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FUEL FOR AND METHOD OF OPERATING A JET ENGINE

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This invention relates to jet engines. In one of its more specific aspects, it relates to a superior fuel composition for jet engines. In another of its more specific aspects, it relates to the operation of continuous flow jet engines. In another of its more specific aspects, it relates to the operation of ram jet and turbo-jet engines. In another of its more specific aspects, it relates to the operation of pulse jet engines.

Jet engines have only in the last few years been used in large numbers for the purpose of propelling aircraft and they have been found to be highly advantageous for use in high speed planes. With the increase in use of such engines, however, a multitude of operational problems has also come to be recognized.

A jet engine comprises three general parts; first, an air intake section; second, a fuel addition and combustion section; and third, an exhaust section. The air intake section and means for effecting such air intake is roughly divided into three classes, i. e., the type found in a ram jet, a pulse jet, and a jet engine employing a rotating compressor, such as a turbine compressor operated by a gas turbine, as motivating power for introducing the air into the combustion section. These different types of air intake systems, though substantially different in mechanical form, all serve the same function in each engine, namely, providing the necessary air supply to the combustion section. The combustion section, including the fuel injection system and the exhaust system, are somewhat similar in each type of engine. The purpose of operation of each of the engine types is similar, namely, to burn the fuel and to utilize as much as possible of the heat energy added in producing thrust for the engine. The major difference in these combustion and exhaust sections is found when comparing the ram jet or pulse jet engine types with the gas turbine engine. In the gas turbine engine, the combustion gases pass through a turbine which utilizes part of the heat energy of the combustion gases in driving the air compressor so as to furnish additional air for the combustion zone. The gases then are exhausted to the atmosphere through the exhaust section or tail pipe with a concomitant production of thrust. In the case of the ram jet and pulse jet engines, the hot gases pass directly from the combustion section to the exhaust or tail pipe section and it is thus more difficult to establish as clear a line of demarcation between the zones of such engines.

The general trend of thought concerning the operation of jet engines has been that hydrocarbons do not vary sufficiently in their burning characteristics to make a material difference in the operation of any given jet engine. For that reason emphasis has for some time been placed on engine research so as to determine the design of a jet engine which would have such a structure as would overcome the multitude of operational difficulties which are inherently encountered in jet engines. Such operational difficulties have to date been only partially overcome by engine design.

Some of the problems which are encountered in the

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operation of such jet engines are exemplified by those encountered in a turbo-jet engine. Performance of a jet engine is dependent to a large extent upon the "temperature rise" which is obtainable in the particular engine. "Temperature rise" is that increase in temperature between the inlet to the combustor and the temperature of the gases at the combustor exhaust outlet. In a turbo-jet engine, the temperature rise must be carefully controlled for the operation of a turbo-jet engine is limited by the ability of the turbine blades to withstand high temperatures. Fuel which is supplied to the combustor is burned in the presence of supplied air and raises the temperature of the combustion gases and unused air by the heat of combustion. An excess of air is conventionally utilized in the operation of turbo-jet engines to control the temperature of the gases contacting the turbine blades. Such a large quantity of air is utilized in the operation of jet engines that the air flow reaches very high velocities. The high air velocities pose many additional problems in the operation of jet engines, which problems are very difficult to overcome. The hot gases are expanded and in the turbo-jet engine are expanded through the turbine section which provides power for the compressor. Further expansion of the gases in a turbo-jet engine, as well as in a ram jet or pulse jet engine, takes place in a rearwardly extending exhaust nozzle to provide a substantial increase in gas velocity. The thrust which is produced by the engine equals the gas mass flowing through the exhaust duct times its increase in speed according to the law of momentum.

For each engine speed at a given altitude, a certain temperature rise is required for the operation of any given jet engine. Combustor inlet pressure and mass air flow through the engine imposes a limitation upon the combustion of any fuel utilized in the operation of the engine. For each combination of combustor inlet pressure and mass air flow there exists for any given fuel a maximum attainable temperature rise which depends upon the combustion stability performance of that fuel under the combination of those conditions. As the operating conditions become more severe, a decrease in combustion stability is encountered. One phenomenon which tends to affect temperature rise in any given engine is known as "cycling." Cycling is an indication of instability of combustion of a given fuel. The flame front within the combustor tends to fluctuate back and forth and many times the instability reaches such a degree that the flame is finally extinguished. The point at which combustion will no longer be sustained is known as the "blow-out" or "cut-out" point. Rich mixture blow-out is the primary controlling characteristic of turbo-jet engine performance since it defines the maximum thrust output at a given altitude. When the temperature rise required at a given engine speed and at a given altitude corresponds to the maximum temperature rise obtainable with a given fuel, a very definite operational limit is imposed upon that jet engine when operating with that specific fuel. In order to operate the engine under more severe operating conditions, it is necessary therefore to obtain and use a fuel which has stable combustion characteristics over a broader range of conditions than the fuel with which the maximum limit of operation has been reached. Similar operational problems are encountered in pulse jet and ram jet engines.

It has been found that many of the operational problems of such jet engines are overcome to a large extent when those engines are operated with a particular hydrocarbon fuel. Hydrocarbon fuels, contrary to general belief, burn differently under different operating conditions. It will thus be seen that although stress has been placed upon research for mechanical design of jet engines, a further limitation is placed upon the individual

engines by the particular fuel being utilized. A desirable jet engine fuel should be readily burnable and should facilitate maintenance of the flame in the combustion zone. The fuel should also produce a high thrust for each unit volume burned and should not cause difficulty such as fouling the engine or fuel injection system.

Hydrocarbon fuels which satisfactorily meet the above requirements should be rated in an order of desirability by their ability to impart heat to air entering the combustion zone while maintaining stable combustion therein. Fuels may be rated in their order of desirability by operating a particular burner under a particular set of operating conditions which include combustion zone inlet air temperature, mass rate of air flow, and constant outlet pressure. An increase in the rate of fuel addition, when the above conditions are fixed, increases the temperature rise of the air in the combustion zone up to a critical point and after that point has been reached any increase in fuel addition results in decreasing the temperature of the combustion gases. A comparison of the maximum temperature rise (ΔT_m) with the ΔT_m obtained with two standard fuels, normal heptane and 2,2,4-trimethylpentane (isooctane) obtained in the same burner and under the same operating conditions makes possible the rating of the tested fuel under such operating conditions. Assigning n-heptane and isooctane arbitrary values of combustion stability of 100 and 0, respectively, the relative combustion stability rating of the test fuel is calculated from the following relation:

$$\sigma = \frac{\Delta T_{m,f} - \Delta T_{m,o}}{\Delta T_{m,n} - \Delta T_{m,o}} \times 100$$

where

σ = Combustion stability rating

$\Delta T_{m,f}$ = Maximum stable temperature rise of the test fuel at the test conditions

$\Delta T_{m,o}$ = Maximum stable temperature rise of isooctane at the test conditions

$\Delta T_{m,n}$ = Maximum stable temperature rise of n-heptane at the test conditions

For a given fuel in a given burner, correlation under different inlet pressures by plotting

$$\Delta T_m \text{ versus } \frac{p^{1.46}}{W a}$$

where

ΔT_m = Maximum stable temperature rise of a test fuel at the test conditions, degrees Fahrenheit

p = Inlet pressure (inches of mercury)

$W a$ = Weight of air entering the burner (pounds per second)

a straight line is obtained. The group,

$$\frac{p^{1.46}}{W a}$$

is termed the reciprocal severity factor. Variation in stability rating with variation in reciprocal severity indicates sensitivity of the fuel to inlet conditions.

Broadly speaking, this invention comprises a new and novel jet engine fuel, namely, a combination of 1-olefins, preferably straight-chain 1-olefins, and normal paraffins boiling within a specific boiling range and the operation of jet engines with such a fuel.

An object of this invention is to provide an improved method for operating jet engines. Another object of the invention is to provide an improved method for operating pulse jet engines. Another object of this invention is to provide an improved method for operating turbo-jet engines. Another object of the invention is to provide an improved method for operating ram jet engines. Another object of the invention is to provide a method for extending the operational limits to decrease the dead band for jet engines. Another object of the invention is to reduce cycling in jet engines. Another object of the invention is to reduce resonance in jet en-

gines. Another object of the invention is to provide an improved fuel for use in jet engines. Another object of the invention is to provide a jet engine fuel which has highly desirable flame propagation characteristics. Other and further objects and advantages will be apparent upon study of the accompanying disclosure.

The assumption that all hydrocarbon fuels burn at such a standard velocity that the operation of a jet engine is not materially affected thereby, is entirely erroneous. The exact reason for the improvement in operation of a jet engine with the fuel of this invention is not known. It is quite possible, however, that much of the improvement is the result of a very high combustion efficiency of the 1-olefin material.

Best operating results are obtained when operating a jet engine on a fuel which has a rate of combustion which is explosive. That fuel should also have a high unit heat release, for as the heat release of the fuel within the combustor increases, a greater mass of gas can be heated to a given temperature and thus an increase in thrust per unit of fuel is obtained. I have found that 1-olefins provide very excellent fuel constituents for jet engines. Such materials have very good combustion stability characteristics. The 1-olefins which I utilize as fuel constituents boil within the range of between 90° F. and 500° F. The straight chain 1-olefins are preferred for use in jet fuels although a single branch in the chain is not seriously deleterious. Although highly branched 1-olefins are not as desirable for jet fuel constituents as straight chain olefins of the same number of carbon atoms, they are, however, preferred over paraffins having the same carbon skeleton although isoparaffins were heretofore thought to be excellent jet fuels. Specific aliphatic 1-olefin materials which form a part of my jet fuel composition are 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-nonene, 1-decene, 1-undecene, 1-dodecene, and 1-tridecene.

Additive materials which improve the combustion stability rating of such materials under some conditions, when added in an amount between 3% and 15% by volume, include ethyl nitrate, tertiary butyl perbenzoate, benzaldehyde, methyl isobutyl ketone, 1,1,2-trichloroethane, ditertiary butyl disulphide, and ethyl ortho silicate.

Tests were made of 1-octene, 1-decene, and diisobutylene, and indicate the superiority of 1-olefins as fuel constituents. Those materials were tested in two burners, namely, a Westinghouse 4-inch single tube research burner (burner A) and a Type W 2-inch burner (burner B) under specific reciprocal severity conditions. These burners had previously been found to provide fuel ratings which correlated very well with ratings obtained with a full scale Westinghouse 9.5A turbojet engine combustor. Results of the tests made with burners A and B are set forth in Table I below.

TABLE I

Selected fuel rating at indicated reciprocal severity factor in two different burners

Reciprocal Severity.....	Burner A		Burner B	
	200	285	1,500	2,200
Fuel:				
1-Octene.....	116	122	152	148
1-Decene.....	104	148		
Diisobutylene ¹	60	74	50	67
25% 1-Octene ²	23	29		
50% 1-Octene ²	58	61	76	68
50% n-Heptane ²	46	41	54	61
Normal Heptane.....	100	100	100	100
Isooctane.....	0	0	0	0
10% 1-Octene in Normal Heptane.....	112	118		
10% 1-Octene ²	4	7		

¹ Branched chain 1-olefin.

² In isooctane.

Study of the above data show that not only do normal 1-octene and normal 1-decene have better ratings than normal heptane but the 1-olefin type substantially retains these desirable characteristics or shows improvement when blended with isooctane. It will also be noted that diisobutylene (2,4,4-trimethyl-1-pentene) is substantially better in rating than isooctane, a paraffin of like carbon structure.

My jet fuel consists essentially of between 5% and 95% by volume of at least one 1-olefin boiling between 90° F. and 500° F. and between 5% and 95% by volume of at least one normal paraffin boiling between 90° F. and 500° F. Specific normal paraffins which are utilized in such a jet engine fuel preferably includes normal hexane, normal heptane, normal octane, and a light paraffinic naphtha. A small portion of normal pentane may be utilized in the fuel for the purpose of improving starting characteristics. It is preferred that the fuel consist essentially of at least 50% by volume of at least one 1-olefin boiling between 90° F. and 500° F. and the balance of the fuel be normal paraffins boiling between 90° F. and 500° F., preferably between 200° F. and 400° F.

Continuous flow type jet engines are operated when the fuels discussed hereinabove are supplied to a given engine at a fuel-air ratio ranging between 0.005 and 0.10. A turbo-jet engine is operated at a fuel-air ratio within the range of 0.005 to 0.040, preferably between 0.01 to 0.03. A ram jet engine operates at a fuel-air ratio ranging between 0.01 and 0.10, preferably between 0.03 and 0.07. It is within the scope of this invention to operate the jet engine with the fuel described above and with the injection of oxygen. If oxygen or an oxygen-supplying compound, such as peroxide, is used for the purpose of supplying oxygen rather than air, the fuel-air ratio would necessarily have to be adjusted accordingly so as to maintain a fuel-oxygen ratio equivalent to the fuel-air ratio disclosed herein. Air is supplied to such jet engines at a combustor inlet air pressure of between 0.2 to 40 atmospheres at a mach number ranging between 0.01 and 1.0. "Mach number" is defined as the ratio of the velocity of a gas to the local velocity of sound in the gas. A turbo-jet combustor is operated at an inlet air pressure between 0.2 and 30 atmospheres, preferably between 0.5 and 10 atmospheres at a mach number between 0.01 and 0.80, preferably between 0.02 and 0.30. A ram jet engine operates at an inlet air pressure of between 0.5 and 40 atmospheres, preferably between 1 and 10 atmospheres and at a mach number between 0.1 and 1.0, preferably between 0.3 and 1.0. Fuel is supplied to the combustor of such jet engines at a temperature ranging between 60° F. and 240° F. The gas turbine has a preferred fuel inlet temperature of between 40° F. and 100° F. while the ram jet engine has a preferred fuel inlet temperature of between 40° F. and 90° F. Air which is supplied to the combustor is preferably supplied at a temperature between -30° F. and 1040° F. The turbo-jet engine is operated at an inlet air temperature between -30° F. and 740° F., preferably between 40° F. and 440° F. A ram jet engine operates at an inlet air temperature between 40° F. and 1040° F., preferably between 140° F. and 540° F. When operating these engines within the above range of conditions, the jet engine fuel of this invention burns within a combustion efficiency range of between 40 per cent and 100 per cent, and ordinarily within the range of from 85 per cent to 100 per cent. The exact fuel-air ratio which is utilized is dependent upon engine design limitations, such as turbine durability and the like. Fuel injection temperatures are dependent upon fuel characteristics such as freezing point and volatility characteristics, as well as upon injection nozzle characteristics.

Pulse jet engines are operated with the greatest efficiency when the fuels discussed hereinbefore are supplied to a given engine at fuel-air ratios ranging between 0.01 and 0.08. It is preferred to operate such an engine while maintaining the fuel-air ratio ranging between 0.03 and

0.07. Much difficulty is encountered in attempting to measure the exact amount of air actually supplied to a pulse jet engine because of the fact that up to about 30 per cent by volume of air may enter the combustion zone through the exhaust zone. A given pulse jet engine may be operated in a range of between 30 and 400 cycles per second, depending upon the size of the engine. By the term "cycle," I mean to include fuel-air inlet, combustion, and exhaust. Operation of a pulse jet engine under the above conditions results in a "temperature rise" which may range from about 340° F. to about 4040° F.

The specific fuel constituents which have been tested and which are set forth in Table I above are merely exemplary of the 1-olefin constituents of this invention and are not intended to limit the invention unduly. As will be evident to those skilled in the art, various modifications of the invention can be made or followed by blending 1-olefins with normal paraffins in the light of the foregoing disclosure and discussion without departing from the spirit or scope of the disclosure.

I claim:

1. An improved method for operating a jet engine which comprises injecting into a combustion chamber of a fixed size a fuel consisting essentially of between 5% and 95% by volume 1-olefins boiling between 90° F. and 500° F.; injecting air into the forward portion of said combustion chamber at a mach number between 0.01 and 1.00, at a pressure of between 0.2 and 40 atmospheres, at a temperature between -30° F. and 1040° F., and at a fuel-air ratio between 0.005 and 0.10; burning said fuel in said combustion chamber at a combustion efficiency within the range of from 40% to 100% so as to heat said air and resulting combustion gases; and exhausting said gases through a rearwardly extending exhaust duct at an exit velocity higher than the flying speed of said engine.

2. An improved method for operating a turbo-jet engine which comprises continuously injecting into a combustor chamber of fixed size a fuel consisting essentially of at least 50% by volume of at least one 1-olefin boiling between 90° F. and 500° F., and normal paraffins boiling between 90° F. and 500° F.; injecting air into the forward end portion of said combustor chamber at a velocity mach number between 0.01 and 0.80, at a pressure of between 0.2 and 8 atmospheres, at a temperature between -30° F. and 740° F., and at a fuel-air ratio between 0.005 and 0.040; burning said fuel in said combustor chamber at a combustion efficiency within the range of from 40% to 100% so as to heat said air and resulting combustion gases; and exhausting said gases through a rearwardly extending exhaust duct at an exit velocity higher than the flying speed of said engine.

3. The method of claim 2, wherein said 1-olefin consists of 1-octene; and injecting said fuel into said combustor chamber at a fuel-air ratio between 0.01 and 0.03.

4. The method of claim 2, wherein said 1-olefin consists of 1-nonene; and injecting said fuel into said combustor chamber at a fuel-air ratio between 0.01 and 0.03.

5. The method of claim 2, wherein said 1-olefin consists of 1-decene; and injecting said fuel into said combustor at a fuel-air ratio between 0.01 and 0.03.

6. An improved method for operating a ram jet engine which comprises injecting into a combustion chamber of fixed size a fuel consisting essentially of at least 50% by volume of at least one 1-olefin boiling between 90° F. and 500° F., and normal paraffins boiling between 90° F. and 500° F., at a temperature between -60° F. and 240° F.; injecting air into the forward end portion of said combustion chamber at a mach number between 0.1 and 1.00, at a pressure of between 0.5 and 40 atmospheres, at a temperature between 40° F. and 1040° F., and at a fuel-air ratio between 0.01 and 0.10; burning said fuel in said combustion chamber at a combustion efficiency within the range of from 40% to 100% so as to heat said air and resulting combustion gases; and exhausting said gases through a rearwardly extending ex-

haust duct at an exit velocity higher than the flying speed of said engine.

7. The method of claim 6, wherein said fuel is injected into said combustor chamber at a fuel-air ratio between 0.01 and 0.03.

8. An improved method for operating a jet engine which comprises injecting into a combustion chamber of fixed size a fuel consisting essentially of between 5% and 95% by volume of at least one 1-olefin selected from the group consisting of 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-nonene, 1-decene, 1-undecene, 1-dodecene and 1-tridecene; and between 5% and 95% by volume normal paraffins selected from the group consisting of n-hexane, n-heptane and n-octane; burning said fuel in said combustion chamber under operating conditions in the presence of air so as to heat said air and resulting combustion gases; and exhausting said gases through a rearwardly extending exhaust duct at an exit velocity higher than the flying speed of said engine.

9. In a method of operating a jet engine having a combustion chamber of fixed size wherein fuel is ignited, the improvement which comprises supplying as the fuel for said engine a fuel consisting essentially of between 5 per cent and 95 per cent by volume 1-olefins boiling be-

tween 90° F. and 500° F. and between 5 per cent and 95 percent by volume normal paraffins boiling between 90° F. and 500° F.

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