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Flat Rating Concept Introduced in the GTX Engine

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Abstract. An attempt has been made to explain the flat rating concept introduced in the GTX engine being developed at GTRE. The contemporary high pressure ratio engines lose thrust rapidly with increase in compressor inlet total temperature (T_1). This loss of thrust with increase in T_1 becomes significant in the case of bypass engine, with thrust drop increasing with increase in bypass ratio. The concept of variable cycle achieved by varying the maximum cycle temperature in order to increase the available dry thrust is explained. In recent days this concept of variable cycle has been recognised in the design of engines for combat aircraft with particular reference to supersonic cruise at altitude. An attempt has also been made to explain the control law in order to achieve the flat rating.

1 Introduction

One of the principal requirements of military aircraft of the 1990's, which will operate with high performance, energy efficient engines, is to have superior engine performance over a wide range of flight conditions. In any aircraft gas turbine engine, it is the flight conditions that have a predominant effect on its performance.

It is well-known that the pressure and temperature vary considerably with altitude and ambient condition. This affects the temperature and pressure of the air entering the compressor of the gas turbine engine. Thus, it would not be possible to design any engine for optimum performance at all flight conditions, since a conventional engine with a fixed design point will give optimum performance at that point only and not for the entire flight spectrum.

2. Design Considerations

Hitherto, the practice has been to design the engine for optimum performance at a particular operating condition viz., sea level static at international standard atmosphere (ISA), and to select the engine parameters based on this operating condition. Thus the ISA sea level static (SLS) condition was the design point which corresponded to a compressor inlet total temperature T_1 of 288°K and inlet total pressure P_1 of 1013 millibar (14.7 psia). Consider now the increase of T_1 and P_1 due to varying flight/ambient conditions as mentioned above. An increase in P_1 is generally advantageous to engine performance, whereas an increase in T_1 causes a deterioration in performance. The correspondence of the design value of T_1 of 288°K to different conditions of the flight spectrum is shown in Fig. 1. This design value of inlet tem-

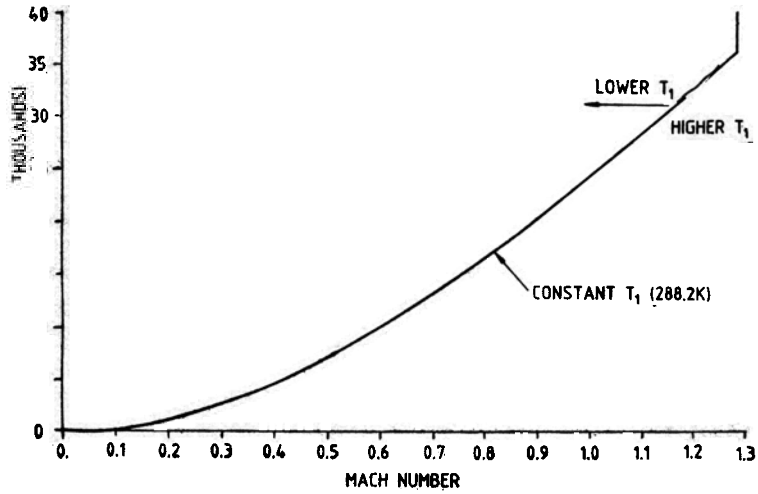

Figure 1. Mach number *vs* altitude at (ISA SLS Temp) $T_1 = 288.2K$.

perature is fairly well matched to the transonic Mach, numbers at high altitudes of flight and to the low subsonic Mach numbers at low altitudes of flight, and with the value of T_1 around 288°K, the compressor operating point is maintained about the same as that at ISA SLS condition (Fig. 2). For compressor inlet temperatures

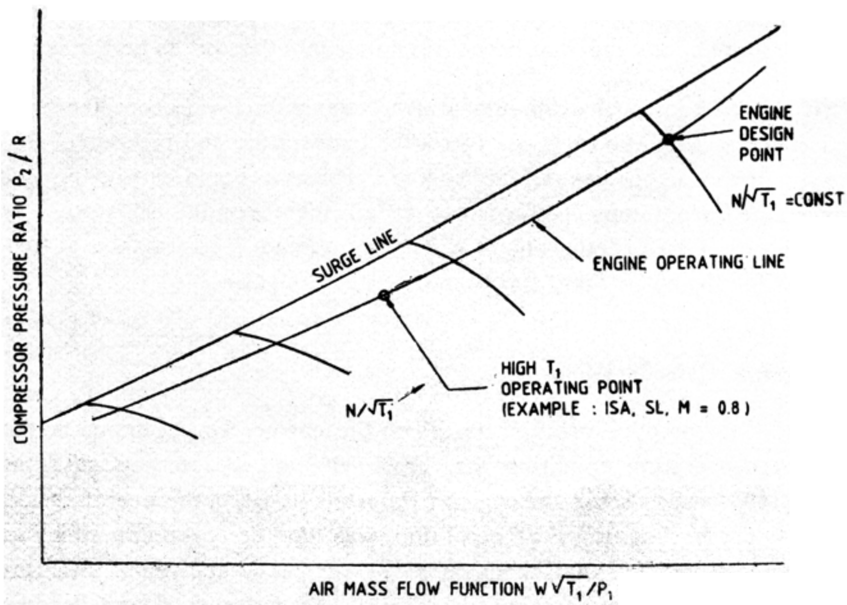

Figure 2. Compressor characteristics.

T_1 lower than 288°K, the compressor performance would be better than that at ISA SLS. But when compressor inlet temperature T_1 is higher than 288°K, the compressor operating point would move away on the operating line from the design point. As a result, the air mass flow parameter $W\sqrt{T_1}/P_1$ and the pressure ratio P_2/P_1 would be inferior to the corresponding design point values. The engine performance would thus be inferior to the design intent. It has been recognized that this fact has to be counteracted for high supersonic cruise at high altitude and for high subsonic operation at low altitude (both cases corresponding to high values of T_1). As a matter of fact, the contemporary high pressure ratio engines lose thrust, often rapidly. Under these conditions, this loss of thrust with increase in T_1 becomes significant in the case of bypass engines, with thrust drop increasing with increase in bypass ratio.

3. Concept

Now, if the engine cycle could be varied so that the engine operates in most of the flight spectrum nearer the design point, then significant improvement in engine performance could be expected. A variable cycle engine would be an ideal solution for this problem. The thermodynamic cycle of the engine can be changed either by providing variable bypass ratios and/or by energy inputs in the different flow passages of the engine. The thermodynamic cycle of the engine is primarily dependent on the maximum cycle temperature and compressor pressure ratio as well as on component efficiencies, mechanical losses, etc. In conventional engines that have to operate at off-design conditions, it has been the practice to maintain the maximum cycle temperature constant i.e. turbine entry temperature is constant at the design value. Consider now the case of high inlet temperature T_1 discussed above. At constant maximum turbine entry conditions (under high T_1) the corrected engine speed $N/\sqrt{T_1}$ falls with corresponding drop in $W\sqrt{T_1}/P_1$. It would, therefore, appear that there is a scope for restoring the cycle to operate at the design point, thereby recovering the thrust drop.

A comparatively simple and direct approach to the problem could be achieved by increasing maximum cycle temperature at the design (high T_1) condition[1]. This increase in maximum cycle temperature under high T_1 condition is accompanied by increase in mechanical RPM to maintain the corrected RPM thereby keeping air mass flow parameter and pressure ratio same as that at ISA SLS condition. In other words, the compressor is made to operate such that the operating point under high T_1 conditions is the same as that at ISA SLS condition; the operating point is aero-thermodynamically retained[2]. It is interesting to note that this concept of variable cycle achieved by varying the maximum cycle temperature has been recognised in recent days for the design of engines for combat aircraft with particular reference to supersonic cruise at altitude[3]. The ratio of the maximum cycle temperature to that at ISA SLS has been referred to as 'throttle ratio' in recent literature. By employing the concept of high throttle ratio design, one can compensate the significant thrust drop associated with high pressure ratio engines under high T_1 conditions. This results in a 'flat rated engine'. The above concept can be applied both for high pressure ratio straight jet engines and to a limited extent to bypass engines.

In a conventional engine, with increase in T_1 under maximum engine operating conditions, the maximum cycle temperature will be essentially constant. Hence as T_1 increases, for fixed maximum cycle temperature, the heat energy added will be less, whereas in the case of an engine employing high throttle ratio design, the maximum cycle temperature increases with increase in T_1 thus tending to maintain the input of energy.

4. GTX Engine Design

The GTX engine was conceived from the basic observation that if the overall pressure ratio can be retained and simultaneously the turbine entry temperature (maximum cycle temperature) is increased above the design point value, then with increase of T_1, the available dry thrust can be significantly increased within the allowable aerothermodynamic limits of the components of the gas turbine engine. Thus GTX 37-14U is a flat rated engine design based on an early and simplified approach to the variable cycle engine high throttle ratio concept with particular reference to the Indian operating requirements of good dry combat performance at low level, high speed and high ambient condition. The engine is a twin spool turbojet with a high compressor pressure ratio having a throttle ratio of 1.13. The performance of this engine and a conventional engine of throttle ratio of unity are compared in Figs 3 to 6. These figures show that both the corrected air flow and pressure ratio with forward speed are well below the design values and there is scope to make use of this underused capacity. The simplest way would be to open the throttle and thereby increase the thrust. The throttle can be opened till the corrected air flow and compressor pressure ratio are

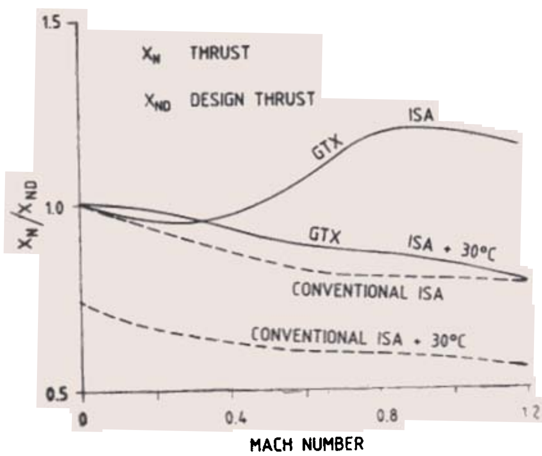

Figure 3. Estimated engine performance—sea level, max dry.

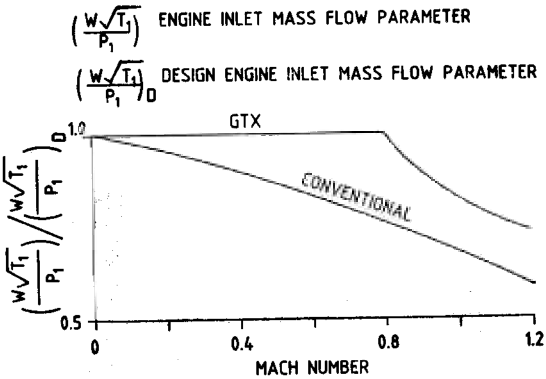

Figure 4. Estimated engine performance—ISA sea level, max dry.

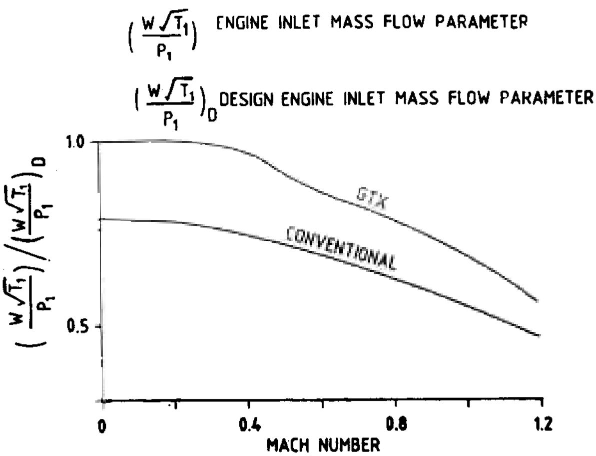

Figure 5. Estimated engine performance—ISA + 30°C sea level, max dry.

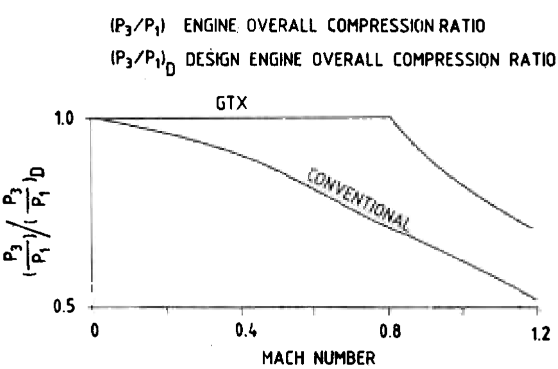

Figure 6. Estimated engine performance—ISA sea level, max dry.

restored to the design values. This then is the background of the GTX concept. The effect of throttle ratio higher than unity as in the case of the GTX engine is clearly seen from Fig. 7. Selection of throttle ratio is limited by the maximum cycle temperature which the turbine technology can permit. In the case of the GTX engine, the maximum cycle temperature is limited at present to 1450°K so as not to exceed the material limits of the turbine blades. However, if this limit could be increased then the flat rating characteristics could be more beneficial at the maximum T_1 con-

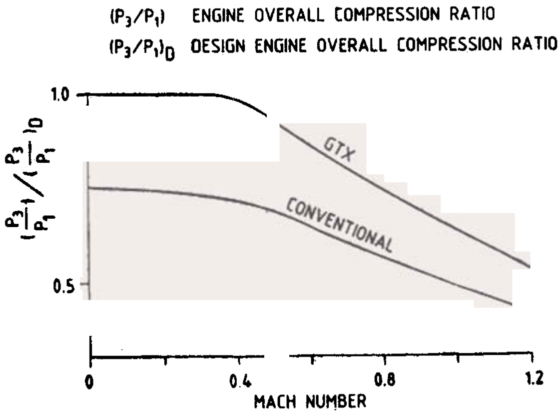

Figure 7. Estimated engine performance—ISA + 30°C sea level, max dr:

ditions. One of the means of increasing the maximum cycle temperature limit is to provide better cooling in the turbine blades and maintain safe blade metal temperatures. Present day methods employ impingement cooling combined with convective cooling and some transpiration cooling. The other methods are to improve the microstructure of the blade material by using methods such as directional solidification and single crystal. Comparison of thrust with Mach number variation in sea level flight of the GTX with two existing engines is shown in Fig. 8.

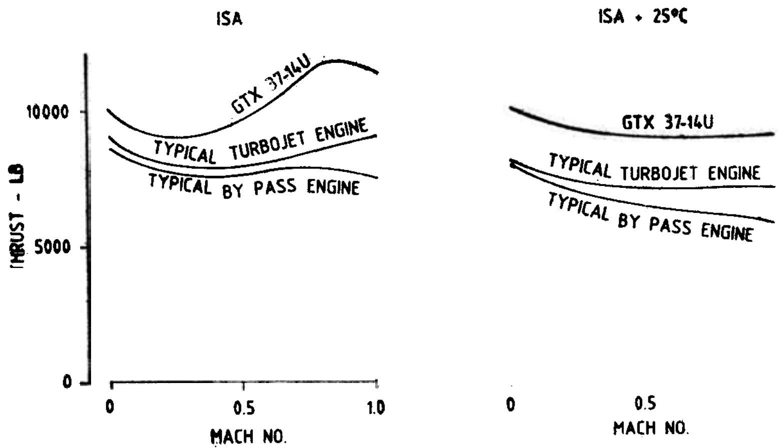

Figure 8. Comparative engine performance—sea level, max dry rating.

5. Control Law

The flat rating of the GTX 37-14U engine is achieved through requisite features built into the fuel control and variable nozzle control systems. The nozzle control law is shown in Fig. 9. The fuel control system in corporates three limiters namely overall pressure ratio limiter, turbine entry temperature limiter and mechanical RPM limiter. For any maximum rating operation under any flight condition, the throttle will be moved to the maximum dry or non reheat position. Depending upon the values of

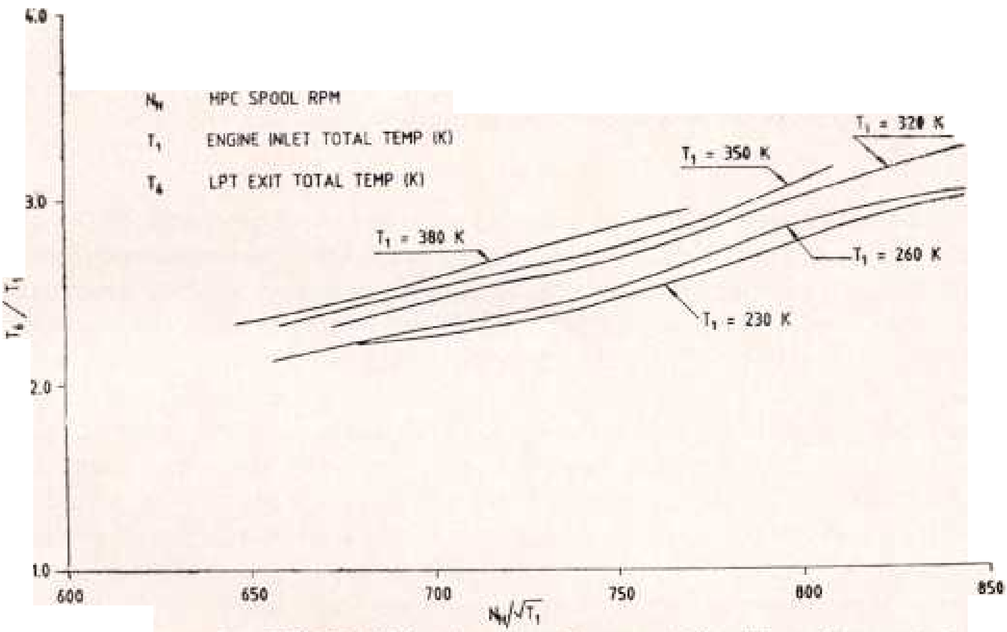

Figure 9. GTX 37—14 U estimated performance, LP turbine exit temperature.

overall pressure ratio, turbine entry temperature and mechanical RPM, keeping in view the limiter values, the maximum RPM corresponding to maximum dry throttle opening will be governed and the engine is expected to give the flat rated performance. Corresponding to any maximum dry or maximum reheat operation the engine JPT will get modified according to the nozzle control law for any given N_H and T_1.

The above functions can be controlled to a greater degree to ensure optimum engine performance at any point by introduction of a full authority digital electronic control system. This would perform the control functions more precisely, in shorter time and with a greater degree of reliability.

6. Concluding Remarks

The concept of variable cycle by varying the maximum cycle temperature in order to increase the dry thrust has been recognised. By employing this concept it would be possible to aerothermodynamically retain the engine contemporary point under high T_1 conditions, same as that at ISA SLS condition. Further the throttle ratio is a function of maximum cycle temperature and better the turbine technology, greater would be the degree of flat rating.

References

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