11.0 Fuels and Lubricants

11.1 Fuels

Fuels, especially fuels for turbines, have two basic functions: a dense energy source and cooling. The energy density of hydrocarbon fuels combusted with air is unsurpassed. As a cooling fluid, state-of-the-art fuels (such as JP-8) have only limited capacity. Current and next generation turbine engines are exceeding the capacity of the fuel to handle the heat load. This is resulting in coking of the fuel and subsequent clogging of fuel passages and ignitors.

The need to use fuels as cooling agents is illustrated in Figure 11.1. This figure shows the aircraft heat loads with respect to time. As is clear, the fuel cooling requirements will rise dramatically when the F-22 comes into use, but even with today's current best fighters, the cooling requirements are exceeding the capacity of the fuel to provide adequate cooling.

Endothermic fuels are the enabling technology for turbines in the future. An endothermic fuel uses the engines waste heat to create a more energy-dense and better combusting fuel. Endothermic fuels are simply fuels that decompose under a thermal stress to absorb heat (provide a heat sink) and give off hydrogen and an olefin. The engine is cooled by heat absorption caused by a chemical process and more energy is available in the combustion process. Figure 11.2 shows the expected performance of the new endothermic fuels and other fuel advancements with respect to time. We are using JP-8 fuel in USAF aircraft today with a reasonable expectation of JP-8+100 being in use by the year 2000.

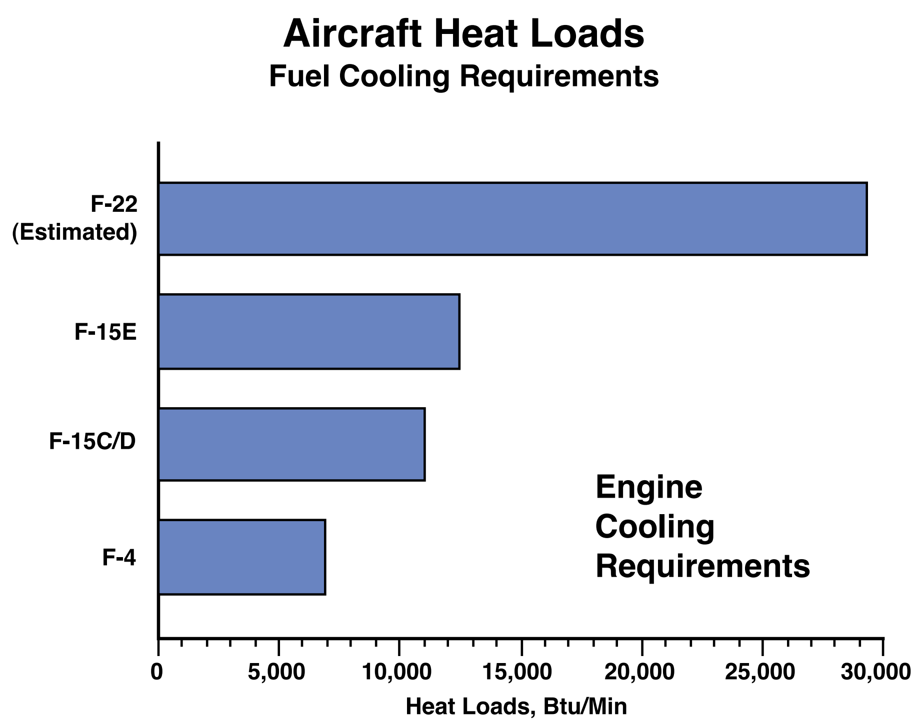

Figure 11.1 Aircraft Heat Loads and Fuel Cooling Requirements

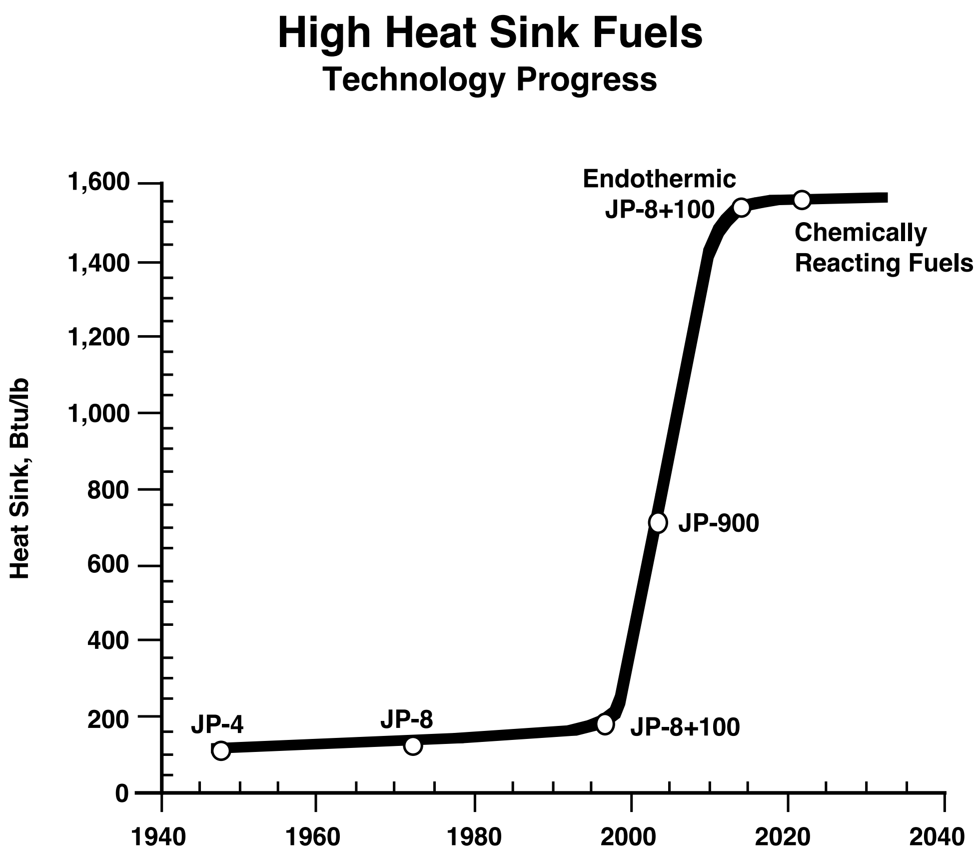

Figure 11.2 High Heat Sink Fuels and Expected Implementation Date

High-payoff items identified as opportunities are:

- Near term: Develop improved thermal stability fuels (achievable 1998-2003) and improved cleaning agents.
- Middle term: Develop endothermic fuels (2005).
- Long term: Develop chemically reacting fuels (2015).

11.2 Recommendations—Fuels

- A well directed program exists on new fuels. Continue the existing program.
- Implement improved thermal stability fuels at a faster rate along with fuel additives to improve engine performance.
- Continue with research on endothermic fuels and move forward the date of implementation into service.

11.3 Fuels—Expanded Descriptions

High Thermal Stability Fuels

The major short-term goal is the improvement in the thermal stability of the fuel. Engine temperatures degrade fuels, causing coking and subsequent engine failure. There is a program at Wright-Patterson AFB to increase the thermal stability of JP-8 by 100ºF (JP-8+100) by 1995. Their next goal is to raise the thermal stability to 575ºF (JP-900) by 2003 with a concomitant increase in the ability of the fuel to act as a heat sink by 500 percent.

Endothermic Fuels

The next stage of the program is to introduce endothermic fuels by 2005. The capability of the fuel to absorb heat should be 10 to 15 times that of JP-900. These fuels will have a higher energy density due to pumping of energy into the hydrocarbon fuel by the waste engine heat. Successful application of endothermic fuels should greatly reduce the cooling needs for advanced turbines and reduce their weight.

Combined Fuel Lubricant (Single Fluid)

An exciting concept is the total elimination of the lubricating fluid in the engines. Replacement of the lubricant would be done by using the fuel as the lubricant. This should pay off by simplifying the logistics, eliminating disposal costs for hazardous lubricant materials, saving weight (approximately 100 pounds per engine) by elimination of the lubricant equipment, and eliminating failures caused by thermal breakdown of the lubricant.

Chemically Reacting Fuels

These are chemical additives for fuel that are used to enhance a desired property.

Hydrogen. The ultimate clean-burning fuel is hydrogen. Investment in the technology is very long term, but has major advantages. The use of hydrogen opens up new possibilities for materials in engine design as the atmosphere is reducing instead of oxidizing as found in a conventional turbine engine. Problems due to hydrogen storage, drag caused by large hydrogen tanks, embrittlement, flammability, and thermal containment need to be addressed.

Hydrazine Elimination. A near-term need is elimination of hydrazine as a propellant for the auxiliary power unit (APU) in F-16 fighters. Hydrazine is toxic and carcinogenic. Its properties make its handling difficult, requiring an extensive logistics chain. There is an effort at Wright-Patterson AFB to find substitutes based on nontoxic ammonium salts, possibly an aqueous system. This effort should be encouraged.

11.4 Lubricants—Summary

Advancements in lubricants and seals, as well as sealants and other nonstructural materials are absolutely critical for the Air Force to meet mission requirements of aircraft and space vehicles of the future. Increasing the thrust to weight ratios of future turbine engines will require the development of efficient lubricants that can withstand these higher temperatures. New lubricants must be developed to reduce the propensity for coking of current engines and when new more efficient engines are fitted to aging aircraft. Turbine engine temperature requirements are exceeding the capacity of state-of-the-art lubricants. Current synthetic polyol esters have an upper temperature limit of 400°F, while perfluoropolyalkylethers, which are under development for future advanced turbine engines, will have upper temperature maximums of 630°F to 700°F. Compatible sealing technology must also be developed hand-in-hand with advanced lubricants. Both liquid and solid lubricant technology developments, including technology for hard coats and wear resistant coatings will be necessary to meet the requirements of both expendable and man-rated engines of the future. Greatly improved liquid and solid lubricants must be developed to increase the lifetimes of spacecraft moving mechanical assemblies, such as control moment gyros and reaction wheels.

Thermal breakdown of lubricants is not currently a major maintenance problem for the USAF. However, future systems may be severely compromised due to lack of adequate lubricants or adequate development of new concepts. High-payoff items are:

- Near term: Increase the thermal stability of polyol ester lubricants to 450°F and increase the stability and capabilities of the perfluoropolyalkylethers and sealing systems to 700°F.
- Middle term: Investigate solid lubricant technology to provide lubrication to 1500°F to 1800°F. Eliminate lubricant completely by use of a single-fluid concept (100 pound weight savings per engine), coupled with endothermic fuel, or use vapor-phase lubricants. Note, however, that the single fluid concept is a very high-risk approach.
- Long term: Use magnetic levitation for motor parts and bearings. Note, however that solid or liquid lubricant may still be required for startup and shutdown.

The elimination of lubricants by use of the single-fluid concept would save approximately 100 pounds per engine. For the F-22 it is estimated that reducing engine weight per engine by one pound. would save 8.7 million gallons of fuel over the aircraft lifetime. The impact is large.

11.5 Recommendations—Lubricants

Both liquid and solid lubricants, wear-resistant coatings, seals, sealants, and other nonstructural materials are absolutely critical for successful Air Force operations in the future. Future systems may be severely compromised by a lack of adequate lubricants and seals or development of alternative concepts. To avoid this:

- Fund research on higher thermal stability in lubricants and seals.
- Encourage further exploration of a single-fluid concept for the elimination of lubricants.
- Continue current program on magnetic levitation and initiate effort to develop compatible solid lubricants.

11.6 Lubricants—Expanded Description

Lubricants

Thermal and oxidative stabilities and interactions with bearing/system materials are the issues. Innovative approaches are needed to achieve adequate materials for current and future aircraft engine designs and for spacecraft lubrication. Solid lubricants and wear-resistant coatings have the potential for replacement of liquids especially in expendable engines and for use in conjunction with magnetic levitation.

Magnetic Materials

The long term solution to many lubrication problems may be the use of magnetic bearings with solid lubrication. This is a long-term area for investment. The questions of weight and type of magnet (permanent or soft) need to be addressed.