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Comparison Between Unleaded Automobile Gasoline and Aviation Gasoline on Valve Seat Recession in Light Aircraft Engines

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16. Abstract

Testing was conducted to determine the potential for excessive valve seat recession in light aircraft engines using unleaded automobile gasoline (autogas) fuel. Two IO320 Lycoming engines were operated on a test stand for a 150-hour duration; one engine used 100LL aviation gasoline (avgas) and the other used unleaded premium autogas.

New original equipment manufacture (OEM) valve seats (hardness Rockwell HRB 40) were installed at the beginning of the test and recession was measured at 16-hour intervals. The air-fuel mixture was precisely controlled by monitoring exhaust gas composition.

Results show valve seat recession using unleaded autogas fuel was not significantly different from 100LL avgas.

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LIST OF ABBREVIATIONS

autogas - Automobile gasoline

avgas - Aviation gasoline

CO - Carbon monoxide

CO_2 - Carbon dioxide

Cst - Centistoke

DOE - United States Department of Energy

FAA - Federal Aviation Administration

HC - Hydrocarbon(s)

hp - Horsepower

hr(s) - Hour(s)

in. Hg. - Inches of mercury

lb/hr - Pound mass per hour

NBS - National Bureau of Standards

NIPER - National Institute of Petroleum and Energy Research

NO_x - Oxides of nitrogen

OEM - Original equipment manufacturer

ppm - Parts per million

ppmC - Parts per million parts carbon

psi - Pounds per square inch

rpm - Revolutions per minute

SAE - Society of Automotive Engineers

VSR - Valve seat recession

$^{\circ}$F - Degrees Fahrenheit

100LL - Aviation gasoline with a Aviation Lean Octane Rating of 100 and with a low lead content

INTRODUCTION

Recent activities continue to emphasize the attractiveness of using automobile gasoline (autogas) in light aircraft. Several common aircraft models are fully certified by the FAA to use the autogas. In addition, the Experimental Aircraft Association has tested the autogas in many programs and maintains that autogas has superior engine wear qualities compared to the aviation gasoline (avgas). The cost of autogas is substantially less than avgas.

It is expected that as the regular leaded grade of autogas is phased out and the lead in leaded fuel is reduced, then more aircraft will be using unleaded autogas in the engines. One potential problem with unleaded fuels is the long suspected problem of increased exhaust valve seat regression (VSR). Normally, the lead in fuel is effective in controlling VSR. The VSR problem is typically aggravated by continuous high-power output and engine speed which are typical in aircraft engines.

PURPOSE

To determine if a potential exists for increased VSR in aircraft as the use of unleaded autogas becomes more common, the FAA entered into an agreement with the DOE and NIPER to conduct an investigative study of the effect of unleaded fuels on VSR in light aircraft engines.

TEST PROCEDURE/APPARATUS

The test procedure involves installing two engines of the same manufacturer and model designation on test stands, operating one on unleaded autogas and the other on 100 low lead (100LL) avgas in identical duty cycles, and monitoring the VSR.

ENGINES

Two Lycoming IO-320 BIA aircraft engines were installed on an engine test stand. A cooling system was fabricated to maintain adequate temperature control of the air-cooled engines. The cylinders were removed from both engines and a top overhaul performed with new piston rings installed. The cylinder bores were in specifications and not modified. The valve seat inserts were removed and replaced by original equipment inserts. The outsides of the new inserts were copper-coated by the manufacturer to provide good heat transfer from the inserts to the head. The engine inspection data are presented in table 1.

TABLE 1. Engine inspection data

Rated horsepower	160
Rated speed, RPM	2700
Cruise speed, RPM	2350
Bore, inches	5.125
Stroke, inches	3.875
Displacement, cubic in.	319.8
Compression ratio	8.50:1
Fuel injector	Bendix, type RSA-5AD1
Fuel requirement	Aviation grade 91/96 octane

VALVE SEAT INSERTS

The valve seat inserts used for these tests were original equipment inserts available from Lycoming. The inserts were an AMS-5710 stainless steel with a hardness of Rockwell C40. The inserts contained 1.4% carbon and 20% chromium. The surfaces of the inserts which were in contact with the engine head were copper-coated by the engine manufacturer to aid in heat transfer from the insert to the head. The inserts were installed by heating the head in an oven to 475°F, cooling the inserts in liquid nitrogen, and installing the inserts quickly. This resulted in a "pinch" or interference fit of 0.010 inches.

FUEL

A premium grade unleaded autogas fuel was procured directly from a local refinery in a single batch of sufficient size to complete all testing. The fuel was stored in a lead-free storage tank. A similar batch of 100LL avgas was also acquired from the distributor and stored prior to the testing. The fuel inspection data from the test fuels are presented in table 2.

TABLE 2. Fuel inspection data

Component	Avgas	Autogas
Normal paraffins, mole %	3.40	8.08
Iso paraffins, mole %	55.73	32.03
Naphthalenes, mole %	0.78	1.57
Olefins, mole %	7.07	5.28
Aromatics, mole %	33.02	53.04
Distillation, D86, °F		
IBP	99	86
10%	151	117
50%	210	210
90%	228	338
EP	288	416

DUTY CYCLE

The engine duty-cycle was chosen to simulate a typical trip including start-up, take-off and climbing to altitude, and descending lasting about 4 hours which is a typical range for many light aircraft. The duty-cycle consisted of the following:

1. Engine start and warm-up at fast idle for 15 minutes.

2. Take-off simulation - Wide-open throttle with full-rich mixture. The dynamometer was programmed to apply appropriate load to limit the engine speed to 2700 rpm. Duration was 15 minutes.

3. Cruise simulation - Throttle and mixture control adjusted to provide 2400 rpm engine speed at 120 hp. The mixture was adjusted to slightly richer than the best power mixture. In actual operation, the fuel mixture was adjusted by monitoring the exhaust gas composition from each cylinder. The mixture strength was adjusted to provide approximately 2% CO concentration in the exhaust. Duration of the cruise mode was 3 hours and 30 minutes.

4. Descent simulation - The descent simulation mode consisted of 2200 rpm engine speed at 25 hp with full-rich mixture. Duration of the descent mode was 15 minutes.

5. Following the descent mode, the engine was allowed to idle for 2 to 3 minutes before stopping the engine.

VALVE SEAT RECESSION MEASUREMENTS

VSR measurements were made at 16-hour intervals. The measurements were made with the use of a jig which allowed compression of both valve springs in a cylinder. This allowed the rocker arm assembly to be removed. A flat plate was attached to the surface which normally holds the valve covers. The distance from the flat plate to the tip of the valve stem was measured using a dial depth gauge. The change in distance measured was equivalent to VSR. The valve train assemblies were fixed and no external adjustments are possible to compensate for VSR.

EXHAUST EMISSION MEASUREMENTS

The engines were fitted with exhaust sampling probes installed in the exhaust port of each cylinder. The exhaust sample was routed through water knock-out traps prior to entering the exhaust analyzers.

The carbon monoxide and carbon dioxide were measured using infrared detection equipment. The unburned hydrocarbons were measured using flame ionization detector equipment. The oxygen in the exhaust was measured using polarographic detector equipment. The nitrogen oxides were measured using a chemiluminescence detector. All of the equipment was calibrated using span gases traceable to the National Bureau of Standards (NBS). All instruments were checked with span and zero gases during each test cycle.

The exhaust was sampled during the beginning of each cruise mode in order to ensure the air-fuel mixture was consistent from cycle-to-cycle. The emissions and air-fuel mixture were checked occasionally during the full-rich take-off power condition.

LUBRICATING OIL ANALYSIS

The lubricating oil used during the tests was Texaco SAE-50 weight aviation lubricating oil. The oil was changed at 50-hour intervals and the used lubricating oil analyzed for wear metals by spectrochemical analysis.

OTHER ENGINE PARAMETERS

Other engine parameters were monitored continuously by a water brake dynamometer/computer system and recorded at approximately 10-minute intervals during the test cycle. The nominal values for the engine cruise condition are listed below and are similar for both engines.

Fuel flow, lb/hr	60
Fuel temperature, °F	90
Intake air temperature, °F	100
Cylinder head temperature, °F	420
Oil pressure, psi	55
Oil temperature, °F	200
Engine rpm	2400
Engine power corrected to sea level, hp	120
Manifold pressure, in. Hg.	2.0

RESULTS AND CONCLUSIONS

AIR-FUEL DISTRIBUTION

Air-fuel ratio has been shown in previous studies (1,2,3) to have a significant effect on VSR. Mixtures associated with higher temperatures produced greater recession. Because of these concerns, the air-fuel mixture was monitored in each cylinder during each of the simulated cruise conditions. The air-fuel mixture was determined by measuring the exhaust composition (CO, CO_2, HC, NO_x) from each cylinder and calculating the air-fuel ratio; however, the CO in the exhaust was the prime indicator of air-fuel mixture during rich operation of the engine.

The CO concentration in the exhaust from both engines during each of the 37 test cycles necessary to complete the 150-hour test is shown in figure 1. The data show the air-fuel mixture was generally consistent for both engines and would not be expected to bias the data. These measurements were performed to provide consistency of results and to control one of the major variables in VSR.

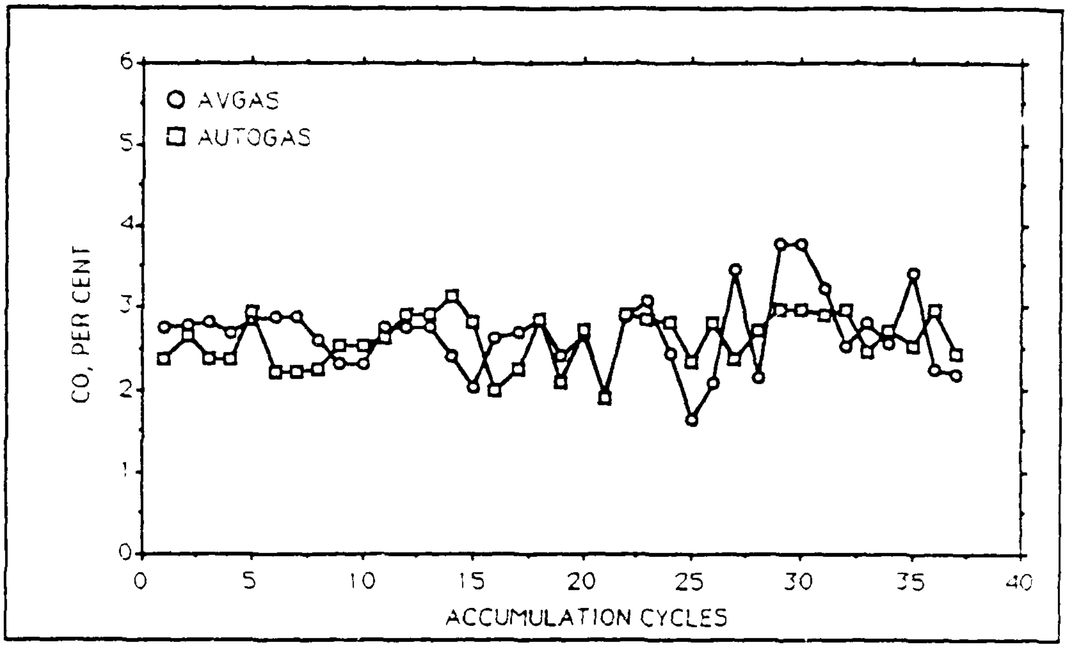

FIGURE 1. Average exhaust CO levels during engine operation

The CO concentrations from each cylinder of the two engines averaged over all of the test cycles are shown in figures 2 and 3. The data indicate that the air-fuel distributions among the cylinders in the two test engines are not excessive. Concentrations from both engines suggested that cylinder No. 2 was running slightly richer than the other cylinders.

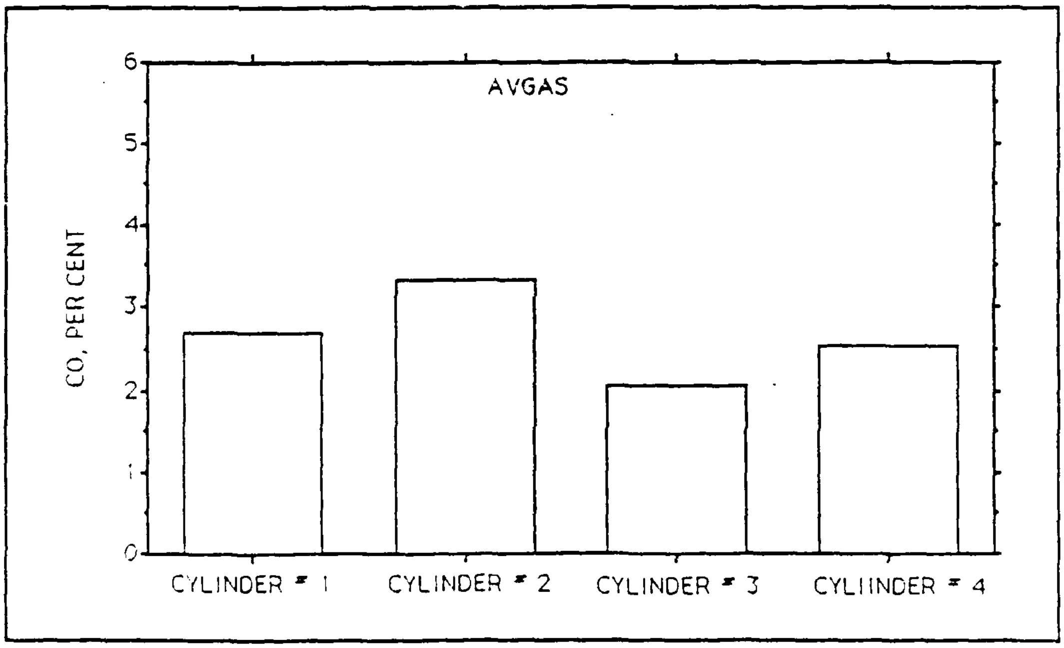

FIGURE 2. CO distribution among cylinders during engine operation with avgas

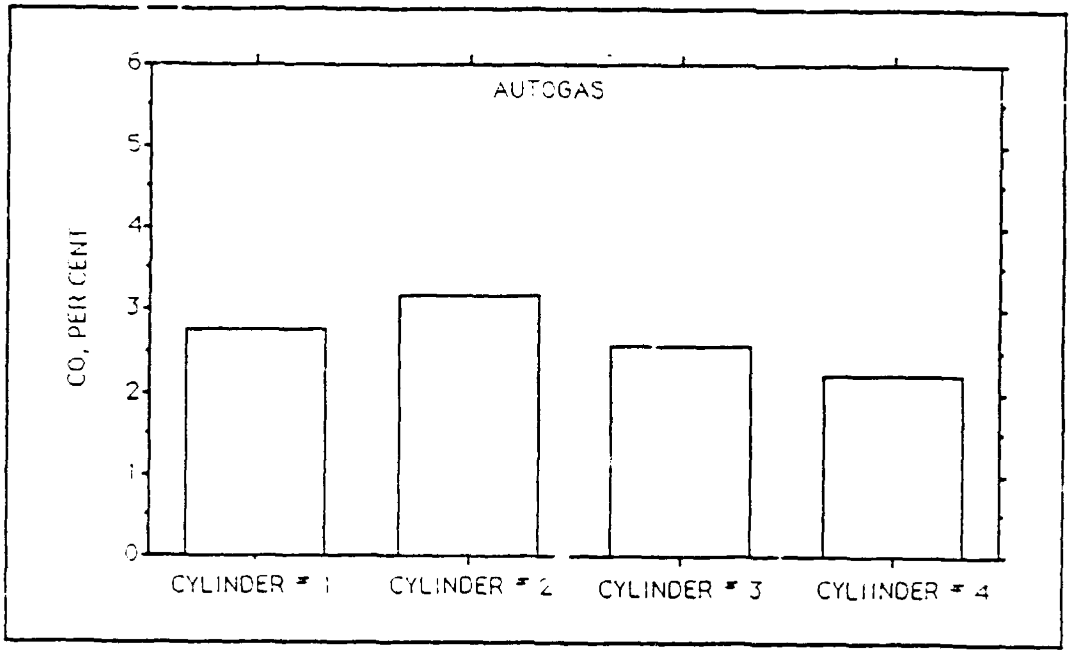

FIGURE 3. CO distribution among cylinders during engine operation with autogas

EXHAUST EMISSIONS

The exhaust products were measured during the cruise condition of each of the test cycles and during the take-off/climb condition of selected test cycles. The emission data were averaged and presented in table 3. The data show similar emission results from both engines which is another indication that the engines were operating at similar air-fuel mixtures.

TABLE 3. Average exhaust emissions

Component	Avgas Engine	Autogas Engine
Cruise		
CO, %	2.6	2.5
CO_2, %	14.2	14.3
HC, ppmC	2450	2350
NO_x, ppm	1170	1180
Take off/climb		
CO, %	8.7	4.7
CO_2, %	8.9	11.0
HC, ppmC	3370	2460
NO_x, ppm	125	530

LUBRICATING OIL ANALYSIS

The lubricating oil used during the tests was Texaco SAE-50 weight aviation lubricating oil. The oil usage rate averaged 0.18 qt/hour for the avgas test and 0.21 qt/hour for the autogas test. The oil and filters were changed at 50-hour intervals and the used lubricating oil analyzed. The used lubricating oil physical properties analysis is presented in table 4.

TABLE 4. Physical property data of used lube oils

Sample Description	Viscosity Cst, 100°C	Water % Vol	Solids % Vol	Total Acid Number
Base lube oil	19.5	0	0	0.04
Autogas - 50 hrs	24.1	<0.05	0.9	1.6
Autogas - 100 hrs	21.9	<0.05	2.7	1.0
Autogas - 150 hrs	22.0	<0.05	0.8	0.6
Base Lube oil	19.5	0	0	0.04
Avgas - 50 hrs	24.2	<0.05	0.2	2.3
Avgas - 100 hrs	23.7	<0.05	0.5	2.0
Avgas - 150 hrs	22.8	<0.05	0.7	1.5

METALS ANALYSIS

The wear metals analyses of the used lubricating oil are presented in table 5. The data show the silicon, iron, chromium, aluminum, and copper to be significantly higher in both engines during the initial 50-hour duration compared to the 100- and 150-hour condition. The metals appear to continue to decrease with time in the 100- and 150-hour condition but to a lesser degree. This probably reflects the additional engine break-in effects due to the upper engine overhaul.

The comparatively high lead levels in the avgas lubricating oil reflect the lead level of the fuel. The used lubricating oil data suggest that the two engines operated in similar fashion during each of the 50-hour intervals. The differences are consistent for both engines even though differences between the 50-hour and 150-hour intervals are apparent.

TABLE 5. Metals analysis

Elemental concentration, ppm by weight

SAMPLE DESCRIPTION	Silicon	Iron	Chromium	Molybdenum	Nickel	Aluminum	Tin	Copper	Lead	Silver	Sodium	Boron	Magnesium	Calcium	Barium	Phosphorus	Zinc
Autogas - 50 hrs	8	45	13	0	0	12	2	51	81	0	1	0	5	4	0	0	4
Autogas - 100 hrs	5	28	2	0	0	2	0	14	47	0	1	0	2	1	0	0	0
Autogas - 150 hrs	5	23	1	0	0	1	0	7	21	0	0	0	2	1	0	0	0
Avgas - 50 hrs	13	45	17	0	1	16	4	57	884	0	1	0	9	4	0	0	8
Avgas - 100 hrs	6	34	6	0	0	9	2	37	878	0	1	0	4	4	0	0	1
Avgas - 150 hrs	2	25	3	0	0	6	1	22	905	0	0	0	2	4	0	0	1

VALVE SEAT RECESSION

The VSR in the intake valves was measured although it was not expected to be a significant concern. The data show the average VSR for intake valves from both engines to be about 0.004 inches during the first 32 hours of operation and remain essentially unchanged during the remainder of the 150-hour test (figure 4).

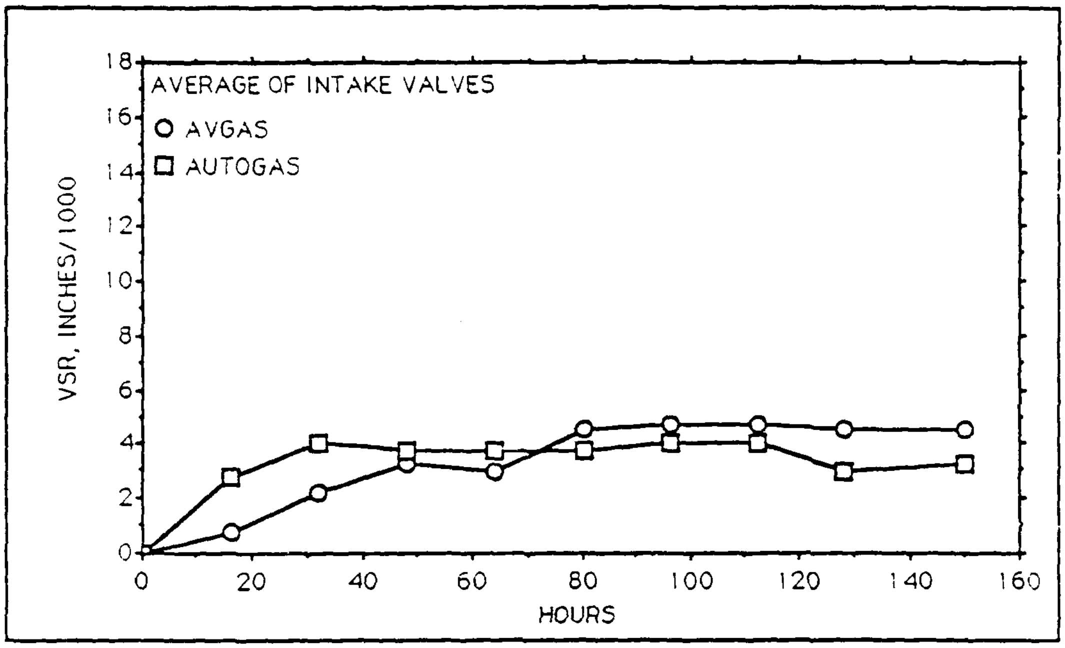

FIGURE 4. Average intake valve seat recession using avgas and autogas

The VSR in the exhaust valves was measured and the averaged VSR data presented in figure 5. The data in both tests show the valve seats recessed about 0.012 inches during the first 80 hours of the test and remained essentially unchanged during the remainder of the 150-hour test.

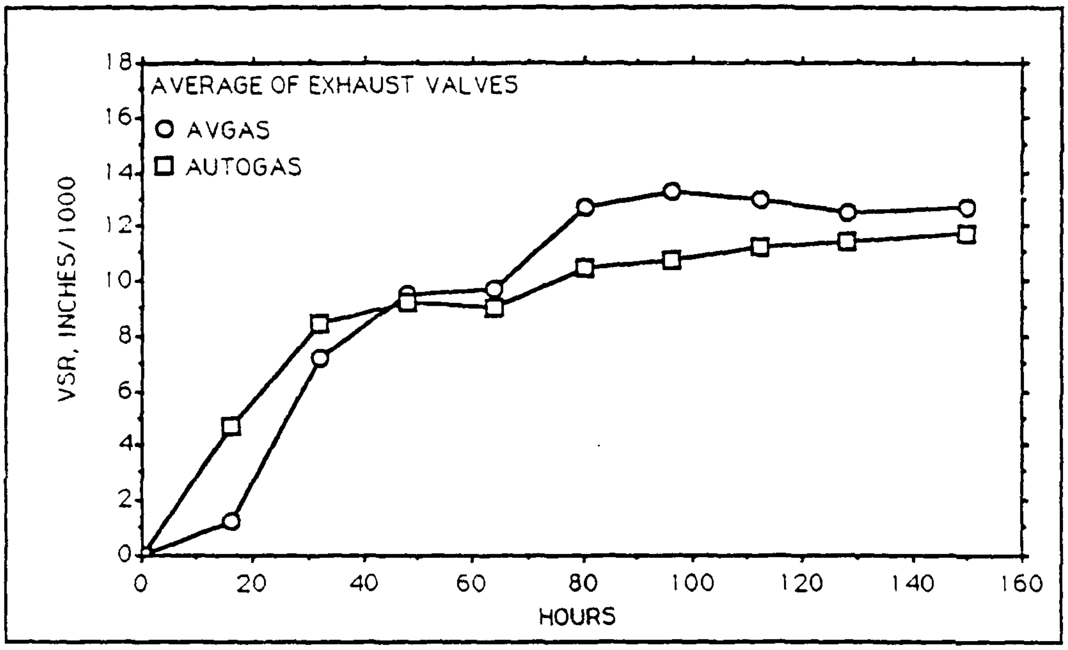

FIGURE 5. Average exhaust valve seat recession using avgas and autogas

The VSR data from individual cylinders in the avgas test are shown in figure 6. The data show again that the VSR increases in each cylinder until about 80 hours into the test and then remains unchanged. The spread among cylinders ranges from about 0.010 inch for cylinder No. 3 to about 0.015 inch for cylinder No. 1. The consistency of the data indicates the conditions which affect VSR do not vary among cylinders during this test.

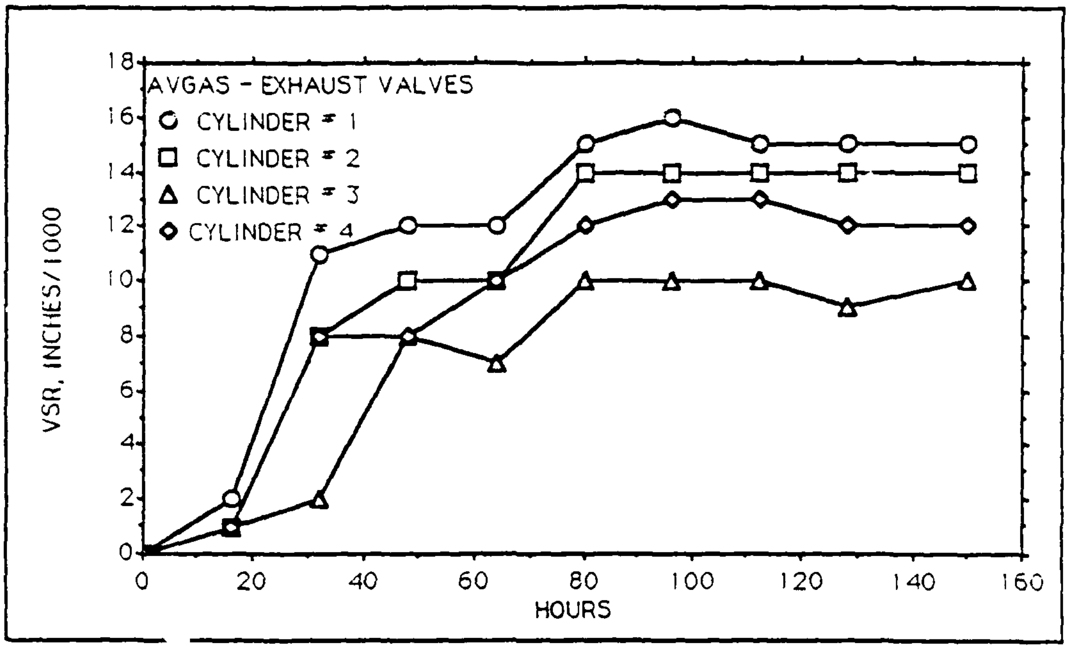

FIGURE 6. VSR in individual exhaust valves, avgas test

The VSR data from individual cylinders from the autogas test are presented in figure 7. The data show most of the recession occurring during the first 32 hours of operation. From 32 to 150 hours, cylinder No. 2 was unchanged. Cylinder No. 3 showed VSR changing only 0.001 inch during the 80- to 150-hour duration. Cylinder No. 4 showed VSR to increase by 0.004 inch in the 32- to 80-hour interval, remain unchanged from 80- to 112-hour interval, and during the 112- to 150-hour interval appears to continue to increase slightly (0.002 inch). The spread among cylinders ranged from about 0.016 inch for cylinder No. 1 to about 0.007 inch for cylinder No. 3. It is interesting to note that cylinder No. 1 received the largest amount of VSR in both tests and cylinder No. 3 received the smallest amount of VSR.

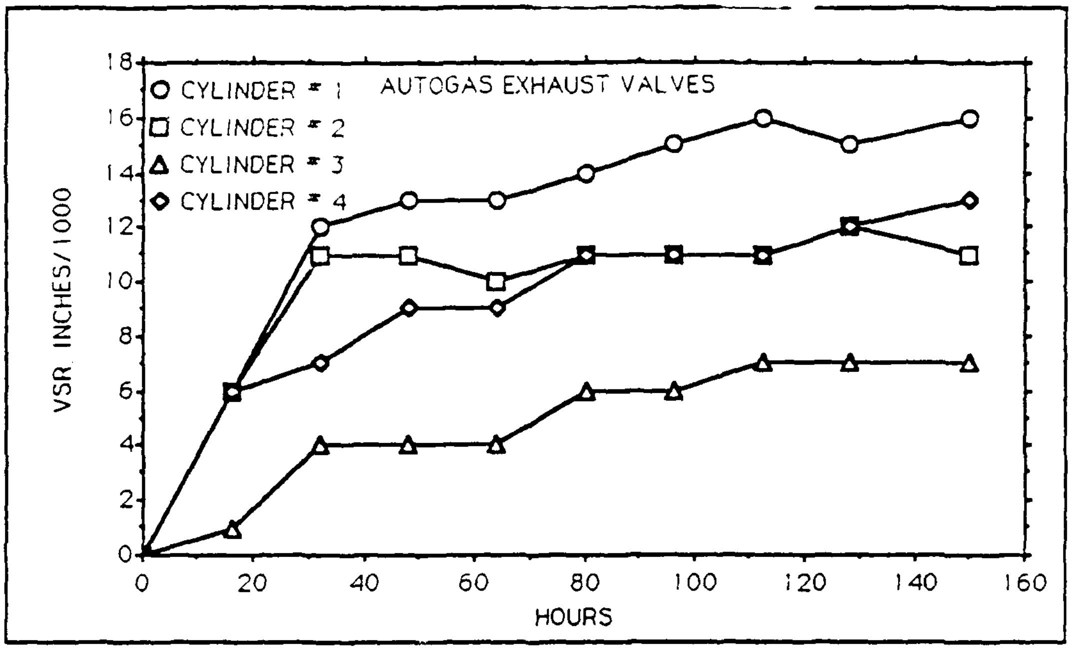

FIGURE 7. VSR in individual exhaust valves, autogas test

VSR data for both tests are presented in tabular form in table 6.

TABLE 6. VSR data, inches/1000

	Avgas Engine Test							
Accumulated Hours	Intake Cylinders				Exhaust Cylinders			
	1	2	3	4	1	2	3	4
0	0	0	0	0	0	0	0	0
16	0	-1	1	3	2	1	1	1
32	1	2	1	5	11	8	2	8
48	1	4	4	4	12	10	8	8
64	1	4	3	4	12	10	7	10
80	2	6	4	6	15	14	10	12
96	2	6	5	6	16	14	10	13
112	2	7	4	5	15	14	10	13
128	1	6	5	6	15	14	9	12
150	1	6	5	6	15	14	10	12

	Autogas Engine Test							
Accumulated Hours	Intake Cylinders				Exhaust Cylinders			
	1	2	3	4	1	2	3	4
0	0	0	0	0	0	0	0	0
16	4	6	-1	2	6	6	1	6
32	6	7	0	3	12	11	4	7
48	6	7	-1	3	13	11	4	9
64	6	7	-1	3	13	10	4	9
80	6	7	-1	3	14	11	6	11
96	6	7	0	3	15	11	6	11
112	6	7	0	3	16	11	7	11
128	5	6	-1	2	15	12	7	12
150	5	7	-1	2	16	11	7	13

CONCLUSIONS

Tests were conducted to determine the potential for VSR in aircraft engines using unleaded automotive fuels. Tests were conducted using unleaded motor gasoline and 100LL aviation gasoline in two similar engines and duty cycles. The engines were run at equivalent air-fuel mixtures and other engine parameters in order to minimize operational differences of the tests. This allowed for the fuel effect to be the major variable. Nominal VSR in the exhaust valves was observed in both engines. However, the results indicate that no significant differences in effects were observed in the VSR of intake or exhaust valves between the unleaded fuel and the 100LL aviation gasoline. VSR differences between the exhaust and intake valves were apparent; however, the effect was consistent for both fuels. In both tests the engines apparently stabilized and experienced little VSR after about 80 hours of operation.

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