GAS TURBINE ENGINE PICTURE

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ABSTRACT

The gas turbine engine continues as a major source of propulsion effort for advanced systems being programmed into the Air Force inventory. Successful operation of these engines will be dependent on several critical improvements in high-temperature operating materials, one such limiting material is the lubricant. In addition, future lubricants will be expected to serve as hydraulic fluid for engine systems. Therefore a major decrease in the rate of internal contaminant generation must also be programmed.

In the consideration of the engine propulsion picture, it will be helpful to establish categories of engines of generally similar requirements. These groups would then face common problems and demand common solutions. Two such categories which can be established on the basis of missions performed are:

(1) Engines for systems operating on the boundaries of the vehicle capabilities.

(2) Engines for systems conducting the current routine missions of the Air Force.

The primary mission of the first category is the exploration of operational flight conditions and the test of first design effectiveness for new aircraft systems. These in general will require fundamental engine technology to be stretched and broadened, and in some instances completely reprogrammed, to achieve the advanced performance established by mission requirements. Current lubrication technology most nearly fits into the latter classification.

Over the span of the past several years, the turbine engine, as a source of propulsive effort, has been scissored by the competitive capability of alternate propulsive systems which do not completely enclose their maximum cycle temperature, and the inherent lag in development of high-temperature operating materials. This is peculiarly true of category I type vehicles. As a result, the competitive position once held by the turbine engine is deteriorating.

From a position of nearly all new development systems being programmed with turbine propulsion nearly a decade ago, current plans envision turbine propulsion for roughly 50% of the projected systems (Fig. 1). The solid line shows what has happened, while the dotted continuation is the projected picture. Casual observation of this trend establishes the conclusion that this engine era is phasing out. However, a close scrutiny of the general operating characteristics of this type engine establishes the fact that future air vehicles would be more versatile, economical, and reliable if the basic capabilities of the turbine engine were to be utilized to the limits of its operating envelope. For example, regardless of final altitude and Mach No., every air vehicle must take off and accelerate to final mission conditions. Consider a particular point in a flight map, say Mach 3 and 60,000 ft altitude. To this point, specific impulse of an air breathing propulsion system is 8-10 times higher than a rocket engine. If the fuel consumption is integrated along an optimum path to the assumed point for rocket and turbine propelled vehicles, the total consumption of the turbine engine is less than 1/4 that of the rocket. If the flexibility of flight path is added to the rocket boost requirements, no comparison is practical.

If the cost per pound of the stores is further considered, the difference in economics between the the two types of engines diverges even more rapidly since the cost of high impulse rocket fuel is generally higher than JP type fuels. Since these engines represent the only practical self-accelerating types for the area of flight speeds considered, the economic importance of the high Mach turbine engine is evident.

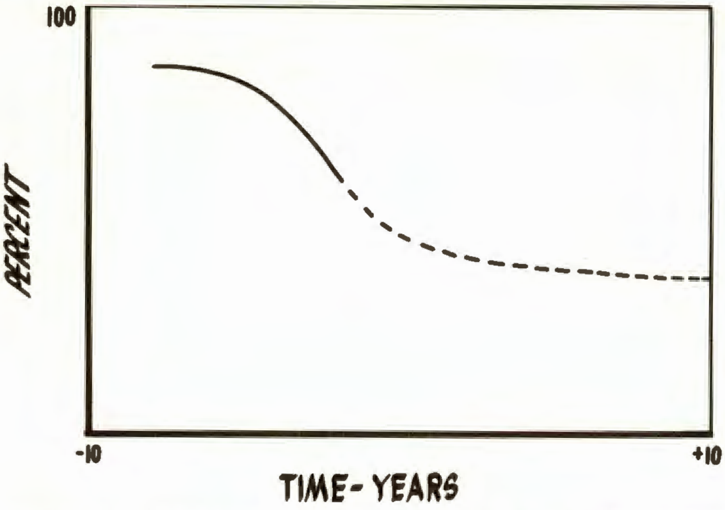

FIGURE 1. PERCENT OF NEW VEHICLE PROPULSION PLANNED FOR TURBINE ENGINES

The limits of operation of a turbine engine can be arbitrarily assigned as:

(1) The point of the operating map at which the pressure ratio of the gas generator (i.e., the compressor pressure ratio divided by the turbine pressure ratio, taking into consideration combustor pressure losses) is equal to or less than one.

(2) The point at which failure rates of engine components jeopardize the capability of the vehicle to operate safely.

Both of the above limits can be expressed as a unique function of temperature with a given design philosophy. Applying these rules to the turbine engine and assuming a continuing trend in technological progress, the temperatures associated with future flight patterns is projected.

Several temperature levels must be recognized. The most significant level is that of the air temperature entering the engine (Fig. 2). This temperature establishes the level to be expected at all other stations within the turbine engine, as well as the external ambient temperatures which occur outside the forward part of the engine. This is also the lowest untreated air temperature for any desired pressurization and/or cooling. As is shown, a 200-300% increase in these temperatures can be expected in the next decade. Levels in excess of 1500°F will be used in planning systems by the end of this period.

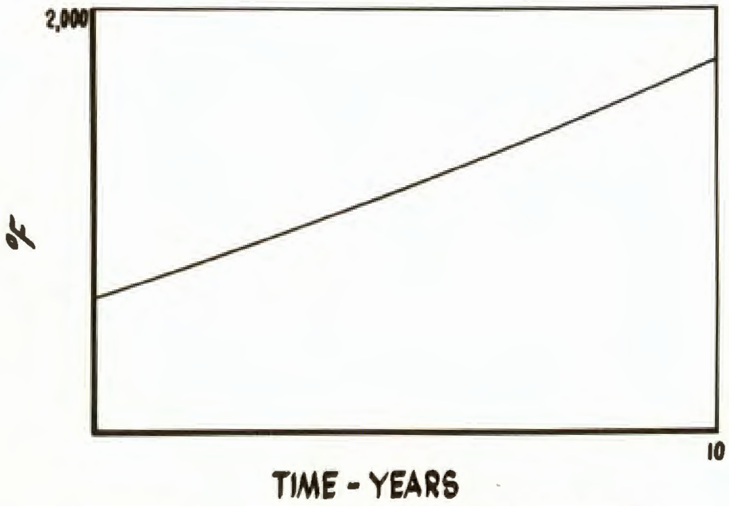

FIGURE 2. MAXIMUM COMPRESSOR INLET AIR TEMPERATURE PREDICTION

Consideration must further be given to the temperature rise which occurs as the incoming air flows rearward over the external heated surfaces of the engine (Fig. 3). Air temperatures at the rear of the engine compartment will range from 200-500°F higher than at the forward end at the present time. At the end of the period,the temperature difference will range from 100-300°F. All ranges are dependent on air quantities directed around the engine installation.

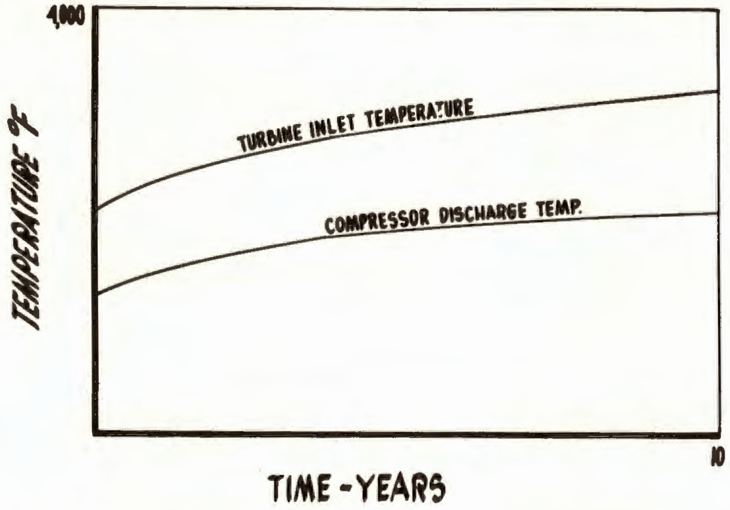

FIGURE 3. PROGRAMMED MAXIMUM INTERNAL TEMPERATURE OF TURBINE ENGINES

The next level of temperature to consider occurs in the compressor discharge area. Increases in this area of 200% are being considered. Values less than 2000°F appear to be the maximum level necessary to perform the missions planned or under study. Middle bearing sump areas will be exposed to temperatures at these approximate levels. No air cooling of shafts or bearing housing are planned.

The highest temperature levels which impinge on rotating machinery are those found at the turbine inlet. Levels approaching 3000°F are now being considered. While the influence of this temperature may not be a direct factor in the requirements of a lubricant, the temperature of the turbine wheels and shafts, which dictate lubricant requirements, are influenced by this level. Turbine metal will normally run higher than compressor discharge air temperatures.

A second series of engines operating in the low to intermediate flight speeds will be required. Engines in this category will support systems such as vertical take-off aircraft, long endurance aircraft, the logistic carriers, and other more general purpose aircraft.

While the area of operations may appear quite simple from a temperature viewpoint when compared to the previous discussion, several major discrepancies in operational experience announce the presence of continuing problems within the spectrum of today's apparently demonstrated limits. Close scrutiny of the range of operation of the sustainer or work horse part of the Air Force is indicated.

Considering again the engine stations at which bearings and therefore lubrication are required, the temperature ranges are noted.

Compressor inlet air temperatures will range from the nominal cold-day operation to the 500°F area. Mid-bearing temperatures will maximize at the 1000°F level. These limits represent little novelty to those familiar with current engine requirments. However, to achieve the thermal efficiency levels required by mission standards of this group of systems, a continuing increase in turbine gas temperatures must be programmed. In the turbine area, then, the level to be expected is only 200-300°F less than that established for the previous engine category.

To complete the picture, a second parameter, the time at the various temperature levels, should be added. The maximum temperature level occurring in the lubrication system will depend on the time necessary for a given system to reach thermal equilibrium and the time the maximum ambient temperatures are flown in a given mission. Accordingly, operation may be classified as to steady-state or transitory mission. The operations proposed in category I vehicles beyond the 600-700°F inlet air temperature are point-mission operations. That is, the vehicle will be programmed to its maximum operating capability with holding times at these conditions being limited to minutes. This mode of operation may be terminated in either of two ways. The temperature levels may be relaxed by the vehicle engines losing speed or the turbine engine cutting off from further operation, with the vehicle continuing to accelerate. In the latter case the bearing and lubrication system may be called upon to protect itself from both temperature extremes (i.e., hot and cold).

The more routine missions of the second category of vehicles can be classed as steady-state operations. Starting at the high-temperature level, operation is programmed to 4 hours and relaxing to compressor air inlet temperatures of about 0°F where operation may continue for a matter of days.

The required increases in efficiency and temperature level have posed a major problem to the designer of turbine engines. Thes problems arise from the necessity to vary the geometry of the several major components of these engines to expand the efficient operating range of the individual components. Methods currently under study include compressors with adjustable pressure ratio and pumping characteristics, constant-speed turbines with variable power extraction factors, and the familiar variable exhaust nozzle area sections.

All these devices envisage motion of material through a high level force field. For example, the closure of a variable nozzle against the pressure of the issuing exhaust can require a force of 30,000-40,000 pounds. Review of various force transmission methods shows the high pressure hydraulic system to be by far the most efficient from the viewpoint of weight, reliability and performance. It is further apparent that a major simplification of external engine configuration and operating efficiency can be achieved if the lubricating fluid can double as the hydraulic fluid.

In general, the properties and requirements are common to both systems with the possible difference that the hydraulic system has a higher susceptibility to failure due to contaminant particle density and size. This susceptibility then emphasizes one further consideration for future lubricants. In all lubrication and hydraulic systems, localized areas occur in which the fluid is subjected to very severe operating temperatures. Generally, lubricants today break down and form residues which contaminate the system and lead to early failure. Therefore, the lubricant of the future system must be evaluated for contaminant generation and/or breakdown into insoluble particles.

It is generally possible to design around a high temperature operating ambient with a low temperature-limited lubricating fluid. Methods include isolating the lubricant carrying elements such as gear boxes and lines, or using large flow rates to minimize the temperature rise per unit volume of the lubricant. Both methods severely complicate the engine configuration due to increased size of lubrication equipment, the addition of insulating material, and the introduction of large lubricant-to-fuel heat exchangers. In addition, if the fuel is unable to carry the heat load of the lubricant, as is the case during extreme altitude operation or aircraft letdown conditions, separate heat sink facilities must be added.

In any case, the problems posed for solution by the use of a temperature-limited lubricant are exponential functions of the difference in temperature between the lubricant and the ambient. Therefore even small improvements in lubricant temperature can effect a major improvement in system performance and simplicity.

In summarizing, it can be concluded that:

(1) Turbine engines can and will have a major role in the propulsion plans of the future.

(2) An urgent need exists for the development of high-temperature operating materials and in particular lubricating materials.

(3) The rate of progress in the development of higher temperature lubricants must be expedited to keep pace with expanding demands on propulsion systems.

With your continued interest and participation, I am quite certain that the problems associated with the operation of the turbine engine at the conditions required by the air vehicles of the future can be solved.