PART 1 : SECTION 3

CHAPTER 5

FUELS

Introduction

1. A gas-turbine engine can operate with a fairly wide variety of fuels, but because of various practical considerations only petroleum hydrocarbons are used. These are the only fuels available which can be produced in sufficient quantity at the present time. Although hydrocarbon fuels are obtained almost exclusively from petroleum, they are becoming available, to an increasing extent, as by-products of coal processing, or by synthesis from coal.

2. The early gas-turbine engines were developed on kerosene (AVTUR), which was chosen to give a reasonable compromise between the requirements of safety and easy ignition. This fuel has proved satisfactory, but bulk production problems limit the quantity that can be produced ; hence the introduction of a wide-cut fuel (AVTAG). The name " wide-cut " is related to the fact that the fuel is distilled over a wider boiling range of the crude oil than either kerosene or gasoline. Other factors which reduce the types of fuel that can be used are the wide range of temperature and pressure over which combustion must occur and the necessity of keeping the weight and volume of the fuel carried to a minimum.

Calorific Value

3. The calorific value is a measure of the heat potential of a fuel. It is of great importance in the choice of fuel, because the primary purpose of the combustion system is to provide the maximum amount of heat with the minimum expenditure of fuel. The calorific value of liquid fuels is usually expressed as centigrade heat units (c.h.u.) per gallon, AVTUR having a value of about 81,500 c.h.u. per gallon. When considering calorific value, it should be noted that there are two values which can be quoted for every fuel, the gross value and the net value. The gross value includes the latent heat of vaporization, and the net value excludes it. The net value is the quantity generally used. The calorific value of petroleum fuels is related to their specific gravity. With increasing specific gravity (heavier fuels) there is an increase in calorific value per gallon but a reduction in calorific value per lb. Thus, for a given volume of fuel, kerosene gives an increased aircraft range when compared with gasoline, but weighs more. If the limiting factor is the volume of the fuel tank capacity, a high calorific value by volume is the more important.

Ignition Characteristics

4. Since the heat released per unit volume of a combustion chamber is very high, and the length of the combustion zone is limited, the flame zone must necessarily be as close as possible to the burner orifice ; consequently the fuel should have the lowest safe spontaneous ignition temperature and low ignition lag characteristics.

Air/Fuel Ratios

5. The exact proportion of air to fuel required for complete combustion is called the theoretical mixture and is expressed as a weight. There are only small differences in ignition limits for hydrocarbons, the rich limit in fuels of the kerosene range being 5 : 1 air/fuel ratio by weight, and the weak limit about 25 : 1 by weight.

Viscosity and Volatility

6. The viscosity of fuel is important because of its effect on the pattern of the liquid spray from the burner orifice, and because it has an important effect on the starting process. Since the engine should be capable of starting readily under all conditions of service, the atomized spray of fuel must be readily ignitable at low temperatures. Ease of starting also depends on volatility, but in practice the viscosity is found to be the more critical requirement. In general the higher the volatility and the lower the viscosity the more easily is efficient atomization achieved.

Flame Extinction

7. The phenomenon of flame extinction is still not fully understood, but from experiments it appears that the type of fuel used has relatively little importance. The air/fuel ratio is, however, a controlling factor and wide-cut gasoline fuels (AVTAG) are more resistant to extinction than a kerosene fuel (AVTUR).

Flame Temperature

8. Flame temperature does not appear to be directly influenced by the type of fuel, except in a secondary manner as a result of carbon

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formation, or of poor atomization resulting from a localized over-rich mixture. The maximum flame temperature for hydrocarbon fuels is roughly 2,000° C. This temperature occurs at a mixture strength slightly richer than the theoretical, owing to dissociation of the molecular products of combustion which occurs at the theoretical mixture. Dissociation occurs above about 1,400° C. and reduces the energy available for temperature rise.

Flame Speed

9. Inflammable air/fuel ratios each have a characteristic rate of travel for the flame which depends on the temperature, pressure, and the shape of the combustion chamber. Flame speeds of hydrocarbon fuels are very low, and range from 1 to 2 ft./sec. under laminar flow conditions. These low values necessitate the provision of a region of low air velocity within the flame tube, in which a stable flame and continuous burning are ensured.

Vapour Pressure

10. The vapour pressure of a liquid is a measure of its tendency to evaporate. The vapour pressure increases with increasing temperature of the liquid. When the vapour pressure becomes equal to the pressure of the atmosphere acting on the surface of the liquid, the liquid boils. Thus the boiling point of a liquid depends on its vapour pressure, the pressure acting on its surface, and its temperature.

11. The vapour pressure of aviation gasoline (AVGAS) at a temperature of 20° C. is about 4 lb./sq. in. absolute. It follows, therefore, that this fuel boils at 20° C. when the atmospheric pressure falls to 4 lb./sq. in. This occurs at an altitude of about 35,000 feet. If the temperature of the fuel is higher, it boils at a lower altitude. All liquids have a vapour pressure although in some it is extremely small. These small vapour pressures, however, become important at high altitudes.

Reid Vapour Pressure

12. The standard adopted for the measurement of vapour pressure of fuels is the *Reid Vapour Pressure* (R.V.P.). This is the absolute pressure determined in a special apparatus when the liquid is at a temperature of 100° F. The maximum R.V.P. allowed in the specification of AVGAS is 7 lb./sq. in. : this may be called a high vapour pressure fuel. AVTUR has an R.V.P. of 0·1 lb./sq. in. and as such is a low vapour pressure fuel, as are all fuels with an R.V.P. of 2 lb./sq. in. or less.

Fuel Boiling and Loss by Evaporation

13. At high rates of climb, fuel boiling and evaporation is a problem which is not easily overcome. A low rate of climb permits the fuel in the tanks to cool and thus reduce its vapour pressure as the atmospheric pressure falls off. However, the rate of climb of many aircraft is so high that the fuel retains its ground temperature, so that on reaching a certain altitude the fuel begins to boil. In practice this boiling has proved to be so violent that the loss is not confined to vapour alone ; layers of bubbles form and are swept through the tank vent with the vapour stream. This loss is analogous to a saucepan boiling over and is sometimes referred to as *slugging*.

Evaporative Losses

14. The amount of fuel lost from evaporation depends on several factors :—

(*a*) Vapour pressure of the fuel.

(*b*) Fuel temperature on take-off.

(*c*) Rate of climb.

(*d*) Final altitude of the aircraft.

Fuel losses as high as 20% of the tank contents have been recorded through boiling and evaporation.

Methods of Reducing or Eliminating Fuel Losses

15. Possible methods of reducing or eliminating losses by evaporation are :—

(*a*) Reduction of the rate of climb.

(*b*) Ground cooling of the fuel.

(*c*) Flight cooling of the fuel.

(*d*) Recovery of liquid fuel and vapour in flight.

(*e*) Redesign of the fuel tank vent system.

(*f*) Pressurization of the fuel tanks.

(*g*) Using a fuel of low R.V.P.

16. **Reduction of the Rate of Climb.** Reducing the rate of climb imposes an unacceptable restriction on the aircraft and does not solve the problem of evaporative loss. This method is, therefore, not used.

17. **Ground Cooling of the Fuel.** This is not considered a practical solution, but in hot climates every effort should be made to shade refuelling vehicles and the tanks of parked aircraft.

18. **Flight Cooling of the Fuel.** The use of a heat exchanger, through which the fuel is circulated to reduce the temperature sufficiently to prevent boiling, is possible. High rates of climb, however, would not allow enough time to cool the fuel without the aid of heavy or bulky equipment. At high T.A.S. the rise in airframe temperature, due to skin friction, increases the difficulty of using this method. On small high-speed aircraft the weight and bulk of the coolers become prohibitive.

19. **Recovery of Liquid Fuel in Flight.** This method would probably entail bulky equipment and therefore be unacceptable. Another method would be to convey the vapour to the engines and burn it to produce thrust, but the complications of so doing would entail severe problems.

20. **Redesign of the Fuel Tank Vent System.** In this way the loss of liquid fuel could be largely eliminated, but the evaporative losses would remain. However, improved venting systems may well make this method possible.

21. **Pressurization of the Fuel Tanks.** There are two ways in which this can be done :—

(*a*) *Complete Pressurization.* This involves keeping the absolute pressure in the tanks greater than the vapour pressure at the maximum fuel temperature likely to be encountered. This eliminates all loss, but means that with gasoline type fuels a pressure of about 8 lb./sq. in. absolute would have to be maintained at altitude and the tank would be subjected to a pressure of 6½ lb./sq. in. at 50,000 feet. The disadvantage is that this would involve stronger and heavier tanks and strengthened structure to hold the tanks.

(*b*) *Partial Pressurization.* This prevents all liquid loss and reduces the evaporative loss. It involves strengthening the tanks and structure, and the fitting of relief valves.

22. **Use of a Fuel of Low R.V.P.** The production of gasoline is considerably augmented by synthetic processes, but the production of kerosene is limited to that obtained by normal distillation. The disadvantage of kerosene lies chiefly in its limitations at low temperature. At temperatures below −40° C. the waxes in the fuel begin to crystallize and may lead to blockage of filters unless remedial measures such as fuel heating are introduced. Starting difficulties under arctic conditions would also have to be solved. The ability to change to kerosene in hot climates, and gasoline-type fuels in cold climates, would overcome many problems, but the limitations of this scheme are obvious. The ideal is to adopt one fuel that is suitable for universal use ; blended fuels of low R.V.P. prove to be the most suitable, as with them losses are largely eliminated and the poor low-temperature characteristics of kerosene are improved upon.

Aviation Turbine Fuels

23. **AVTUR.** One type of fuel for use in gas-turbine engines is AVTUR. This is a kerosene-type fuel with a boiling range of 150° to 300° C. and a freezing point of −40° C. The American equivalent is J.P.5.

24. **AVTAG.** Another fuel, AVTAG, is a wide-cut gasoline with a wider boiling range and a freezing point of −60° C. AVTAG is similar to, and interchangeable with, the American fuel known as J.P.4, but a slight difference in specification affects the relative storage stabilities, and the two fuels must therefore be stored separately.

25. **AVCAT.** A further type of fuel, AVCAT, which is equivalent to the American J.P.5 but has a higher flash point, is used by the Royal Navy. It is particularly suitable for storage in aircraft carriers.


Instrument panel
from a
Mk4 Jet Provost
(XP558)