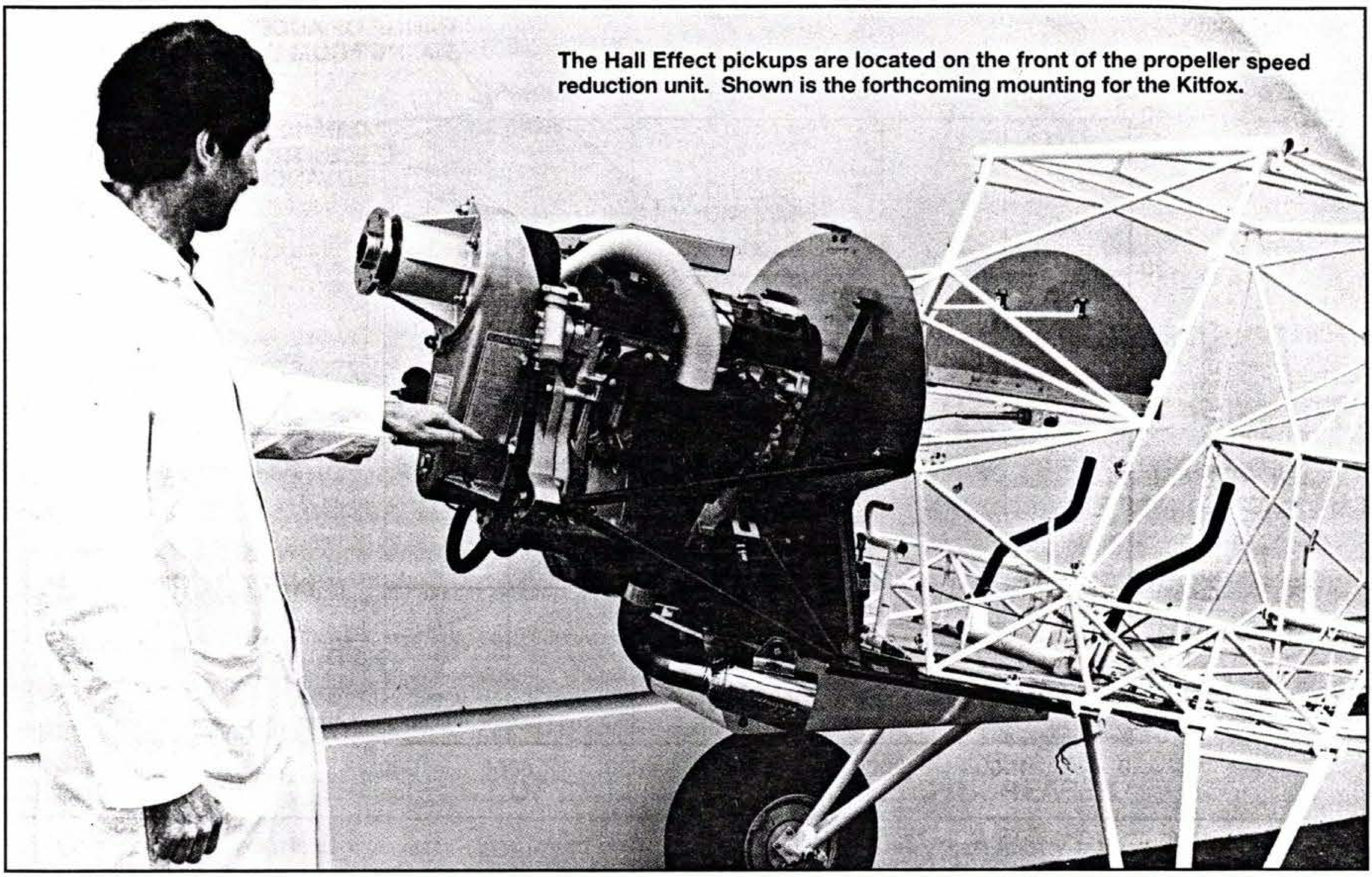

The Hall Effect pickups are located on the front of the propeller speed reduction unit. Shown is the forthcoming mounting for the Kitfox.

Camputer Dual Electronic Ignition System

Development For The CAM 100

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Auto Engine Conversions and Ignition Systems

It is easy to understand why there is a lot of interest in auto engine conversions as replacements for traditional aircraft engines.

Many pilots are very happy with the significant advantages offered by conversions. The relatively low cost of parts, the benefits of water cooling and the reduced fuel consumption are appealing improvements. In most areas of North America an easy to install cabin heat system will greatly extend the flying season. The absence of shock cooling is a definite advantage. Significantly improved fuel consumption and being able to use unleaded gasoline are big pluses. The list of advantages goes on and on.

A feature of auto engines that concerns some pilots is the ignition system. If you are used to having traditional dual magneto ignitions then change to an engine with one system, it seems like something is missing. You don't have that key on the instrument panel to check on run up or the security of a dual system. It is true that modern automotive electronic ignition systems, if carefully selected, are very reliable. It is also true that plug fouling in auto engines is virtually a thing of the past. However, it is hard to argue that a dual system would not be better.

Some auto engines are factory equipped with dual ignition. These ignitions are generally engineered for economy or pollution control, not primarily for reliability. They often use a distributor which eliminates a lot of the dual effect. Also, they are not generally found on engines that would make the best conversions.

Hearing the concerns some pilots have about ignitions prompted Canadian Airmotive to develop a dual electronic ignition system for the CAM 100. The CAM 100 is the leading 100 hp auto engine conversion and an excellent replacement for the Continental O-200.

Designing the Specifications

We found that the development of the CAM 100 ignition system was not as easy as anticipated. An old fashioned points ignition with one coil and a distributor is simple to comprehend. A modern dual ignition system with one coil per cylinder, electronic advance, engine rpm limiting and optimized dwell time proved to be a very significant project.

The first job was to separate myth from reality and establish the system specifications. Starting with the spark plugs, did they have to be dual? This could be retrofitted but would be costly, partly negating one advantage of the conversion. Our survey of auto

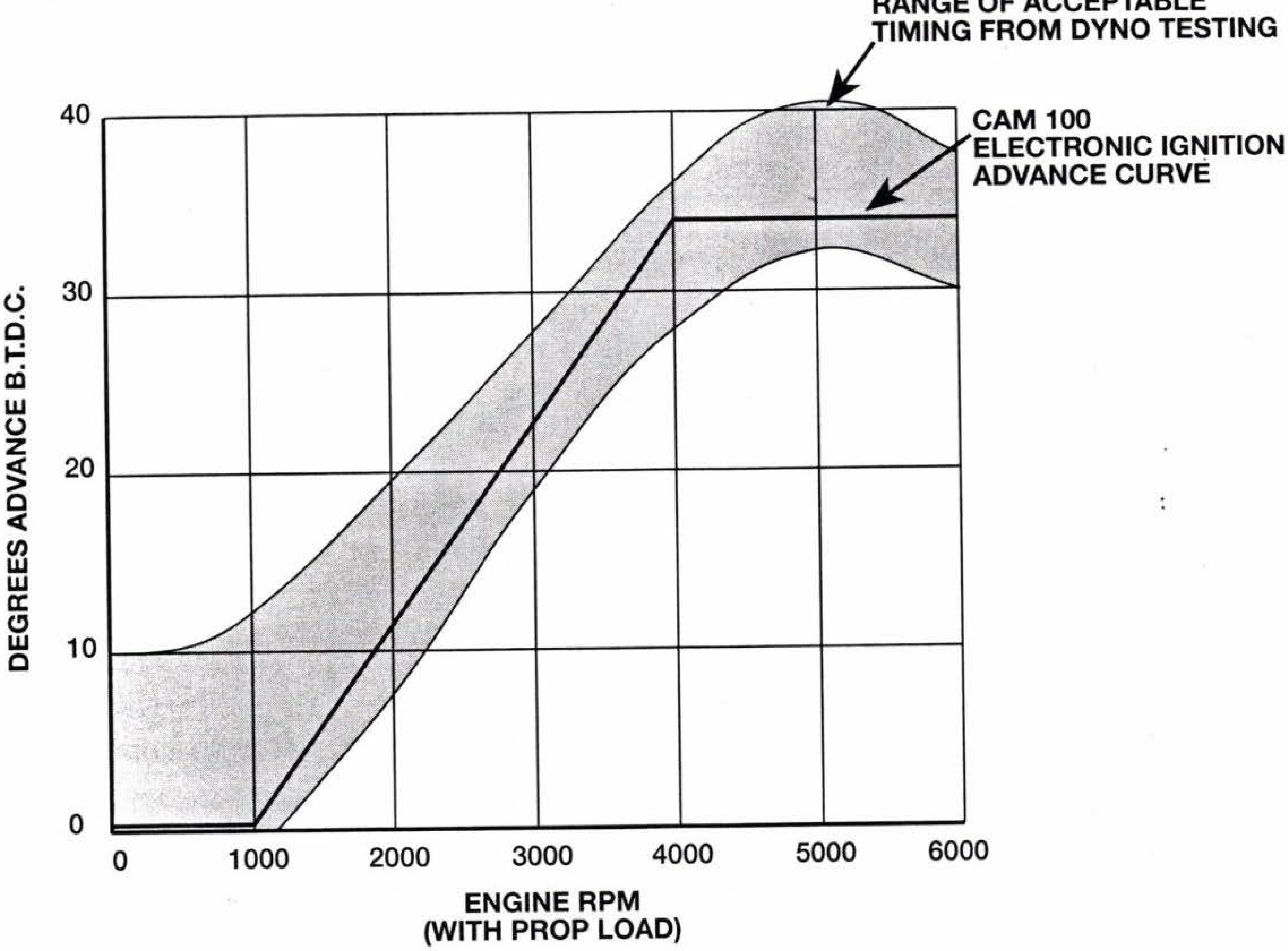
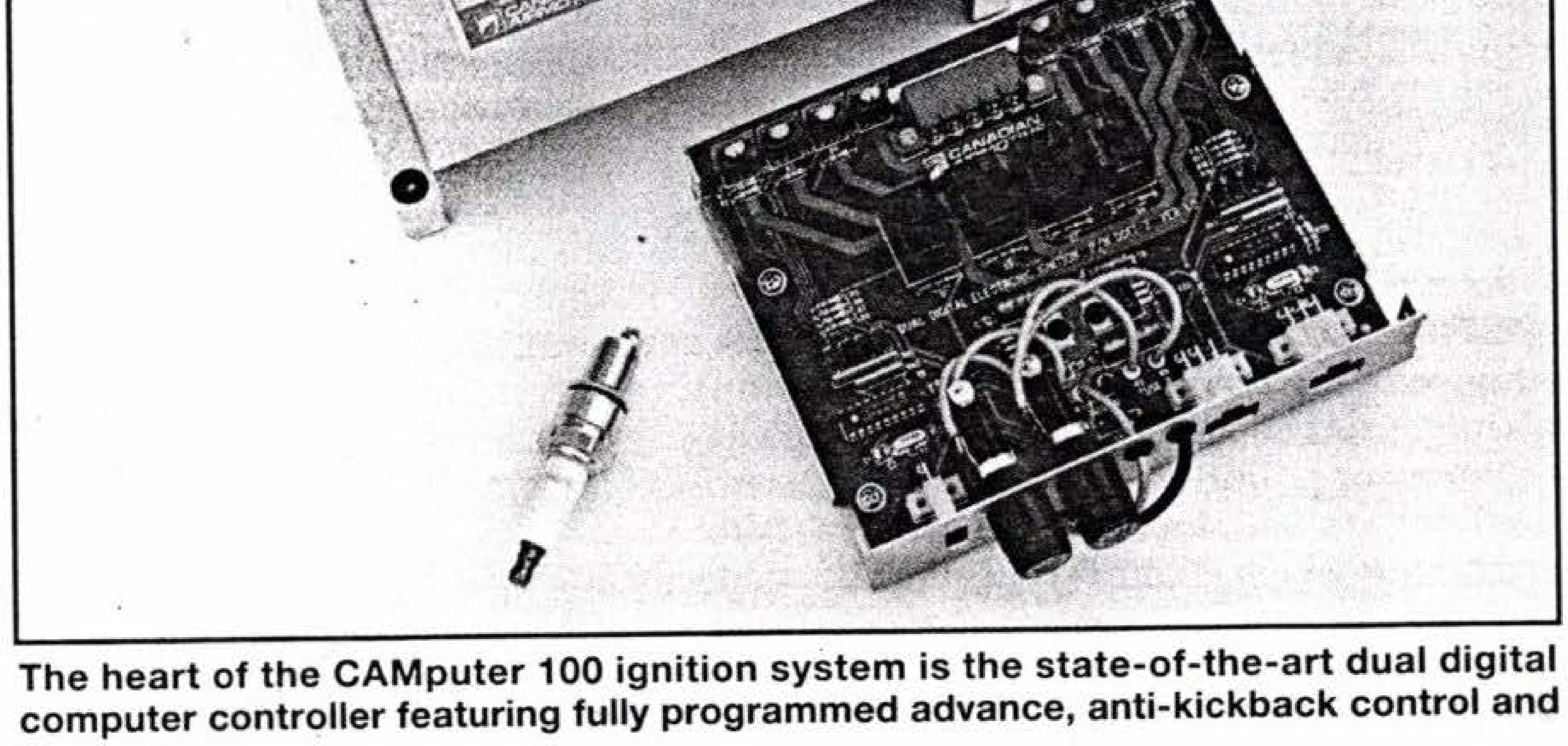


FIG. 1 CAM 100 ELECTRONIC IGNITION ADVANCE CURVE

repair records and mechanics indicated that plug failures were almost nonexistent. This is apparently due to cleaner fuel, better plugs and the strong spark provided by modern electronic ignitions. We became convinced that dual plugs would not add significantly to reliability. Proper maintenance was all that was required. In the unlikely event of a plug failure, dyno tests showed the engine would still produce 65% power.

Further investigation revealed we could improve reliability by providing one coil per spark plug and making all pickups and electronics dual and separate. This would even allow running one system on a small backup battery, preventing an aircraft electrical failure from stopping the engine. This advantage we would share with magnetos. In all other respects it appeared the CAM 100 system would be an improvement. Because the system utilizes an independent coil for each spark plug, all switching for the coils is low voltage (12V) and is done electronically.



The heart of the CAMputer 100 ignition system is the state-of-the-art dual digital computer controller featuring fully programmed advance, anti-kickback control and rev limiting.

There is no distributor to switch the high voltage to the plugs, which means no potential failures from cracked distributor caps or eroded contacts. Compared to magnetos, the CAM 100 system would be lighter and less expensive, have a proper ignition advance and a hotter spark. Theoretically it should also be more reliable.

The next specification to establish was the operating temperature range. We decided that the ignition system would have to operate flawlessly from -40 degrees C. (-40 degrees F.) to 100 degrees C. (212 degrees F.). We have a customer in Alaska who uses his Full Lotus floats equipped plane from the snow in wintertime to tend his trap line, which goes to prove that some people do actually fly at -40 degrees. 100 degrees could be attained in the engine compartment where the sensors and coils are located. The ignition control computer would be installed inside the cockpit to reduce the temperature extremes it is subjected to.

The system should work properly at low voltage. We established that 8 volts might be all that was available

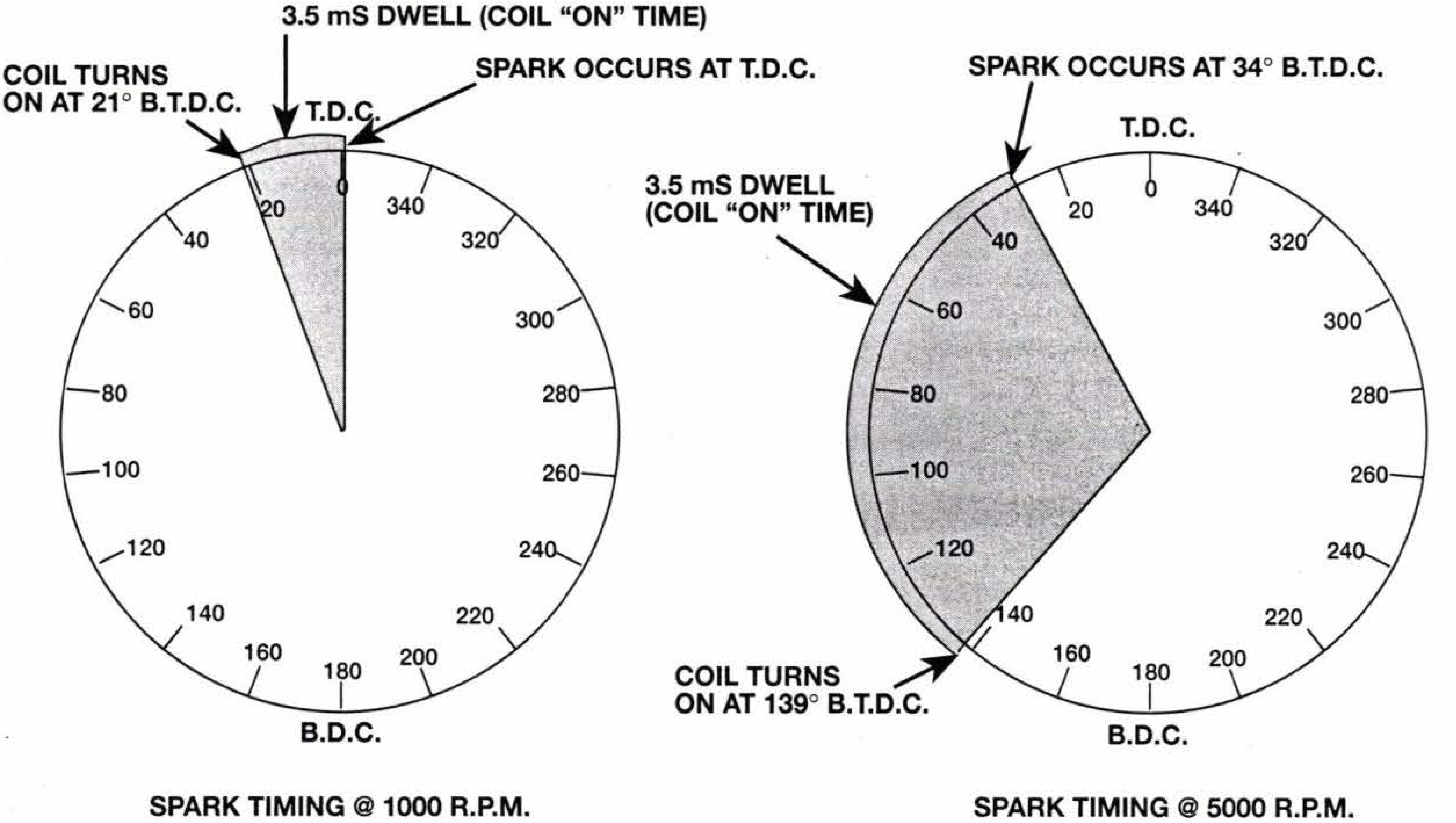


FIG. 2. THE EFFECT OF DWELL AS ENGINE SPEED INCREASES

with a very low battery that was just turning the engine over. At the upper limit 20 volts could occur as a result of a regulator failure. Outboard motors without regulators can raise the system voltage to 18 volts with a fully charged battery and no accessories turned on. If the battery was accidentally disconnected, the system voltage could go even higher. We would incorporate protection to prevent destruction of the ignition in case extreme over voltage ever occurred. A proper advance curve was mandatory to optimize power and efficiency. No advance at very low speeds and a strong spark would aid hand propping. Rev. limiting would prevent engine damage. The ignition system would have to function properly at very low rpm, as might occur with hand propping. In the event the engine stopped and the operator forgot to turn off the ignition switch, the system would have to turn itself off. This feature would prevent unnecessary battery drain and possible coil damage due to overheating.

The advance curve was established using a variable timing system. A mechanism was built that allowed the ignition timing to be adjusted while a CAM 100 test engine was running on a test stand. To approximate the load while flying, the engine was fitted with a propeller selected to allow maximum permissible rpm at full throttle. The test stand was configured as a dynamometer to allow horsepower measurements. During test runs we monitored power output and fuel consumption at various rpm while changing the ignition timing. We also did comparisons with different qualities of fuel. Acceptable timing was defined as the range within which rpm was maintained within 50 rpm of the maximum for that particular throttle opening. We also established that the preferred fuel was premium unleaded, although lower quality fuel was acceptable in an emergency.

These tests generated a graph indicating a band of acceptable timing. The band we used was based on regular unleaded fuel (see Figure 1). Premium unleaded fuel produced a wider band of acceptable timing. The stock timing was very advanced at 5000 rpm and then started to roll off and retard at higher rpm. We did not find this desirable as the timing approached dangerously close to the limit of detonation. We selected a timing curve that ramped up from 0 degrees at 1000 rpm to 34 degrees BTDC at 4000 rpm. Above 4000 rpm advance remained at 34 degrees BTDC. This curve was within the limits established by testing.

After establishing the performance specifications we searched for an off-the-shelf product. There was nothing available that was ideal. All options were very expensive. A key objective with the CAM 100 is affordability which depends on all components being very competitively priced.

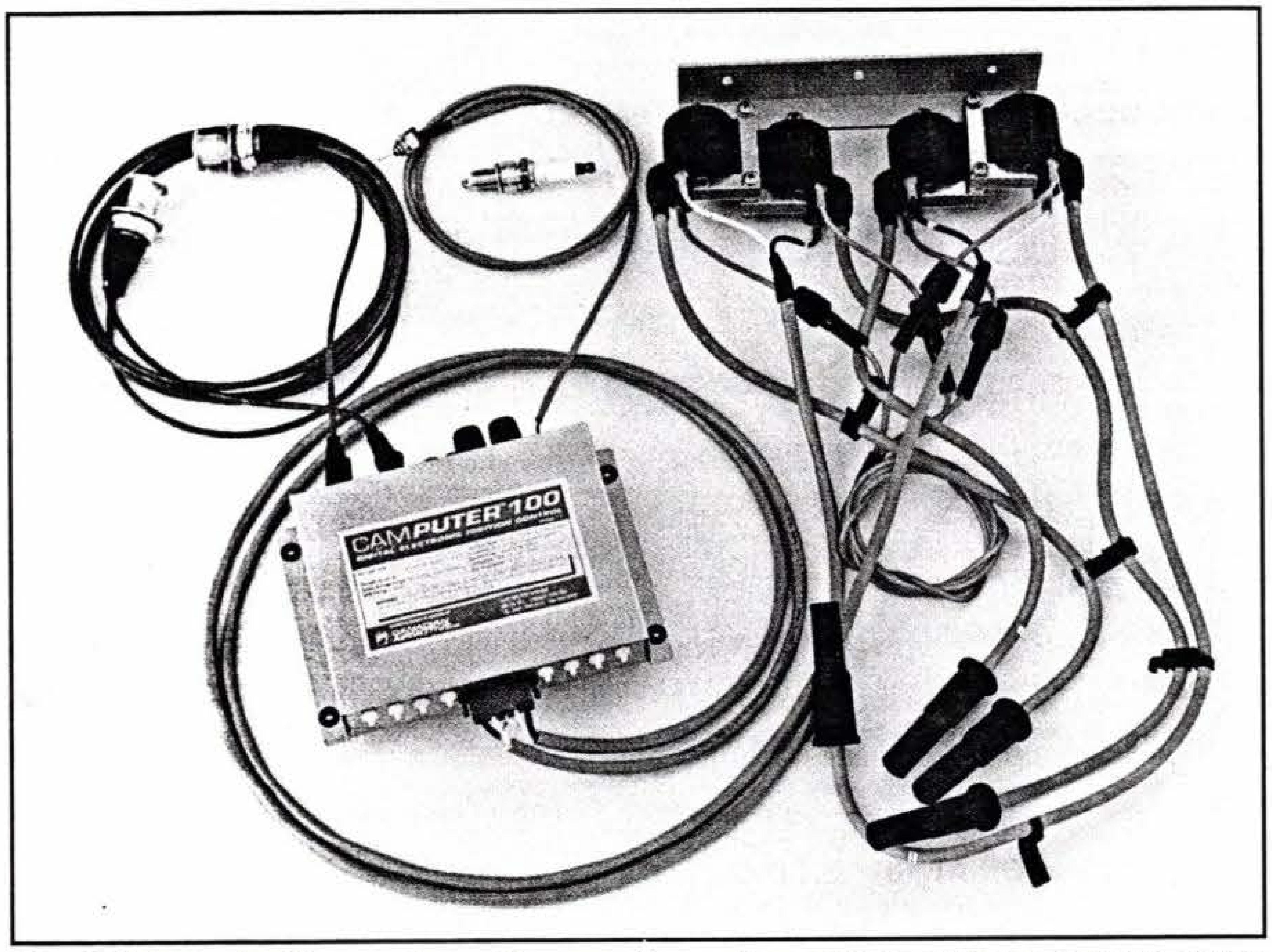
We decided to design and manufacture our own ignition system. There were many potential solutions so we started with the simplest and most cost effective possibility.

Experimenting To Find The Best System

The first approach was to design a system utilizing existing automotive reluctors, pickup coils, and electronic modules as found on some other conversions. We discovered that pickup coils from Dodge or Ford V-8s worked well when combined with the compact electronic modules from GM distributors. All these components are well proven, inexpensive and readily available. We fabricated our own test reluctors as the stock units were too small in diameter to accommodate the four pickup coils we needed. (The reluctor is a metal rotor on the distributor shaft that spins by the pickup coils. As a ridge on the reluctor passes a pickup coil, it induces a current in the coil.)

The spark advance system would be a mechanically rotated plate. The pickup coils would be mounted on the plate. The plate rotates as the throttle is opened. This type of advance is used extensively on outboard motors. The whole combination did work but had limitations.

The reluctor type of trigger puts out a signal somewhat similar to a sine wave. The modules turn the ignition coils on as the wave crosses up through zero. They turn off, and the coil sparks, as the signal next crosses zero,



The CAMputer ignition system. Because the system utilizes an independent coil for each spark plug, all switching for the coils is low voltage (12 V.) and is done electronically.

on the way down. The second zero crossing occurs when the reluctor ridge and the pickup coil are lined up.

This automotive system produces undesirable dwell times; dwell being the time the coil is turned "on." The spark occurs as the coil is turned "off." As the engine turns faster the time between turn "on" and turn "off" (the dwell) decreases, ultimately resulting in a weaker spark at high speeds. This is not a linear relationship with speed, but at very low speeds the dwell is very long - long enough to seriously overheat our lightweight coils during a prolonged idle.

We also needed a good spark at hand propping speeds. A reluctor setup that would produce enough signal at very low speeds would overload the module at high speeds and cause double sparking. The high signal output from the pickup coils at high rpm could be electronically controlled but that did not solve the coil heating problem.

In the stock (four cylinder) automotive ignition system the reluctor produces a signal which causes the coil to produce a high voltage. This process repeats four times per revolution or every 90 degrees. The high voltage is then routed to the correct spark plug by the distributor rotor. In our modified system each plug would fire once per crankshaft revolution, an arrangement called a waste spark system. This results in 180 degrees between signals when the reluctor is driven by the cam, meaning that the signal from the pickup coil is stretched out twice as far as in a normal four cylinder engine. At low speeds the slope of the signal from the reluctor/coil combination was so flat between the peaks that the module had trouble deciding when it was crossing zero. This sometimes resulted in an extra spark at the wrong time.

After much experimenting with various setups, we abandoned this approach as being inadequate for our application.

The Computer Solution

As this low tech approach wasn't successful our next approach was a high tech one using a programmable onboard computer controller.

First, we had to determine the best method of triggering the ignition. Our research indicated that latching hall effect switches triggered by flywheel magnets would be the preferred system. Hall Effect switches have been used for years to trigger automotive ignitions. Latching Hall Effects go low as one magnetic pole passes them and stays low until the opposite pole passes them, when they again go high. (Low means the input terminal is effectively connected to ground. High means it is isolated from ground.) As we wanted a dual system, each pickup assembly had to have two completely independent Hall Effect switches. These are not readily available so we had to design and manufacture our own. The two Hall Effects switches are mounted on a circuit board and potted inside an anodized aluminum holder. The holders mount in adjustment slots in the front of the prop speed reduction housing. The two magnets are mounted in the flywheel. One sensor assembly triggers cylinders 1 and 4, the other cylinders 2 and 3. Hall Effects are very reliable and once set up at the correct timing will need no further adjustment.

We had already established the optimum dwell and ignition advance curve so the next problem was discovering the best way of translating it into a system that could be programmed. A common approach is to use a lookup table to set the degree of advance based on the engine rpm. We came up with a more elegant solution that may be unique, certainly we could find nothing published like it. We use solid state counters to translate the time it takes for the flywheel to do part of a revolution into the amount of advance and the relative number of degrees of dwell without using a chart or lookup table.

We also incorporated other desirable features, all part of our system of using counters. We designed the timing so the spark will remain at TDC (top dead center) up until idle speed when it starts to advance. This ensures that someone hand propping the engine will not experience a kickback (a welcome feature for anyone experienced in hand propping). We did not want any possibility of the spark over advancing and causing detonation. To prevent this we located the magnet that causes the Hall Effect to go low at 34 degrees BTDC (before top dead center), our maximum advance. When the spark advances to 34 degrees, at about 4000 rpm, it locks onto this signal and cannot advance any more. Detonation caused by over advanced ignition can cause serious engine damage and the telltale pinging might not be audible in an aircraft. We prevent this from occurring by providing a mechanical cue to the ignition indicating that it has reached full advance.

Another advantage of the counters occurs if the engine were to stop with the ignition still switched on. The counters run out of capacity after about 2 seconds and shut off any coil that may be energized. This prevents coil overheating and damage. With a resistance of only 1.5 ohms the coils will absorb about 100 watts and soon get very hot.

We also set up the dwell time so it was longer than normal at cranking speeds to ensure a strong spark even at low battery voltage. At higher speeds dwell is optimized around 3.5 mS. to give a good spark, reduce coil heating and save electrical power.

At about 6500 rpm the sparks start to cut out to limit the engine to safe maximum rpm. This works very well.

Running the engine up to 6500 rpm on the dyno and then backing off on the load (to allow over revving) results in only a slightly different exhaust note. The engine refuses to rev any higher.

We initially built the circuit on a breadboard using discreet CMOS logic chips to prove it would work. When we were satisfied with the circuit we then translated most of the hardware in the logic system into a program run by the micro controller.

Some Interesting Discoveries

During the development we discovered some things we hadn't realized before. The time that the coil is on (the dwell time) actually works against the advancing timing (see Figure 2). If the coil is turned on at 21 degrees BTDC at 1000 rpm with a dwell time of 3.5 mS. the spark will occur at TDC. In other words, it takes the crankshaft 3.5 mS. to turn 21 degrees at 1000 rpm. At 5000 rpm the engine will turn five times as far during the dwell time and the spark will occur 105 degrees after the coil is turned on. The spark will then occur at 105 - 21 = 84 degrees after TDC. The dwell time will effectively retard the spark 84 degrees between 1000 and 5000 rpm. In order to advance the spark to 34 degrees BTDC at 5000 rpm the coil on time will have to advance to 34 degrees. The coil on time will also have to advance the 84 degrees that the dwell retards the timing for a total advance of 84 + 34 = 139 degrees BTDC.

The automotive reluctor and pickup coil system gets around the above effect by always having the spark occur as the reluctor ridge and pickup coil line up. The advance is achieved by moving the pickup coil relative to the reluctor position. The coil on time is set far enough ahead so that even at high rpm enough dwell remains to produce a spark. This, combined with the reluctors non-linear feature with speed (the dwell time does not reduce as fast as the rpm increases), produces an acceptable dwell time for automotive systems.

Another interesting discovery was the length of spark (in free air) required to run the engine. A common test of an ignition system is to haul out a spark plug, place it on the block, crank the engine and watch for a spark. I have done this and assumed that seeing what looked like a healthy spark meant that the system was O.K. In fact, a spark that will only jump .040" in free air will probably not even get an engine started. We discovered that a minimum spark length for this engine is 3/8" (in free air) and 1/2" is desirable. If you have an engine that will start but will not accelerate it may be a spark problem. At idle the compression pressure is low and a weak spark will jump the plug gap. As soon as you open the throttle the engine takes a gulp of air, the compression pressure rises and the weak spark no longer jumps the plug gap.

Using a big heavy duty coil can produce a spark that will jump 1" or more in free air. Dyno testing the engine did not show any performance advantage to a spark this hot. We did find that excessively high spark voltages caused problems with cross firing and radio interference.

Performance was also not effected by reducing the plug gap from .040" to .030". The reduced plug gap will allow an engine to run with a lower secondary ignition voltage. Increasing the plug gap eventually causes misfiring.

Finding the Best Components

Investigating coils, we looked at many shapes and sizes. Most were eliminated because of cost or weight. We did not want to use dual coil units (the ones with two spark plug wires), to avoid the possibility of a failure in one side affecting the other. We settled on a proven lightweight coil that is used on jet skis, snowmobiles and light industrial engines and is available from several manufacturers.

This coil was bench tested with a simple transistor setup driven by a frequency generator. Watching the pattern on an oscilloscope and monitoring current draw and spark length, we established the optimum dwell, or coil on time. A dwell under 2 mS. did not allow enough time for the coil windings to saturate and the spark was weak. Over 4 mS. had little effect on spark length but did increase coil heating and power consumption. We also verified that the coils would operate well at a frequency equivalent to over 6000 rpm.

To protect the rest of the system from being effected by one coil failing, each coil has its own fuse (or breaker, if you wish). In the unlikely event of one coil shorting out, it would immediately blow the fuse and have no effect on the supply to the other coils.

The output transistors that control current to the coils are a critical feature. We are using MOSFET transistors that switch quickly and have a built in zener diode that limits over voltage. When the coils are turned off and the magnetic field collapses, a high voltage spike appears at the transistors. The built in diode limits this spike to 250 volts. This spike helps to produce a strong spark as it induces a high voltage in the secondary windings. However, this high voltage is also hard on the coil insulation. Limiting the spike to 250 volts allows a high enough spark voltage to jump the plug gap while limiting the magnitude of the voltage the coil insulation must withstand.

We experimented with current limiting to protect the output transistors from shorted coils but found it produced too much voltage drop. The fuses (breakers) mentioned above protect the transistors without any voltage drop.

As the electronics in our computer controller are completely dual we had to have a method of switching the output to the ignition coils from one side of the board to the other. Each coil could be driven by both transistors (main and backup) at the same time. However, if one transistor failed it could pull down the output from the other and prevent the coil from firing. Our first solution used a large 4 pole switch. This worked well but the cable from the controller to the instrument panel was too bulky. We decided to move the switching onto the board. Some research uncovered a small relay rated for the electrical loads we needed that would function at a vibration level of 10G. The relays are switched by a simple single pole toggle switch on the instrument panel. The Main side of the switch keeps the relay coils energized. If there is a failure in the relay coils or selector switch, the relays will unlatch and select the Backup side of the board.

Both the Main and the Backup sides have their own 5 volt power supplies and filters. A surge suppressor is used to control any large spikes that could get onto the supply lines. The suppressor also serves as reverse connection protection. If the power wires are hooked up backwards the suppressor will conduct and immediately blow the fuses.

Both the Main and the Backup sides of the board have their own micro controller. The unit we use, an 18 pin I.C. made by Microchip, has extensive uses in industrial controls and also has the virtue of low cost. Each micro controller has its own quartz crystal that regulates the "clock" frequency. It runs fast, at 16 MHz, a speed only fairly recently exceeded by desktop computers. It uses a simplified set of 33 instructions; even so a printout of the program for this ignition fills six pages (see Figure 3). During production, programming a new chip is simple. A master chip is placed in a programmer socket and the read button is pressed. The programmer reads the program into its memory and veri-

SYSTEM TICK HAS OCCURRED (30.5 MICROSECONDS)

0018	004	CLRWDT		;CLEAR WATCHDOG TIMER
0019	201	MOVF	RTCC,W	;GET NEW RTC VALUE
001A	028	MOVWF	CAPTURE	;UPDATE MEMORY

DO EDGE DETECTION ON TDC AND BDC INPUTS

001B	C00	MOVLW	MASKINPUT	;GET INPUT DATA POLARITY MASK
001C	185	XORWF	PORTA, W	;GET CURRENT PORTA DATE
001D	029	MOVWF	A_SAVE	;SAVE IN MEMORY
001E	18A	XORWF	A_OLD,W	;TEST FOR CHANGES
001F	02B	MOVWF	A_CHANGE	;KEEP CHANGES
0020	149	ANDWF	A_SAVE,W	;KEEP "HIGH" CHANGES
0021	02C	MOVWF	A_HIGH	;SAVE IN MEMORY
0022	249	COMF	A_SAVE,W	;GET INVERTED DATA
0023	14B	ANDWF	A_CHANGE,W	;KEEP "LOW" CHANGES
0024	02D	MOVWF	A_LOW	;SAVE IN MEMORY
0025	209	MOVF	A_SAVE,W	;GET PORTA DATA AGAIN
0026	02A	MOVWF	A_OLD	;UPDATE MEMORY

PERFORM ENGINE RUNNING TIMEOUT DETECTION

0027	20B	MOVF	A_CHANGE,W	;GET ANY CHANGES
0028	743	BTFSS	STATUS,Z	;TEST CHANGES, SKIP IF ZERO
0029	A33	GOTO	RUNNING	;ELSE PROCEED AS RUNNING
002A	20E	MOVF	COUNTO,W	;GET LOW COUNT BYTE
002B	10F	IORWF	COUNT1,W	;INCLUDE HIGH COUNT BYTE
002C	643	BTFSC	STATUS,Z	;SKIP IF RESULT IS NON ZERO
OO2D	A00	GOTO	START	;ELSE ENGINE STOPPED, GOTO START

FIG. 3. PART OF THE MICROCONTROLLER PROGRAM

fies it. The master is then replaced in the socket by the new chip and the program button pressed. The programmer writes the program to the new chip and verifies that it is correct. It then blows a built in "fuse" in the chip, making it impossible to copy the program. This eliminates the necessity to pot the circuit, making it serviceable at the factory if necessary.

The Testing Program

We established a rigorous 50 hour testing program which served as the initial verification for the Popular Flying Association in the United Kingdom. The PFA regulates homebuilts in England and their engineers helped with the formulation of the test program.

As well as 50 hours of flight testing there were other comprehensive tests required. We did extensive testing on the dyno at -40 degrees C. (-40 degrees F.) to 100 degrees C. (212 degrees F.) from 8 volts up to 18 volts. Bench testing included extended running checked with an oscilloscope and the most demanding of all, the "shake and bake" endurance test. A shaker table driven by an electric motor was built. A heat lamp mounted above the table did the baking part, subjecting the ignition module to a scorching 100 degrees C. (212 degrees F.). The ignition box was mounted on the shaker table and operated for 250 hours while being shaken drastically. During the endurance test the ignition module operated at an elevated voltage. The system passed the test with a faultless performance.

Production

The CAMputer circuit boards are produced professionally using wave soldering to achieve the most reliable solder joints. The assembled board is sprayed with a conformal coating to protect it from moisture and corrosion damage. The completed board is then mounted in a conductive alodined aluminum housing.

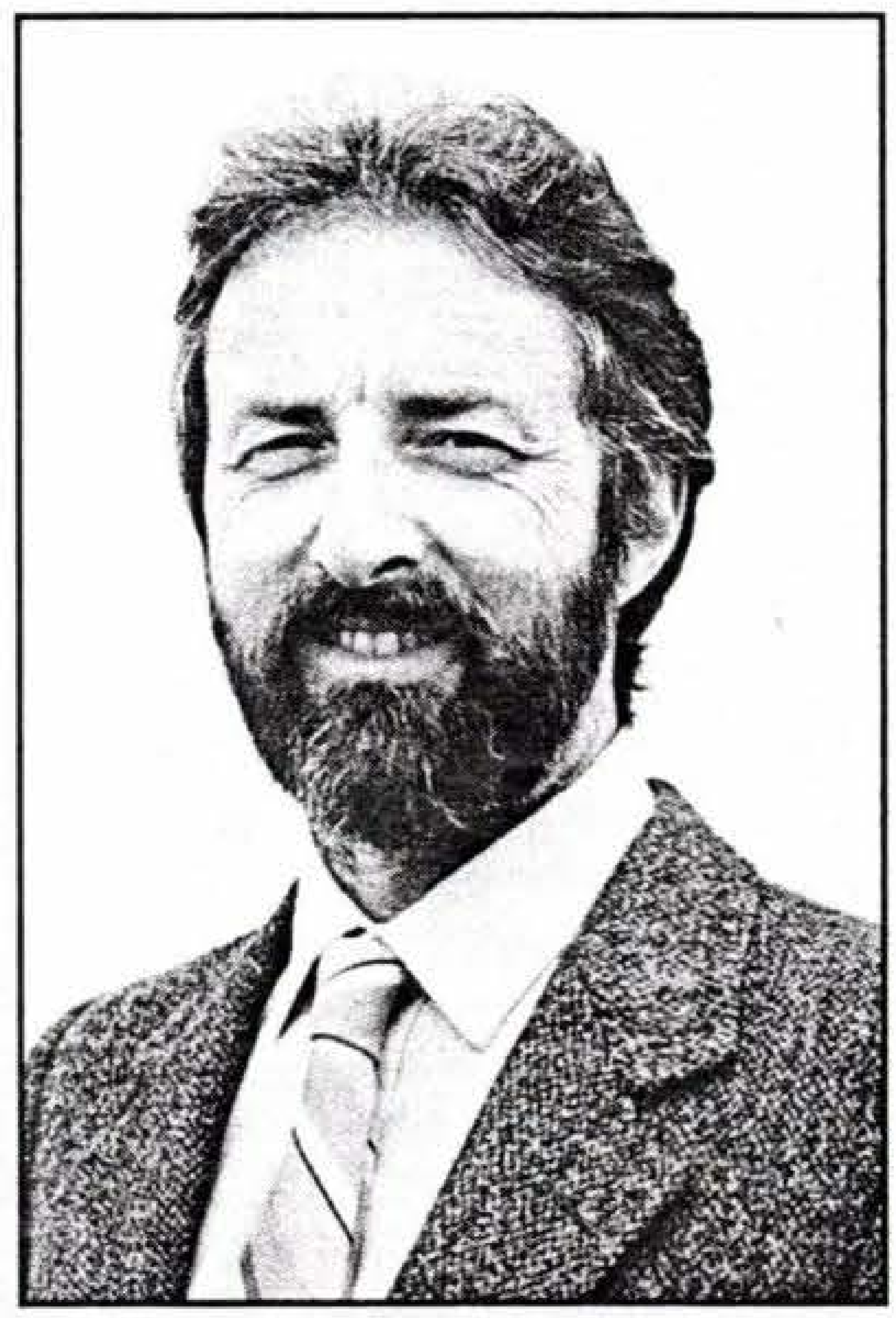
An electric powered flywheel is used to test each ignition throughout the entire CAM 100 rpm range. Current draw, spark advance, spark voltage and rpm limiting are all tested for both sides of the dual system.

Each completed CAM 100 engine is test run on the dyno before it is shipped. The complete CAMputer 100 ignition is retested at the same time with the engine it will be installed on.

In Hind Sight

Developing the CAMputer 100 ignition system, in hind sight, proved to be an extensive undertaking. The level of difficulty in the design process was essentially determined by the high performance standards set by Canadian Airmotive, that we had to meet. It would have been an easier job if we accepted a lower standard, but that would have meant compromises in the performance of the ignition. For example, if we had used heavier coils we would not have had to be so specific about the dwell times. A timing curve that ramped up as soon as the engine started turning would have been simpler, but wouldn't have offered protection against kickback while hand propping. If we left off the rev limiting someone might have damaged their engine while test running with no propeller.

The entire development project took us twelve months, which was longer than expected. The effort has proved to be worthwhile. The CAMputer has proved to be a winner, especially in terms of reliability. In all our testing, right from the time the first production unit was produced, we have yet to record a single malfunction while flying. This is a prime example of the benefit of state of the art technology when applied to aviation. ◆



About the Author

Peter Brooke, A.S.T., is a founding member of the Applied Science Technologists and Technicians of British Columbia (ASTTBC), a member of the Society of Automotive Engineers (SAE) and manager of R&D for Canadian Airmotive. He was the development team manager for the CAM 100 aircraft engine and the CAMputer dual digital electronic ignition. He has twenty years experience in the design of mechanical and electronic products.