

EPA Evaluation of the "W/A WAAG-Injection System"

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October 1980

Test and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
U.S. Environmental Protection Agency

EPA Evaluation of "W/A WAAG-Injection System" under Section 511 of the Motor Vehicle Information and Cost Savings Act

The following is a summary of the information on the device as supplied by the Applicant and the resulting EPA analysis and conclusions.

1. Marketing Identification of the Device:

Trade Names:

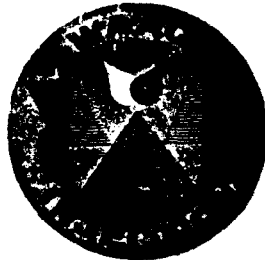
"Waag Power-Jector"
"Power-Jector"

Marketing names:

"W/A Waag-Injection System"
"Water/Alcohol Waag-Injection System"
"Waag Water/Alcohol Fuel Injection System"

Trade Mark:

"There is no trade mark, but this logo will be used on all literature and packaging."



"There is only one model and the unit number on Instructions and Warranty are purchase order numbers assigned by us."

2. Inventor of the device and patents:

a) Norman E. Waag, U. S. Patent No. 3987774
3110 Broadview Rd.
Cleveland, OH 44109
Approved October 26, 1976

b) "Exhibit "A" is a copy of the patent" (Attachment A of this evaluation).

3. Manufacturer of the Device:

Engineered Fuel Systems, Inc.
Colony Plaza - Suite 1220
6451 North Federal Highway
Fort Lauderdale, FL 33308

4. Manufacturing Organization Principals:

Lorne A. Cameron, Jr., President
Alex C. Cameron, Secretary

5. Marketing Organization in U. S. /Identity of Applicant:

Engineered Fuel Systems, Inc.
Colony Plaza - Suite 1220
6451 North Federal Highway
Fort Lauderdale, FL 33308

6. Identification of Applying Organization Principals:

Lorne A. Cameron, Jr., President
M. Aynslee Cameron, Vice President and Treasurer
Alex C. Cameron, Secretary

7. Description of Device (as supplied by Applicant):

a) "Purpose of the Device:

1. Increase engine efficiency
2. Increase life of the internal combustion engine
3. Prevent contamination of the engine caused by carbon
4. Prevent "Dieseling"
5. Increase the effective Horsepower
6. Increase octane number up to as much as ten numbers higher
7. Reduce "Blow-By"
8. Increase life of oil
9. Reduce emissions of CO₂ and NO_x
10. Increase gas mileage"

b) Theory of Operation: (numbers contained in the following description refer to patent diagram-Attachment B)

"Exhibit "C" is a detailed drawing of this device," (Attachment B of this evaluation).

"In operation, the apparatus of the invention begins to function when the operator starts the engine and the supplementary fuel such as water/alcohol is contained in reservoir 1. It may be seen that the engine immediately creates a vacuum in its intake manifold and an exhaust gas pressure varies with the torque requirements of the engine."

"The apparatus of the invention has a fluid passage connection to said manifold and it uses said vacuum and exhaust gas. It provides a vacuum passage tube 19 and 20 connecting the intake manifold 21 with the vacuum chamber 12 and an exhaust gas passage tube 3 connecting the exhaust manifold 5 with the fuel reservoir 1."

"The various functions performed by said apparatus under the operator's control include the following:

Charging the Fuel Chamber

The supplementary fuel is brought to the fuel chamber 11 for use and consists of charging the said fuel chamber 11 with supple-

mentary fuel from said reservoir 1. This is accomplished as the vacuum in the vacuum chamber 12 builds up sufficiently high to overcome the pump spring 18 of the diaphragm pump and thus causes the diaphragm to depress into the vacuum chamber 12. This action of the diaphragm 13 creates a vacuum in the adjacent fuel chamber 11 and which will be overcome as said vacuum draws a charge of supplementary fuel into the said chamber from the reservoir 1 through the fuel outlet 7 and fuel passage 15 and thereon through the fuel inlet check valve 14. The exhaust pressure in the reservoir 1 is available to aid the flow of said fuel into said fuel chamber 11. During said operation the fuel outlet check valve 16 remains closed."

"After the said fuel chamber 11 has been charged the said supplementary fuel is discharged therefrom to the engine carburetor as follows:

For High Torque Requirements

When the vacuum from the intake manifold 21 is reduced during periods of high torque requirements with part or open throttle valve conditions, pump spring 18 overcomes the reduced vacuum in the vacuum chamber 12 urging said diaphragm 13 against the supplementary fuel charge in the fuel chamber 11 closing inlet check valve 14 and forcing said supplementary fuel through outlet check valve 16 through tube passage 17 through shut-off solenoid 30 through tube passage 35 to metering jet 37 and nozzle 36 and finally into carburetor throat and thereon to venturi 40.

For Low Torque Requirements

When the operator has increased the engine RPM the vacuum decreases and the pump spring 18 thereby forces the diaphragm 13 to the end of its stroke, the exhaust manifold 5 builds up sending exhaust gas pressure through exhaust gas passage tube 3 into reservoir 1, pressurizing supplementary fuel therein and urging said supplementary fuel through reservoir outlet tube 7 through inlet fuel passage tube 15 forcing inlet check valve 14 open to permit pressurized supplementary fuel to enter fuel chamber 11 and thereon through outlet check valve 16 and thereon to said carburetor.

The operator may then set the throttle valve for steady RPM operation and obtain substantially the same result aided by the supply of supplementary fuel resulting from the dominant use of the exhaust gas pressure.

For Variable Torque Requirements

When the operator has a variable engine RPM requirement with a variable torque requirement with or without a variable throttle valve setting requirement, the apparatus of the invention will immediately supply the supplementary fuel to the engine car-

buretor as the engine transmits a dominant vacuum and/or a dominant exhaust gas condition to the diaphragm and metering apparatus of the invention.

During deceleration or idling the invention becomes inactive because the vacuum and exhaust gas conditions are minimal and it is imperative that no supplemental fuel be injected at such times.

Applicant's apparatus is therefore unique in the manner of delivering supplementary fuel to the carburetor of an internal combustion engine in its use of the above atmospheric pressure received from the engine's exhaust manifold and the use of the less than atmospheric pressure or partial vacuum pressure received from the engine's intake manifold when each said pressure is in dominance in the respective manifold.

Having thus described this invention in such full, clear, concise and exact terms as to enable any person skilled in the art to which it pertains to make and use the same, and having set forth the best mode contemplated of carrying out this invention, I state that the subject matter which I regard as being my invention is particularly pointed out and distinctly claimed in what is claimed, for being understood that equivalents or modifications of, or substitutions for, parts of the above specifically described embodiment of the invention may be made without departing from the scope of the invention as set forth in which is claimed."

8. Applicability of the Device (claimed):

"The Water/Alcohol WAAG-Injection System is applicable to all internal combustion engines with the exception of:

- a) The Wankel Rotary Engine
- b) All two-stroke engines that mix gasoline and oil
- c) All diesel engines for the present time pending final engineering tests.
- d) All aircraft engines."

9. Device Installation, Tools and Expertise Required (claimed):

Installation of the W/A WAAG-Injection System can only be done by authorized trained dealers of the device. Exhibit D, (Attachment C of this evaluation) was the initial installation description provided by the Applicant. The Applicant, subsequent to EPA evaluation commencement (July, 1980), submitted the revised instructions provided as Attachment J of this evaluation. In these revised instructions, mention is made of sophisticated engine diagnostic equipment and distributor test machines; however, no requirements for the dealer to obtain such equipment are mandated.

10. Device Operation (claimed):

- a) "Fill tank or reservoir regularly with 1/2 gallon of water

and 1/2 gallon of alcohol plus one capful of inhibitor.
b) Please see Exhibit "D" (Attachment C)

11. Device Maintenance (claimed):

- a) "Keep water and alcohol plus Inhibitor tank or reservoir filled.
- b) Clean out filter at (E) as shown on Installation Instructions, Part A - Page 4, using 9/16" wrench to loosen fitting.
- c) If necessary blow out metering jet (K) as shown on Installation Instructions, Part A - Page 4 with air pressure.
- d) No particular skills are required."

12. Effects on Vehicle Emissions (non-regulated) (claimed):

"The Water/Alcohol WAAG-Injection System while operating, functioning properly or malfunctioning will not cause a vehicle to emit into the ambient air any substance other than pollutants regulated by EPA (hydrocarbons, carbon monoxide, and oxides of nitrogen, or normal atmospheric conditions constituents, such as carbon dioxide, or water vapor) in a quantity differing from that emitted in the operation of the vehicle without the device."

13. Effects on Vehicle Safety (claimed):

"The Water/Alcohol WAAG-Injection System while operating, functioning properly or malfunctioning will not result in any unsafe condition endangering the motor vehicle, its occupants, other persons, or property in close proximity to the vehicle."

14. Test Results - Regulated Emissions and Fuel Economy (submitted by Applicant):

- a) Automotive Exhaust Emission and Fuel Economy Test Report
Olson Engineering, Inc.
Huntington Beach, CA (Attachment D)

Project 6193
Complete test 1973 Plymouth Duster
Car selected by California Air Resources Board

- b) California Air Resources Board
Haagen-Smit Laboratory
Project 2V7908-1973 Plymouth Valiant
Car owned by State of California
Emissions Tests Completed (Attachment E)

Fuel Economy Test incomplete:
The engine was not properly
cleaned and complete tests
may be rerun.

- c) California Air Resources Board
Haagen-Smit Laboratory
Project 2V908-1974 Ambassador
Car owned by State of California
Emissions Tests completed (Attachment F)

Fuel Economy test incomplete:
The engine was not properly
cleaned and complete tests
may be rerun.

"Note: We (the Applicant) have been advised by Ron Wagner, C.A.R.B. Engineer in charge of these tests, that we have been recommended for an exemption under California State Law to VC27156. Although we have not received official documentation, we have been told it only awaits the Director's signature."

d) Society of Automotive Engineers
Paper 214 - R.I. Potter, June 11, 1948 (Attachment G)

e) Society of Automotive Engineers
Paper 215 - C.H. Van Hartesveldt, June 11, 1948 (Attachment H)

f) Statements from individuals
relating actual experience with
the W/A WAAG-Injection System. (Attachment I)

15. Information Gathered by EPA:

A detailed report of the test data gathered by the EPA is reflected in EPA report, EPA-AA-TEB-81-2, "Emissions and Fuel Economy Effects of the W/A WAAG-Injection System" provided as Attachment K. A brief description of this testing effort is provided below:

a) A 1979 Chevrolet Nova was tested according to the Federal Test Procedure (FTP) and the Highway Fuel Economy Test Procedure (HFET). A total of seven FTP's and five HFET's were used for this evaluation. Tests were conducted in three configurations, using commercially available, unleaded fuel; 1) "Baseline" configuration - vehicle tuned to vehicle manufacturer's specifications, 2) "Parameters Adjusted" configuration - vehicle tuned to vehicle manufacturer's specifications except for additional 8° spark advance and with .003 in. smaller carburetor jets installed per agreement with Engineered Fuel Systems personnel, and 3) "Device Installed" configuration - vehicles tuned as in (2) and with device operational. Device manufacturer specified mileage accumulation (1000 miles and/or 4 gallons of water/alcohol consumed) was performed according to the Automobile Manufacturer's Association (AMA) driving schedule after "parameters adjusted" testing and prior to "device installed" testing per device manufacturer's instructions i.e. after "parameters adjusted" testing, engine design parameters were reset to vehicle manufacturer's specifications and specified mileage was accumulated with device operational. These exhaust emissions and fuel economy test data are detailed in Attachment K. The vehicle was also driven on-the-road to assess vehicle operational characteristics with the device installed.

b) A 1977 Dodge Aspen was tested with those procedures and in those configurations cited in 15.a) above. A noted exception in the "parameters adjusted" and "device installed" configurations was that

vehicle driveability limitations permitted the installation of carburetor jets only .002 in. smaller than those supplied by the vehicle manufacturer as standard equipment. A total of seven FTP's and seven HFET's were performed. These test data are detailed in Attachment K. The results from this vehicle were not included in the general conclusions because of a substantial shift in emissions (apparently vehicle induced) between the "parameters adjusted" and "device installed" tests.

c) A 1978 Mercury Zephyr was tested with those procedures and in those configurations cited in 15.a) above. A total of seven FTP's and seven HFET's were used for his evaluation. These test data are detailed in Attachment K.

d) A 1979 Ford Granada was tested in two supplemental programs. A summary of the procedures used for each supplemental program follows:

1. First Supplemental Program (See Attachment K)

- a. All vehicle pre-test adjustments were performed by representatives of the Applicant.
- b. The test procedures and configurations were the same as those cited in 15.a) above. Two Hot Start LA-4 tests (first 1372 seconds of the FTP starting with a warmed-up stabilized vehicle) per FTP/HFET test sequence were added.
- c. The 1000 mile (and/or 4 gallons of mixture consumed) "clean-out" procedure was deleted with the consent of the Applicant to expedite testing.
- d. The "device installed" configuration adjustments were performed by representatives of the Applicant (as they would perform them in the field) with EPA personnel observing. Adjustments performed included: 1) NO change in carburetor main jet size, 2) modification to both the centrifugal and vacuum advance distributor curves and 3) advancing the basic ignition timing from nominal (8° BTDC) to 10° BTDC.
- e. A total of six FTP's, six HFET's and ten Hot LA-4's were conducted for consideration in this evaluation.

2. Second Supplemental Program (See Attachment K)

- a. The Hot LA-4 test procedure was primarily used for this phase of the evaluation. The test configurations were the same as those cited in 15.a) above with the following exceptions for distributor advance curve and ignition timing.

- 1) Mean Distributor - set to vehicle manufacturer's nominal specifications

- a) Baseline - nominal ignition timing (8° BTDC)
 - b) Parameters Adjusted - nominal +4° initial timing
 - c) Device Installed - nominal +4° initial timing
- 2) EPA-Modified Distributor - set to maximum vehicle manufacturer's production tolerance limit
- a) Parameters Adjusted - nominal +2° initial timing
 - b) Device Installed - nominal +2° initial timing
- 3) WAAG-Modified Distributor - set by representatives of the Applicant for the First Supplemental Program
- a) Parameters Adjusted - nominal +2° initial timing
 - b) Device Installed - nominal +2° initial timing
- Sixteen Hot LA-4 tests were conducted for this portion of this evaluation.

b. Water/Alcohol flow rates were measured during vehicle operation according to the following driving cycles:

- 1) FTP
- 2) HFET
- 3) AMA
- 4) LA-4
- 5) Modified LA-4 (acceleration rates of 5.0 mph/sec rather than standard 3.3 mph/sec)

These measurements were conducted at both 3500 lb. IW and 4000 lb. IW dynamometer settings and with both a "yellow" and a "blue" injection pump spring.

e) Society of Automotive Engineers (SAE) paper #690018, "Inlet Manifold Water Injection for Control of Nitrogen Oxides - Theory and Experiment."

f) Report #ADA 00332, Contract #DDA D05-72-C-0053, "Water Induction Studies in a Military Spark Ignition Engine."

g) Taylor and Taylor; Copyright 1961; "The Internal Combustion Engine,"; Chapter 6, "Effects of Operating Variables on Detonation".

h) Edward Obert; Copyright 1973; "Internal Combustion Engines and Air Pollution"; Chapter 9, "Knock and the Engine Variables".

i) Charles Fayette Taylor; Volume 1; Copyright 1966; "The Internal-Combustion Engine in Theory and Practice"; Chapter 12, "The Performance of Unsupercharged Engines"

j) Charles Fayette Taylor; Volume 2; Copyright 1968; "The Internal-Combustion Engine in Theory and Practice"; Chapter 2, "Combustion in Spark-Ignition Engines II: Detonation and Preignition".

k) Henein and Patterson; Copyright 1972; "Emissions from Combustion Engines".

l) State of California Air Resources Board (CARB), Executive Order D-91, "WAAG Enterprises, W/A WAAG Injection System". (Attachment L)

m) Verbal discussions with Ron Wagonner, California Air Resources Board, between 8-14-80 and 9-11-80, regarding CARB Executive Order D-91.

n) State of California Air Resources Board Staff Report; March 13, 1974; "Evaluation of the Tetrahedron Associates, Inc., 'Powerjector' Device for Exemption from the Prohibitions of Section 27156 of the Motor Vehicle Code" (Attachment M)

o) State of California Air Resources Board Staff Report; December 13, 1974; "Evaluation of the Tetrahedron Associates, Inc., 'Water-Motive Demand Injector' Device for Exemption from the Prohibitions of Section 27156 of the Motor Vehicle Code" (Attachment N)

16. Analysis:

a) Description of Device: The description of the device originally provided by the Applicant was found to deviate from the actual device submitted for testing. When informed of the discrepancy, Mr. Lorne Cameron, Jr. of Engineered Fuel Systems, Inc., indicated that the description contained in the 511 Evaluation request was only applicable to boats. He stated that all references to any connection of the W/A WAAG-Injection System to the exhaust manifold should be deleted. Only the device connection to the intake manifold is appropriate for automobile applications.

The device tested included provisions for a water/alcohol mixture low-level warning light which was not included in the original device description. This provision was not used during this evaluation and does not in any way bear on the results.

b) Applicability of the Device: The applicability requirements stated in the application appear to be correct, however, the installation instructions do not specifically address fuel injected and variable venturi fuel delivery systems. For these cases, conventional carburetor jets do not exist and therefore, should be specifically exempted from fuel delivery system modifications.

c) Device Installaion: The original installation instructions submitted by the Applicant do not provide adequate guidance in the area of carburetor jet replacement. The replacement of those components requires specific knowledge relative to the construction of the carburetor and is considered beyond the "minor knowledge of the engine" level.

Subsequent to 511 Evaluation Application submittal, the Applicant revised the device installation procedures. The revision requires installation by an authorized device dealer who has received at least 4 hours of training in the installation procedure. Other major differences in the two sets of installation instructions are provided in Attachment K.

Further, the WAAG Dealer Manual (Attachment J), which contains the revised installation instructions and technical and marketing information, includes the following passages as technical guidance to the dealer:

Item #8 "Eliminate heat sensors in the line from the vacuum spark advance to the carburetor. Also in cars with two hoses from the distributor, eliminate the retard line (on some Ford models)."

Item #12 Referring to the EGR valve, "Although we cannot tell you to block it off, we suggest you use your own judgement as that valve should be checked each time water and alcohol is added. The EGR valve is not to be considered a successful part of the emissions system."

If authorized dealers perform the Applicant suggested modifications, it could be regarded as tampering and is subject to the legal liabilities afforded under Section 203 of the Clean Air Act.

Additionally, neither the original nor the revised installation instructions specifically prohibit the device from being connected to the vacuum source for the exhaust gas recirculation (EGR) valve. When advised of this fact, Mr. Lorne Cameron indicated that the EGR vacuum hose could not be used due to insufficient vacuum. He also indicated that such a coupling could seriously impair the effectiveness of the EGR valve operation. It is therefore, recommended that future installation instructions specifically prohibit such a coupling to the EGR vacuum source.

During the period of the evaluation test program, it is estimated that the average device installation time for a "trained mechanic" was from 2-3 hours. This estimate assumes that all replacement parts (carburetor jets, gaskets, if required, etc) are immediately accessible and does not include the time spent "troubleshooting" the vehicle to assure that it is properly tuned to vehicle manufacturer's specifications.

d) Device Maintenance: The maintenance requirements specified in the application appear to be correct. However, Item #6 of the WAAG Dealer Manual (Attachment J), "Customer Service Instructions", pertains to engine troubleshooting and assumes the ultimate purchaser has the knowledge of a trained mechanic. Additionally, these instructions do not include directions for the owner to inspection of all hoses for wear/deterioration and leaks, both vacuum and water/alcohol mixture on a periodic basis. Further, since the consumption rate of water/alcohol is vital to the control of NOx emissions, the owner should be advised in the service instructions to monitor this rate and notify his dealer if the consumption rate does not comply with Applicant recommendations.

The Customer Service Instructions recommend that the vehicle not be operated for more than 100 miles without the solution of water-alcohol-inhibitor. However, no provisions are made for low-level indicator testing.

e) Effects on Vehicle Emissions (non-regulated): Non-regulated emission levels were not assessed as part of this evaluation. Since the device injects a mixture of water and alcohol, the potential for increased aldehyde formation as part of the combustion process may exist.

f) Safety of the Device: If for some reason the device malfunctions or the operator allows the water/alcohol mixture to become depleted when traveling in a remote area, the increased spark advance and carburetor enrichment associated with the device could cause serious engine damage from prolonged severe knock. Examples of potential damage are perforated pistons and burned valves.

Although the likelihood of such an occurrence is remote, the possibility does exist and the ultimate purchaser of the W/A WAAG-Injection System should be made aware of the potential dangers and warned to be alert to excessive engine knock. It is recommended that the Applicant develop a method of detecting water/alcohol mixture flow and provide a warning device, other than listening for engine knock, to alert the operator to a device malfunction.

g) Test Results supplied by the Applicant:

1) Vehicle exhaust emissions and fuel economy data obtained according to EPA test procedures were collected at Olson Engineering, Inc. (OEI) and were submitted by the Applicant. These data are deemed insufficient to substantiate the Applicant's claims because only one test sequence (1 FTP and 1 HFET) per condition (1 test sequence in the "baseline" configuration and 1 test sequence in the "device installed" configuration) were performed on one vehicle.

Based on information obtained from the OEI test report provided by the Applicant and from the California Air Resources Board (CARB) regarding the testing conducted by OEI, it was determined that maintenance was performed on the carburetor of the Olson test vehicle between test sequences and that the spark plugs had also been changed between the test sequences. There was also a question of the appropriateness of the inertia and road load horsepower settings used to properly represent the test vehicle. Further, the method used to purge the test vehicle engine of deposit build-up deviated from that specified in the Applicant's 511 Evaluation Application (subsequent information provided by the Applicant appears to encompass the procedure used by Olson Engineering).

2) The data obtained at CARB indicated that the device did not produce a statistically significant improvement in the fuel economy of the vehicles tested. The engine "clean-out" procedures used at OEI were also used by CARB. These data were deemed unacceptable for use in this evaluation because the Applicant indicated in the 511 Evaluation Application that the engines of the vehicles tested at CARB were not properly cleaned. It is assumed by the EPA that this indication on the part of the Applicant is a direct result of the "clean-out" methodology used in previous testing and thereby invalidates both the OEI and CARB data. It should be noted that the alternate method of engine deposit

clean-out used by both OEI and CARB is no longer recommended by the device manufacturer as a total clean out procedure. The 1000 miles of operation with the system operational is recommended as a minimum procedure even if preliminary clean out procedures are used.

The data collected at CARB was also deemed unacceptable because the vehicles used were not considered to have representative emission control hardware and replicate testing in each test configuration was not performed. Without replicate testing, the variability associated with the test facility can not be assessed and may mask the effectiveness of the device.

3) The test fuel used by OEI and CARB, on at least one vehicle, has high octane characteristics. The octane number of a fuel governs the amount of spark advance tolerated by a given engine. Since the octane number of the fuel is critical to the effectiveness of the W/A WAAG-Injection System, due to the engine design parameter adjustments made in conjunction with its use, a fuel with an octane number more representative of commercial fuel should have been used in testing by both OEI and CARB. Such a practice would have provided a better assessment of the potential or effectiveness of the device while in use by the ultimate purchaser.

4) Results of testing at Automotive Testing Laboratories in Ohio could not be evaluated due to the Applicant's assertion that the test vehicle had not been properly "baselined" by the contractor.

h) Information Gathered by EPA:

Both the dynamometer testing and subjective on-road evaluations conducted by the EPA are discussed in detail in Attachment K. Since this document presents an indepth analysis of the effort put forth by EPA, a duplicate presentation is not provided.

17. Conclusions

In summary, throughout all three phases of the testwork reported on the W/A WAAG-Injection System, significant increases were found in fuel economy; however corresponding increases were found in regulated emissions, both as measured from the vehicle manufacturer's specifications.

It should be noted that although the fuel economy increases observed were statistically significant under controlled laboratory conditions, the magnitudes of these increases were small. The magnitudes of the corresponding and also statistically significant increases in regulated emissions were larger and require further development to eliminate.

When the vehicles were evaluated on the road, no significant driveability problems were found.

The observed changes in fuel economy and emissions for the vehicles tested were primarily a result of the engine design parameter adjustments.

Throughout the approximately one year period encompassed by the testing reported herein, the Applicant expended considerable efforts and private resources in the acquisition of test vehicles and in contracted testing with a private laboratory, in an effort to provide EPA with technical information concerning the effects of the W/A WAAG-Injection System on fuel economy and emissions.