State of California
AIR RESOURCES BOARD

EXECUTIVE ORDER D-97-1
Relating to Exemptions under Section 27156
of the Vehicle Code

BAE
BAE TURBOCHARGER KIT #28-0000C

Pursuant to the authority vested in the Air Resources Board by Section 27156 of the Vehicle Code; and

Pursuant to the authority vested in the undersigned by Sections 39515 and 39516 of the Health and Safety Code and Executive Order G-45-5;

IT IS ORDERED AND RESOLVED: That the installation of the BAE Turbocharger Kit #28-0000C manufactured by BAE of 3032 Kashiwa Street, Torrance, CA 90505, has been found not to reduce the effectiveness of required motor vehicle pollution control devices and, therefore, is exempt from the prohibitions of Section 27156 of the Vehicle Code for 1980 gasoline-powered Volkswagen Rabbit, Scirocco, and Jetta passenger cars equipped with manual transmissions and three-way catalysts with closed-loop feedback controls.

This Executive Order is valid provided that installation instructions for this device will not recommend tuning the vehicle to specifications different from those submitted by the vehicle manufacturer.

Changes made to the design or operating conditions of the device, as exempted by the Air Resources Board, that adversely affect the performance of a vehicle's pollution control system shall invalidate this Executive Order.

Marketing of this device using an identification other than that shown in this Executive Order or marketing of this device for an application other than those listed in this Executive Order shall be prohibited unless prior approval is obtained from the Air Resources Board. Exemption of a kit shall not be construed as an exemption to sell, offer for sale or advertise any component of a kit as an individual device.

This Executive Order does not constitute any opinion as to the effect that the use of this device may have on any warranty either expressed or implied by the vehicle manufacturer.

THIS EXECUTIVE ORDER DOES NOT CONSTITUTE A CERTIFICATION, ACCREDITATION, APPROVAL, OR ANY OTHER TYPE OF ENDORSEMENT BY THE AIR RESOURCES BOARD OF ANY CLAIMS OF THE APPLICANT CONCERNING ANTI-POLLUTION BENEFITS OR ANY ALLEGED BENEFITS OF THE BAE TURBOCHARGER KIT #28-0000C.

No claim of any kind, such as "Approved by Air Resources Board" may be made with respect to the action taken herein in any advertising or other oral or written communication.

Section 17500 of the Business and Professions Code makes untrue or misleading advertising unlawful, and Section 17534 makes violation punishable as a misdemeanor.

Section 43644 of the Health and Safety Code provides as follows:

> "43644. (a) No person shall install, sell, offer for sale, or advertise, or, except in an application to the state board for certification of a device, represent, any device as a motor vehicle pollution control device for use on any used motor vehicle unless that device has been certified by the state board. No person shall sell, offer for sale, advertise, or represent any motor vehicle pollution control device as a certified device which, in fact, is not a certified device. Any violation of this subdivision is a misdemeanor."

Any apparent violation of the conditions of this Executive Order will be submitted to the Attorney General of California for such action as he deems advisable.

Executed at El Monte, California, this 3rd day of October, 1980.

K. D. Drachand, Chief
Mobile Source Control Division

State of California
AIR RESOURCES BOARD

Staff Report

July, 1980

Evaluation of the BAE #28-0000C Turbocharger Kit in Accordance with Section 2222, Title 13 of the California Administrative Code

I. Introduction

BAE, of 3032 Kashiwa Street, Torrance, California 90505 has applied for exemption of a turbocharger kit from the prohibitions of Section 27156 of the Vehicle Code. This kit, #28-0000C, is intended for Volkswagen Rabbit, Scirocco, and Jetta passenger cars with three-way catalysts and manual transmissions.

BAE has submitted back-to-back emission tests conducted on a 1980 Volkswagen Scirocco at an independent laboratory. Confirmatory tests were conducted on the same vehicle at the Air Resources Board (ARB) laboratory in El Monte.

II. Turbocharger System Applicability

BAE's kit #28-0000C is designed for Volkswagen (VW) Rabbit, Scirocco, and Jetta models having gasoline-powered, 1588cc (97 CID) displacement engines with manual transmissions and three-way catalyst systems with closed loop feedback controls. These vehicles have Bosch mechanical fuel injection and electronic ignition. The distributors are controlled by a centrifugal advance mechanism and a vacuum advance/retard diaphragm.

The turbocharger kit is not applicable to Volkswagen vehicles with diesel engines or automatic transmissions, or to Volkswagen trucks, vans, or Dasher models.

The design of the stock vehicles has the engine mounted transversely with the intake manifold above the exhaust manifold on the side of the engine between the engine block and the firewall. The original exhaust manifold is replaced by a BAE manifold that bolts directly to the turbocharger inlet. This locates the turbocharger between the engine and firewall just under the exhaust manifold. The BAE exhaust manifold has a port for the feedback control oxygen sensor and a tap for exhaust sampling. The turbine outlet is connected to the stock exhaust system by a short curved tube.

On the intake side, the original duct joining the VW air inlet control box and the intake manifold is replaced by a 3" diameter pipe from the flow control box to the compressor inlet, and a 2" diameter pipe from the compressor outlet to the intake manifold. A pressure relief valve is inserted in the compressor outlet pipe as a boost control to limit intake manifold pressure to 7 psig.

A water injecton system is included in the kit to reduce detonation. The water is piped from a small reservoir through an electric pump to the compressor inlet pipe. A control box sensing compressor outlet pressure and distributor rpm determines the water flowrate by feeding a variable voltage to the electric pump.

Two conditions must be met before water will begin to flow: (1) engine speed must be at least 1500 rpm, and (2) a positive pressure must be sensed in the compressor outlet pipe. Water passes through a fixed 0.0225 inch diameter orifice in the water line, and flow is directly proportional to engine speed once it is initiated.

Turbocharger lubrication is provided by a steel braided line from the oil filter cap to the turbocharger bearing housing. Oil return is gravity fed from the turbocharger bearings to the oil pan through a second, larger diameter, steel braided line.

BAE provides all parts including miscellaneous installation hardware in the #28-0000C kit. Installation instructions are provided along with drawings and schematics of key features. BAE recommends tuning to original manufacturer's specifications with a suggestion to use the highest octane unleaded fuel available.

IV. Test Program

A 1980 Volkswagen Scirocco with a five speed manual transmission was used for testing. The vehicle had approximately 4000 miles on the odometer at the start of testing. The following test procedure was used to determine emissions of the unmodified (baseline) vehicle at both Mardikian and the ARB laboratories:

One cold start CVS-75 at road load horsepower (1XRL)

One hot start Highway Fuel Economy Test (HFET) at 1XRL

One cold start CVS-75 at twice road load horsepower (2XRL)

One hot start HFET at 2XRL

The same test sequence was conducted on the vehicle after the turbocharger installation to provide a back-to-back emissions comparison.

V. Applicant's Test Data

The applicant's emission test data in Table 1 was generated at Mardikian Engineering Automotive Research Center. The vehicle was tested at 2000 lbs. inertia weight and 1XRL = 9.1 horsepower. The percent difference from baseline emissions is given in parentheses. Large percentage increases in hydrocarbons (HC) are due mainly to the unusually low magnitude of baseline HC numbers.

Table 1

Applicant's Emission Data

Test	Load	Test Date	(grams/mile) HC	CO	NOx	(mi/gal) FE
Baseline CVS-75	1XRL	2/19/80	0.09	1.32	0.87	30.31
Device CVS-75	1XRL	3/31/80	0.26(188%)	1.96(48%)	0.40(-54%)	31.03(2%)
Baseline CVS-75	2XRL	4/11/80	0.49	1.51	0.80	24.27
Device CVS-75	2XRL	4/3/80	0.43(-12%)	1.87(24%)	0.61(-24%)	26.39(9%)
Baseline HFET	1XRL	4/11/80	0.03	0.15	0.83	38.64
Device HFET	1XRL	4/2/80	0.18(500%)	0.24(60%)	0.50(-40%)	39.23(2%)
Baseline HFET	2XRL	4/11/80	0.05	0.31	1.48	28.73
Device HFET	2XRL	4/2/80	0.09 (80%)	0.26(-16%)	0.47(-68%)	31.05(8%)

VI. ARB Test Data

ARB emission testing was conducted at the Haagen-Smit Laboratory in El Monte, California, on the same vehicle tested by the applicant. The turbocharger kit was removed, and the vehicle was returned to its stock configuration for the ARB tests.

Engine tune-up parameters were set to manufacturer's specifications. Tank fuel (Chevron unleaded) was specified as the test fuel for all tests. The same emissions tests were run on the Scirocco at the ARB lab as were run at Mardikian. The only differences in testing were that the ARB test used the certification inertia weight of 2250 lbs. versus 2000 lbs. at Mardikian, and road load horsepower (1XRL) was taken as 9.8 versus 9.1 at Mardikian. The ARB used 1XRL = 9.8 hp as a worst case representing the certification horsepower for a VW Rabbit convertible.

In addition to the emissions test series, some steady state tests were conducted to verify horsepower increases, water injection rates, and boost pressure. These results are given in Appendix II. The water injection switch cut-in/cut-out pressure is approximately 0.5 psig. An informal before-and-after driveability test was conducted to detect obvious surge, detonation, hesitation and other driveability problems that might occur. The turbocharged vehicle exhibited good driveability in all respects. Severe detonation occurred in one instance as a results of a kink in the water injection line stopping water flow.

ARB emissions data is presented in Tables 2 and 3 for the naturally aspirated and turbocharged vehicle, respectively. Table 4 is a comparison of naturally aspirated versus turbocharged emissions data with the percent difference from baseline emissions given in parentheses. Again, the low magnitude of some baseline emission values make some large percentage increases or decreases negligible.

Some of the data in Table 3 (noted by an asterisk) was not considered in the evaluation due to water leakage from the water injection unit into the compressor inlet pipe. This leakage could have affected emissions or fuel economy results.

The emissions data from the turbocharged vehicle that was used in Table 4 was taken with the water injection system disabled. Chart recorder traces of intake manifold pressure showed no positive (gage) pressure during the CVS-75 or HFET tests. According to BAE design specifications, water injection should occur only under conditions of positive intake manifold (gage) pressure, therefore, the water injection system leakage was considered secondary to testing the turbocharger system.

Table 2

ARB Emission Data - Naturally Aspirated VW Scirocco

Test	Load	Test Date	(grams/mile) HC	CO	NOx	(mi/gal) FE
Baseline CVS-75	1XRL	6/19/80	0.13	1.01	1.20	24.7
Baseline CVS-75	1XRL	6/26/80	0.16	0.87	1.18	24.8
		Average	0.14	0.94	1.19	24.8
Baseline CVS-75	2XRL	6/20/80	0.12	0.92	1.47	23.0
Baseline HFET	1XRL	6/19/80	0.04	0.05	1.64	34.6
Baseline HFET	1XRL	6/26/80	0.04	0.09	1.57	34.2
		Average	0.04	0.07	1.60	34.4
Baseline HFET	2XRL	6/20/80	0.06	0.13	0.99	27.0

Table 3

ARB Emissions Data - Turbocharged VW Scirocco

Test	Load	Test Date	(grams/mile) HC	CO	NOx	(mi/gal) FE
Device CVS-75*	1XRL	7/22/80	0.17	1.05	0.54	24.8
Device CVS-75	1XRL	7/31/80	0.05	1.24	0.67	25.4
Device CVS-75	2XRL	7/23/80	0.28	1.42	0.71	22.9
Device HFET*	1XRL	7/21/80	0.05	0.09	0.71	33.6
Device HFET*	1XRL	7/22/80	0.05	0.16	0.72	29.4
Device HFET	1XRL	7/21/80	0.05	0.13	0.78	33.5
Device HFET	1XRL	7/31/80	0.02	0.19	0.57	35.7
		Average	0.04	0.16	0.68	34.6
Device HFET	2XRL	7/21/80	0.05	0.26	0.43	27.1
Device HFET	2XRL	7/23/80	0.05	0.24	0.53	27.1
		Average	0.05	0.25	0.48	27.1

*Data not used for comparison due to leaking water injection system.

Table 4

ARB Data - Comparison of Naturally Aspirated vs. Turbocharged Scirocco Emissions

Test	Load	(grams/mile) HC	CO	NOx	FE
Baseline CVS-75	1XRL	0.14	0.94	1.19	24.8
Device CVS-75	1XRL	0.05 (-64%)	1.24 (32%)	0.67 (-44%)	25.4 (2%)
Baseline CVS-75	2XRL	0.12	0.92	1.47	23.0
Device CVS-75	2XRL	0.28 (133%)	1.42 (54%)	0.71 (-52%)	22.9 (0%)
Baseline HFET	1XRL	0.04	0.07	1.60	34.4
Device HFET	1XRL	0.04 (0%)	0.16 (129%)	0.68 (-58%)	34.6 (1%)
Baseline HFET	2XRL	0.06	0.13	0.99	27.0
Device HFET	2XRL	0.05 (-17%)	0.25 (92%)	0.48 (-52%)	27.1 (0%)

V. Discussion

The only significant changes in emissions indicated by Table 4 are an across the board reduction in oxides of nitrogen (NOx), and an increase in hydrocarbons (HC) on a cold start CVS-75 test at 2XRL. The other increases or decreases in emissions and fuel economy are insignificant. The HC increase at 2XRL is due entirely to HC in the cold transient phase that may have been caused by a long cranking period or a restart.

The overall lower NOx might be attributed to an increase in catalyst efficiency as a result of turbocharging. The turbine housing may be acting as a thermal reactor or "afterburner" by mixing the exhaust at temperatures high enough to cause the HC and CO to combine with oxygen. This would deplete the oxygen in the exhaust gas that would otherwise reach the catalyst. Lower exhaust gas oxygen concentrations would enhance the reducing atmosphere in the three-way catalyst and improve its NOx reduction efficiency. The oxygen sensor signal would not be affected since the sensor is upstream of the turbine. The oxidation process in a three-way catalyst may be adversely affected by the lower oxygen content if the catalyst temperature is reduced, but this might be offset by the HC and CO burned in the turbine housing.

The data from the Mardikian laboratory shows the same trends of significant NOx reduction as the ARB data. The Mardikian data, however, is not directly comparable to ARB data because 1) the water injection system may have been leaking, 2) the test inertia weight was less than the certification inertia weight, 3) the vehicle may have been run with the timing advanced, and 4) instrument and dynamometer calibrations may be different from ARB equipment.

Figure 1 in Appendix I is a comparison of naturally aspirated versus turbocharged horsepower at wide open throttle (WOT). The differences between BAE and ARB data are due mainly to dynamometer calibration (note also the difference in CVS-75 fuel economy between Tables 1 and 4). ARB horsepower data was taken in third gear to limit maximum wheel speed. Both sets of data show roughly 30 to 40 percent increase in horsepower for the turbocharged engine at WOT at engine speeds over 3500 rpm. Boost is limited to approximately seven psig as specified by the applicant (see figure 2, Appendix I).

ARB emissions tests were conducted at 1XRL and 2XRL, but no positive pressure was observed in the intake manifold during the tests. Since the water injection system is not designed to supply water under vacuum, it was disabled to prevent leakage that might affect emissions measurements. As an example of possible effects

of water injection, the difference in fuel economy in Table 3 on the HFET at 1XRL (marked with asterisks) is due to water injection. The test of 7/21/80 consumed 17 ml of water while the test of 7/22/80 consumed 35 ml of water. The difference of 18 ml of water is apparently responsible for a four mpg difference in fuel economy. A leaking check valve was replaced between these tests, but the water leakage increased. The basic problem appears to be intermittent operation of the water pump under vacuum conditions caused by a faulty water injection control module.

Water injection was not necessary on emissions tests, but it is necessary on this vehicle to prevent detonation under conditions of positive manifold vacuum. The reservoir used by BAE holds about a liter of water. Based on the flow data in figure 3, Appendix I, the reservoir can be emptied in a relatively short time under boost. A "low water" indicator or other warning device should be incorporated to avoid engine damage from a dry water reservoir.

The presence of the BAE system does not require any change of original VW tune-up parameters, routine engine adjustments, or servicing. The distributor is not physically modified. A check valve is used to dump positive pressure on the retard side of the advance/retard diaphragm to avoid timing advance under boost.

VI. Conclusion and Recommendation

Emission tests indicate that the BAE #28-0000C turbocharger kit will not adversely affect emissions when installed in accordance with instructions submitted to the ARB. The staff recommends that BAE be given an exemption from the prohibitions of VC 27156 for this kit for 1980 Volkswagen Rabbit, Scirocco and Jetta passenger cars having manual transmissions and three-way catalysts with feedback controls.

FIG 1: VW SCIROCCO - HORSEPOWER vs. RPM

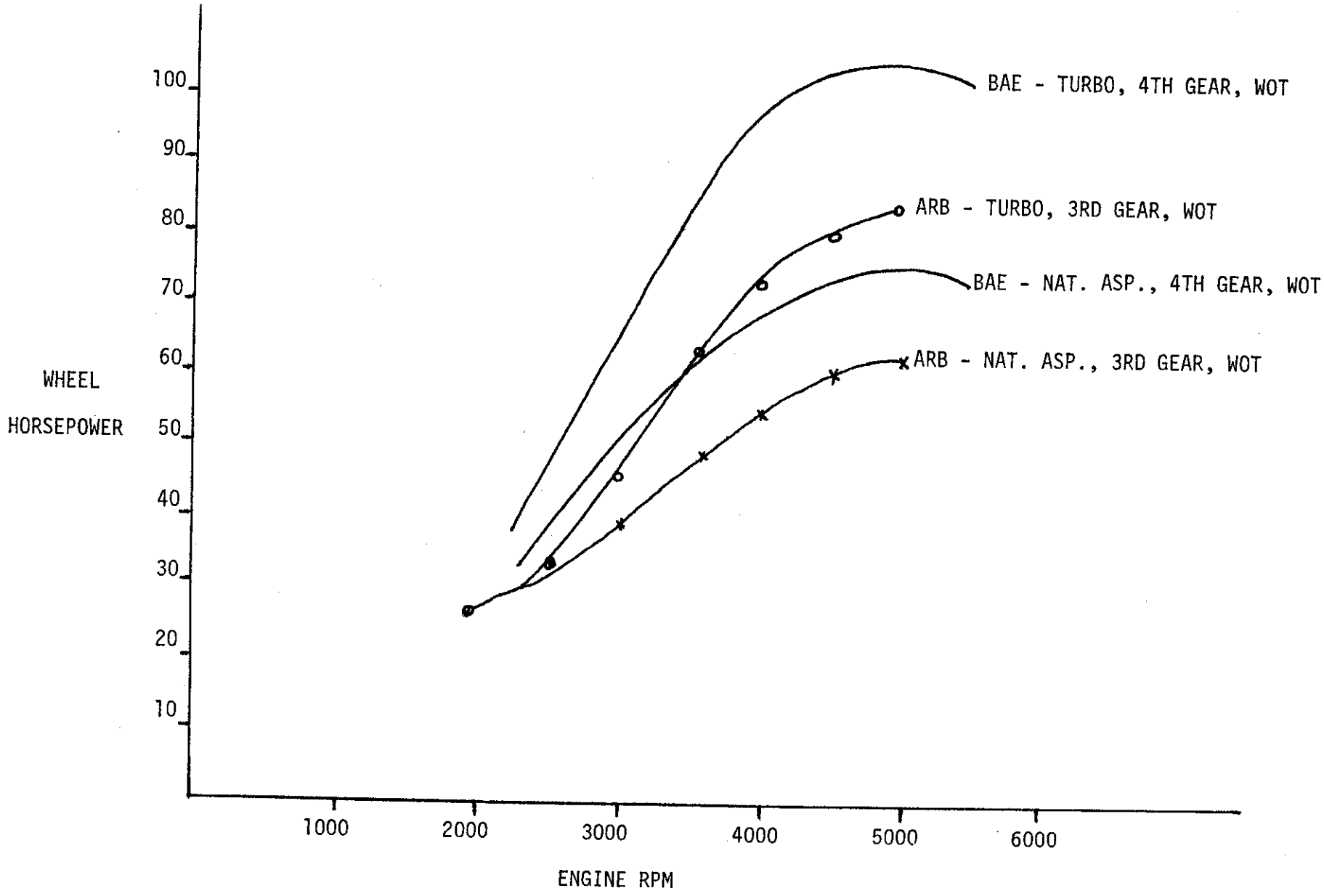


FIG 2: BOOST PRESSURE vs. RPM - TURBOCHARGED VW SCIROCCO

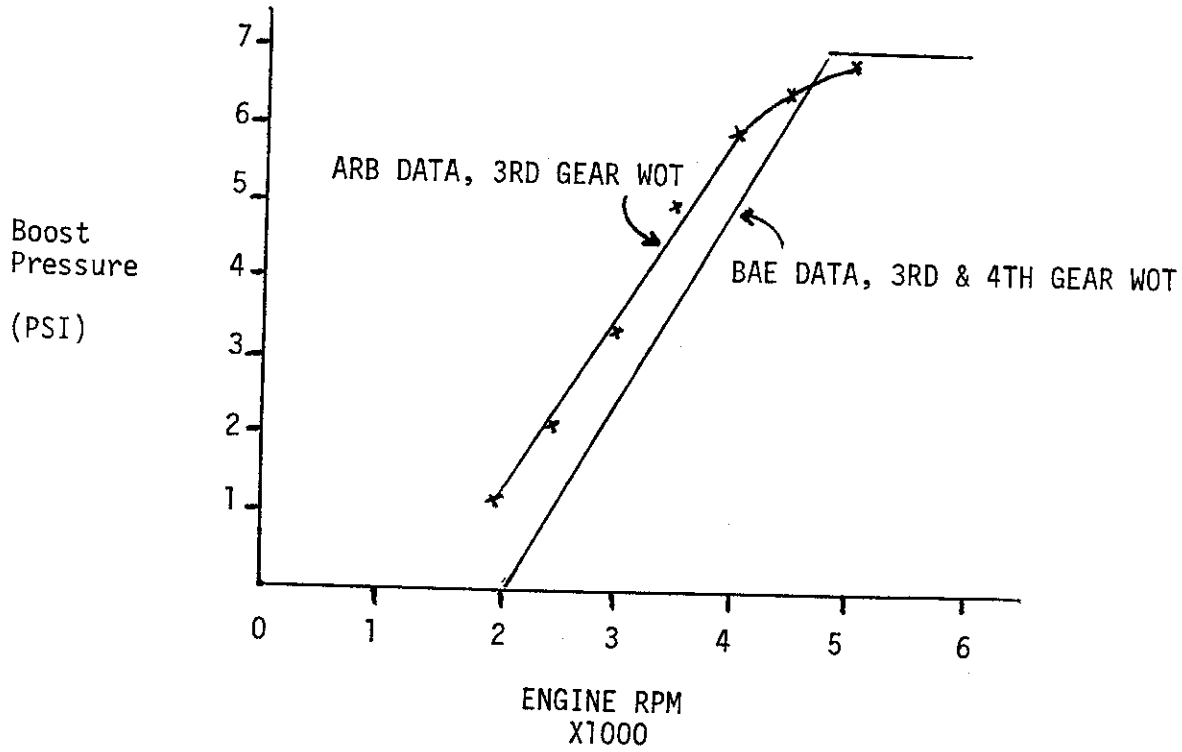
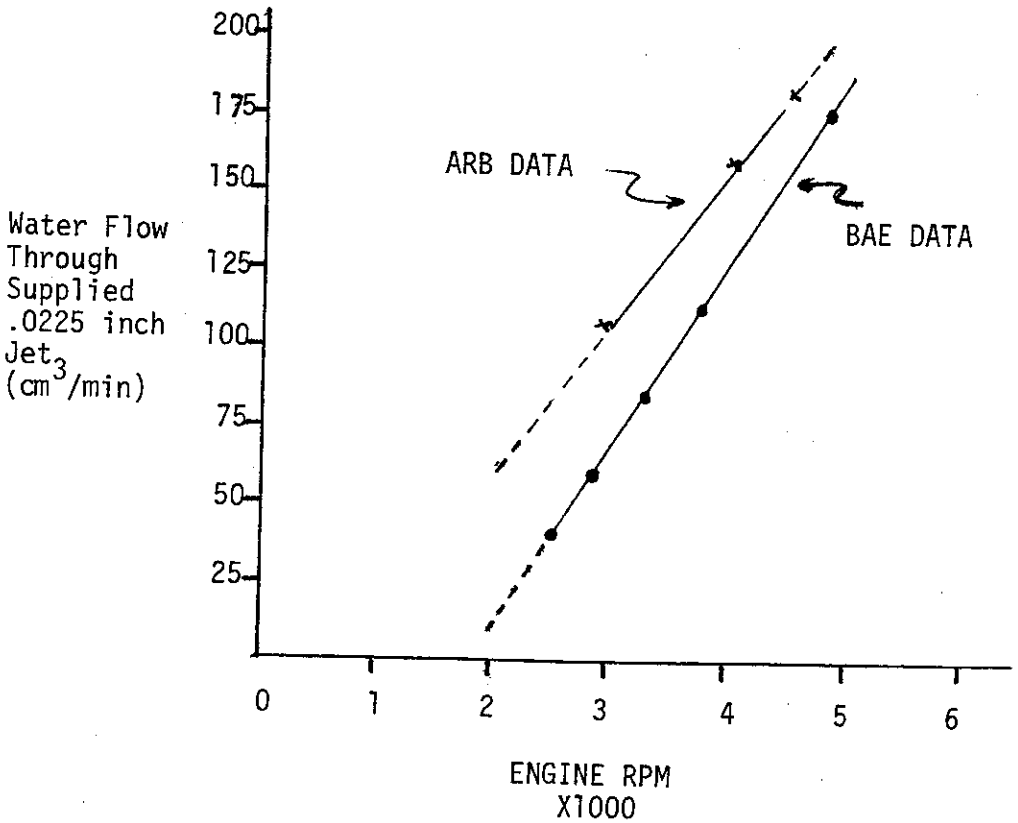


FIG 3: WATER FLOW vs. RPM UNDER BOOST CONDITIONS



ARB Data - Steady States*

Engine RPM	Indicated Horsepower			Vehicle Speed (mph)		Device Boost (psig)	Water Injection Rates (ml/sec)
	Baseline	Modified	% Increase	Baseline	Modified		
2000	28	28	0	22	27	1.2	-
2500	32	34	6	28	33	2.2	-
3000	40	46	15	38	39	3.4	60/33
3500	46	62	35	41	47	5.0	-
4000	52	74	42	43	53	6.0	158/58
4500	60	80	33	45	60	6.5	140/46
5000	67	-	-	58	-	-	-

*performed in 3rd gear