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ANALYSIS OF FACTORS CONTRIBUTING HIGH JET PIPE TEMPERATURE A SNAG OF TYPICAL TURBO JET ENGINE

P.Sethunathan[1], T.R.Krishnamani[2], R.Sathyapriya[3], M.Geetha[4]
[1]*Assistant Professor, Department of Aeronautical Engineering, Paavaai Group of Institutions, Namakkal,*
[2]*UG Student, Department of Aeronautical Engineering, Paavaai Group of Institutions, Namakkal,*

ABSTRACT: The heat transfer conditions in automotive exhaust piping are only recently being studied in depth because of their important role in the design and optimization phases of exhaust after-treatment systems. High Jet pipe temperature is one of the critical parameter which controls the engine operation. The high jet pipe is governed by fuel flow and airflow through the engine. The temperature reduction done by Burner tests, combustion chamber throat area checking, compressor efficiency. The engine control system is designed so that the exhaust gas temperature will normally be maintained with in safe margin.
KEYWORDS: HJPT, Flame tube, Compressor, Burner test, Throat area check.

I. INTRODUCTION

The turbojet engine was manufactured at ENGINE DIVISION, HAL. Since 1957 under license of Rolls Royce and fitted on Basic trainer aircraft. This Engine works on the principle of Brayton cycle (the Constant Pressure cycle).This Engine has seven stage axial flow compressor, which are driven by single stage impulse reaction turbine. The engine produces 4200 Lbs of thrust at 9500 RPM and specific fuel consumption is 1.106 lbs/lbs/hrs. Its net weight is 420 Lbs. Its max Jet pipe temperature is 647 degree centigrade. It consists of the following major subassemblies Air intake assembly, Compressor Rotor & turbine assembly, Delivery casing & combustion chamber assembly, Exhaust & jet pipe assembly.

1.1 Performance checks

Engines are tested in test bed to check the performance of the engine. The tests are carried out to evaluate the engine performance. All engines that are built do not pass through the performance test due to several snags like; High Jet pipe temperature, High Vibration, Abnormal noise, High oil consumption ,Surge & Stalling, Low oil pressure, RPM fluctuation, Compressor delivery pressure drop, Miscellaneous. Due to the vast field in the above snag high contribution towards engine rejection, the study and analysis has been limited to High Jet Pipe Temperature.

1.2 Importance of the problem

High jet pipe Temperature is a phenomenon where exhaust gas temperature of the engine is more than limit (647 °C). The high JPT is in turn related to turbine inlet temperature. If JPT becomes more than the Specified limit, there is a danger of turbine blade damage, The high JPT can be due to rich fuel mixture .It is governed by airflow, fuel flow and design of engine, JPT is measured by four thermocouples located in Jet pipe and the average is indicated in the gauge which is located in the cockpit, JPT can be attributed to the malfunctioning of the burner and variation in throat area of the combustion chamber and less air flow, compressor efficiency and compressor surge, Our paper deals with the causes for High Jet Pipe Temperature, effect of high JPT and the remedial action for high JPT.

II. LITERATURE REVIEW

Dr. S.G. Hooker, Chief engineer of Bristol Aero engines

The jet pipe, which is secured by a flange on the exhaust-cone outer casing, carries thermocouple bosses for the measurement of JPT and both the jet pipe and exhaust cone are surrounded by a reversal heat-insulating blanket. In addition, there is a light alloy jet-pipe shroud, which is secured to the combustion-chamber outer casing and surrounds the exhaust cone and jet pipe, providing a cooling air space between the two. The shroud has a stainless- steel inducer riveted to its rear end, so that the jet gases induce the flow of cooling air. Detail design of the Orpheus in its present form began in December 1953,and progress was extremely rapid from the outset. The first material was ordered early in 1954, and all the detail drawings had been issued to the shops by the end of June of that year.

James D. Murphy, CEO of after burner Inc.

The after burner jet pipe is made from a heat resistant nickel alloy and require more insulation than the heat of combustion being transferred to the aircraft structure the jet pipe may be of a double skin construction with the outer skin carrying the flight loads and the inner skin the thermal stress; a flow of cooling air is often induced between the inner and outer skins, provision is also made to accommodate expansion and contraction and to prevent gas leaks at the jet pipe joints.

I.P. Kandylas, A.M. Stamatelos

The heat transfer conditions in automotive exhaust piping are only recently being studied in depth because of their important role in the design and optimization phases of exhaust after -treatment systems. The complex geometry of the exhaust line and the special on conditions complicate the problem of accurately estimating several important heat transfer parameters. This paper initially summarizes the current status of knowledge regarding heat transfer phenomena in automotive exhaust systems. Experimental data from state and transient heat transfer measurements in automotive exhaust systems are presented and analyzed by means of a comprehensive transient computer model covering all exhaust piping configurations (single wall, double wall with air gap or insulation) already d elsewhere. Examples are presented, illustrating the application of the model in the comparative assessment of different exhaust configurations. In conjunction with existing models which simulate the operation of three-way catalytic converters and of other exhaust gas after-treatment devices, the model is already integrated in a CAE package for the support of exhaust system design optimization

III. DESIGN SPECIFICATIONS

The turbo jet is a straight flow turbo jet engine with a seven stage axial flow compressor and a single stage turbine. It has a Can annular type combustion system incorporating seven combustion chamber and Lucas Duplex burner. A feature of engine is that the main rotating assembly comprises a single unit in which compressor rotor is coupled by al light but rigid shaft to the turbine wheel, this unit being mounted in two bearings only.

3.1 Leading particulars of typical turbojet engine

In general it's a straight flow single stage turbine with seven stage axial flow compressor of anti clockwise rotation from rearview this consist of 85 entry guide vane blades and 13 exit guide blades this compressors of 6 stator &7 rotor blades to increase the pressure levels of last stage of compressor. The combustion chamber is a kind of straight flow, annular casing with separate combustion chamber. There are 7 combustion chambers flitted in this engine, numbering 1 is the uppermost, clockwise from the rearview.

The jet engine consists of single stage axial flow turbine which helps to rotate the shaft by helping to circulate the compressor blade, by which stator and rotor comprises of 63&125 blades respectively.

3.1.1 Jet pipe specification

Weight (including insulating bracket)- l511b(68.6kg)
Length - 92.865in
Propelling nozzle diameter - 18.4in

Table - 3.1

Speed(rpm)	Thrust (lbs)	JPT (^{o}c)	SFC (lb/lb/hrs)
9500	4200	647	1.106 max

3.2 Jet pipe

A strap unit to the jet point ring secures this. A cone gasket providing a gas seal at the point. A bellow unit incorporated at the front end of the jet pipe and two roller units fitted at the rear permit expansion.

Four thermocouples and jet pipe temperature limiter of the fuel system are installed in the rear end of jet pipe. Trimmers are installed in the jet pipe nozzle during engine test to control the thrust. The number and position of the trimmer vary in individual test pipes a heat insulating blanket is insulated around jet pipe.

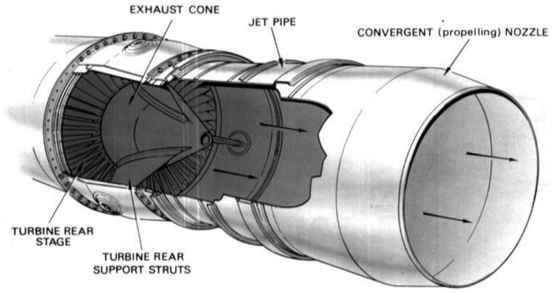

Fig-3.1 Jet Pipe

3.3 Jet pipe temperature limiter

This unit functions in conjunction with a venture in the barometric pressure control capsule chamber cover to prevent the jet pipe temperature from exceeding the maximum permissible limit. The unit comprises of a quartz rod housed in a mnemonic sheath, the assembly being bolted to a mounting face on the jet pipe with the sheet portion is enclosed by a cover which embodies a plate valve, being retained by a spring loaded plate. Air inlet and outlet connections are provided above and below the valve. External pipes to the engine delivery casing and the barometric pressure control capsule chamber limit these respectively.

The venture is located in the pipeline between the intake from the jet pipe temperature limiter and the barometric pressure control connections to the engine intake, the throat of the venture being connected to the capsule chamber.

3.4 Jet pipe temperature limiter operation

When the engine running sheath and quartz rod are attain the temperature of the exhaust gases, at the different linear expansion co-efficient of the rod and the sheath cause sheath to lengthen greater extent than the rod, thereby progressively decreasing the spring loading of the phase valve. this decreases the spring tension at maximum jet pipe temperature, will permit the valve to open and allow the compressor delivery pressure to flow through the venture.

The increase in velocity and consequent pressure decrease of the air at the venture throat reduces the pressure in barometric pressure control chamber and capsule tends to expand. This opens the barometric pressure control half-ball valve and reduces fuel flow to the engine.

The ensuring decrease in temperature to gases in the jet pipe then tends to cause the limiter valve to close and equilibrium is obtained at a predetermined jet pipe temperature.

IV. HIGH JET PIPE TEMPERATURE

High JPT is a phenomenon where the temperature of the exhaust gas goes above the specified limit as the result of rich air fuel ratio. Rich air fuel ratio may be caused mainly because of improper functioning of the burner and decrease in the dimension of the combustion chamber throat area. Due to these defects the exhaust gas temperature goes above the specified limit (647°C) causing damage to the blades of the turbine wheel.

The engine control system is designed so that the exhaust gas temperature will normally be maintained within a safe margin. However no system can be designed to compensate for operational malpractices. It is foolish to treat over temperature lightly. The fact that the turbine does not fly or the engine melt away is no reason to assume that the engine cannot be or has not been damaged. Several momentarily high over temperature may have as profound an effect on the engine as a single prolonged one of the lesser degree. Excessive internal temperature aggravates such condition as creep or deformation of sheet metal parts and shortens the life of the engine in general. So it is an important aspect to study the cases for high Jet Pipe Temperature and the rectification procedure involved in high JPT. Our project deals with the causes for high JPT and the test carried out to rectify the problem.

4.1 Causes for high JPT

The important causes for high JPT are improper functioning of burners and variation in combustion chamber throat area. Improper functioning of JPTL and fuel accessories may also account for high JPT.

4.2 Effects of high JPT

Due to high JPT the exhaust gas temperature goes beyond the limit which melts the blades of turbine and also it may damage the engine itself.

V. VARIOUS TESTING METHODS

5.1 Burner Test

Before connecting the unit to be tested to the rig. Check that all rig pipes, T-pieces, banjos etc.... are thoroughly clean and free from internal burrs. Where T-pieces are used for pressure tapping's, ensure that they are as large as possible with smooth, straight bores to minimize the pressure drop between the tapings and the unit, if double banjos are used for pressure tapping's, check that banjo lost drillings are of an adequate size to minimize the pressure drop. Connect the stem of the T-piece to the unit or gauge so that the air or fuel flow past through the straight top of the "T". Fit pressure tapings as close as possible to the unit under test to ensure that any pressure drop in the rig pipes is not included with the gauge reading

When opposing static pressure to the unit, lock the pressure in the system so that any leaks are immediately apparent. Disconnect all pipes from the unit that are not required during a specified test and fit suitable blanks to the unit and/or pipes. Whenever gauge readings vary from the permissible limits specified in the test instructions, check the rig connections, gauge, pipes etc... Before making any adjustments to the unit under test. In the following tests, use fuel to specification D. Eng.R.D 2494. The fuel temperature must be within 20° and 21° unless otherwise stated. Adjust the rig temperature controller as necessary to maintain the fuel temperature within the limits, specified for each other. When carrying out the in filtering procedure, use in filtering oil to specification D.Eng.R.D. 2490 or DEF 2001. An inspector should witness all the tests.

5.2 Pressure drop test

- Connect a flexible pipe from "Number one Burner" connection on the test rig to the pressure test fixture.
- Switch on the rig and open the supply valve.
- Apply a flow of 90GPH and note down the pressure gauge reading.
- Close the main supply valve and disconnect fixture.
- Fit the strainer to the fixture and disconnect the rig.
- Open the main supply valve; re-apply the flow specified in operation 3 and note down the pressure gauge reading.
- Close the main supply valve and switch off the rig.
- Remove the fixture from the rig and withdraw.

5.3 Spray angle test

Disconnect the flexible return pipe on the trolley from its transport union and place it in the test rig fuel drain tray.

- Fit the burner shroud assembly adapter to the burner holder on the test trolley, then raise the retractable screen into position.
- Remove the burner completely with its connected supply pipes from the test rig and insert it into the adapter. Then adjust the burner holder direct to the burner spray into the burner spray into the collector. Fit the rig telecentric eyepiece into the clamp support and tighten the clamp.
- Fit the prefix level indicator to the front end of the telecentric eyepiece and adjust the eyepiece so that the burner shroud face is level.
- Switch on the rig, open the supply valve and apply an inlet pressure of 200 Psi.
- Fit the spray angle indicator to the rear end of the telecentric eyepiece and check that spray angle is 85°+/- 2°
- Open second burner needle valve, and adjust the main supply valve, and the fuel flow.

Table 5.1

Total flow (gph)	Inlet pressure (psi)	Spray angle (degrees)
8.6	300	Not less then 78°
10.4	350	Not less then 78°
13.6	400	Not less then 78°
18.0	450	Not less then 78°
23.6	500	Not less then 78°
49.0	600	92° to 96°

5.4 Final leakage test

- Ensure that the gaco seal on the fixture is serviceable.
- Connect an air supply to the burner body and fit the approved fixture to the atomizer orifice.
- Immerse the burner fuel and apply a pressure of 150 Psi, no leakage is permissible.
- Release the air pressure and disconnect the burner.

VI. COMBUSTION CHAMBER THROAT AREA CHECKING

6.1 Check combustion chamber stator 'X' and 'Y' throat gap areas.

The stator throat gap areas are controlled by the 'X' and 'Y gaps. The 'X' gap is the minimum-distance between the trailing edge of the end blade of a stator segment and the convex side of the adjacent stator segment and the blade. The 'Y' gap is the minimum distance between the trailing edge of any stator segment blade and convex side of its adjacent blade in that segment. The throat areas are obtained by multiplying the 'X' and 'Y' gaps by the length of the throat gap.

Set the tool kit checking equipment. Position the comparator setting block in the comparator setting gauge, retaining the block in position with the spring loaded effect. Ensure that all mating surface are scrupulously clean. Locate the fixed anvil of the throat gap gauge against the formed gauging surface of the comparator setting gauge. Position the throat gap gauge so that the moving log contacts the gauging face of the setting block ensuring that the fixture anvil miss still making correct contact pivot gap gauge about the fixed anvil until the minimum reading is obtained, then set gap gauge dial "0"and lock it into position. Note the position of the gap gauge total travel pointer.

6.2 Check the 'Y' Gaps

- Position the tool kit gauge template, locating on the trailing edges of the stator blades and on the segment inner rim of the combustion chamber.
-With the fixed anvil of the throat gap gauge resting lightly on the edge form by the radial slot in the gauge template, position the fixed anvil on to trailing edge of the blade.
- Pivoting on the fixed anvil, more the gauge until the moving log contacts the convex face of the previous blade and the minimum reading is obtained.
- Add or subtract accordingly any variation from the present nominal dimension and record the dimension obtained.
- Repeat the procedure for all 'Y' gaps.
- Remove the tool kit equipment and using internal micrometer, measure and record the length of each throat gap; that is the distance between the inner and outer rims.
- Multiply the length of each 'Y' throat gap by its width in order to determine its area.
- Carry out the foregoing procedure on the remaining combustion of the engine set.

6.3 Check the 'X' gaps

-Measure and record each 'X' gap and its length then determine its area.
- If the final checking fixture is used, obtained access to the 'X' gaps through the operator in the fixture.
- Slide the gauge template into position over the 'X' gap to be checked.
- Employ the method as described previously for checking 'Y* gaps.
- Dismantle the combustion chamber from the fixture.
- If the area recorded is not within the tolerance quoted, estimate the amount of correction necessary then carefully bend the trailing edge of a particular stator blade(s) in the required direction up to the maximum of 0.0100 inch.

VII. TESTS CONDUCTED IN THE JET ENGINE TEST BED

7.1 At 9500 RPM conduct one hour endurance test:

- Carryout a ten second motoring cycle and check, the oil and fuel pump delivery pressure.
- Carryout two false starts.
- Inspect the fuel leaks particularly at the flange joints.
- Carryout two starts, one of which must be from cold, the other at a convenient position during the test.

7.2 Preliminary Running

Run for 5 minute at idling conditions (3250 RPM) prior to checking by setting the following:

- Installation and instrumentation.
- Closures of the turbine drain valves. (it usually closes at 5 Psi compressor delivery pressure)and ensure that it will be found closed at 10 Psi compressor delivery pressure.
- Oil, Fuel, air and gas leaks - checks to be carried out at 4000 RPM.

-Generator and hydraulic pump functioning to be checked.
-Recording oil pressure at 9025 RPM. It should be greater than or equal to 45Psi.
- Fuel pump pressure 1500 Psi maximum at 9025 RPM. The Back Pressure Controller (BPC) must not be adjusted at any period of test. Low oil pressure warning switch operating pressure – Throttle back slowly and check.
- The low oil pressure, warning light operates within limit of 25 +/- 2Psi. The pressure, oil temperature and speed at which the light commences to flicker will be recorded.
- Low fuel pressure warning switch operating pressure - check the fuel pressure warning.
- Light comes into operating at 5 +/- 0.5 Psi. This check will be carried out by reducing.
- The fuel pump balking pressure slowly at an engine speed of 3250 RPM.
- The balking pressure must not be reduced below 2 Psi.
- Set ground idling speed, adjust the throttle to give 3320 +/- 25 RPM at 30° throttle angle. To avoid frequent resetting of the idling RPM the prevailing ambient pressure must be taken into account on final test. Add or subtract 43 RPM to or from the nominal ground idling RPM for each inch of mercury that ambient pressure is below or above 30 inch of mercury.
- The maximum JET PIPE TEMPERATURE spread at ground idling conditions (3250 RPM) is 95°C.
- Set Jet pipe Temperature Limiter (JPTL) to 685 +/- 5°C to adjust the JPTL setting proceed as follows.
- Slacken the gland nut.
- Retain the adjusting screw and slacken the lock nut.
- Turn the adjusting screw clockwise to increase the setting temperature and vice versa.
- Restrain adjusting screw and tighten the lock nut. Retighten the gland nut.
- Trim the jet pipe nozzle to obtain 4200 +/- 84 lbs, ISA SLS thrust at 9500 RPM with the CCU throttle valve. Set to obtain 9800 RPM then set the 81^{11} +/- 2° angle to governor to obtain 9500 +/- 23 RPM. The maximum JPT spread above the configuration RPM is 60° C.

7.3 Inspect the pressure and scavange oil filter

7.3.1 Endurance running

- Run for 5 minutes at idling RPM. then take the oil level in the tank.
-Adjust the fuel pump governor to give 9800 +/- 25 RPM.
- Run at 9025 RPM for 20 minutes.
- Run at 9260RPM for 50 minutes.
- Run at 9500 RPM for 50 minutes.
- Inspect the scavenge oil filter and the oil consumption rate at the above mentioned periods.

7.3.2 Accessory loading

-Hydraulic pump and 5.1 KW DC generator accessory loading.
- Acceleration and Air Fuel Control (AFRC) ranging.
- Carryout Air Fuel Ratio Control ranging checks and set Air Fuel Ratio Control and carryout 2 accelerations from ground idling.

7.4 Engine test data

Date: 02/02/15 — New/Rectification/Overhauled: Overhauled
Engine Number: HC 51010/441 — Shroud Number: N/A (Not Application)
Type: Turbojet — Oil Specification: DERD 2487

R.P.M		THRUST		PUMP		JETPIPE TEMPERATURE		AIRINLET TEMPERATURE
						Average of 4 thermocouples		
Observed	correct	observed	correct	Inlet psi	Outlet Psi	Observed	correct	
9300	9189	3450	3803	24	1325	628	605	22°
9500	9389	3710	4090	23	1310	633	630	22°
9700	9584	3985	4393	22	1340	679	654	22°
9025		2900		25	1330	608		30°
9260		3164		24	1320	631		30°
9500		3495		34	1130	657		30°

CONCLUSION

High JPT is a phenomenon where exhaust gas temperature becomes more than the specified limit. If JPT becomes more than the specified limit, there is a danger of turbine blade damage/failure. The High JPT is governed by fuel flow and air flow through the engine. High JPT can be attributed to malfunctioning of burners and throat area of combustion chamber.

Checks to be carried out at unit; Check JPTL, Check Thermocouple , Check Trimmer, Check fuel accessories. If all the above checks are satisfactory and high JPT still persists then following checks are to be carried out. Rig test burners and adjust burner flow to minimum side. Check throat area of the flame tube and correct if required to check & ensure compressor efficiency during final acceptance testing.

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