SHEAR STABILITY OF MULTIGRADE ENGINE OILS

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DS 49 S-1

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Institute of Petroleum Fleet Tests

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AMERICAN SOCIETY FOR TESTING AND MATERIALS

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Prepared by the
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Research and Development Division VII B
on the Shear Stability of Fluids

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I. SUMMARY

Two car fleet programs sponsored by the Institute of Petroleum (I.P.) were conducted on ten ASTM Reference Oils as part of an ASTM program to study methods of evaluating the shear stability characteristics of polymer containing oils. The results obtained from one fleet consisting of conventional cars, i.e., cars having separate oil charges for their engines and their gear boxes, agreed well with the average results from six U.S. car fleets. A second fleet, made up of cars having a common oil charge for the gear boxes and the engine crankcases, sheared the reference oils substantially more than the other fleets. Viscosity loss results from the second fleet correlated poorly with those from all shear stability bench tests and with results from the other fleets.

II. INTRODUCTION AND BACKGROUND

In 1969, ASTM R&D Div. VII B-1 Subsection on the shear stability of crankcase oils initiated a program "to study ways of evaluating the shear stability of polymer-containing oils under conditions closely related to service". Since then, 13 ASTM Reference Oils (ARO's) were formulated and evaluated in six United States car fleets and in a variety of bench tests. These results are summarized in ASTM data series report, DS49, published in early 1973.[(1)*]

The current report summarizes data from two fleets which were used in tests conducted by the Institute of Petroleum members recently. One fleet was made up of cars which used the same oil charge in both the engine and the transmission (hereafter referred to as integral gear box cars). The other fleet was of conventional design. Both fleets had seven cars and each fleet evaluated seven of the 13 ARO's although the seven were not the same oils in each case.

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*Numbers in parentheses designate references at the end of report.

Regression analyses were conducted to determine how well the various fleets agreed and to see if any of the bench tests could satisfactorily predict an oil's shear stability as determined with the integral gear box car fleet.

III. PROGRAM

Test Oils - The ten SAE 10W/40 ARO's used in the two European fleets are shown in Table 1 along with their V.I. improver type. The average 210 and 100 F new oil viscosities determined by seven participants (six I.P. participants plus laboratory P) are compared to those determined by laboratory "P", which was the only laboratory that determined the viscosities of both the base oils and the finished blend. In addition, the viscosities with and without the V.I. improvers are shown along with the 0 F Cold Cranking Simulator viscosities of the finished blends.

Car Fleets - The data on the two car fleets are summarized in Table 2. The test lab which ran each car is listed along with the vehicle make, model, number of cylinders, cubic inch displacement (CID), mileage at start of test, test date and estimated oil consumption rate.

Test Designs - The two fleet tests were conducted using the two 7X4 Incomplete Latin (Youden) Square test designs[2] shown in Table 3. Although each car evaluated only four oils, this design allows each viscosity loss to be corrected for car severity effect as was done with the U.S. fleet data. These calculations are shown in Appendix Tables B-1 through B-4.

IV. EXPERIMENTAL DATA

Fleet Viscosity Data - The field viscosity data submitted by each sample processor are shown in Appendix Tables A-1 through A-4. Each oil sample was stripped in accordance with the revised* procedure. In most cases at least two different laboratories stripped the used oil samples taken from each car and reported the results. An oil (ARO-100) containing 5% mineral spirits was supplied to each oil sample processor to check their stripping procedures. If the processor could not strip all of the diluent out of the sample without removing the light ends of the oil, their data were questioned and, if not satisfactorily re-run, discarded.

The average viscosity losses obtained for each oil in each phase of the program are shown in Tables 4 and 5 at both 210 and 100 F.

Appendix Tables B-1 through B-4 show the statistical treatment of field data for each I.P. fleet and the viscosity losses for each temperature. Section 1 of each table shows the average viscosity losses for each car in each phase of the program. Section 2 shows the average viscosity losses obtained for each oil in each car. Section 3 shows the steps in calculating the correction for car effects. The corrected average viscosity losses are underlined. The uncorrected averages are also shown for comparison. Section 4 shows Analysis of Variance results which determine whether or not the phase, car and oil effects were significant.

V. RESULTS AND DISCUSSION

I.P. Fleets versus U.S. Fleet Data - The corrected average viscosity losses obtained with each of the two I.P. fleets are compared to the corrected U.S. Six-Fleet average in Table 6. Fleet B, the conventional fleet produced viscosity losses which were essentially the same as the six U.S. fleets. The U.S. Fleets' results, which were summarized in ASTM DS-49, showed that oil thickening occurred to varying degrees and a satisfactory correction could not be made. In view of the high degree of correlation between the U.S. fleets and

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*Procedure revised April 14, 1971 (see page 42, DS-49).

I.P. fleet B, it is probable that oil thickening occurred here also. However, the degree of thickening for the two I.P. Fleets is not known because no single graded oils were evaluated. The substantially higher shearing severity of the integral gear box Fleet A, is apparently due to the additional shearing which takes place in the transmission.

Results of regression analyses between the various fleets are shown in Table 7. These results show that Fleet B data correlate* very well with the U.S. six-fleet average. In contrast, Fleet A results do not correlate well with the other fleets.

Bench Test Data versus Fleet A Data - Since Fleet A was quite different in its shear severity, it was selected for comparison with all of the available bench and laboratory engine test results. The viscosity losses are shown in Table 8. In order to determine the degree of correlation between the bench tests, laboratory engine tests, and Fleet A results, regression analyses were conducted. These results are shown in Table 9. The data in all cases show that the integral gear box cars shear the oils substantially more than any of the bench tests or laboratory engine tests. None of the bench or laboratory engine tests gave a satisfactory correlation. In addition, the intercepts are unreasonable high (2.4 to 4.0 cSt).

Bench Test Data versus Fleet B Data - Since Fleet B data are very similar to the U.S. six-fleet average, correlation comparisons presented in Table 10 were made using only the best** viscosity loss data from each type of bench test. Correlation results from linear regression analyses of the best

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* For a perfect linear correlation the standard error of estimate must be "zero" and the correlation coefficient must be "one". It is also desirable, but not essential, for the intercept to be "zero" and the slope to be "one".

** Best in this case denotes the highest correlation coefficient with U.S. six-fleet data.

bench test data versus fleet data, U.S. and B, are shown in Table 11. Note that the U.S. fleets' correlation results are similar to those reported in DS-49 even though only seven ARO's were included instead of the 12 or 13 ARO's in the other analysis.

In all of the laboratory bench tests, the Fleet B results correlated somewhat better than U.S. six-fleet results. In laboratory engine tests, Fleet B correlation coefficients were equivalent to or slightly poorer than U.S. fleet results.

Precision of Program (Both Fleets A & B) - This program was designed so that the precision of the viscosity determination method, the stripping procedure and the car's ability to shear test oils repeatably could be determined.

The pooled reproducibility standard deviation for fresh oil at 210 F was 0.06 cSt. This value was calculated from the fresh oil viscosities of the 10 AROs determined by seven laboratories. The data from the eighth lab were omitted from the analysis because several of their results were outliers. The calculated fresh oil viscosity determination reproducibility is as follows:

$$\text{Reproducibility} = \sigma_R \cdot \sqrt{2} \cdot t_{41} = 0.06 \times 1.414 \times 2.02 = 0.17 \text{ cSt.}$$

Where: σ_R is the reproducibility standard deviation

t_{41} is the student t @ the 95% confidence level and 41 degrees of freedom.

The ASTM reproducibility in percent is calculated by dividing reproducibility by the average oil viscosity.

Therefore:

$$\text{Reproducibility \%} = \frac{0.17}{15.04} \times 100 = 1.13\%$$

The reported reproducibility for the ASTM D-445 method is 0.70%.

The pooled reproducibility standard deviation obtained for the combined stripping operation and viscosity determinations at 210 F was determined to be 0.17. This value was calculated from the results shown in Appendix Tables A-1 and A-2 where two different laboratories stripped the same used oil samples and determined their viscosities at 210 F. The calculated reproducibility of the combined operation is as follows:

$$\text{Reproducibility (Combined)} = \sigma_{R_c} \cdot \sqrt{2} \cdot t_{48} = 0.17 \times 1.414 \times 2.01 = 0.49 \text{ cSt}$$

When this reproducibility is compared to the reproducibility obtained with the fresh oil viscosity determinations alone, it indicates that about 0.46 cSt of the reproducibility was contributed by the stripping operation. The data from any lab that did not strip ARO-100 (the oil which contained 5% mineral spirts) so that its 210 F viscosity was within specified limits were omitted from the analyses. One laboratory's data were omitted on this basis.

The car fleet program included some repeat tests by adding a fifth phase to the original program. This fifth phase consisted of re-evaluating the shear stability of several test oils in the same cars in which they were run previously. This part of the program was added to establish an independent measure of a car's ability to shear the test oils repeatably. The pooled repeatability standard deviation was calculated to be 0.29 cSt from the Phase V and matching data shown in Appendix Tables A-1 and A-2 after one outlier[4] was omitted. This standard deviation includes the stripping and viscosity determination variations in addition to the repeatability or a car's shearing ability. The calculated repeatability of the combined operation is as follows:

$$\text{Repeatability (Combined)} = \sigma_{R_c} \cdot \sqrt{2} \cdot t_7 = 0.29 \times 1.414 \times 2.37 = 0.97 \text{ cSt.}$$

CONCLUSIONS

- Cars in the I.P. fleet test which used separate sumps for their engines and gear boxes, although different in displacement and in average engine speed, gave virtually identical average viscosity losses for multigrade oils as the U.S. fleets.

- Cars in the I.P. fleet test having a common sump for the engine and the transmission sheared multigrade oils more severely than those having separate sumps.

- Current bench tests do not adequately predict the viscosity loss behavior of multigrade oils in integral gear box engines.

- A bench test that is suitable for predicting viscosity loss performance of multigrade oils in U.S. fleets should also be adequate for predicting viscometric performance in most other conventional cars with separate sumps for their gear boxes and engines.

REFERENCES

1. Shear Stability of Multigrade Crankcase Oil - Establishment of Field Data and Correlation with Laboratory Engine and Bench Test Results DS-49 ASTM 1973.

2. W. G. Cochran and G. M. Cox, "Experimental Designs", Second Edition, Page 523 Incomplete Latin Square - Plan 13.2 John Wiley and Sons, Inc., 1962, N.Y.

3. A. W. Talbot, W. A. Wright, and H. I. Morris, "A Bench Scale Engine Test for Shear Stability of Multigrade Engine Oils", SAE Paper 730485, presented at Detroit, Michigan, May 1973, SP-382.

4. Manual on Determining Precision Data for ASTM Methods on Petroleum Products and Lubricants, Spring 1973 Edition, Page 37, Paragraph 5.6.

TABLE 1

VISCOSITIES OF ASTM REFERENCE OILS

ARO Oil No.	V.I. Improver Type	SAE Viscosity Grade	210°F Viscosity, cSt. 7-Lab. Avg.* Finished Blend	210°F Viscosity, cSt. Lab. P Finished Blend	210°F Viscosity, cSt. Lab. P Without V.I. Improvers	210°F Viscosity, cSt. Lab. P Polymer Contributed	100°F Viscosity, cSt. Finished Blend 7-Lab.Avg.	100°F Viscosity, cSt. Finished Blend Lab P	CCS Viscosity @ 0°F, cP Finished Blend Lab P
101	Polymethacrylate-1	10W/40	15.07	15.05	5.71	9.34	86.36	86.19	2040
102	Polymethacrylate-2	10W/40	14.99	15.02	5.83	9.19	85.98	85.93	2030
103	Polyisobutylene	10W/40	15.03	15.02	4.84	10.18	97.59	98.09	1970
104	Olefin Copolymer-1	10W/40	14.96	14.96	6.15	8.81	109.02	108.9	1960
105	Vinyl Copolymer	10W/40	14.93	15.05	5.67	9.38	83.99	84.54	1930
106	Polyacrylate	10W/40	14.96	15.01	5.65	9.36	76.40	76.95	1940
107	Polyalkylstyrene	10W/40	15.19	15.15	5.49	9.66	97.91	97.58	2000
108	Olefin Terpolymer	10W/40	14.98	15.00	5.47	9.53	104.73	105.1	1880
109	Styrene Polyester	10W/40	15.25	15.23	5.36	9.87	90.27	90.81	1940
110	Olefin Copolymer-2	10W/40	15.04	15.00	5.19	9.81	104.54	104.4	1950

* Six I.P. Laboratories Plus Laboratory P.

TABLE 2

TEST VEHICLE CHARACTERISTICS - INSTITUTE OF PETROLEUM FIELD TEST

Vehicle No.	Test Lab.	Vehicle Make	Vehicle Model	Engine Cyl.	Engine CID	Mileage at Start	Date of Test Start	Date of Test Finish	Est. Oil Consump. Rate Miles/qt.
				FLEET A					
1	A	BLMC*	1100(HT/I)**	4	67	50,870	6/70	12/70	1,920
2	C	Peugeot	204 (HT/I)**	4	69	12,562	8/70	7/71	1,500+
3	B	BLMC*	1100(HT/AI)**	4	67	59,119	6/70	5/71	2,000+
4	I	BLMC*	Mini (SW/I)**	4	52	46,548	6/70	8/70	1,500+
5	A	BLMC*	1800 (HT/I)**	4	110	16,287	7/70	3/71	2,020
6	H	BLMC*	1300 (S/I)**	4	80	7,196	6/70	10/70	2,400+
7	G	Peugeot	204 (HT/I)**	4	69	19,185	1/72	8/72	1,500
				FLEET B					
1	A	Vauxhall	Viva (HT)**	4	71	25,560	7/70	2/71	1,560
2	D	Rootes	Rapier (HT)**	4	105	27,991	6/70	11/70	1,400
3	B	Volkswagen	1200 (HT)**	4	73	48,777	7/70	11/72	800
4	E	Ford	Cortina (S)**	4	97.5	21,298	8/70	11/70	1,600
5	F	Ford	Cortina (SW/A)**	4	97.5	10.057	7/70	9/70	-
6	F	Ford	Zephyr (HT/A)**	V6	183	41,343	7/70	9/70	-
7	I	Triumph	1300 (HT)**	4	79.5	31,267	6/70	8/70	1,500+

* British Leyland Motor Company

** S - 2 or 4 door sedan
HT- 2 or 4 door hard top
SW- Station Wagon

A - Automatic Gear Box
I - Integral Gear Box

TABLE 3

I.P. FIELD TEST DESIGNS

FLEET A

Car No.	ARO No. Used in Phase I	II	III	IV
1	104	103	108	109
2	110	108	109	101
3	103	109	101	102
4	108	101	102	104
5	109	102	104	110
6	101	104	110	103
7	102	110	103	108

FLEET B

Car No.	ARO No. Used in Phase I	II	III	IV
1	104	105	106	107
2	110	106	107	101
3	105	107	101	102
4	106	101	102	104
5	107	102	104	110
6	101	104	110	105
7	102	110	105	106

TABLE 4

VISCOSITY LOSS RESULTS FROM I.P. FIELD TESTS

(FLEET A)

ARO Oil No.	210°F Avg. Viscosity Losses, cSt.				100°F Avg. Viscosity Losses, cSt.			
	Phase I	Phase II	Phase III	Phase IV	Phase I	Phase II	Phase III	Phase IV
101	3.16	3.40	2.97	3.44	15.02	16.32	13.27	16.87
102	5.17	5.19	4.51	4.08	27.35	25.60	21.80	20.22
103	3.67	4.41	4.80	4.48	19.15	29.62	32.35	29.79
104	4.07	3.97	5.55	4.53	32.41	32.00	45.77	34.65
108	4.86	5.84	5.20	4.49	36.41	44.53	40.04	33.18
109	3.62	2.85	3.24	3.37	15.25	10.97	15.58	18.14
110	3.92	3.33	2.80	4.67	27.93	25.61	22.27	36.83

TABLE 5

VISCOSITY LOSS RESULTS FROM I.P. FIELD TESTS

(FLEET B)

ARO Oil No.	210°F Avg. Viscosity Losses, cSt. Phase I	Phase II	Phase III	Phase IV	100°F Avg. Viscosity Losses, cSt. Phase I	Phase II	Phase III	Phase IV
101	0.78	2.25	1.30	3.25	0.06	9.98	4.58	15.18
102	2.68	3.45	3.71	2.44	12.12	15.17	17.62	8.71
104	2.46	1.31	2.07	2.70	18.71	10.11	14.95	21.43
105	3.79	4.49	3.74	3.24	19.43	19.62	14.56	12.32
106	3.98	3.86	4.76	4.04	12.48	10.73	15.74	12.83
107	2.26	1.11	2.95	3.32	10.87	1.44	18.35	20.85
110	1.41	0.60	-0.38	0.22	9.95	4.36	-4.76	0.84

TABLE 6

VISCOSITY LOSS DATA - I.P. FLEETS AVERAGES VERSUS U.S. SIX-FLEET AVERAGE

ARO Oil No.	Visc. Loss, cSt., @ 210°F After 1,500 Miles		
	I.P. Fleets		U.S. Six Fleet Average
	A*	B	
101	3.38	2.02	1.64
102	4.73	3.18	3.03
103	4.54	-	1.75
104	4.47	2.11	2.04
105	-	4.06	4.06
106	-	3.78	3.85
107	-	2.25	2.17
108	5.07	-	2.37
109	3.17	-	0.04
110	3.59	0.55	0.34

* Cars in Fleet A had a common oil sump for the engine and transmission.

TABLE 7

REGRESSION ANALYSES - COMPARISONS OF U.S. AND I.P. FLEETS

Equation Model: $Y = b + mX$

Where Y is the U.S. Six-Fleet Average
and X is the I.P. Fleet Averages

	Intercept (cSt.) b	Slope m	Std. Error	Corr. Coef.
U.S. vs. I.P. (B)	-0.3	1.1	0.12	0.996
U.S. vs. I.P. (A)	-3.3	1.2	0.66	0.827
Fleet B vs. Fleet A	-2.7	1.2	0.94	0.704

TABLE 8

SHEAR STABILITY OF ASTM OILS IN LABORATORY BENCH TESTS, LABORATORY ENGINE TESTS AND I.P. FLEET A TESTS

			210°F Viscosity Losses, cSt., for ARO's						
			101	102	103	104	108	109	110
Diesel Injector Nozzle Type									
Lab. J*	5	Passes	2.16	3.90	2.48	2.44	3.23	2.18	1.11
	20	Passes	3.23	4.71	2.87	2.84	3.76	3.02	1.32
Lab. C*	1	Pass	2.60	3.77	1.91	2.05	2.51	2.47	0.91
	5	Passes	3.85	5.14	3.36	3.38	4.00	3.62	1.76
	10	Passes	4.27	5.53	3.74	3.66	4.29	4.06	1.99
Lab. L*	20	Passes	2.92	4.40	2.43	2.85	3.15	2.56	1.22
Lab. M*	5	Passes	1.68	2.72	1.56	1.84	2.39	1.64	0.71
	10	Passes	2.31	3.71	1.95	2.26	2.70	2.07	0.85
	20	Passes	2.97	4.49	2.38	2.65	3.05	2.64	1.17
Power Steering Pump Type									
Lab. A*	5	Minutes	0.79	1.20	0.47	0.93	1.36	0.52	0.66
	1	Hour	2.17	3.25	1.44	1.75	2.08	1.75	0.85
	2	Hours	2.98	3.95	1.88	2.14	2.64	2.31	1.51
	4	Hours	3.68	4.61	2.46	2.66	3.21	3.09	1.47
	6	Hours	3.96	5.01	2.88	3.04	3.55	3.59	1.72
Lab. D*	4	Hours	3.44	4.90	2.70	2.59	3.29	3.29	1.43
Lab. R*	1	Hour	2.62	3.97	2.97	2.11	2.33	2.65	0.99
Sonic Shear									
Lab. A*	10	Minutes	2.22	3.83	1.00	1.31	1.48	2.07	0.49
Lab. B*	5	Minutes	1.93	3.50	0.97	1.19	1.51	1.74	0.43
Kady Mill									
Lab. T*	6	Hours	1.49	3.30	1.19	2.05	2.26	1.47	0.57
Motored V-8 Engine									
Lab. N*	0.5	Hour	0.29	0.86	0.52	0.74	0.97	0.26	0.29
	3	Hours	0.96	2.22	1.77	1.30	1.93	0.70	0.53
	10	Hours	1.80	3.39	2.57	2.07	2.79	1.52	0.78
	24	Hours	2.64	3.96	3.15	2.50	2.97	1.73	0.95
Motored Single-Cylinder Engine**									
Lab. N*	0.5	Hour	0.44	0.77	0.40	0.46	0.84	0.20	0.00
	3	Hours	1.02	2.25	1.32	1.21	1.77	0.68	0.22
	6	Hours	1.66	2.80	1.95	1.60	2.33	1.24	0.41
	10	Hours	1.95	3.21	2.32	1.68	2.55	1.47	0.51
	24	Hours	2.83	3.97	3.10	2.20	3.11	2.25	0.89
L-38 Engine Test									
Lab. T*	10	Hours	1.33	2.60	1.70	1.46	1.92	1.30	0.58
MS VC Engine Test									
Lab. G*	16	Hours	2.55	3.99	3.47	3.03	3.60	1.59	1.27
U.S. Six-Fleet Average			1.64	3.03	1.75	2.04	2.37	0.04	0.34
I.P. "Fleet A" Average			3.38	4.73	4.54	4.47	5.07	3.17	3.59

* This lab code refers to the companies which contributed data for DS-49. See Reference 1.
** Data obtained from SAE paper shown in Reference 3.

TABLE 9

RESULTS OF LINEAR REGRESSION ANALYSES USING
BENCH TESTS, LABORATORY ENGINES AND FLEET DATA

Equation Model: Y = b + mX

Where Y is the I.P. Fleet A Results and
X is the Bench Test, Laboratory Engine and
U.S. Fleet Data

			Intercept (b)	Slope (m)	Std. Error, cSt	Corr. Coef.
Diesel Injector Nozzle Type						
Lab. J	5	Passes	2.8	0.6	0.6	0.72
	20	Passes	3.0	0.4	0.7	0.51
Lab. C	1	Pass	3.5	0.3	0.8	0.31
	5	Passes	3.0	0.3	0.7	0.43
	10	Passes	3.1	0.3	0.8	0.38
Lab. L	20	Passes	3.0	0.4	0.7	0.51
Lab. M	5	Passes	2.8	0.7	0.6	0.65
	10	Passes	3.1	0.5	0.7	0.54
	20	Passes	3.2	0.3	0.7	0.44
Power Steering Pump Type						
Lab. A	5	Min.	2.9	1.5	0.6	0.68
	1	Hour	3.4	0.4	0.8	0.38
	2	Hours	3.5	0.3	0.8	0.27
	4	Hours	3.6	0.2	0.7	0.24
	6	Hours	3.5	0.2	0.8	0.24
Lab. D	4	Hours	3.5	0.2	0.8	0.30
Lab. R	1	Hour	3.4	0.3	0.8	0.34
Sonic Shear						
Lab. A	10	Min.	4.0	0.1	0.8	0.12
Lab. B	5	Min.	3.9	0.2	0.8	0.21
Kady Mill						
Lab. T	6	Hours	3.2	0.5	0.6	0.61
Motored V-8 Engine						
Lab. N	0.5	Hour	2.8	2.4	0.3	0.94
	3	Hours	2.8	1.0	0.4	0.90
	10	Hours	2.7	0.7	0.5	0.80
	24	Hours	2.8	0.5	0.6	0.70
Motored Single-Cyl. Engine						
Lab. N	0.3	Hour	3.3	2.0	0.5	0.79
	3	Hours	3.1	0.9	0.5	0.80
	6	Hours	2.9	0.7	0.6	0.73
	10	Hours	3.0	0.6	0.6	0.68
	24	Hours	3.0	0.4	0.7	0.57
L-38 Engine Test						
Lab. T	10	Hours	2.9	0.9	0.6	0.70
MS VC Engine Test						
Lab. G	16	Hours	2.4	0.6	0.4	0.87
U.S. Six-Fleet Average			3.2	0.6	0.5	0.83

TABLE 10

SHEAR STABILITY OF ASTM OILS IN THE BEST* LABORATORY BENCH TESTS AND LABORATORY ENGINE TESTS COMPARED TO U.S. AND I.P. FLEET TEST RESULTS

	210 F Viscosity Losses, cs by the Various Test Methods								
ARO Oil No.	Diesel Injector Nozzle 10 Passes	Power Steering Pump Test	Sonic Shear 10 min.	Kady Dispersion Mill 6 h	Motored Engine 3 h	L-38 10 h	MS VC 16 h	U.S. Six-Fleet Average 1,500 Miles	I.P. Fleet B 1,500 Miles
101	2.31	2.17	2.22	1.49	0.96	1.33	2.55	1.64	2.02
102	3.71	3.25	3.83	3.30	2.22	2.60	3.99	3.03	3.18
104	2.26	1.75	1.31	2.05	1.30	1.46	3.03	2.04	2.11
105	4.85	4.49	4.78	3.88	3.24	3.75	4.94	4.06	4.06
106	2.99	3.18	3.19	2.30	2.45	3.31	4.65	3.85	3.78
107	2.36	1.96	2.10	1.56	1.44	2.35	3.72	2.17	2.25
110	0.85	0.85	0.49	0.57	0.53	0.58	1.27	0.34	0.55

*The best results are based on their correlation coefficients when correlated with the U.S. Six-Fleet average.

TABLE 11

CORRELATION OF BEST BENCH AND LABORATORY ENGINE TEST DATA WITH FLEET DATA

Equation Model: $Y = b + mX$

Y = I.P. Fleet B Results or
U.S. Six-Fleet Average Results

X = Bench or Engine Test Results

Bench or Engine Test	Fleet	Intercept (b)	Slope (m)	Std. Error, cSt	Corr. Coeff. R
Diesel Injector, 10 passes	U.S.	-0.131	0.934	0.61	0.90
	I.P. B	0.134	0.880	0.52	0.92
Power Steering Pump, 1 hr.	U.S.	-0.113	1.015	0.51	0.93
	I.P. B	0.156	0.955	0.41	0.95
Sonic Shear, 10 min.	U.S.	0.402	0.799	0.61	0.90
	I.P. B	0.625	0.758	0.49	0.93
Kady Disp. Mill, 6 hr.	U.S.	0.251	1.015	0.69	0.88
	I.P. B	0.507	0.951	0.61	0.89
Motored V-8 Engine, 3 hr.	U.S.	0.130	1.336	0.38	0.96
	I.P. B	0.434	1.228	0.37	0.96
L-38, 10 hr.	U.S.	-0.011	1.119	0.33	0.97
	I.P. B	0.312	1.025	0.35	0.96
MS-VC, 16 hr.	U.S.	-1.022	1.006	0.27	0.98
	I.P. B	-0.618	0.923	0.30	0.97

APPENDIX TABLE A-1

SHEAR STABILITY DATA FROM I.P. FIELD TEST

(Stripped,[1] Used Oil Viscosity at 210°F, cSt. - Fleet A)

Car No.	Used Oil Processed by:[2]	Test Phase, ARO/cSt.				
		I	II	III	IV	V(3)
1	A	104/10.98	103/10.62	108/9.80	109/11.98	-
	D	104/10.81	103/10.63	108/9.76	109/11.78	-
2	D	110/11.48	108/9.09	109/11.93	101/11.60	-
	B	110/10.76	108/9.19	109/12.09	101/11.67	-
3	B	103/11.42	109/12.4	101/12.17	102/10.87	102/10.54
	D	103/11.31	109/12.4	101/12.04	102/10.96	102/10.53
4	I	108/10.11	101/11.63	102/10.42	104/10.39	104/11.11
	F	108/10.14	101/11.72	102/10.42	104/10.47	104/10.42
5	A	109/11.67	102/9.83	104/9.43	110/10.41	-
	D	109/11.59	102/9.77	104/9.39	110/10.33	-
6	H	101/ -	104/ -	110/ -	103/ -	-
	A	101/11.91	104/11.03	110/12.24	103/10.55	-
	D	-	104/10.96	-	-	-
7	E	102/9.82	110/11.71	103/10.23	108/10.49	-

(1) Revised stripping procedure dated April 14, 1971 used.

(2) Test car participant's data shown first except for Car 2 when Lab C ran the car but Lab D processed the used oils.

(3) Phase V data not included in analyses shown in Appendix Tables B-1 through B-4.

APPENDIX TABLE A-2

SHEAR STABILITY DATA FROM I.P. FIELD TEST

(Stripped,(1) Used Oil Viscosity at 210°F, cSt. - Fleet B)

Car No.	Used Oil Processed by:(2)	Test Phase, ARO/cSt. I	II	III	IV	V(4)
1	A	104/12.53	105/10.44	106/10.24	107/11.93	-
	D	104/12.47	-	106/10.16	107/11.81	-
2	D	110/13.58	106/11.19	107/12.34	101/11.50	101/13.11
	B	110/13.69	106/11.02	107/12.14	101/12.14	101/12.50
3	B	105/11.13	107/14.06	101/13.92	102/12.59	-
	D	105/11.15	107/14.10	101/13.63	102/12.51	-
4	E	106/10.98	101/12.82	102/11.28	104/12.26	-
	-	-	-	-	-	-
5	F	107/12.97	102/11.57	104/12.93	110/14.78	110/14.60
	I	107/12.89	102/11.51	104/12.86	110/14.86	110/14.40
6	F	101/14.32(3)	104/13.46	110/15.44(3)	105/11.79(3)	-
	I	101/14.26	104/13.84	110/15.39	105/11.60	-
7	I	102/12.24	110/14.37	105/11.15	106/10.70	-
	F	102/12.39	110/14.51	105/11.23	106/11.13	-

(1) Revised stripping procedure dated April 14, 1971 used.

(2) Test car participant's data shown first.

(3) Failed to complete 1,500 miles - terminated 1 qt. low.

(4) Phase V Data not used in analyses shown in Appendix Tables B-1 through B-4.

APPENDIX TABLE A-3

SHEAR STABILITY DATA FROM I.P. FIELD TEST

(Stripped,(1) Used Oil Viscosity at 100°F, cSt. - Fleet A)

Car No.	Used Oil Processed by:(1)	Test Phase, ARO/cSt. I	II	III	IV	V(3)
1	A	104/77.30	103/67.80	108/64.59	109/73.32	-
	D	104/75.92	103/68.14	108/64.80	109/71.95	-
2	D	110/76.89	108/59.89	109/73.68	101/68.89	-
	B	110/76.34	108/60.51	109/75.70	101/70.10	-
3	B	103/79.03	109/79.3	101/73.65	102/65.99	102/64.63
	D	103/77.85	109/79.3	101/72.50	102/65.54	102/64.30
4	I	108/68.05	101/69.59	102/64.06	104/74.25	104/77.00
	F	108/68.60	101/70.50	102/64.30	104/74.50	104/74.00
5	A	109/75.12	102/60.42	104/63.06	110/67.75	-
	H	109/66.30	102/59.90	104/62.30	110/62.90	-
	D	109/74.93	102/60.34	104/63.44	110/67.67	-
6	H	101/ -	104/ -	110/ -	103/ -	-
	A	101/71.34	104/76.91	110/82.27	103/67.80	-
	D	-	104/77.12	-	-	-
7	E	102/58.63	110/78.93	103/65.24	108/71.55	-

(1) Revised stripping procedure dated April 14, 1971 used.

(2) Test car participant's data shown first except for Car 2 where Lab C ran the car but Lab D processed the used oils.

(3) Phase V data not used in analyses shown in Appendix Tables B-1 through B-4.

APPENDIX TABLE A-4

SHEAR STABILITY DATA FROM I.P. FIELD TEST

Stripped,[1] Used Oil Viscosity at 100°F, cSt. - Fleet B

Car No.	Used Oil Processed by:[2]	Test Phase, ARO/cSt. I	II	III	IV	V[4]
1	A	104/90.62	105/64.37	106/60.61	107/76.83	-
	D	104/90.0		106/60.72	107/76.89	-
2	D	110/94.01	106/65.66	107/77.94	101/70.51	101/72.11
	B	110/95.17	106/65.69	107/80.79	101/71.85	101/74.72
3	B	105/60.09	107/94.81	101/83.45	102/77.99	-
	D	105/69.03	107/95.74	101/80.12	102/76.55	-
4	E	106/63.92	101/76.38	102/68.36	104/87.59	-
		-	-	-	-	-
5	F	107/87.40	102/71.50	104/95.20	110/103.90	110/103.50
	I	107/86.29	102/70.13	104/92.95	110/103.50	110/101.00
6	F	101/86.90[3]	104.98.70	110/109.60[3]	105/72.00[3]	-
	I	101/85.70	104/99.12	110/109.00	105/71.34	-
7	I	102/73.02	110/99.37	105/69.96	106/62.35	-
	F	102/74.70	110/101.00	105/68.90	106/64.80	-

(1) Revised stripping procedure dated April 14, 1971 used.

(2) Test car participant's data shown first.

(3) Failed to complete 1,500 miles - terminated 1 qt. low.

(4) Phase V data not used in analyses shown in Appendix Tables B-1 through B-4.

APPENDIX TABLE B-1

ANALYSIS OF I.P. FIELD TEST DATA

(FLEET A)

SECTION 1

210°F Vis. Losses, cSt., after 1,500 Miles

CARS	PHASES I	II	III	IV
1	4.07	4.41	5.20	3.37
2	3.92	5.84	3.24	3.44
3	3.67	2.85	2.97	4.08
4	4.86	3.40	4.57	4.53
5	3.62	5.19	5.55	4.84
6	3.16	3.97	2.80	4.48
7	5.17	3.33	4.80	4.49
A_j (1)	28.47	28.99	29.13	29.23

SECTION 2

210°F Vis. Losses, cSt., after 1,500 Miles

CARS	OILS 101	102	104	110	103	108	109	(2)
1			4.07		4.41	5.20	3.37	17.05
2	3.44			3.92		5.84	3.24	16.44
3	2.97	4.08			3.67		2.85	13.57
4	3.40	4.57	4.53			4.86		17.36
5		5.19	5.55	4.84			3.62	19.20
6	3.16		3.97	2.80	4.48			14.41
7		5.17		3.33	4.80	4.49		17.79
(3)	12.97	19.01	18.12	14.89	17.36	20.39	13.08	(4) 115.82

SECTION 4

ANALYSIS OF VARIANCE

Source	S.S.	D.F.	Mean Sq.	F-Ratio
(11) Phases	0.0490	3	0.0163	0.0891
(12) Car Adj.	4.5923	6 E_b	0.7653	4.1842*
(13) Oils	12.8828	6	2.1471	11.7392*
(14) Error	2.1954	12 E_e	0.1829	
(5) Total	19.7195	27		

Uncorrected Sum of Sq. = 498.8006

Corrected Term C = 497.0811

$$\mu = \frac{E_b - E_e}{21\ E_b}$$

$$\mu = \frac{0.7653-0.1829}{16.0713}$$

μ = 0.0362 (Car Correction Factor)

* Significant at the 95% Confidence Level.

SECTION 3

CARS	OILS 101	102	104	110	103	108	109
1			17.05		17.05	17.05	17.05
2	16.44			16.44		16.44	16.44
3	13.57	13.57			13.57		13.57
4	17.36	17.36	17.36			17.36	
5		19.20	19.20	19.20			19.20
6	14.41		14.41	14.41	14.41		
7		17.79		17.79	17.79	17.79	
(6)	61.78	67.92	68.02	67.84	62.82	68.64	66.26
(7)	38.91	57.03	54.36	44.67	52.08	61.17	39.24
(8)	-370.68	-407.52	-408.12	-407.04	-376.92	-411.84	-397.56
(9)	347.46	347.46	347.46	347.46	347.46	347.46	347.46
W_j (10)	15.69	-3.03	-6.30	-14.91	22.62	-3.21	-10.86
Y_j	13.54	18.90	17.89	14.35	18.18	20.27	12.69
$(Y_j/4)$*	3.38	4.73	4.47	3.59	4.54	5.07	3.17
Avg.**	3.24	4.75	4.53	3.72	4.34	5.10	3.27

* Corrected Avg. Vis. Losses

** Uncorrected Avg. Vis. Losses

APPENDIX TABLE B-2

ANALYSIS OF I.P. FIELD TEST DATA

(FLEET B)

SECTION 1

210°F Vis. Losses, cSt., After 1,500 Miles

		PHASES			
		I	II	III	IV
CARS	1	2.46	4.49	4.76	3.32
	2	1.41	3.86	2.95	3.25
	3	3.79	1.11	1.30	2.44
	4	3.98	2.25	3.71	2.70
	5	2.26	3.45	2.07	0.22
	6	0.78	1.31	-0.38	3.24
	7	2.68	0.60	3.74	4.04
A_j	(1)	17.36	17.07	18.15	19.21

SECTION 2

210°F Vis. Losses, cSt., After 1,500 Miles

		OILS							
		101	102	104	110	105	106	107	(2)
CARS	1			2.46		4.49	4.76	3.32	15.03
	2	3.25			1.41		3.86	2.95	11.47
	3	1.30	2.44			3.79		1.11	8.64
	4	2.25	3.71	2.70			3.98		12.64
	5		3.45	2.07	0.22			2.26	8.00
	6	0.78		1.31	-0.38	3.24			4.95
	7		2.68		0.60	3.74	4.04		11.06
	(3)	7.58	12.28	8.54	1.85	15.26	16.64	9.64	(4) 71.79

SECTION 3

		OILS						
		101	102	104	110	105	106	107
CARS	1			15.03		15.03	15.03	15.03
	2	11.47			11.47		11.47	11.47
	3	8.64	8.64			8.64		8.64
	4	12.64	12.64	12.64			12.64	
	5		8.00	8.00	8.00			8.00
	6	4.95		4.95	4.95	4.95		
	7		11.06		11.06	11.06	11.06	
	(6)	37.70	40.34	40.62	35.48	39.68	50.20	43.14
	(7)	22.74	36.84	25.62	5.55	45.78	49.92	28.92
	(8)	-226.20	-242.04	-243.72	-212.88	-238.08	-301.20	-258.84
	(9)	215.37	215.37	215.37	215.37	215.37	215.37	215.37
W_j	(10)	11.91	10.17	-2.73	8.04	23.07	-35.91	-14.55
Y_j		8.09	12.72	8.42	2.19	16.25	15.10	9.02
$(Y_j/4)$*		2.02	3.18	2.11	0.55	4.06	3.78	2.25
Avg.**		1.90	3.07	2.14	0.46	3.82	4.16	2.41

* Corrected Avg. Vis. Losses
** Uncorrected Avg. Vis. Losses

SECTION 4

ANALYSIS OF VARIANCE

Source	S.S.	D.F.	Mean Sq.	F-Ratio
(11) Phases	0.3929	3	0.1309	0.8461
(12) Cars Adj.	9.3286	6 E_b	1.5547	10.0497*
(13) Oils	37.7595	6	6.2932	40.6800*
(14) Error	1.8573	12 E_e	0.1547	
(5) Total	49.3383	27		

Uncorrected Sum of Sq. = 233.4027

Corrected Term C = 184.0644

$$\mu = \frac{E_b - E_e}{21\ E_b}$$

$$\mu = \frac{1.5547 - 0.1547}{21(1.5547)}$$

μ = 0.0428 (Car Correction Factor)

* Significant at the 95% Confidence Level.

APPENDIX TABLE B-3

ANALYSIS OF I.P. FIELD TEST DATA

(FLEET A)

SECTION 1

100°F Vis. Losses After 1,500 Miles

CARS		PHASES I	II	III	IV
	1	32.41	29.62	40.04	18.14
	2	27.93	44.53	15.58	16.87
	3	19.15	10.97	13.27	20.22
	4	36.41	16.32	21.80	34.65
	5	15.25	25.60	45.77	36.83
	6	15.02	32.00	22.27	29.79
	7	27.35	25.61	32.35	33.18
A_j	(1)	173.52	184.65	191.08	189.68

SECTION 2

100°F Vis. Losses After 1,500 Miles

CARS	OILS 101	102	104	110	103	108	109	(2)
1			32.41		29.62	40.04	18.14	120.21
2	16.87			27.93		44.53	15.58	104.91
3	13.27	20.22			19.15		10.97	63.61
4	16.32	21.80	34.65			36.41		109.18
5		25.60	45.77	36.83			15.25	123.45
6	15.02		32.00	22.27	29.79			99.08
7		27.35		25.61	32.35	33.18		118.49
(3)	61.48	94.97	144.83	112.64	110.91	154.16	59.94	(4) 738.93

SECTION 4

ANALYSIS OF VARIANCE

	Source	S.S.	D.F.	Mean Sq.	F-Ratio
(11)	Phases	27.2136	3	9.0712	0.5529
(12)	Cars Adj.	259.3396	6 E_b	43.2232	2.6348*
(13)	Oils	2029.8051	6	338.3008	20.6221*
(14)	Error	196.8568	12 E_e	16.4047	
(5)	Total	2513.2151	27		

Uncorrected Sum of Sq. = 22013.4817

Corrected Term C = 19500.6266

$$\mu = \frac{E_b - E_e}{21\ E_b}$$

$$\mu = \frac{43.2232-16.4047}{907.6872}$$

μ = 0.0295 (Car Correction Factor)

* Significant at the 95% Confidence Level.

SECTION 3

CARS	OILS 101	102	104	110	103	108	109
1			120.21		120.21	120.21	120.21
2	104.91			104.91		104.91	104.91
3	63.61	63.61			63.61		63.61
4	109.18	109.18	109.18			109.18	
5		123.45	123.45	123.45			123.45
6	99.08		99.08	99.08	99.08		
7		118.49		118.49	118.49	118.49	
(6)	376.78	414.73	451.92	445.93	401.39	452.79	412.18
(7)	184.44	284.91	434.49	337.92	332.73	462.48	179.82
(8)	-2260.68	-2488.38	-2711.52	-2675.58	-2408.34	-2716.74	-2473.08
(9)	2216.79	2216.79	2216.79	2216.79	2216.79	2216.79	2216.79
W_j (10)	140.55	13.32	-60.24	-120.87	141.18	-37.47	-76.47
Y_j	65.63	95.36	143.05	109.07	115.07	153.05	57.68
$(Y_j/4)$*	16.41	23.84	35.76	27.27	28.77	38.26	14.42
Avg.**	15.37	23.74	36.21	28.16	27.73	38.54	14.99

* Corrected Avg. Vis. Losses
** Uncorrected Avg. Vis. Losses

APPENDIX TABLE B-4

ANALYSIS OF I.P. FIELD TEST DATA

(FLEET B)

SECTION 1

100°F Vis. Losses, cSt., after 1,500 Miles

CARS	PHASES I	II	III	IV
1	18.71	19.62	15.74	20.85
2	9.95	10.73	18.35	15.18
3	19.43	1.44	4.58	8.71
4	12.48	9.98	17.62	21.43
5	10.87	15.17	14.95	0.84
6	0.06	10.11	-4.76	12.32
7	12.12	4.36	14.56	12.83
A_j (1)	83.62	71.41	81.04	92.16

SECTION 2

100°F Vis. Losses, cSt., after 1,500 Miles

CARS	OILS 101	102	104	110	105	106	107	(2)
1			18.71		19.62	15.74	20.85	74.92
2	15.18			9.95		10.73	18.35	54.21
3	4.58	8.71			19.43		1.44	34.16
4	9.98	17.62	21.43			12.48		61.51
5		15.17	14.95	0.84			10.87	41.83
6	0.06		10.11	-4.76	12.32			17.73
7		12.12		4.36	14.56	12.83		43.87
(3)	29.80	53.62	65.20	10.39	65.93	51.78	51.51	(4) 328.23

SECTION 4

ANALYSIS OF VARIANCE

Source	S.S.	D.F.	Mean Sq.	F-Ratio
(11) Phases	31.2724	3	10.4241	0.8752
(12) Car Adj.	466.9005	6 E_b	77.8167	6.5340*
(13) Oils	603.1613	6	100.5268	8.4409*
(14) Error	142.9138	12 E_e	11.9094	
(5) Total	1244.2480	27		

Uncorrected Sum of Sq. = 5091.9241

Corrected Term C = 3847.6761

$$\mu = \frac{E_b - E_e}{21\ E_b}$$

$$\mu = \frac{77.8167 - 11.9094}{1634.1507}$$

μ = 0.0403 (Car Correction Factor)

* Significant at the 95% Confidence Level.

SECTION 3

CARS	OILS 101	102	104	110	105	106	107
1			74.92		74.92	74.92	74.92
2	54.21			54.21		54.21	54.21
3	34.16	34.16			34.16		34.16
4	61.51	61.51	61.51			61.51	
5		41.83	41.83	41.83			41.83
6	17.73		17.73	17.73	17.73		
7		43.87		43.87	43.87	43.87	
(6)	167.61	181.37	195.99	157.64	170.68	234.51	205.12
(7)	89.40	160.86	195.60	31.17	197.79	155.34	154.53
(8)	-1005.66	-1088.22	-1175.94	-945.84	-1024.08	-1407.06	-1230.72
(9)	984.69	984.69	984.69	984.69	984.69	984.69	984.69
W_j (10)	68.43	57.33	4.35	70.02	158.40	-267.03	-91.50
Y_j	32.56	55.98	65.38	13.21	72.31	41.02	47.82
$(Y_j/4)$*	8.14	13.98	16.34	3.30	18.08	10.25	11.96
Avg.**	7.45	13.41	16.30	2.60	16.48	12.95	12.88

* Corrected Avg. Vis. Losses
** Uncorrected Avg. Vis. Losses

APPENDIX TABLE C-1

PARTICIPANTS IN ASTM/IP SHEAR STABILITY PROGRAM

Cooperating Agency	Car Fleet	Sample Stripping
British Petroleum, U.K.	●	●
Edwin Cooper, Inc.	●	●
Esso - France	●	
Esso Petroleum Co., Ltd.	●	●
Lennig, G.B.*	●	●
Lubrizol	●	●
Minoc - Fr.**	●	
Mobil	●	●
Shell	●	●

* Now Rohm & Haas, U.K. Limited

** Now Rohm & Haas, France S.A.

DATA ANALYSIS PANEL OF
ASTM R&D DIV. VII B

R. M. Stewart (Gulf), Chairman

M. F. Smith, Jr. (Paramins Labs.)

R. J. Pecora, Jr. (Texaco)