<u>Weber DCOE Fuel Economy Improvement</u>

A Road Test Evaluating the Impact
of
Ignition Timing Vacuum Advance on Highway Fuel Mileage

Overview :

This study looks at the difference that ignition timing with vacuum advance can make on the fuel economy of a Weber DCOE-fitted sports car. Several carefully controlled fuel economy tests were conducted during January, 2008 at highway cruising speeds covering a total distance of approx. 1000 miles. The first set of these tests featured mechanical-only (<u>ie</u>. "non-vacuum") ignition timing advance using a conventional points-type distributor. The second set of tests held all other factors constant, and added only vacuum advance to the ignition timing. The results of the study, including methodology, test car specifications, test procedures and controls, and comparison of the fuel economy results are presented. A summary and discussion conclude the report.

A brief synopsis of the preliminary test results shows a **<u>fuel economy improvement of approx. 20-25 %</u>** from the addition of vacuum advance alone to the test vehicle's ignition timing. Note that this study covered fuel economy improvements only for highway cruising speeds. Similar studies are now being planned to investigate potential improvements to around-town or "city" mileage at lower speeds, as well as the use of "ported" vacuum versus "manifold" vacuum.

Contents :

1. The reason for vacuum advance :

Most road-going cars through the 1960's, including the test vehicle used here, were equipped with a distributor-type ignition system, which typically included contact breaker points, centrifugally-activated mechanical advance, and a vacuum-activated advance unit. The mechanical portion of the spark advance feature allows changes in the timing only in response to engine RPM. Although different combinations of springs connected to the mechanical advance's counterweights can alter the RATE of change (ie. "ignition curve shape"), and internal tabs can control the maximum "built-in" advance, the final amount of mechanical advance, and when it comes in, is still proportional only to engine RPM.

Vacuum advance works together with mechanical advance to allow for optimum spark timing that is proportional to both RPM and LOAD. At idle or part-throttle cruising speed (say 65 mph. at 2800 rpm on a level road), the engine is under very light load and the air/fuel ratio is leaner. This less dense charge burns slower, so therefore it must be ignited earlier in the cycle to produce peak pressure at the optimum point . Since a manifold vacuum signal is typically high under this light load condition (small opening of DCOE throttle plates at high cruise rpm's) , the distributor's vacuum advance unit reads the strong signal and literally "pulls in" extra timing advance of perhaps 15-20 degrees or more to ignite the charge earlier for optimized combustion. This aspect of "load sensitivity" is a key design element of the vacuum advance concept for improved fuel economy.

As soon as the throttle plates are opened under load (acceleration, WOT, or going up a hill) , vacuum disappears almost instantly along with vacuum advance, and the system returns to mechanical-only spark advance levels (now less advanced) for optimum combustion of the richer, faster-burning charge. This simple but effective pairing of both speed and load sensitivity for timing advance gives a performance street car "the best of both worlds". Other frequently found benefits of vacuum advance in addition to fuel economy are better tractability, smoother idling, and cooler operating temperatures.

2. Test Vehicle Specifications

The vehicle used for this test is the author's 1967 Austin Healey 3000 Mk III, shown in **Figures 1** and **2**, which he has owned and driven almost daily for the last 34 years. Recently, the original stock engine has been uprated to the equivalent of a "Fast Road Spec" level of tuning, which was the basis for this test. The engine enhancements included fitment of triple Weber 45DCOE's , as well as a Mallory dual point distributor with vacuum advance. The engine specs are shown in **Figure 3** below.

Fig. 1 - Test Vehicle

Fig. 2 - Test Vehicle

Fig.3 – Fast Road Engine Specs

- Std. engine bored to +.040 over
- Cosworth 84.5 mm. pistons
- Carillo con. Rods
- Denis Welch Racing "DWR-8" 280 deg. cam with vernier adjuster
- Stock 9:1 compression ratio (retained to run on 93-oct. pump gas- OK)
- Triple Weber 45-DCOE model 152 "G" carbs with DWR intake manifolds/ K&N filters
- DWR exhaust headers
- Mallory 27-series dual point distributor with vacuum advance and standard contact points
- Dual MSD 6-series CD ignition boxes
- Dual MSD hi-output coils
- Dual Facet electronic fuel pumps
- DWR electronic tach & fuel gauge
- Dyno-Jet on-board AFR computer, Bosch LSU-4 wideband sensor
- Real-time AFR and manifold vacuum gauges
- Stock crank
- Slightly lightened flywheel
- Engine fully balanced
- Custom-made alum. Radiator
- Alum. Sump & Oil cooler
- Heavy-duty ground skid plate
- Stock transmission with O.D.
- Vintage Air A/C
- Dynomometer output : 157 rwhp (approx. 200 bhp. est.)

3. Vacuum from where ? – The DCOE test setup

The test vehicle was fitted with triple Weber 45DCOE, model 152 “G” carbs. This Weber version has idle by-pass screws and 4 progression holes (“G” = Germany) in the transition circuit. For purposes of the initial test, “manifold” vacuum was used, which is generally a strong vacuum signal obtained from an access point downstream (engine side) of the throttle plates. Subsequent tests now being planned will use “ported” vacuum, along with a vacuum amplifier. Ported vacuum is obtained from an access point upstream (air cleaner side) of the throttle plates.

Figure 4 shows one of the specific locations on the Weber DCOE which serve as the test access points for manifold vacuum takeoff. These locations are existing inspection ports (2), adjacent to and just downstream of the throttle plates, which are part of the carb body casting. By using the existing threaded orifices in the carb, no drilling or permanent mods were required to pull manifold vacuum.

Fig. 4 - Manifold vacuum access point

Fig. 5 - Vacuum Fitting – top

Fig. 6 - Vacuum Fitting - base

Figures 5 and **6** show one of the vacuum takeoff fittings. This prototype is CNC-machined from brass hex stock. A steel screw with the correct thread pitch is silver- soldered to the base and center-drilled. The brass shaft is turned down to clear the carb body, with a 3/8” hex collar retained for easy installation or removal. A cup washer and O-ring (identical to those used on the Weber idle mixture screws) is fitted at the base for good vacuum seal.

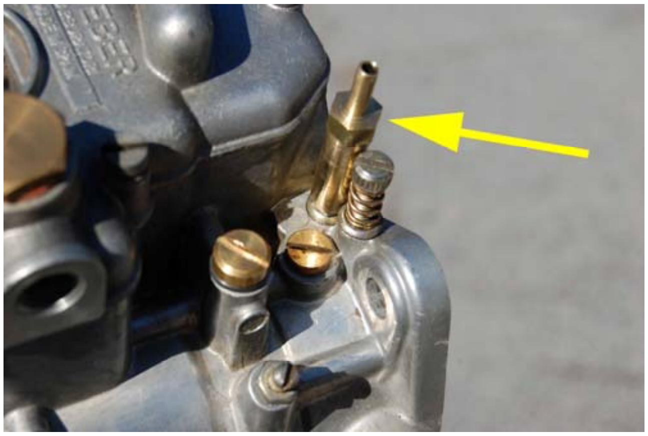

Fig. 7 - Fitting installed – side view

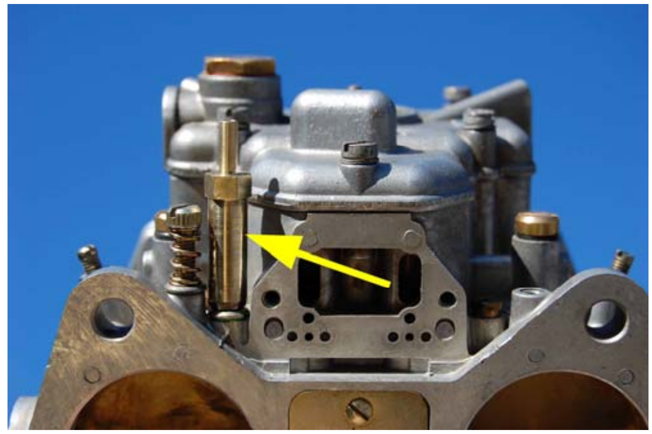

Fig. 8 – Fitting installed – rear view

Figures 7 and **8** above show one fitting installed, and **Figures 9** and **10** below show the final fittings as tested. Note that a “Y” fitting was used to merge the two incoming takeoff point lines coming from the carb. A brass “Tee” type fitting was then used to route the outgoing vacuum signal through two copper lines – one goes to the distributor vacuum advance unit, and the other to an in-dash vacuum gauge, as shown in **Figure 11**. The brass “Tee” fitting has screw-on couplings to facilitate in-situ gauge measurements under the hood if desired.

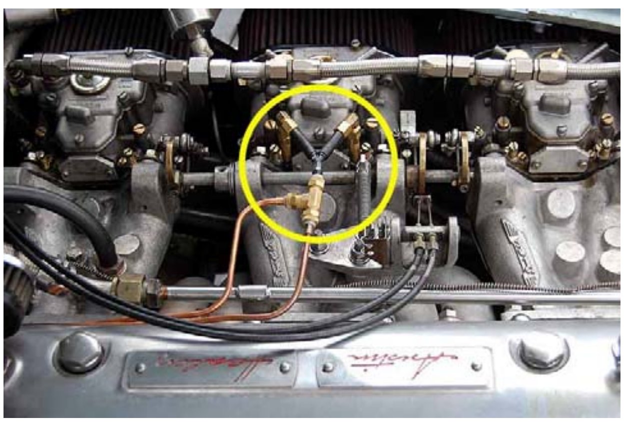

Fig. 9 - Fittings as tested

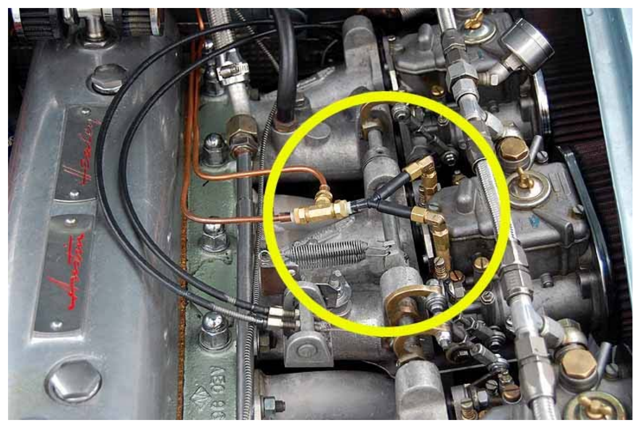

Fig. 10 - Fittings as tested

Note that the manifold vacuum signal will likely have strong pulsing at idle, although this will usually smooth out at higher rpm’s. On the test vehicle’s multi-carb setup using manifold vacuum, an experiment during test setup showed that the pulsing at idle was partially dampened by selecting specific signal access ports which correspond to opposing cylinders in the engine’s firing order. In the case of the test vehicle’s in-line 6 cylinder engine, the firing order is 1-5-3-6-2-4, therefore cylinders 3 and 4 are opposing. Conveniently, these correspond to both runners of the center DCOE carb, so this was chosen as the vacuum takeoff configuration for testing. At this point it is unknown how or if the strength and stability of the vacuum signal will be affected by the total number of carbs and lines used to pull vacuum, location of takeoff points, the diameter of the vacuum lines, or other factors. These considerations will be investigated in follow-on testing.

Alternate tests are now being planned for the use of “ported” vacuum, coupled with the use of a vacuum amplifier, not unlike some of the EGR pollution controls used in the mid-80’s. Under this concept, the strong manifold vacuum signal is temporarily stored in a reservoir canister, or “amplifier”, which helps neutralize pulsing. The ported signal, which is upstream of the throttle plates and much weaker (maybe 1.5 - 2" Hg. vs. 10-15" Hg .of manifold vac.), is used as the "intelligence" to trigger the release of the stronger, manifold-derived vacuum stored in the reservoir to advance the timing ,based on load indications. Results of these tests will be posted when completed.

The specific model of distributor used in the Manifold Vacuum testing is a Mallory "27" Series dual point unit, part number 2767801, shown in **Figure 12**. This features an adjustable vacuum advance unit. A 3/32" allen wrench is inserted into the vacuum unit's opening to make the adjustment. Turning the screw clockwise increases the amount of vacuum advance, and counterclockwise reduces the advance. Apart from the side-mounted vacuum canister, the "27" Series distributor is in all material respects functionally identical to it's non-vacuum cousin, the "23" Series with mechanical-only advance.

Fig. 11 - AFR and manifold vac. gauges

Fig.12 – Mallory "27" Series distributor

4.   Ignition settings – Before and After

The purpose of this test was to determine what effect, if any, vacuum advance would have on a DCOE- fitted engine's fuel economy. Therefore, it was important to keep all other factors constant and to test only the difference that the addition of vacuum advance might make. This was accomplished by first setting up the distributor with mechanical-only advance settings that gave good performance and street manners, without the use of added vacuum advance ("Before"). The vacuum advance line was disconnected from the distributor and blanked off, rendering it inoperable. The first series of fuel economy runs were then conducted with this configuration, and the actual mechanical advance settings used on the Mallory distributor for the tests are shown below :

A. Without vacuum advance ("Before") :

- ☐ Idle (mechanical only) : 16 degrees at 950 rpm.
- ☐ Distributor "built-in" : 20 degrees (adjustable)
- ☐ Total (mechanical only) : 36 degrees (16 + 20)

- ☐ Advance curve : begins at approx. 1300 rpm, "all-in" at 2700 rpm
- ☐ Engine torque peak : approx. 4500 rpm
- ☐ Curve springs : 2X orange (mostly linear ramp)

By comparison, the original Healey distributor was a Lucas model 25D6 with vacuum advance. It's factory specs for the mechanical only advance portion were fairly similar to the Mallory test setup :

- Idle (mechanical only) : 15 degrees at 650 rpm.
- Distributor "built-in" : 20 degrees
- Total (mechanical only) : 35 degrees (15 + 20)

B. With vacuum advance ("After") :

The second series of tests retained the exact same mechanical advance baseline settings, then added in vacuum advance ("After"). The vacuum advance takeoff line was re-connected to the distributor, with the vacuum canister adjuster being set to give the following advance figures :

At Idle :

- Existing manifold vac at idle : 10" Hg.
- Baseline idle (mech. only) : 16 degrees
- Added vacuum advance at idle : + 18 degrees
- **Total advance at idle** : **34 degrees** (16 + 18)
  (mech. + vac. – no load)

At Max :

- Baseline idle (mech. only) : 16 degrees
- Distrib "built-in" : 20 degrees
- Added vacuum advance at max : + 22 degrees
- **Total max advance** : **58 degrees** (16 + 20 + 22)
  (mech. + vac. – no load)

These vacuum advance settings produced very smooth and tractable running throughout the entire range, with good acceleration and no "pinging", run-on, or dieseling. Although further fine tuning could be done, these settings resulted in excellent overall performance of the car and therefore were settled on for the second series of test runs.

5. Test conditions and environment :

It was beyond the scope of this effort to conduct a rigorous and statistically-based scientific study with elaborate instrumentation and long-term sampling. Instead, a series of carefully controlled "real-world" tests were performed and controlled according to best practices methods. The test conditions and environmental conditions are documented below :

- Period – month of January, 2008
- Location – north of Atlanta, Georgia, USA
- Distance covered – 1000 + miles
- Weather – clear, cold (30-50 deg. F.), no wind
- Terrain – flat to gently rolling Piedmont topography
- Road type – U.S. Interstate or limited-access 4-lane
- Road surface – smooth concrete
- Fuel type – 93 octane unleaded pump gas (no methanol added)
- Weight – car and driver only, plus fuel
- Engine data – see attached specs in **Fig. 3**

6. Testing methodology, procedures, and controls :

It was obviously important that the test results be not only accurate, but also repeatable under the same circumstances. In support of that goal, the following methodology, procedures, and controls were used to govern the tests :

- □ Fuel measurement – fill / re-fill to graduated mark in tank filler
- □ Fuel type – refill at same station with same grade
- □ Road course – travel same road for approx. the same distance
- □ Driving style – average, "non-aggressive" for all tests, maintain fairly constant speed
- □ Air conditioner turned off
- □ Speed ranges – see below

7. Fuel economy test results :

The fuel economy tests were conducted according to the procedures and controls above. Three speed ranges that covered the high speed part throttle cruise (HSPTC) phase of operation were evaluated. These ranges were 50-60 mph, 60-70 mph, and 70-85 mph, respectively. Fuel economy figures for the non-vacuum advance configuration ("before") were measured over a combined distance of approx. 500 miles, and then a mean average fuel economy figure for Non-vacuum HSPTC was calculated. The **"Before"** results are summarized below :

Test Set	**Speed Range**	**Trans. / rpm.**	**Vacuum Advance**
Test set # 1	50-60 mph.	4^{th} O.D. / 2200 rpm.	No
Test set # 2	60-70 mph.	4^{th} O.D. / 2600 rpm.	No
Test set # 3	70-85 mph.	4^{th} O.D. / 3000 rpm.	No

Ave. economy, test sets 1-3 (approx. 500 total miles), **without** vacuum advance : **20.5 mpg**

The vacuum advance was then connected, and the same series of tests was re-run with all other factors held constant, including baseline ignition settings and Weber DCOE jetting.
The **"After"** results are shown below :

Test Set	**Speed Range**	**Trans. / rpm.**	**Vacuum Advance**
Test set # 4	50-60 mph.	4^{th} O.D. / 2200 rpm.	Yes
Test set # 5	60-70 mph.	4^{th} O.D. / 2600 rpm.	Yes
Test set # 6	70-85 mph.	4^{th} O.D. / 3000 rpm.	Yes

Ave. economy, test sets 4-6 (approx. 500 total miles) , **with** vacuum advance : **25.4 mpg**
The best mileage obtained for any of these segments was an impressive
30.9 mpg. recorded during Test set #5.

Net average improvement from vacuum advance : **Approx. 20-25%**

8. Summary and discussion :

This study shows that the addition of vacuum advance to a DCOE-equipped car can make a tangible improvement in fuel economy under certain conditions. The results obtained from this exercise, although preliminary, are considered by the author to be reliable, accurate, and repeatable under similar circumstances. Nonetheless, the following caveats and limitations should be taken into consideration when reviewing these results:

A. Baseline tuning

The test vehicle was already in a well-tuned state, including reasonably well adjusted carburetion. A poorly tuned engine cannot be expected to deliver good performance or fuel economy under any circumstances, even with the addition of vacuum advance. This is especially true if the Weber DCOE's are improperly setup or adjusted. A highly recommended source of information on tuning Webers is the "Sidedraft Central" discussion group on Yahoo.com. Particularly useful procedures for DCOE setup and calibration are found in a white paper on that site by moderator Keith D. Franck entitled "How-to Quit Guessing and dial in to perfection" . Also highly recommended is the use of an AFR unit for Weber tuning. Without an AFR unit, it is highly unlikely that the optimum overall Weber settings and resulting fuel economy improvements will be realized.

B. Highway vs. city mileage

As stated earlier, the mileage figures in **Section 7** are based upon driving at sustained highway cruising speeds, also referred to herein as high speed part-throttle cruise (HSPTC). This phase of the DCOE's operation sees small throttle plate openings, lean mixture, light load, and high vacuum. These factors in combination form a "best-case scenario" for the addition of vacuum-based timing advance and optimum combustion. The vacuum advance at HSPTC allows the same cruising speed to be maintained with less throttle opening , thereby improving fuel economy. The test results support this. However, the tests did not address "city" driving, and therefore the level of potential improvement for around town driving is unknown at this time. Follow-up testing is planned to investigate this.

C. "Ported" vs. "Manifold vacuum

The choice of whether to use "ported" or "manifold" vacuum sources seems to be controversial, to say the least, among long-time tuning veterans, as a Google search will quickly reveal. To paraphrase the famous American writer, Samuel L. Clemens (a.k.a. Mark Twain), " If you take a thousand experts on this topic and lay them end-to-end, they'd never reach a conclusion .....". This study chose to use manifold vacuum simply as a matter of convenience rather than preference. Although the Weber DCOE design does not appear to have explicitly anticipated a provision for a vacuum advance takeoff port, it was nonetheless relatively easy to obtain as described in **Section 3** above. A follow-on study is planned which will use DCOE "ported" vacuum, along with a vacuum signal amplifier, and the results will be compared.

D. Race car vs. Street car

It is important to note that a true race-prepped car (on the track, in competition) will be in a vastly different operating environment than a typical performance street vehicle, and therefore will have different ignition timing needs. The race car on the track is operating at WOT most of the time, with heavy load, rich mixture, and virtually no vacuum. Idle and light-load part throttle cruise conditions are not in the racing picture (unless unfortunately you're losing the race !), and better fuel economy is not usually the first thing that comes to mind when you're about to pass that Morgan in front of you. Many successful vintage car racers will actually "lock-down" the distributor's mechanical advance to a fixed maximum advance setting and go with it. In fact, Mallory makes a model of distributor specifically designed for this. For these and other reasons, vacuum advance really doesn't make sense for most race cars. However, if you're driving a street performance vehicle, there's really no reason not to have vacuum advance, since it will likely improve economy and overall driveability, with no noticeable impacts on performance.

E. Scalability / Adaptability

This test was conducted on a single test vehicle in a limited timeframe, and it is readily acknowledged that further improvements may be realized with different settings and more testing. It is also unknown how the results might scale to other platforms. However, it is the author's hope that owners of other classic sports cars fitted with Webers, such as Lotus, Alfas, Datsun Z's, Triumphs, etc. may find this information helpful in their search for improved DCOE fuel economy. As always, any feedback or "lessons learned" from others is appreciated.

9. Acknowledgements and thanks

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