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ORENDA ENGINES LIMITED.

Inter-Departmental Memorandum.

Date	:	15th February 1957.
To	:	Mr. F.D.M.Williams - Chief Dev. Engineer - Controls.
From	:	D.E. Morrison - Chief Combustion Engineer
Subject	:	FUEL PROPERTIES.

The attached table lists some fuels and their properties in which we are interested. There follows a brief discussion of combustion characteristics and a comparison of thrust and S.F.C. which could be expected from the Iroquois using J.P.4 and Pentaborane fuels.

There are other boron compounds, either in hydride form or combined with other light metal hydrides which may offer performance gains approaching pentaborane, but with better physical properties (excepting toxicity) for handling in engine fuel and combustion systems. No useful data is available on these as yet, but results of some preliminary theoretical chemical investigation indicating [illegible] hand.

Additional data is required in order to assess the merits of magnesium [illegible] as an afterburner fuel. It may well be an acceptable compromise between the high performance, but toxic, pentaborane and the relatively low performance hydrocarbon fuels for an application where a high S.F.C. can be tolerated.

D. E. Morrison,
Chief Combustion Engineer.

c.c. [illegible]
F.H. Keast
J.H. [illegible]
[illegible]
Orig.

DEM/jmc.

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	Freezing Point °C	Boiling Point	Specific Gravity	Stoichiometric Fuel Air Ratio	Combustion Temp. °K	Heating Value CHU Per lb.	Heating Value CHU x 10^6 Per Cu.Ft.	Air specific impulse L.B. thrust/(lb/sec. of fuel) At Stoichiometric Fuel/Air Ratio	Fuel specific impulse L.B. thrust/(lb/sec. of fuel)
BORON HYDRIDES									
Diborane (S)	-165	[illegible]	.447	.0669	2671	17500	.488	185	2700
Pentaborane (L)	[illegible]	[illegible]	.61	.0763	2754	18000	.611	181	2500
LIGHT METALS									
Boron	[illegible]	[illegible]	2.32	.105	2938	12500	1.87[illegible]	185	1800
Magnesium	650	[illegible]	1.74	.353	3100	6020	0.653	224	800
Aluminum	660	[illegible]	2.70	.261	3404	7400	1.247	212	800
SLURRIES *									
Boron	-	-	[illegible]	.081	2600	11610	0.810	178	2200
Magnesium	-	-	[illegible]	.113	2640	8170	0.525	184	1600
Aluminum	-	-	[illegible]	.102	[illegible]	8860	0.635	184	1800
*50% solids by wt suspended in octene (analogous to gasoline.)									
HYDROCARBONS									
J.P.4	-59	200	[illegible]	.067	2300	10430	0.500	171	2500
J.P.1	-59	210	.80	.067	2300	10430	0.520	171	2500
Gasoline	-59	100	[illegible]	.067	2300	10430	0.472	171	2500
Shell T[illegible] (Alkylated Naphthalenes)	-	-	[illegible]	.067	-	10300	0.617	171	2500
Shell Coking Cycle Stock	-	[illegible]	[illegible]	.067	-	9700	0.582	171	2500
Octene	-	-	[illegible]	.067	[illegible]	[illegible]	0.480	171	2500
H1CAh.			[illegible]7					255	

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HYDROCARBON FUELS.

There is no evidence that any one hydrocarbon fuel has a practical advantage from the combustion point of view. Heating value per pound of fuel, stiochiometric mixture temperature rise, molecular weight of the products of combustion, air specific impulse, hence thrust available from the fuels do not vary significantly.

Flame speeds ("fundemental") are of the order of 3 ft/sec. which indicates that the same combustion volume is required for all the hydrocarbon fuels.

Flammability limits and spontaneous ignition temperature vary considerably among the hydrocarbons, but can be expected to have only second order effect on the burning range and ignition process for combustion equipment of the type in use on the Iroquois.

Rig tests indicate that the present combustor operates reasonably satisfactorily at conditions equivalent to 80,000 ft, and higher on J.P.1. Fuel properties of other hydrocarbons will not have a significant effect on extending the altitude range or improving combustion efficiency at any altitude.

SUPERFUELS.

Included in super fuel category are boron (and other light metal) compounds or slurries of these in a hydrocarbon vehicle.

PENTABORANE.

Pentaborane is the only presently known liquid fuel in this category which could be readily used for combustion tests on rigs or engine on the basis that it is a liquid at normal temperature and pressures. (Boiling point 55°C). Limitations are noted below.

For pentaborane the heating value per pound is 16000 CHU/LB as compared to 10,300 to 10,500 for hydrocarbon fuels. Stoichiometric temperature is 2671°K as compared to 2300 for the hydrocarbons. Air specific impulse at stoichiometric ratio is 185 seconds as compared to 171 for the hydrocarbons. This means that a large improvement in specific fuel consumption could be expected on a thermodynamic basis, if pentaborane was to be used in place of J.P.4 for either the bare Iroquois engine or for the engine and after-burner at existing temperature limits when using J.P.4 (998°K - T_{4T} & 1750°K - T_{8T})

With stoichiometric mixture in the A/B substantial increase in maximum total thrust could be expected. For example, it is estimated that at S.L.S. max. thrust of 29170 lbs, using J.P.4 could be increased to 37500 lbs. with pentaborane burned in the primary combustor and the afterburner for nearly the same specific fuel consumption as given by J.P.4.

"Fundemental" flame speeds have been measured up to 169 ft/sec as compared to 3 ft/sec for hydrocarbons. This indicates that some flame tube primary zone volume reduction might be possible using pentaborane.

Length reduction of afterburner combustion space and reduction of flame holder blockage could be expected for similar reasons. A boron compound burned satisfactorily over a 100/1 flow range in gas stream velocities up to 500 ft/sec (nearly that in Iroquois jet pipe) with no flame holder.

Pentaborane and its products of combustion and poisionous (35 PPM dangerous) Pentaborane is thermally unstable, having limited use as heat sink and probably would cause deposits in hot areas of fuel lines and around fuel injection points. Boron oxide, a combustion product, is deposited on stationary components, such as flame tube walls, and turbine nozzles, and causes erosion of turbine blades, at temperatures below approx. 1300°K - 1600°K. This is a definite limitation to primary combustion.

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use. However, it is believed that afterburner deposits could be effectively dealt with.

MAGNESIUM SLURRY - (50-60% By weight in hydrocarbon E.G. Octene or J.P.4)

Reports at hand up to 1952 publication date, indicate that substantial afterburner thrust increase can be obtained with a Magnesium slurry,fuel as compared to that for a straight hydrocarbon fuel. This would occur in applications where advantage can be taken of the higher combustion temperature available, and oxide deposits could be dealt with as in the afterburner application.Magnesium oxide melting point is 3000°K

This data also states that considerable improvement in stable burning range over hydrocarbon fuels was obtained with magnesium slurry, from 0 to 1.4 equivalence ratio and the upper limit was pump capacity in these tests.

High reactivity of this fuel indicates that high efficiency could be maintained over a wider burning range and flame holder blockage might be reduced

The performance of the afterburner model in these tests when using the hydrocarbon fuelwas sufficiently mediocre, that further literature study is required to sort out what improvement could be expected using magnesium slurry in an afterburner which gives reasonable performance on the hydrocarbon fuel alone. A check on theoretical data indicates that a 50% magnesium slurry burned in the Iroquois afterburner at stoichiometric mixture ratio should give 32,900 lbs. thrust as compared to 29,170 lbs. for J.P.4, an increase in max. thrust of 4.3%. In this case thrust boost of the afterburner increases for 42.5 to 62.9%. However, specific fuel consumption is more than doubled, going from 2.20 for J.P. 4 to 5.15 for the magnesium slurry.

For application where very high combustion temperature can be tolerated and higher thrusts are needed, magnesium offers an advantage in that it will burn very well at equivalent ratios greater than 1, due to the fact that the magnesium will combine with the water vapour and carbondioxide in the hydrocarbon products of combustion.

Screw type pumps - stainless steel rotor and synthetic rubber stator - has delivered slurries satisfactorily, although some stator wear has occurred. Metering and flow characteristics of magnesium slurries up to 60% concentration were similar to the hydrocarbon carrier. The slurry fuels followed the conventional orifice equation.

LIGHT METALS.

Little information is available on these fuels. Storage, pumping, metering and injection of light metals in powder form offer substantial problems. Use of slurries appears to be a better method of handling these, although potential combustion performance is compromised considerably.

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COMPARISION OF IROQUOIS S.L.S. PERFORMANCE - USING J.P.4 and PENTABORANE FUELS.

			ENGINE.	ENGINE & AFTERBURNER.	
J.P.4	T_{6T}	°K	998	998	998
	T_{7T}	°K	998	1750	2160 *
	Fg	Lbs	20200	26200	29170
	% Boost		0	30	42.5
	S.F.C.		0.909	2.200	2.220
	Air Spec.Impulse (sec)		72.2	93.7	104
	Fuel Spec.Impulse (sec)		3960	1640	1620
PENTABORANE	T_{6T}	°K	998	998	998
	T_{7T}	°K	998	1750	2580 *
	Fg	Lbs	20200	26200	27500
	% Boost		0	30	35.5
	S.F.C.		0.595	1.44	2.10
	Air Spec.Impulse (sec)		72.2	93.7	134
	Fuel Spec.Impulse(sec)		6070	3600	1710
	% improvement S.F.C. & Range.		34.5	34.5	5.66 (on S.F.C. only)

Afterburner combustion efficiency in all cases = 90%

* Obtained with Stoichiometric fuel-air ratio.

REFERENCES.

1. NACA RM E56B27 - Tables and charts for Thermodynamic calculation involving air and fuels containing boron, carbon, hydrogen and oxygen.
2. NACA RM E52E01 - An experimental investigation of the Comb. properties of a hydrocarbon fuel and several magnesium and boron slurries.
3. NACA RM E52H25 - Effect of water vapour on combustion of magnesium hydrocarbon slurry fuels in small scale afterburner.
4. NACA RM E51C23 - Status of combustion research on high energy fuels for ram jets.