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(NASA-TM-75395) SOME ASPECTS OF AIRCRAFT JET ENGINE FUELS (National Aeronautics and Space Administration) 11 p HC A02/MF A01 CSCL 21D G3/28
N79-20264
Unclas
17285

Translation of "Niektore zagadnienia paliw do lotniczch silnikow turbinowych," Technika Lotnicza i Astronautyczna, Vol. 33, Sept. 1978, pp. 11-12

NATIONAL AERONAUTICS AND SPACE ADMINISTRATTON
WASHINGTON, D.C. 20546

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Increasing aircraft velocities and consequently the resulting greater heating of fuels stored in fuel tanks of aircraft, required an improvement of existing utilized fuels and the development of new kinds of jet fuels for the purpose of achieving greater thermal stability of these fuels. The Polish petroleum industry is also tooling up for the production of a new fuel with greater thermal stability. /11*

Modern military aircraft, and recently also civil passenger aircraft, have attained velocities which exceed considerably the velocity of sound. It is very likely that the introduction of new types of transport and passenger aircraft for which attainment of flight velocities on the order of 2500 km/hour will be a routine matter is going to be increasingly more commonplace. Probably flight velocities will further increase in the near future. Preliminary work on the design of aircraft which will fly at velocities exceeding 10 to 12 times the velocity of sound is already going on at the present time in the United States of North America.

Increasingly more stringent requirements stemming from missions assigned to modern aircraft compel designers to improve the designs proper and utilize better and more efficient sources of energy which will enable them to meet these requirements.

The operation of a turbojet engine, like that of any other source of propulsion, is determined by a combination of

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* Numbers in the margin indicate pagination in the foreign text.

design characteristics of the engine and the properties of the fuels used for its propulsion.

At the present time, all turbojet engines used both in military and civil aviation, as well as most rocket engines used for space research and military purposes, operate on hydrocarbon fuels of the petroleum type.

Hydrocarbon compounds as components of fuels used for propulsion of turbojet aircraft engines are especially important. Combined with liquid oxygen, they are used in the first stages of space rockets. The composition of the T-1 fuel, known in our country, combined with liquid oxygen is used in Soviet space rockets. The first stage of the Saturn Moon rocket also operated on hydrocarbon fuel. The American Jupiter, Thor or Atlas rockets operate on the same fuel.

The future development of aircraft will not only depend on the increase in the quantity of fuel consumed during a flight (while for the usual subsonic aircraft, fuel consumption is as high as 120 l/min, for large supersonic aircraft, for example the Concord aircraft, it is 240 l/min, and as the velocity increases further, fuel consumption will be as high as 400 l/min), but also on an improvement of its operational characteristics.

Economic aspects involved in operating aircraft will play a substantial part in a search for new ways of obtaining better fuels. At the present time, it is estimated that the cost of fuel represents about 50% of the total cost of operating aircraft. The increase in demand for fuel in the USA in 1975was three times greater than in 1966.

Because of such high consumption and a possible fuel shortage for turbojet aircraft engines, the possibility of lowering requirements applying to fuels had to be taken into consideration. The latter entailed lowering of requirements which could be compensated by suitable design of the engine. However, due to the above mentioned rapid development of supersonic aircraft and the necessity of maintaining high operational efficiency and reliability of the engine, the possibility of such a trade off is limited to a considerable degree.

Thus, the conclusion can be drawn that increased production and improved properties of fuels used for turbojet aircraft engine propulsion will be realized by introducing new, improved and more efficient technologies and processes.

<u>Operating Conditions of Aircraft Turbojet Engine Fuels.</u>

Aerodynamic heating of the entire structure, and hence also of the fuel stored in tanks occurs during the flight of an aircraft at supersonic velocity. The effect of this heating increases with increasing flight velocity and decreasing altitude. Obviously the increase in temperature is not an infinite magnitude, and it lasts only until the instant at which a balance occurs between the quantity of heat brought to the surrounding medium as a result of friction and the quantity of heat removed from the surrounding medium. Investigations have shown that at a flight velocity with Mach number Ma = 4, and altitude H = 6100 m, the equilibrium temperature stabilizes after 90 to 120 seconds at 680° C. Thirty minutes later, at the same velocity, at an altitude H = 36000 m, this temperature is barely 310° c.

This characteristic is especially important for combat aircraft, which currently tend to fly at lower altitudes while approaching target. The latter follows from tactical considerations, since the probability of hitting the aircraft is considerably reduced during flights at great supersonic velocities and low altitudes.

Although a part of the thermal energy from the heated surface of the aircraft is transferred to the surrounding medium, a greater part of this energy is transferred to the structure of the aircraft and to the fuel stored in its tanks. Besides flight velocity and altitude, heating of fuel in tanks also depends on the conductivity and the thermal capacity of materials separating the fuel from external surfaces of the aircraft, the surfaces of the tanks, the endurance, the initial temperature and the physical-thermal properties of the fuel /12
proper. For example, heating of fuel in the tanks of an aircraft flying at velocity Ma = 2.7 will cause an increase in the temperature of the fuel to about 135° C.

Besides aerodynamic heating, the temperature of the fuel also increases as a result of various operations performed in the feed, control and cooling systems of the engine, etc.

For these reasons, in many cases, the heating of fuel determines conditions which are pertinent to the quality and selection of appropriate structural materials.

Changes in Quality of Fuel During Flight of Aircraft at Supersonic Velocities Ma ≈ 3.

When noninsulated wing tanks are used in an aircraft besides the main tanks in the fuselage, during the first flight stage, before the aircraft attains a supersonic cross-country velocity, the engine must be supplied with fuel from these tanks. The point is that these tanks should be empty during the flight stage in which the temperature of dry walls of a tank attains a value on the order of 250 - 270° C, the purpose being to avoid excessive fuel losses due to evaporation and to prevent intense oxidation along with simultaneous formation of spontaneous compounds and a solid phase.

For example, if 10 tons of fuel are stored in wing tanks during takeoff and 0.4 - 0.7% of this fuel is left after the aircraft attains a cross-county flight velocity, assuming that only 1% of this residue undergoes oxidation, 400 - 700 g impurities are left over in the tanks in the form of a solid phase (insoluble sediments and tar) after each flight of this kind.

A certain portion of the solid phase formed as a result of oxidation of the main bulk of the fuel during takeoff and acceleration of the aircraft must be added to this weight.

The essential portion of the fuel is stored in tanks located in the fuselage of the aircraft. Fuel from these tanks begins to be consumed during the initial phase of flight at a cross-country velocity. The temperature of the fuel begins to rise, because before it arrives to combustion chambers, the fuel is generally utilized to receive heat from many exchangers (cooling of cockpit, hydraulic fluids, oil, etc.) and also due to compression in high pressure fuel tanks.

At the time during which the altitude is being lowered, when fuel consumption is reduced, the temperature of the fuel behind the oil cooler increases rapidly to values on the order of magnitude 260 - 280° C, and it remains at this level for a relatively long time during the final stage of the flight.

Toward the end of the flight, there is usually a 5 - 10% fuel reserve left in the aircraft's fuselage tanks whose temperature during landing is 110 - 130° C. Under these conditions, coagulation of fine particles into coarser ones is taking place at a rather fast rate. Before the next flight, the aircraft is refueled with fresh fuel, which while entraining impurities contained in its tanks may give rise to all kinds of defects. Thus, from the standpoint of fuel purity, each successive flight of the aircraft takes place under more difficult conditions.

Under these conditions the reliability of the engine deteriorates from flight to flight. Dirt in filters, lower heat conductivity in heat exchangers due to deposits, or improper operation of control subassemblies resulting from an elimination of clearances in their internal elements by particles of the solid phase which penetrated inside together with the fuel, may cause malfunctioning of the engine at any instant.

Clearly the conditions in which hydrocarbon fuels are used in supersonic aircraft engines and in rockets are different, and therefore these fuels must meet different requirements.

For example the Soviet RD-107 rocket engine with a thrust of 100,000 dynes in the vacuun of space uses hydrocarbon fuel. Basically no fuel heating is observed immediately after the rocket is launched, since the rocket passes throught the dense layers of the atmosphere in less than a few dozen seconds. However, despite the fact that the rocket engine has been operating for 2 - 8 minutes and that additional nitrogen is supplied to fuel tanks, a solid phase and sediments may be formed in the fuel (especially in the cooling system in which the fuel is heated to a temperature of 180 - 220° C before it passes to the combustion chamber).

To sum up the above, it can be stated that a change in conditions under which hydrocarbon fuels used in turbojet and rocket engines operate, related above all to a rise in temperature, resulted in more stringent requirements on the quality of these fuels.

Investigations established that after heating to a temperature exceeding 100° C, type T-1, T-2, T-5 or TS-1 fuels undergo intense oxidation, as a result of which a solid phase (insoluble deposits and tar) is formed very rapidly, which deposits dirt in filtering elements and settles in subassemblies of fuel systems and in tanks. At the present time, this problem is no longer of purely theoretical interest--it is a problem of great practical importance. According to data on combat aircraft of the US Air Force, every third crash which occurred while flying supersonic aircraft was caused by inadequate quality of the used fuel, its low thermal stability and tendency to form insoluble deposits and tars.

Fuels that have been developed for aircraft flying at transonic (subsonic and slightly supersonic) velocities turned out to be completely unsuitable for aircraft flying at great supersonic velocities, mainly because of their thermal stability.

For these reasons, and also on account of the fact that methods for obtaining, transporting and storing fuels over long periods of time and the utilization of many grades of fuels created serious difficulties durring their use, development of fuels that can fully meet the requirements of rapidly developing aircraft propulsion from the standpoint of the structural materials used and also from the standpoint of operational requirements became mandatory.

Future Fuels for Aircraft Turbojet Engines.

Among requirements which must be satisfied by future aviation fuels, two play a key part: high thermal stability, i.e. no formation of deposits during oxidation, and good lubricating properties.

Currently research is being conducted in three different directions whose purpose is to obtain high quality fuel grades. These directions are as follows:

1) elaboration of new technologies for refining distillate used as raw material for secondary processing processes;

2) utilization of hydrocarbon groups which will ensure that high quality fuels are obtained;

3) elaboration of polyfunctional additives which will considerably improve the properties of the fuel in which they are introduced.

Due to economic considerations and lack of necessary industrial installations, the first two directions are being implemented slowly. On the other hand, the third direction is currently undergoing most intensive elaboration.

Considerable attention is being given at the present time to an elaboration of additives which will improve the thermal stability and lubricating properties of fuels. The main requirements which such additives must meet are: very high solubility in fuel at any temperature and complete insolubility in water. Moreover, these additives must not cause a deterioration of other properties of fuels, for example, increase their tendency to form carbon deposits or static electricity. They must be an effective anti-oxidizer which remains active up to a temperature of 250 - 300° C.

The Polish petroleum industry is tooling up for the production of a new fuel. Its production technology has been elaborated on the basis of imported crude oil. A distillate with appropriate physicochemical properties used as a raw material in the production of the fuel is obtained from processing crude oil. The distillate will be refined using a hydrorefining process. A special additive will be added to the hydroraffinate obtained in this manner, which will yield the new product. Compared to fuels used in Poland at the present time, this fuel certainly represents an innovation. However due to fast progress in propulsion and rocket design, it is not the last word in this field.

REFERENCES

1. Rozenovich, Ye. V., Aviatsionnyye topliva, smazki i spetsial'nyye zhidkosti (Aviation fuels, lubricants and special liquids), USSR Ministry of Defense Press, Moscow, 1956.

2. Chertkov, Ye. V. and V. G. Spirkin, Primeneniye reaktivnykh topliv v aviatsii (Use of jet fuels in aviation), Transport Press, Moscow, 1974.

3. Chertkov, Ye. V., K. V. Rybakov and V. N. Zrelov, Zagryazneniya i metody ochistki 'neftyannykh topliv (Impurities in fuels and methods for their removal), Khimiya Press, Moscow, 1970.

4. Zaloga, B. D. et al., Metody otsenki ekspluatatsionnykh svoistv reaktivnykh topliv i smazochnykh materialov (Methods for evaluating operational properties of jet fuels and lubricants), Mashinostroyeniye Press, Moscow, 1966.

5. Papok, K.K., V. A. Piskunov and P. G. Yurenva, Nagary v reaktivnyk dvigatelyakh (Carbon deposits in jet engines), Transport Press, Moscow, 1971.