EFFECT OF FUEL SYSTEM SNAGS ON THE PERFORMANCE OF A MILITARY TURBOJET ENGINE

R.K. Mishra; K.S. Jayasimha and S.N. Mistry
Regional Center for Military Airworthiness (RCMA) (Engines)
Center for Military Airworthiness and Certification (CEMILAC)
Bangalore-560 093, India
Email : rkmishra_gtre@yahoo.com

Abstract
Various snags in the fuel system of a military turbojet engine are analyzed and the effect on the engine performance is studied. Causes of the defects and remedial measures suggested to address such snags are also highlighted in this paper.

Introduction
Turbojet engines have been used widely for trainer and lightweight fighter-bomber applications. They generally operate at extreme conditions and often unscheduled missions during training and combat modes. Rapid throttle excursions and 'g' load variations during different maneuvers cause high cyclic stresses on engine components and unusual demands on engine accessories [1]. As a result, engines and their systems develop snags forcing for premature withdrawal from service affecting the fleet management. Apart from the snags reported from the major modules, the snags of systems and sub-systems also pose serious concerns affecting the performance of the engine. Therefore investigating the snags/defects to analyse their root cause and taking remedial measure are essentially required for maintaining the airworthiness of these systems. This paper presents various snags of the fuel system of a turbojet engine and analyses their effects on the overall performance of the engine. Nature of various defects encountered in the engine due to fuel system snags, cause of the defect and remedial measures suggested to avoid such snags are also highlighted.

Engine Configuration
The schematic layout of the turbojet engine under consideration is shown in Fig.1. It is a straight flow single spool turbojet engine of 20 kN thrust class. The compressor module comprises of multi stage axial compressor made of high alloy steel blades and vanes with aluminum alloy disc. It is driven by a single stage turbine which is made of a nickel base alloy. It has a can-annular type combustion system incorporating duplex atomizers. The main rotating assembly comprises a single unit in which the compressor rotor is coupled by a rigid shaft to turbine wheel. The rotor system is mounted on two ball type bearings. The major accessories of the engine are starting system, ignition system, fuel system, lubrication system and secondary air system for seal pressurization, generator cooling etc. which are mounted on the accessory drive driven by the engine main shaft.

Operating Principle of the Fuel System
To analyse snags pertaining to the fuel system and to arrive at the reason of snags, it is necessary to understand the operating principle of the fuel system.

The system comprises of a fuel pump with a low pressure filter and a combined control unit (CCU). The CCU incorporates a manually controlled combined throttle valve and a shut-off cock, an idling by-pass valve, a flow distributor and a barometric pressure control. The other components in the fuel circuit are air-fuel ratio control unit (AFRCU) incorporating a pressure ratio switch, a Jet pipe temperature limiter (JPTL), fuel burners and associated pipe lines as schematically shown in Fig.2.

The fuel pump is mounted on the accessory drive of the air intake casing. It is a positive displacement, variable stroke, multi plunger type and delivers fuel to the burners via the throttle valve and shut-off cock and flow distributor to the CCU.

The throttle valve comprises a fluted spindle in a sleeve that incorporates rows of staggered ports. Opening move-
ment of the pilot’s throttle lever rotates the spindle to uncover a progressively increasing number of ports and vice versa. It is the only manually controlled portion of the fuel system and is linked to the pilot’s throttle lever. All other controlling devices operate automatically to modify the fuel flow requirements of the engine under any given conditions.

On starting the engine, the pump plunger moves to its full stroke and the fuel pump rotor revolves. The fuel at the increasing pressure is conveyed to the throttle valve and shut-off cock of the combined control unit. For starting purposes, the pilot’s throttle lever is set to the idling position thereby opening the shut-off cock and the throttle valve. At the low fuel pressure prevailing at the beginning of the starting cycle, all the fuel is delivered to the primary line of the burners, closing the dump valve en-route.

As the fuel flow increases, the primary burner pressure increases. This causes the distributor plunger to open thereby allowing fuel to flow to the main line of the burners. When the throttle valve is opened, the flow to the burners increases until the engine rpm reach the desired maximum at full throttle. The pump governor then operates to adjust the pump plunger stroke to control the fuel flow which ensures that the maximum rpm is not exceeded. The various automatic controls cause the fuel pump servo piston to increase or decrease the pump delivery and so make the desired correction for variations in operating conditions.

In the CCU, fuel leaving the throttle valve enters the spring chamber of the flow distributor plunger and closes the dump valve. The primary system supply flows past the enclosed dump valve and through a single outlet on the CCU to the primary manifold which supplies fuel to all burners. The flow distributor plunger operates in a sleeve incorporating a number of metering slots connected by interconnected radial ducts to the main supply connections to the burner. When the pressure in the plunger spring chamber increases sufficiently to overcome the spring-loading, it moves the distributor plunger to uncover a progressively larger area of the metering slots. When full operating flow is available from the throttle valve, the plunger is in the fully open position.

At fixed throttle settings, the barometric pressure control in CCU regulates the fuel flow to compensate for the changes in aircraft speed and altitude. The AFRCU controls the rate of fuel flow increase when accelerating, thereby preventing the engine surge and excessive jet pipe temperatures which would result from over fuelling. To prevent excessive jet pipe temperature, JPTL device is fitted in the jet pipe and gives a pneumatic signal to override the barometric pressure control and so reduce the fuel flow until the jet pipe temperature is again within the permitted maximum.

**Engine Performance Parameters**

Thrust and rate of acceleration are the most important engine performance parameters of a military turbojet engine. They can be expressed in terms of measurable parameters such as rpm, JPT and slam time. The engine cycle parameters such as pressure, temperature, air flow rate and fuel flow rate are directly linked and are proportional to the engine rpm. Any fluctuation in rpm or rpm not attaining the required level will affect the thrust and will not be able to meet the mission requirements. Similarly, in the absence of turbine entry temperature measurements in a service engine, the JPT is a health monitoring parameter. JPT within the specified limit ensures a safe life of the engine hot end components. The reported snags in these parameters during ground run or at flight over a period of five years are presented in the following sections.

**Engine RPM**

The commonly reported snags related to engine RPM are as follows;

- Idle RPM inconsistent
- RPM stuck at 26-27%
- RPM fluctuation
- RPM not exceeding 60% during ground run
- RPM drops or varies when throttle is at constant setting
- No response of RPM to throttle movement
- Max RPM not reaching 100% at ground or at an altitude or exceeds the limit

**Jet Pipe Temperature**

The snags related to jet pipe temperature (JPT) are their high values exceeding the permissible limit during ground test or in flight or during a slam operation. Operation beyond the specified temperature for the specified time can lead to erosion of hot end components and deterioration of engine performance [1,2]. On the other hand, operation at JPT below the stipulated minimum tempera-
ture at take-off or at certain maneuvers may provide lower thrust than the demand for the mission.

Engine Slam

Engine slam is defined as the acceleration of the engine from ground idle or flight idle condition to the max rpm within a specified time. It is the engine’s response to the throttle movement and the fuel system should be compatible to cater this rate of fuel flow requirements of the engine [3]. The slam time greatly depends on the configuration of the engine and architecture of the fuel system. It is generally defined as a function of ambient temperature based on a standard day atmosphere. The major snags reported during slam acceleration are rpm fluctuation and response time beyond the acceptable limit at ground or at any altitude.

Defect Analysis

Snags related to fuel system affecting the engine performances as mentioned in the previous section have been investigated to find the root cause of the problem so that remedial measures can be taken to prevent such occurrences in future. It may be noted that all the systems and accessories are thoroughly checked, calibrated and are tested for performance as per the maintenance and overhaul manual. Units free from leakages and meeting the acceptance criteria are allowed for fitment in the engine. The engine is then subjected to the Acceptance Test Procedure (ATP) monitoring the system behaviour and engine critical parameters. On successful completion of ATP, engine is cleared for fitment in the aircraft. The snags presented in this paper are developed over a period due to service exploitation. The role of major components in the fuel system is studied and cause of the defect has been highlighted. In addition, there are cases of oil leak from gland drain of fuel pump. This drain is meant for relieving excess fuel only. Fuel leak is also observed from fuel pump bleeding point which is a serious safety concern. Cases of failure to start the engine at ground due to malfunction in fuel system have also been noticed.

The snags of RPM exceeding beyond 100% on ground or in air and RPM fluctuation along with JPT fluctuation are analyzed with rig testing of fuel system accessories. Servo filter and amplifier valve in the fuel pump are found blocked causing the above problem. Unlike in the oil system where low oil pressure is detected by electronic sensors, there is no such provision in fuel circuit in this engine for detecting any blockage. The max RPM of the engine outside the allowable band of 100 ± 0.5 % at full throttle during flight at different altitudes is found attributed to disturbed setting of altitude calibration of CCU. Similarly, during ground run, with throttle fully open, RPM not exceeding 75% or 82% as in some cases are also found due to improper altitude calibration/settings and flow distribution calibration in CCU. Though the calibration of accessories are carried out as per well laid procedures in the presence of certification authorities, sometimes the setting is found to get disturbed due to operational environments. RPM getting stuck at some intermediate stage, i.e., at 83% or 85%, and max RPM not attaining 100% at take-off were also found due to snags in JPTL. This can result due to shifting of reference temperature datum in the JPTL. The cause for shift in reference temperature is due to malfunction of spring and their squared-ness and surface finish going out of limit resulting in improper valve operation. The crystal rod sensor in JPTL can attribute to the said snag which was established by testing. These types of snags are very rare and generally occur towards the end of service period when the systems are due for overhaul. Gradual deterioration of system performance with respect to service hour is under study for the complete population to re-establish the life of various accessories in the fuel system and is beyond the scope of the present paper.

The inconsistence in idle RPM and even high idle RPM is found as the outcome of improper settings in CCU and AFRCU. Whenever there is a replacement of any accessories in fuel system at operational unit, it needs to be tuned to match the engine requirement. In the absence of an altitude engine test bed both at overhaul base and at operational base, effective altitude setting of the integrated system on engine highly depends on skill of the operator and such snags are most likely to occur. The throttle angle to fuel flow rate relation should be maintained by resetting and calibrating the CCU as shown in Fig.3. The above analysis shows that the RPM related snags may arise due to defects or malfunction in fuel pump, CCU and AFRCU independently or jointly.

Most of the defects pertaining to JPT are interrelated to fluctuations in RPM or RPM exceeding the specified maximum limit. In some cases, the JPT overshoots during slam check at ground or during slam operation at altitude. Malfunction of AFRCU and JPTL were found to be the main cause of JPT not building up or exceeding the limit. AFRCU is highly sensitive to the adjustment and proper adjustment is required to maintain the mixture ratio suitable for the entire operation.
High slam time in a jet engine at ground or in flight results in a mission delay and does not fulfill the operational requirements of the engine or aircraft. Sometimes engine enters to surge during slam acceleration which is a serious safety concern. The pilot declares the incident as a surge based on a ‘bang noise’ associated with sudden RPM drop and JPT shoot up. As there is no surge detection and control system in this type of early gas turbine engines with a fixed area exhaust nozzle and without variable guide vanes, the pilot has to strictly adhere to the operational limitations and effective maintenance practices to be followed.

While investigating such cases, defects are hardly confirmed at ground test bench where simulating the flight condition and engine attitude is merely not possible. However, thorough analysis of the functioning of fuel system accessories led to find fault in AFRCU settings or drift in settings during operation. Any reduction in pressure build up or pressure fluctuation in AFRCU can result in a drastic variation in slam timing. Periodic sea level calibration, altitude calibration and air-fuel ratio calibration need to be carried out to ensure proper slam time. The role of CCU in attaining a desired slam time is also very important.

The contribution of the fuel system accessories towards the total snags reported over a period of five years is shown in Fig. 4.

Remedial Measures

From flight safety point of view, any snag or malfunction of the engine or deterioration in its performance needs to be addressed at the earliest. Remedial measures arise from the investigation based on the case or situation should be implemented in the accessories or in engine based on the category or criticality of the defect to ensure the reliability and suitability of repaired accessories in the engine and the repaired engine for fitment in aircrafts for service.

Several approaches are commonly employed in gas turbine industries to address the defects or failures. The approach depends on the attributability, i.e., whether it is due to a design inefficiency, material failure, or due to lapses in manufacturing processes or in assembly [4]. The failure sometimes attributes to the lapses on the part of user such as deviation from storage procedure, lapse during on-site maintenance and inspection or deviating from the operational limitations. There are also several instances where attributing the cause is not easily possible.

As the defect investigations show that the RPM related snags may arise due to defects or malfunction in fuel pump, CCU and AFRCU independently or jointly, the units and causes responsible for the said snag is required to be identified precisely. Defects related to idling RPM vary from engine to engine and hence whenever CCU or AFRCU are replaced in an engine, the idle RPM should be adjusted to suit the individual engine requirement. Idling by-pass valve adjustment need to be carried out as per instructions given in the maintenance manual. Periodic calibration and settings of CCU and AFRCU to meet the sea-level and altitude conditions will help in maintaining a steady RPM reaching the desired setting with respect to the throttle excursion. Similarly, proper setting in AFRCU can resolve many issues related to high JPT as well as slam time. Further, maintaining a high level of fuel discipline, selection of correct jet size and atomizers within a narrow band of flow rate and spray quality can help to address many snags in the fuel system of the aero engine.

After the modification or rectification, the performance of the accessories is demonstrated on an engine in test bench. In some cases, it becomes necessary to carry out flight evaluation of the engine with modified/rectified accessories in a test aircraft or to monitor the performance of the engine during operation.

Conclusion

The overall performance of a jet engine is highly affected by the snags/defects encountered in its fuel system. Study of various defects of fuel system accessories over a period help to identify the unit prone for malfunction due to lapses in maintenance or due to engine demands to meet the operational requirements and environment. Engine overall performance can be defined in terms of its RPM, JPT and slam time, and any deterioration in these parameters can affect the aircraft mission. The present study reveals that defects/snags in fuel system accessories, i.e., in fuel pump, CCU, AFRCU and JPTL, can affect the engine RPM, JPT and slam time independently or jointly. The defects in respective accessories should be addressed as per the remedial measures suggested by investigating team. The clearance of the repaired accessories for fitment in engine should be based on successful demonstration of the post-modification performance. Number of engine premature withdrawals due to defects in fuel system are to
be reduced at a fast pace to ensure high reliability and safety of man and machine.

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References


