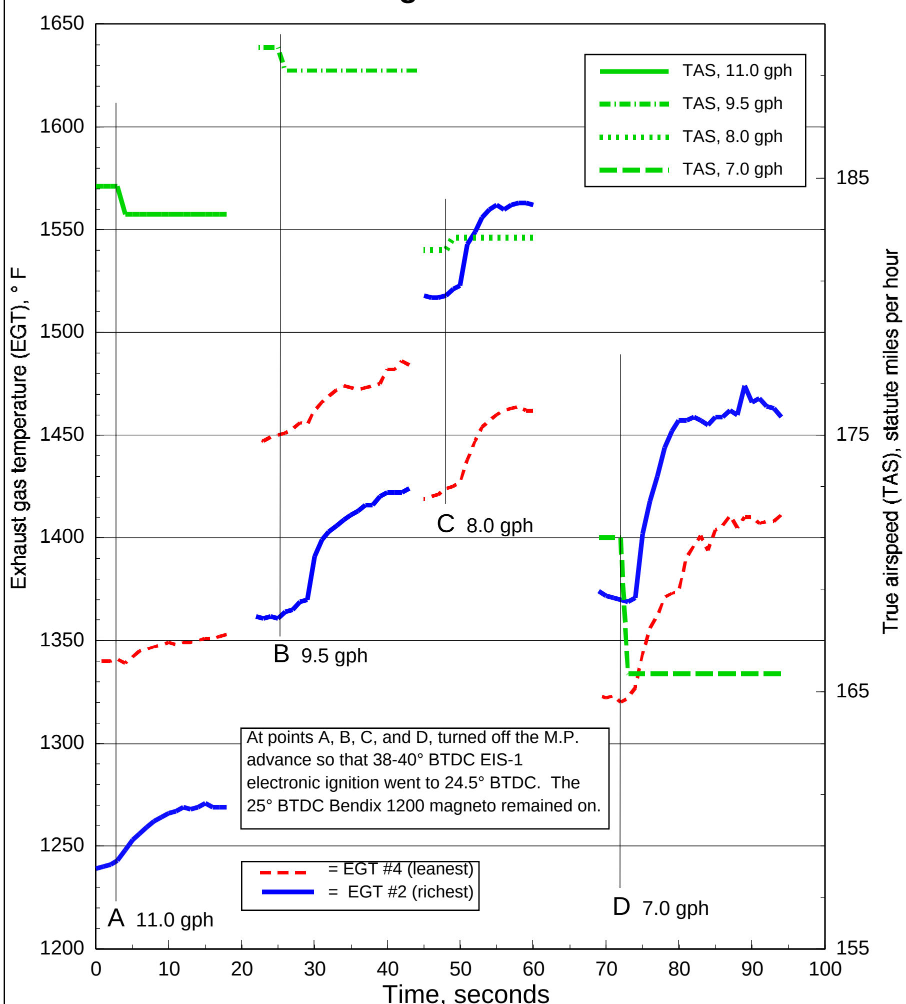
Textron Lycoming's Flyer newsletter states that they allow *"leaning to peak EGT at 75% power and below on our direct drive normally aspirated engines."*[4] They also state that *"leaning past the peak (EGT) is not recommended".*

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 <u>important</u> 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.**

**Figure 13D.**




Change in EGT and TAS when ignition timing reduced from ~40° to 24.5° BTDC, 4 different fuel mixtures: Mooney N6057Q, 12/15/01. 12,500' density, w.o.t., 2550 RPM. Bottom spark plugs on Electroair EIS-1. Top spark plugs on Bendix 1200 mag @ 25° BTDC timing.

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

**4) There must be no evidence of noticeable roughness.**

**Other electronic ignition systems may perform differently than the EIS-1 system tested here and may be the subject of future study by the CAFE Foundation.**

BIBLIOGRAPHY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**4 Lycoming Flyer--Key Reprints, page 41. 1996. Textron Lycoming, 652 Oliver Street, Williamsport, PA. 17701. Page 41.**



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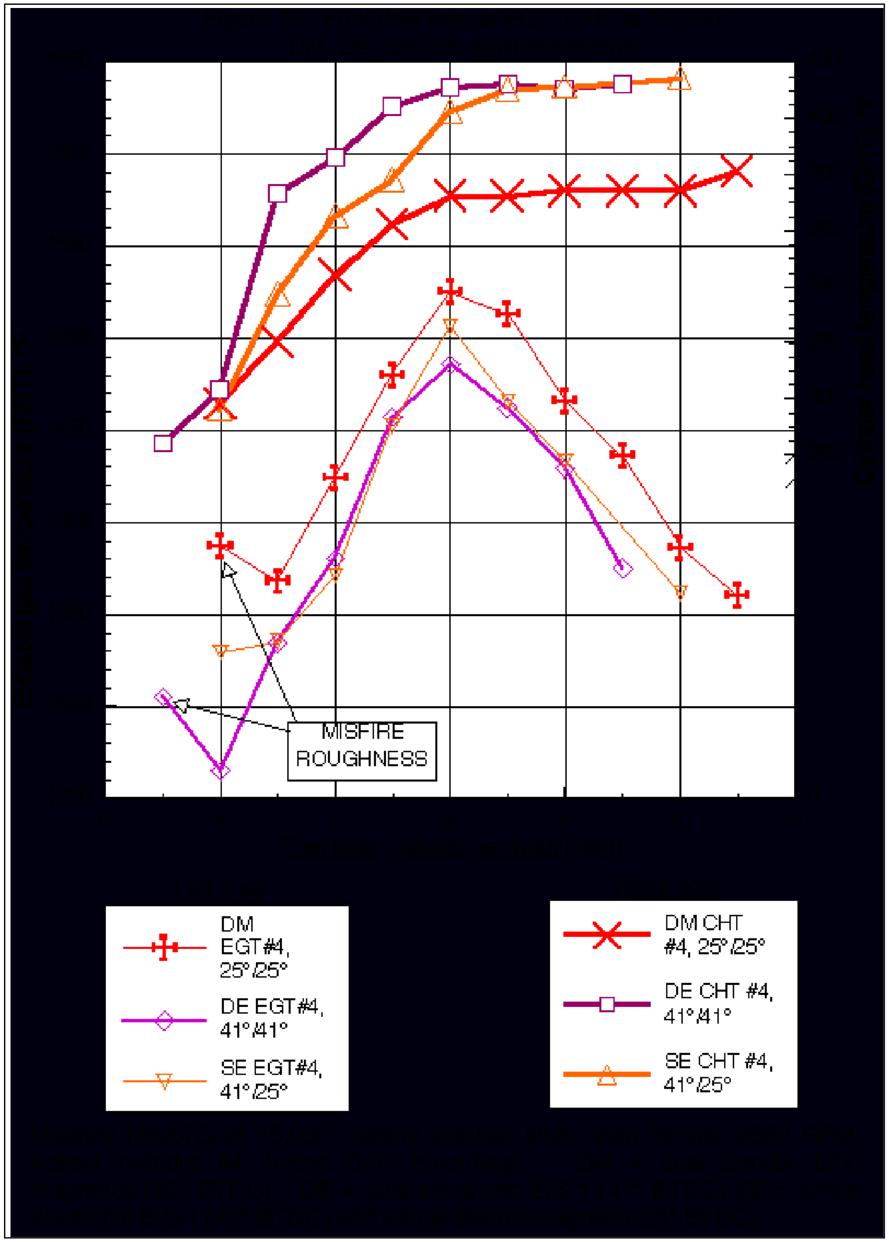
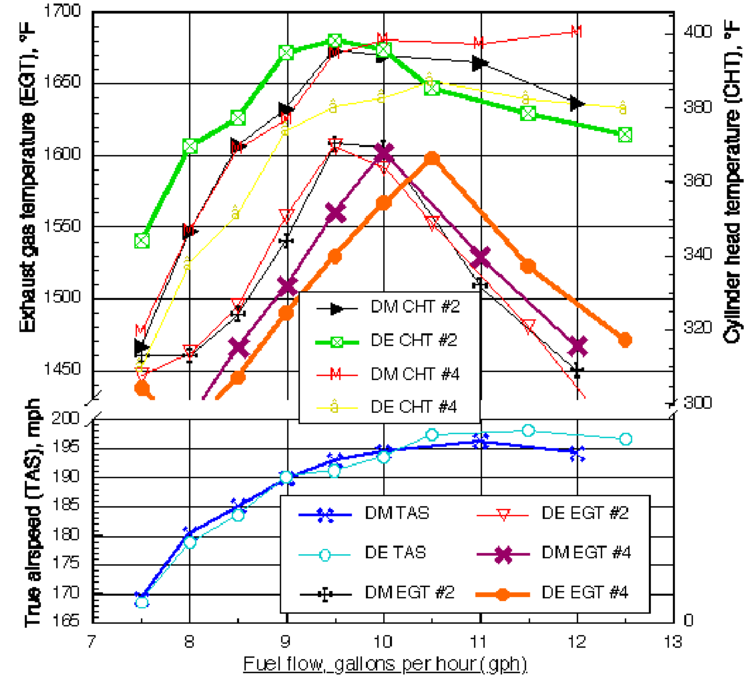


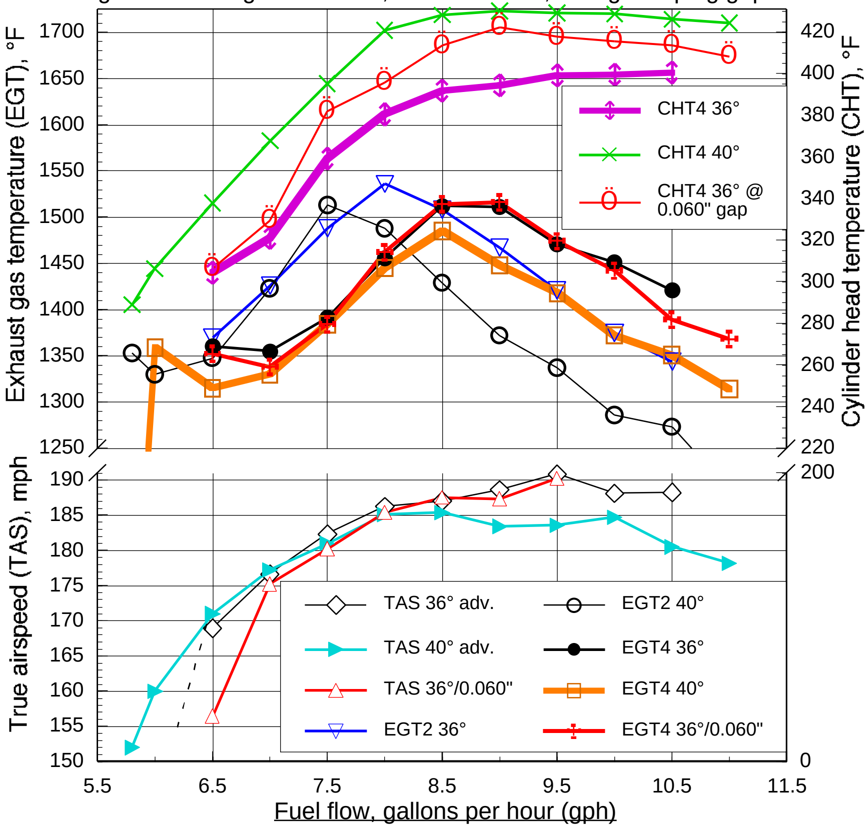

Figure 14. Fuel flow versus EGT, CHT and TAS: DM v. DE ignition.




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 magnetos @ 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 19. SE ignition: EGT, CHT and TAS, timing and plug gap effects.




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.

Figure 19 Explanation:

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 40° plummeted due to frequent cycles of severe misfire.