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AN EVALUATION OF FPC-1 FUEL PERFORMANCE CATALYST

BY

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MARCH 28, 1988

UHI Corporation

and

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UHI TECHNICAL REPORT

ABSTRACT

A test program to determine the effect of FPC-1 fuel catalyst on the fuel economy of the Jelco busses, in Valders, Wisconsin, was conducted under the direction of Paul Kramer with Ridge Motor Supply, Craig Flinders and Kim LeBaron with UHI Corporation, and Mike Siebert with Jelco Bus Lines. The reduction in fuel consumption was determined from a carbon-balance method which is based on measurements of the exhaust gases from the busses. Results of the test show that the catalyst can provide cost savings up to 6.1% for the diesel fleet which was evaluated. Further, an in house engine disassembly has shown that internal engine components are showing significant signs of reduced carbon buildup since the addition of FPC-1 to the bulk fuel supply.

INTRODUCTION

This report summarizes the results of field tests conducted on the Jelco fleet of busses to measure the reduction in fuel consumption due to an iron-based fuel catalyst, FPC-1.

The fuel catalyst, an aftermarket product containing ferrous picrate, has been subjected to extensive engine testing in independent laboratories at universities and Environmental Protection Agency (EPA) recognized facilities. These tests, in both gasoline and diesel powered vehicles, have demonstrated that the catalyst can provide fuel savings ranging from about 2% to 10%, depending upon factors such as the operation and condition of the equipment, and the fuel quality.

The tests have included the EPA Federal Test Procedure (FTP) and Highway Fuel Economy Test (HFET), the Society of Automotive Engineers (SAE) J-1082 Suburban and Interstate Test Cycles, CRC cold start driveability test, and a computerized engine dynamometer test sequence.

Over a decade of field testing, primarily in heavy duty diesel fleets, substantiates the laboratory and road test results, and suggests an average in-house improvement in fuel economy greater than that documented by the EPA and SAE test. Field applications have also shown that the catalyst inhibits the formation of hard carbon deposits on pistons, valves and other combustion chamber surfaces, and gradually consumes pre-existing carbon deposits, which potentially further reduces maintenance and operating costs.

Until late 1973, vehicle fuel consumption was measured primarily by various test track or road test procedures. In September 1973, the U.S. Environmental Protection Agency utilized a carbon balance method to determine fuel economy in conjunction with its chassis dynamometer vehicle emissions test. This method relies on measurements of vehicle exhaust flow and emissions rather than direct measurement of fuel consumption.

By 1974, the carbon balance method was used solely in the EPA cold start emissions test cycle (LA-4 Cycle). In 1975, the cycle was modified by adding a hot start, and was known as the Federal Test Procedure (FTP). Later a highway driving simulation was developed which is known as the Highway Fuel Economy Test (HFET).

A series of tests by Ford Motor Company compared techniques of direct measurement of fuel consumption (volumetric or gravimetric) to the carbon balance method. The results, published as SAE Paper 75002, entitled "Improving the Measurement of Chassis Dynamometer Fuel Economy," stated

> "...fuel economy results obtained by carbon mass balance calculation of carbon containing components in the vehicle exhaust are at least as accurate and repeatable as those obtained by direct fuel measurement of fuel consumed."

The study also determined that the critical factors in the measurement of fuel consumption with the carbon balance method are the measurement of CO_2, the use of standardized test equipment and procedures, and correction for differences in ambient conditions. The complete paper is included in Appendix A.

UHI TEST PROCEDURES

The fuel consumption test method utilized by UHI and Ridge Motor Supply involves exhaust gas measurements of a stationary vehicle. No chassis dynamometer is required so driver error and tire/roll slippage are eliminated as sources of inaccuracy. The method produces a value of equipment fuel consumption with FPC-1 relative to a baseline value established with the same piece of equipment. Though the test is not as controlled as a laboratory test, care is taken to ensure consistency and accuracy. Engine speed and load are duplicated from test to test, and measurements of exhaust and ambient temperature and pressure are made to perform appropriate corrections. The carbon balance method represents a practical, economic and repeatable approach to determine relative fuel consumption in the field.

Exhaust gases are analyzed by state-of-the-art infrared (NDIR) exhaust gas analyzers made by the Sun Electric Corporation (SGA-9000) to measure CO_2, CO and unburned hydrocarbons, which are all carbon-containing exhaust gases. In addition, oxygen concentration in the exhaust is measured. The SGA-9000 is approved by the EPA for vehicle emissions analysis and is calibrated internally using calibration gases recommended by Sun Electric. Specifications for the analyzer are given in Appendix B.

TECHNICAL APPROACH

A fleet of diesel powered busses owned and operated by Jelco was selected for the FPC-1 evaluation. Table I shows the engine and mileage of the four busses used throughout the test. Of the busses evaluated for the baseline portion of the evaluation, four busses, unit nos. 3506, 3520, 3653, and 3727 were present, and consequently used for the FPC-1 treated segment of the evaluation. Unit no. 3505 was in the shop for a major engine overhaul, and was unavailable for the treated segment of the evaluation.

The SGA-9000 exhaust analyzer and the thermocouple instrumentation were calibrated and a leak test on the sampling hose and connections was performed. Each bus engine was then brought up to stable operating temperature as indicated by the engine water temperature and exhaust temperature. No exhaust gas measurements were made until each bus engine had stabilized at the operating condition selected for the test. A 50/50 blend of diesel fuel was exclusively used throughout the evaluation.

The baseline fuel consumption test consisted of five sets of measurements of $CO2$, CO, unburned hydrocarbons (measured as $CH4$), $O2$, and exhaust temperature, made at 60 second intervals for each engine test speed of full throttle, and 2200 rpm. The measurements for full throttle and 2200 rpm are summarized in Table II, and the actual measurements are contained in Appendix C.

After the baseline test, on January 21, 1988, the fuel storage tank, from which the busses are exclusively fueled, was treated with FPC-1 at the recommended level of 1 oz. of catalyst to 12.5 gallons of diesel fuel (1:1600 volume ratio). The busses were then operated with the treated fuel and accumulated an average of 3,528 miles per bus when, on March 9, 1988, the fuel consumption test described above was again repeated for each bus. The measurements for the busses with treated fuel are also summarized in Table II, and the actual measurements are contained in Appendix D.

It should be noted, that fuel temperatures for the baseline and treated segments of the evaluation were very similar. As such, it is not necessary to correct for fuel temperature changes as a result of ambient conditions between the baseline and treated segments of the evaluation. Since fuel temperature density affect the amount of fuel injected into the combustion chamber at a given rpm, it is sometimes necessary to correct for fuel density and temperature. Lower fuel temperatures increase fuel density, which in turn increases the amount of fuel injected into the combustion chamber at any given time. It is only natural that emissions readings would slightly increase with a decrease in fuel temperature.

Throughout the entire fuel consumption test, an internal self-calibration of the exhaust analyzer was performed after every two sets of measurements to correct instrument drift.

A new analyzer exhaust gas filter was installed before both the baseline and treated fuel test series so that a qualitative analysis could be made when comparing the baseline filter to the FPC-1 treated filter. The in-line particulate trap showed a significant reduction in the amount of exhaust solids being expelled from the bus exhausts. More will be discussed regarding the particulate trap under the heading "**CONCLUSIONS**".

Engine operating speeds of full throttle, and 2200 rpm were selected to demonstrate the correlation of the exhaust analysis with fuel consumption. Though the higher engine speed is more realistic, less fuel would be consumed by the engine operating at the lower speed for the same load. For a diesel engine with no air flow throttling, this will result in lower volumetric concentrations of carbon-containing exhaust gases, which can be observed from the measurements obtained from the exhaust analyzer during the evaluation.

From the exhaust gas concentrations measured during the test, the molecular weight of each constituent, and the temperature of the exhaust stream, the fuel consumption may be expressed as a "performance factor" which relates the fuel consumption of the treated fuel to the baseline. The calculations are based on the assumption that the fuel characteristics, engine operating conditions and test conditions are essentially the same throughout the test. Appendix E summarizes the assumptions and equations required for the calculations.

RESULTS

Table III shows the overall performance factors using the Carbon Balance Procedure, for the fleet, for the baseline and treated fuel tests at full throttle and 2200 rpm. The combined rpm's showed an improvement in fuel economy for the fleet of 6.1%.

Conclusions

The following conclusions may be made from the results of the FPC-1 evaluation conducted for Jelco Busses:

* The addition of FPC-1 to the diesel fuel used by Jelco Busses, resulted in a fuel economy improvement of 6.1% using the combined full throttle and 2200 rpm data.

* The in house engine disassemblies showed a significant reduction in hard carbon deposits, with FPC-1 treated fuel, when compared to a similar engine using untreated fuel.

* The inline particulate trap showed a significant reduction in exhaust solids levels when using FPC-1 treated fuel. It should be noted that the baseline particulate trap was subjected to the bus exhausts for a total of 23.5 minutes. The treated particulate trap was subjected to the bus exhausts for 24.5 minutes. (see attached photos)

Baseline Particulate Trap   Treated Particulate Trap

Table I

Busses Used
Throughout FPC-1 Evaluation Tests

Unit No.	Type	Engine	Miles
3506	Isuzu	6BD-1	2,780
3520	Isuzu	6BD-1	2,852
3653	Detroit	8.2-T	4,583
3727	Detroit	8.2-T	3,150

Table II

Summary of Exhaust Measurements During Baseline and Treated Fuel Tests

Engine Speed	CO2 Vol%	CO Vol%	O2 Vol%	HC ppm	Exhaust Temp
Combined full throttle and 2200 rpm					
Base	2.477	0.030	18.28	17.3	364.7'F
Treated	2.31	0.028	18.60	20.6	359.3'F

Table III

Volume Fractions and Performance Factor
Full Throttle and 2200 RPM

	Baseline	Treated
VFCO	0.00030	0.00028
VFHC	0.00001732	0.00002057
VFCO2	0.0247	0.0231
VFO2	0.1828	0.1860

Mwt1	29.1274	Mwt2	29.1148
pf1	246581.8513	pf2	263249.8327
PF1	184869.1389	PF2	196073.2617

$$196073.2617 - 184869.1389 = \frac{11,204.1228}{184869.1389} \times 100 = 6.1\%$$

ANALYSIS OF
JELCO
MONTHLY FUEL RECORDS

ABSTRACT

The purpose for conducting this monthly, vehicle fuel use, fuel economy evaluation is to determine, via in house records, the affect FPC-1 is having on the Jelco busses regarding fuel economy. Although simply stated, this task can be a very frustrating and an invalid test procedure. The purpose for conducting a fuel economy evaluation is to eliminate as many of the uncontrolled variables as possible, and duplicate loads and environmental conditions from month to month, and test to test.

The purpose for this text is two-fold. First, it will be shown why an in house fuel economy evaluation can not be conducted, at this time, on the Jelco fleet. Second, it will be shown why the Carbon Balance Procedure is the only reliable means of determining fuel economy when all factors and conditions are considered. This document is intended to show the importance of duplicating data points,(loads, driving conditions, temperature, drivers, idle time, fuel changes, tire pressure, etc., etc.) in determining real, vehicle fuel economy on a month to month basis.

DEVELOPING DATA BASE

In developing a data base for in house fuel economy testing, it is necessary that a reliable, permanent, portion of the fleet be identified, and insure that those vehicles are included in this test fleet for the entire term of the evaluation. Adding and dropping vehicles from an evaluation creates a high level of error in the data being accumulated for the evaluation. Such is the case in the Jelco fleet. Bus nos. 3074, 3208, 3470, 3519, and 3727 do not appear during several of the months of the baseline data, which include 12-86, 1-87, 2-87, 4-87, 5-87, 9-87, 10-87, 11-87, and 12-87. This means that 28% of the fleet was replaced during this one year period, (12-86 21 busses, 12-87 21 busses) in which new fuel economy trends begin affecting overall fuel economy.

In conjunction with the above mentioned busses that do not appear on a regular basis throughout the baseline data base, nos. 3470, 3519, and 3727 have at least two months and as many as six months in which fuel economy shows 0 miles per gallon. Additionally, bus nos. 3264, 3314, and 3524 have at least one month and as many as four months in which fuel economy shows 0 miles per gallon. This now eliminates 38% of the fleet because of an incomplete baseline data base.

DATA REPEATABILITY

Another important part of monthly fuel economy testing is the repeatability of the data. For instance, if a bus averages 5.5 mpg, in order to have any statistical meaning, the fuel economy data points could only deviate from 5.25 mpg to 5.75 mpg, or less. This type of data repeatability vary's about ±4.5% for an average of 5.5 mpg. It is possible to show evidence of an improvement, if the improvement with FPC-1 is above the ±4.5% deviation at this statistical frequency. On the other hand, if the same bus averaged 5.5 mpg, and the monthly data showed that the bus got 8.5 mpg one month, and 2.5 mpg another month to average 5.5 mpg, there is now a loading factor, with a deviation that would mask any improvement seen. This type of a data base would show an error factor or deviation of ±71%. It would be impossible to show an 8% improvement with deviations in fuel economy of this magnitude.

In analyzing the Jelco baseline data base, 100% of the busses showed at least a ±9% error factor or deviation between the high and the low mpg figure for the baseline period. Further, 95% of the fleet showed an error factor or deviation of ±10% between the high and the mpg figure for the baseline period. Even more revealing was the fact that 81% of the fleet showed an error factor or deviation of ±30% for the baseline period evaluated.

DUPLICATING LOADS

It is apparent, from the above statistical errors, that it is virtually impossible to duplicate loads from month to month. It would be impossible to show an 8% improvement with FPC-1 with monthly statistical deviations of this magnitude. It is important to note, that almost all fleets have the same problems duplicating loads, high and low idle time, driver inconsistency, environmental change, tire pressure, etc., etc., problems that have been presented in the Jelco baseline data base. As mentioned early in this text, all of the variables that need to be controlled to run a reliable month to month fuel economy analysis make it an impossibility to duplicate data in this type of testing.

YEAR TO YEAR COMPARISONS

Another possibility can be explored in determining fuel economy on a fleet basis. This approach compares like months, from year to year, to determine if vehicle loading and fuel consumption remain constant in a twelve month period. In the case of the Jelco fleet, 12-86 showed an average 6.96 mpg, with a fleet error factor or deviation of ±733% when comparing the lowest mpg data point for that month with the highest mpg data point.. In 12-87, the average fuel economy was 6.10 mpg with a fleet error factor or deviation of ±250%. Again, this factor was arrived at when comparing the lowest mpg data point for the month with the highest mpg data point. From December 1986 to December 1987, fuel economy changed .86 mpg or 12.4%. Again, using this method it would be impossible to show an 8% improvement with a statistical average deviation of ±491%.

FREQUENCY OF DATA POINTS

Another problem to overcome with this data is the lack of mileage accrued on the busses. The more mileage accumulated on each bus, along with the increase in fill-ups, helps to broaden the data base making the data more reliable. However, in the case of the Jelco fleet, some of the busses accumulate only 3500 miles per year. Again, this heightens the importance of each data point, because of the reduced frequency in fill-ups, and accumulated miles. Also, the missing months from the baseline data base leaves gaps in the complete baseline data picture as well as taking away important data frequency points. However, it is unlikely that it would change the deviation or error factor from a month to month basis based on the type of operation involved.

GRAPHS

The graphs included with this analysis will verify the information incorporated in this text. The baseline data sheet shows fuel economy figures as UHI Corporation received it on a month to month comparison. The vehicle numbers are in the left hand column going vertically down the page. The corresponding data and month are next to the vehicle number going horizontally across the page. The column furthest to the right shows the percentage change in fuel consumption, by vehicle, from the highest to the lowest mpg figure for the baseline data period.

CONCLUSIONS

By comparing in house, month to month, fuel usage data for both baseline and treated segments of the evaluation, an average error factor exists of ±56.3%. Consequently, any attempt to show a 5% to 8% fuel economy improvement is masked by large deviations in fuel usage from month to month, per unit.

It should be noted that the data does not represent inaccurate record keeping on the part of Jelco, but rather documents a frequently occurring characteristic of most industrial and commercial fleets; namely, that the many and changing variables found in operating an over-the-road fleet are inherent, and simply do not supply consistent and reliable data.

UHI Corporation recommends that Jelco investigate the advantages of utilizing a Carbon Balance test procedure to determine changes in fuel consumption. By eliminating most of the inherent variables found in field testing, the Carbon Balance procedure has been demonstrated to be both accurate and repeatable.

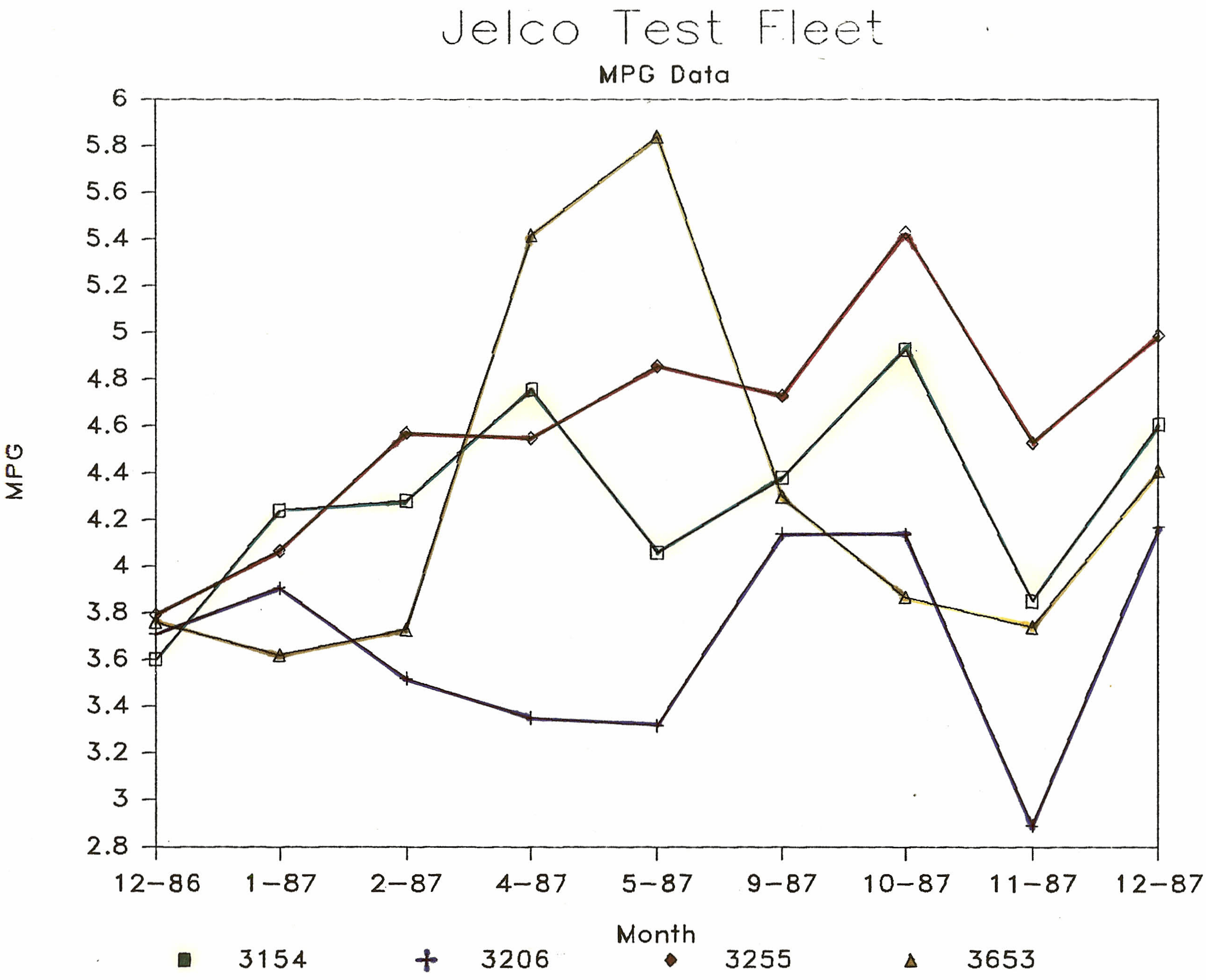
CARBON BALANCE TESTING

For many years, UHI Corporation has been involved in an intense program to determine the most reliable and repeatable procedure for fuel economy testing. Because of our research, we have found that many of the problems that are seen in the Jelco fleet baseline data base, are typical for the industry. It is one thing to want to see any product work as claimed. However, it is another thing to overcome those very variables that prohibit the products ability to work. For this reason, UHI Corporation investigated the procedure recognized and used by organizations and companies such as the EPA, Ford Motor Company, Systems Control, etc., etc. called the carbon balance procedure.

When one looks at the Carbon Balance Procedure, many of the variables that clouded the possibilities of an accurate test with FPC-1 disappear. Problems such as tire inflation, driver inconsistencies, environmental changes, excessive idle time, fuel changes, etc., etc., have a bearing on the evaluation. Engine rpm, exhaust temperature, pressure, and flow are monitored to insure that loads are duplicated. When the loads are duplicated, emissions readings are then taken to evaluate the affect of FPC-1 on that particular piece of equipment. Further, many data points are taken to insure accuracy via frequency of data collection. All that is necessary, is that a minimum 3,000 miles be accumulated on each vehicle to insure that the catalytic nature of FPC-1 has taken affect.

Jelco Baseline Data
1986-87

Unit No.	12-86	1-87	2-87	4-87	5-87	9-87	10-87	11-87	12-87	% change
3154	3.6	4.24	4.28	4.76	4.06	4.38	4.93	3.85	4.61	37
3206	3.71	3.91	3.52	3.35	3.32	4.14	4.14	2.89	4.17	31
3255	3.79	4.07	4.57	4.55	4.86	4.73	5.43	4.53	4.99	43
3264	29.96	0	0	0	0	2.46	4.2	4.55	5.06	92
3290	3.76	3.62	3.73	5.42	5.84	4.3	3.87	3.74	4.41	38
3312	5.44	5.14	5.59	5.96	6.83	5.45	6.52	5.39	5.52	25
3314	0	0	2.84	4.85	4.95	6.42	4	4.12	2.99	115
3321	3.51	3.53	3.65	3.63	5.29	5.45	5.47	5.43	6.09	74
3505	9.02	8.99	8.66	8.71	9.68	6.89	12.66	9.78	9.6	46
3506	8.09	7.94	7.71	8.22	8.4	12.68	6.64	6.54	5.96	113
3519	0	0	0	0	0	0	11.82	5.34	6.94	121
3520	9.04	9.15	9.14	9.44	9.61	9.28	9.43	9.21	8.74	10
3522	8.07	7.85	8.05	7.68	7.89	7.72	8.1	7.1	7.84	14
3523	12.02	5.06	7.98	9.93	10.12	8.87	8	9.86	10.23	58
3524	8.06	4.01	8.15	7.78	8.18	7.96	7.88	7.67	0	51
3526	8.3	8.63	7.84	8.93	9.18	47.16	10.46	9.24	10.47	83
3621	6.92	6.99	6.72	7.38	7.65	12.21	7.88	7.55	7.19	45
3653	8.11	7.93	8.12	8.21	8.72	8.74	8.6	8.47	8.55	9
3666	8.41	7.75	11.91	8.08	8.77	11.45	8.11	8.34	6.77	76
3727	0	0	0	0	0	11.34	7.5	7.63	8.01	51
3470	6.29	5.85	6.91	11.98	7.18	0	6.47	8.03	0	51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3.6
3.4
3.2
3
2.8
MPG
12-86
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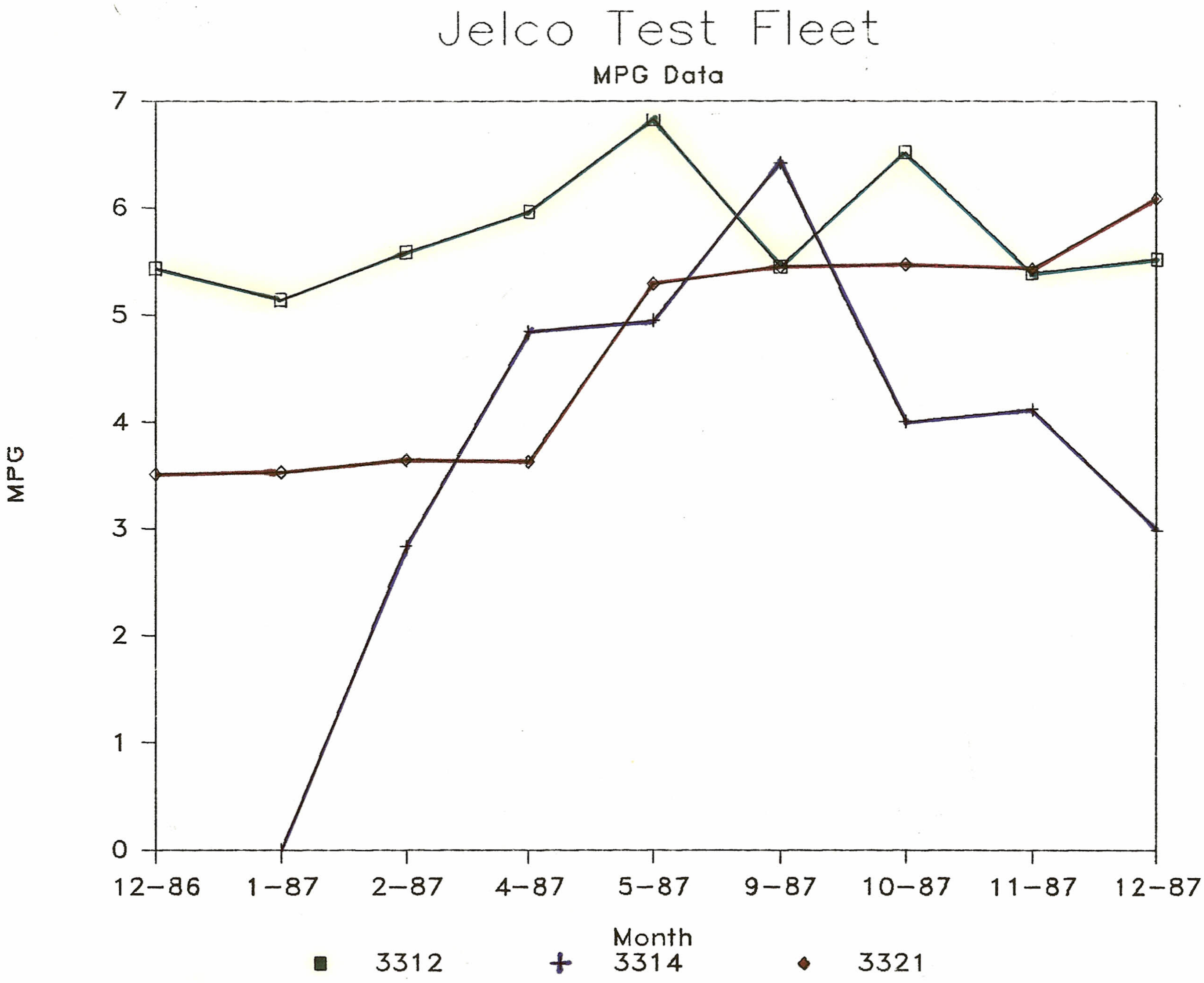
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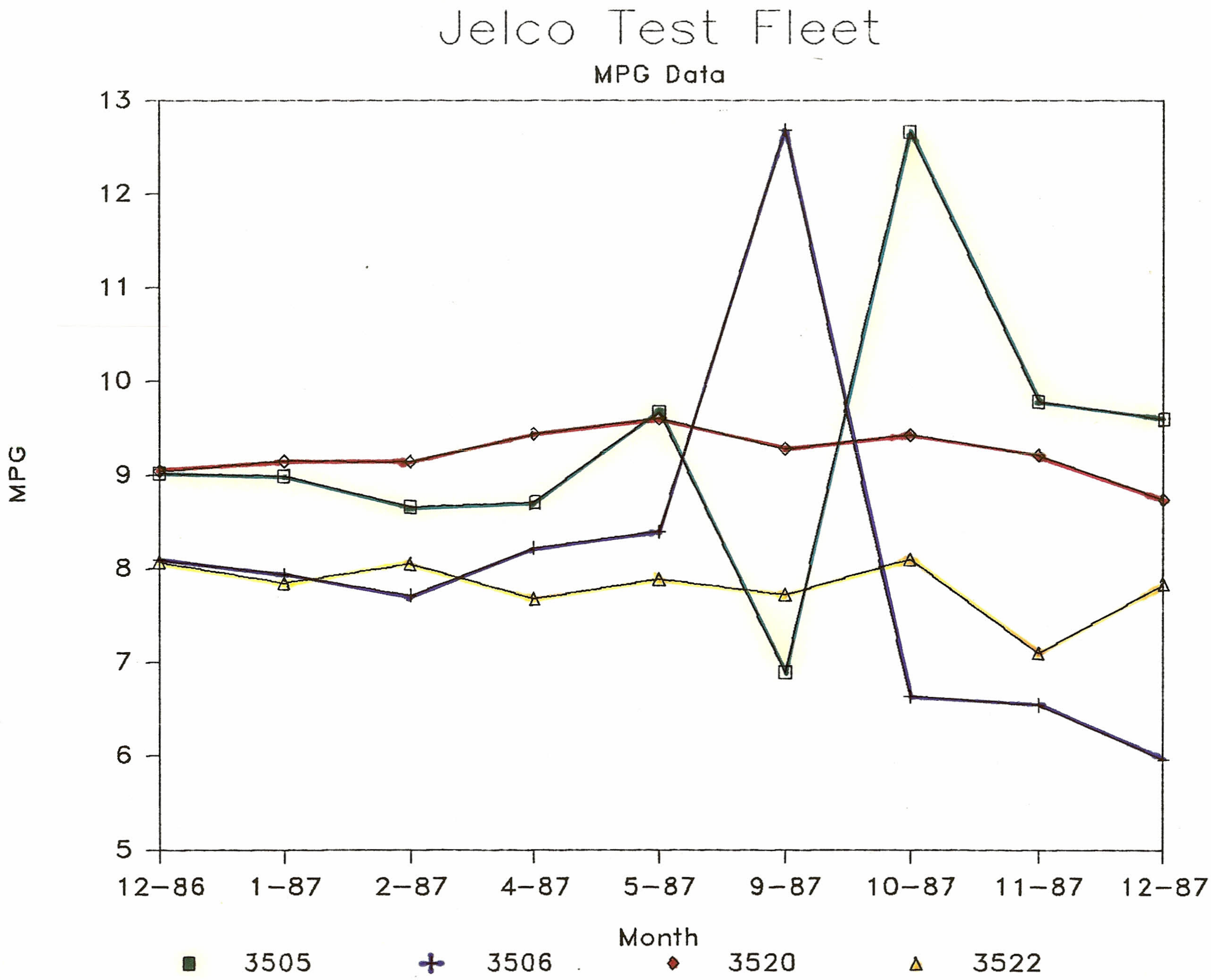
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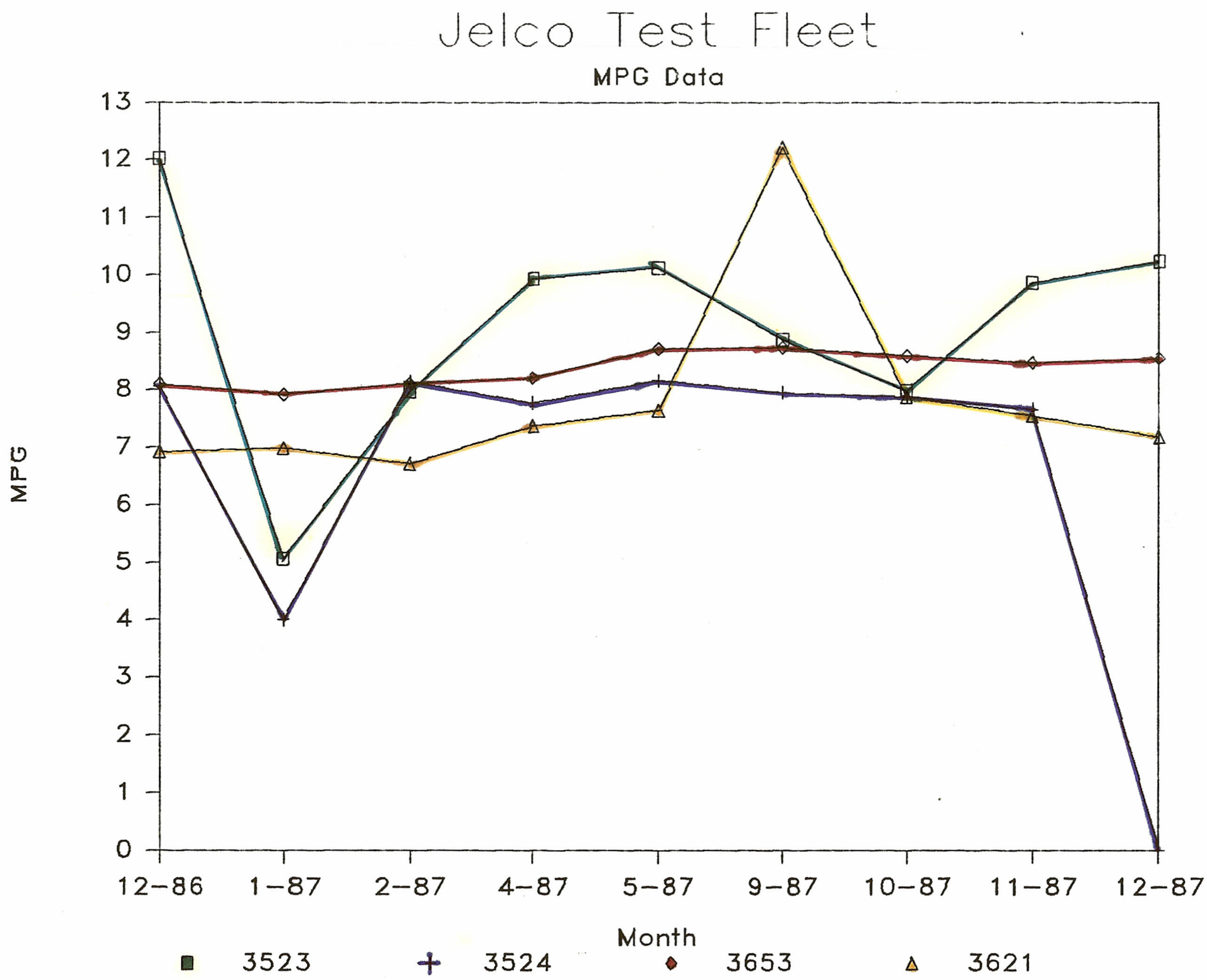

Jelco Test Fleet
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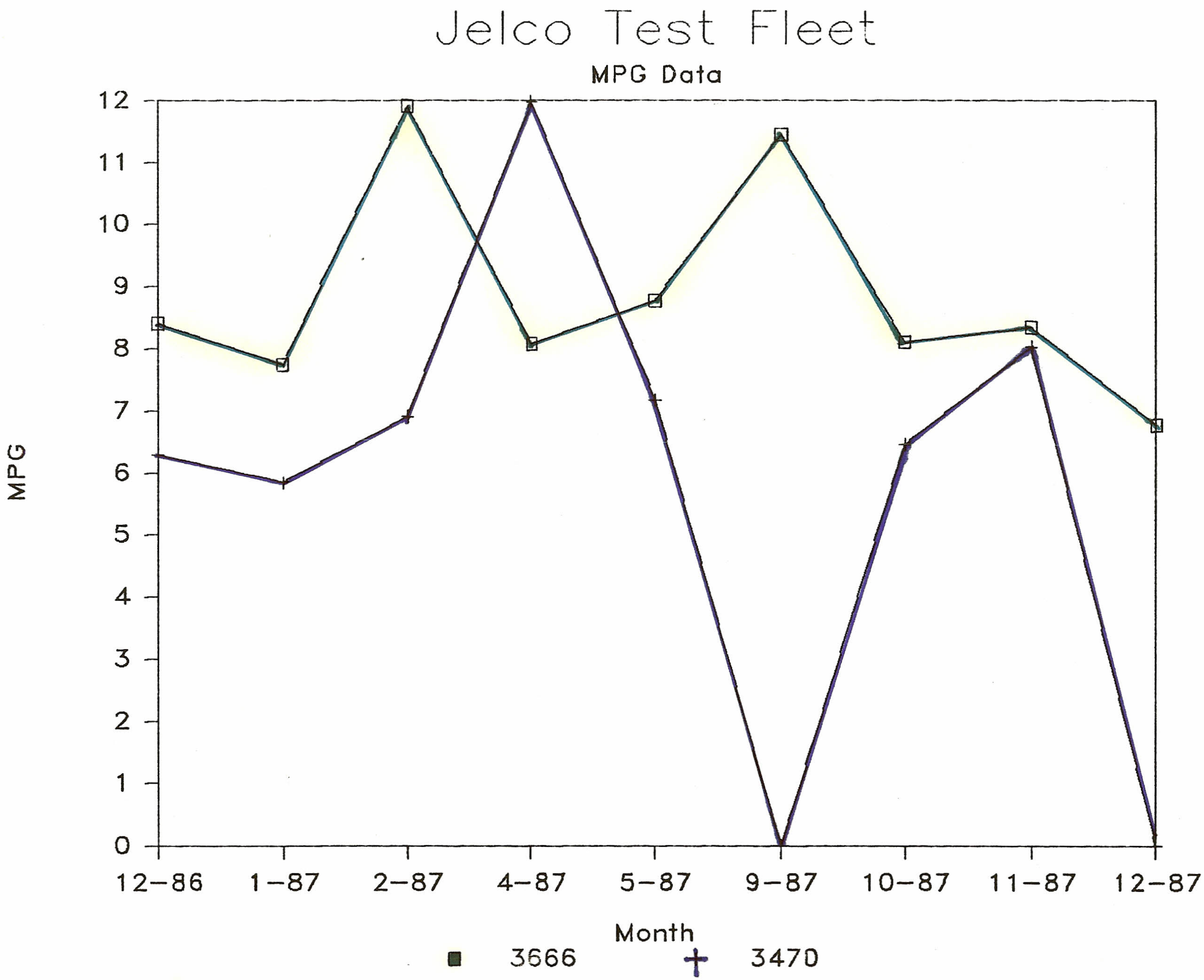
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Month
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