ENCLOSURE (B) 11

ENGINE TEST OF ALCOHOL AS AVIATION FUEL

——(In Two Parts)——

by

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PART I

by

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Research Period: 1944-1945

SUMMARY

Objective of Project The object of this test was to find the fundamental engine performance of ethyl alcohol as aviation gasoline by the single cylinder testing machine, proceeding to the full scale engine test.

Significant Results Ethyl alcohol has very high anti-knock properties as compared with usual aviation gasoline. In spite of its octane number being only about 92, its maximum allowable boost is over (+) 600mm Hg in single-cylinder Kinsei 4 type aircooled test engine.

It is apt to cause autoignition even at lower boost which easily changes to preignition. We get the diagram (drawn from memory) of the limit of the autoignition as shown in Figure I(B)11.

According to Figure I(B)11:

1. Autoignition does not occur at any air-fuel ratio below (+)0 boost.

2. Autoignition begins to occur between (+)0 and (+) 100 boost, and the HP is somewhat higher in the area of autiognition.

3. The area limited by autiognition on the lean side and the rapid decrease in the HP on the rich side becomes much narrower above (+)400mm boost.

4. There is no safe combustible area at (+)600mm boost.

Autoignition begins at definite temperature which is just 200°C in this test. This temperature is supposed to have some relation to slow oxidation of alcohol.

I. INTRODUCTION

A. History of Project

Since April, 1944, we began to use ethyl alcohol as an aviation fuel. At first we blended it into gasoline only about 10% by volume and tested the engine performance carefully. However, with the increasing shortage of aviation gasoline, its blending ratio was increased rapidly to 30, 50 and 75% for experimental purpose, and finally, in October, we began to test pure ethyl alcohol as the fuel for the training airplane (50% blend of ethyl alcohol was the highest ratio actually used in training plane.). Above experiments by full scale engines were done mainly at the First Naval Technical Depot at YOKOSUKA. The following experiments were done particularly on the single cylinder engine performance of pure ethyl alcohol from October, 1944 to March, 1945.

B. Key Research Personnel Working on Project

Eng. Comdr. K. NAKATA
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II. DETAILED DESCRIPTION

A. Description of test apparatus

Single cylinder testing machine

"Kinsei" 4 type air cooled cylinder
Cylinder diameter 140mm
stroke 150mm
Compression ratio 66(variable compression)
Maker: Ishikawajima Aircraft Company Ltd.
Engine Counterbalanced and maximum Engine Speed 3000 R.P.M.

B. Test Procedures

1. Physical and chemical properties of used ethyl alcohol We used ethyl alcohol whose various properties were established as "1 alcohol" in the Naval Fuel Specifications.

General The alcohol may be added as specified to gasoline.

1. Purity: 99 wt % min.
2. Specific gravity (15°/4°C);0.797 max.
3. Distillation:
   distillate at 78-80°C. 95% min.
4. Reaction neutral
5. Solubility in water

This alcohol shall be mixed at any temperature and be a clear solution.

C. Methods of Tests

We made three tests of engine performances in order to find the anti-knock properties of pure ethyl alcohol:

1. The first test series was the boost-up method; namely, we elevated the intake air pressure from (-) 100mm Hg for each 100mm boost, and found when the fuel began to detonate, as judged by exhaust flame color. We called this point "the maximum boost of the fuel."

2. The second test consisted of changing the air-fuel ratio; at every boost we changed the air-fuel ratio from the rich side to the lean side by regulating the fuel supply, and measured the change of the HP accompanied with the air-fuel ratio.

3. The engine's ignition was switched off at every air-fuel ratio and it was determined whether the engine continued to run; that is, whether ethyl alcohol already began autoignition or not. We called this point the limit of autoignition; that is, the boost at which autoignition began. As a rule, when the rear spark plug temperature exceeded 200°C, autoignition occurred.

D. Results

By above mentioned method the engine performance diagram (Figure 1(B)11) of pure ethyl alcohol was obtained which had the brake horsepower as ordinate and the air-fuel ratio as abscissa.

III. CONCLUSIONS

A. On the Anti-knock Properties

By these single cylinder engine tests, ethyl alcohol proved itself to be very high anti-knock fuel. For example, normal aviation gasoline which had 91 octane number began to detonate at about (+) 200mm boost, but pure ethyl alcohol did not detonate regardless of air-fuel ratio, even at (+)600mm boost if mixture was rich enough. From this point of view, the anti-knock property of pure ethyl alcohol seems to be no problem, but it has other various weak points as an aviation fuel, such as volatility. Even if an excess of ethyl alcohol is supplied into the intake for the purpose of increasing its vapor pressure, the amount of vapor evolved does not increase, since ethyl alcohol has a fixed boiling point. In the case of the full scale engine, therefore, the distribution of fuel to every cylinder becomes very bad, which causes the detonation. We cannot conclude that ethyl alcohol has very high anti-knock property from the single cylinder engine test alone. It actually has high anti-knock property by single cylinder engine test, but often it proves to be low anti-knock value by full scale engine tests.

B. Autoignition of Ethyl Alcohol

Another weak point of ethyl alcohol as an aviation fuel is its autoignition property. Ethyl alcohol has the property of beginning autoignition under high pressure and temperature. Autoignition induces preignition, which is not desirable. If the area limited by the beginning point of autoignition of the lean side, and the point of rapid fall of the HP on the rich side, is called "the safe combustible area," it becomes very narrow at (+) 300mm boost as shown in the diagram.

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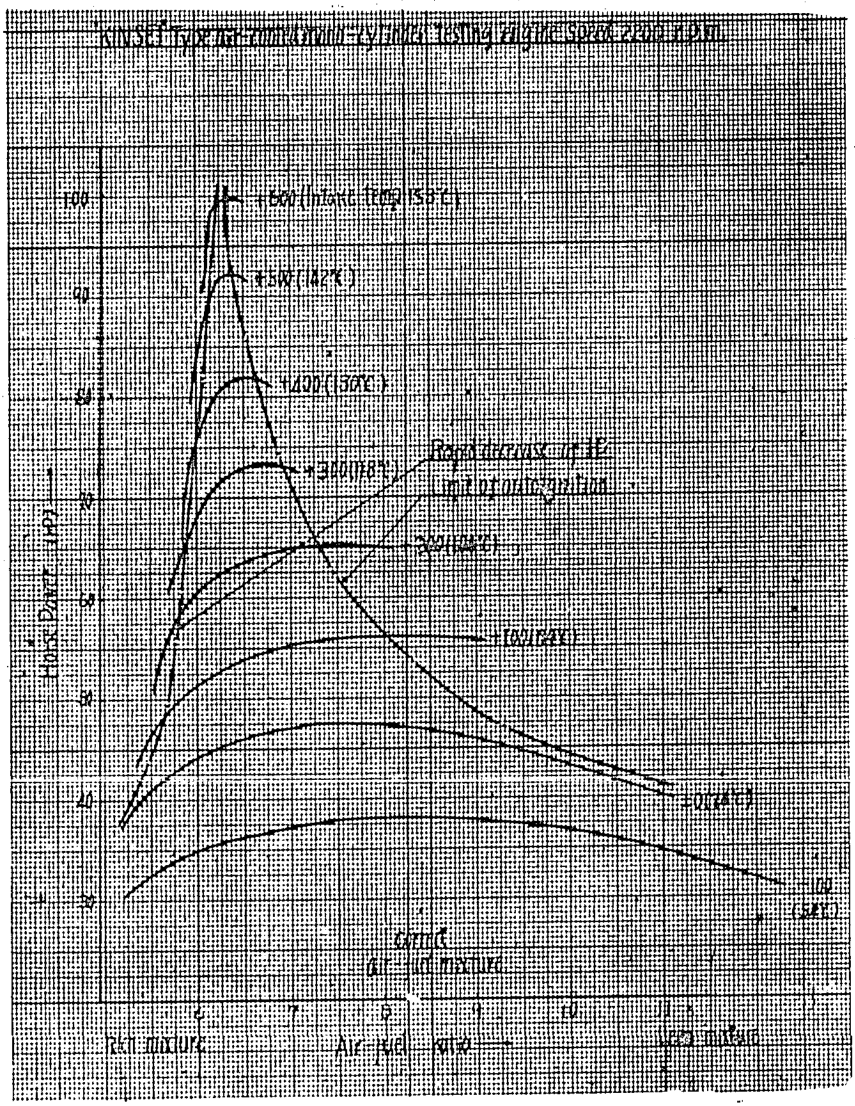

Figure 1 (B)11
ENGINE PERFORMANCE DIAGRAM OF ETHYL ALCOHOL

ENCLOSURE (B)11

PART II

by

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Research Period: 1944-1945

SUMMARY

To examine the practical value of alcohol as an aviation fuel, especially to improve its volatility, the author examined the effect of blending ethyl ether, acetone, and gasoline with ethyl alcohol.

The effect of the latter two was satisfactory, but the former was not satisfactory because of its knocking tendency.

I. INTRODUCTION

A. The Characteristics of Alcohol

1. Heat of combustion of alcohol is less than that of gasoline, thus fuel consumption of alcohol is increased.

2. Latent heat of vaporization of alcohol is very large; thus its volatility is very poor, and the difficulties of starting, acceleration and cylinder distribution of the fuel arise, but its anti-knock property is improved by the cooling effect of alcohol.

3. Corrosive Action on Aluminum Alloys and Steel. Because of these properties, the setting of carburetor fuel flow must be changed, and the addition of arsenic soda (sodium arsenite) (5mg/100cc of alcohol) is necessary to prevent corrosion. In this way, for the training planes of 1000 to 1500 hp class, alcohol can be used for limited performance, but for first class planes, alcohol cannot be used as fuel because it limits the performance of engines.

B. Key Research Personnel Working on Project

CHEM. ENG. LT. COMDR. T. NAKAYAMA

II. DETAILED DESCRIPTION

A. Description of the Test Apparatus

The aircraft engine "Kinsei" 5 type was used for testing these fuels. Its characteristics were:

14 cylinders and double-row radial air-cooled,
Compression ratio, 7.0
Carburetor type,
Cylinder bore 140mm, stroke 150mm,
Maximum output power 1300 hp at 2550 r.p.m. and
+350mm Hg (aviation gasoline with octane rating 91 was used).

Water brake type dynamometer was used.

B. Test Procedure

The mixtures of alcohol with ethyl ether, acetone or gasoline were tested by "Kinsei" 5 type engine. The test was made at every boost (±)0, (+)100, (+)200mm Hg, etc., and the minimum fuel consumption of each mixture, temperatures of cylinders, and exhaust gas were recorded. Thus, the volatility performance characteristics of each mixture were observed.

C. Experimental Results

The mixtures of alcohol and blending fuels had the properties and performance results as shown in Table I(B)11.

III. CONCLUSIONS

Ethyl ether has high volatility, but it causes detonation. Therefore, its allowable concentration is very small, and consequently, it cannot be blended in sufficient quantity to affect the volatility of the mixture.

Acetone has good volatility and anti-knock properties, and its blended fuel showed the best performance. The more acetone added, the better the resulting fuel.

Gasoline had a higher heat of combustion than the other blending agents, so that the fuel consumption of the gasoline alcohol blend was lowest. However, the effect of the gasoline on anti-knock properties and volatility was not as great as that of acetone.

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Table I(B)11
PROPERTIES AND ENGINE PERFORMANCE CHARACTERISTICS OF ALCOHOL BLENDS

		Octane Number	Vapor Pressure	Distillation Temperature (°C) First	10%	50%	90%	97%	Engine Performance ** Max.boost (mm Hg)	Max. hp	Fuel Consumption (lit/hr)
Alcohol	100%	92	0.19		78	78	78	78	+250	1210	610
Alcohol Ethyl Ether	95% 5%	90	0.28	65	78	78	78	78	+200	1124	537
	90% 10%#	89	0.31	60	76	76	78	78	+200	1130	590
	80% 20%	89	0.51	48	78	78	78	78	+150	1087	533
Alcohol Acetone	90% 10%	91	0.31	60	76	76	78	78	+300	1202	
	90% 10%#	90	0.31	60	76	76	78	78	+350	1290	670–770*
	80% 20%	91	0.38	58	76	76	78	78	+350	1325	625–775*
Alcohol Water	95% 5%	92							± 0	878	Fuel consumption is the same rate as for aviation gasoline.
Aviation Gasoline	100%	87							+150	1010	
Alcohol iso-Octane	80% 20%	90	0.25	67	73	76	78	79	+100	951	
Alcohol Benzene	80% 20%	87		67	70	75	78	86	+100	971	
Alcohol Toluene	80% 20%	89	0.21	71	76	76	77	79	+100	971	
Alcohol iso-Propyl-ether	80% 20%	90	0.27	65	70	76	79	79	+100	979	
Alcohol Pine root oil	80% 20%	85		75	77	78	167	181	+ 50	909	
Alcohol A92G	80% 20%	85		59	72	77	138	179	+100	984	

0.15% leaded -*Allowable range of change of fuel consumption **At 2500 RPM