PART 1 : SECTION 3

CHAPTER 8

JET PIPES, TEMPERATURE MEASUREMENT, AND TEMPERATURE CONTROL

JET PIPES

Introduction

1. The purpose of the jet pipe (tail pipe) is to conduct the burnt gases from the engine and in so doing to extract more energy from the flow. The length of the pipe is set by the position of the engine in the fuselage or nacelle, but for the reasons given below it is desirable that the jet pipe should be as short as possible. Most engines have a single straight pipe, but the jet pipe may be slightly curved and may consist of a single pipe at the entry point but split into two exhaust nozzles (known as a bifurcated jet pipe).

Function

2. Fig. 1 shows a typical jet pipe and nozzle. At point 1 the gas enters after leaving the turbine and from points 1 to 2 the gas flow is subsonic and therefore decreases in velocity with an accompanying rise in pressure. Points 2 to 3 form the convergent nozzle section within which the gas flow is expanded (accelerated) to leave at a higher speed and decreased pressure, thus extracting more energy and increasing the propulsive force.

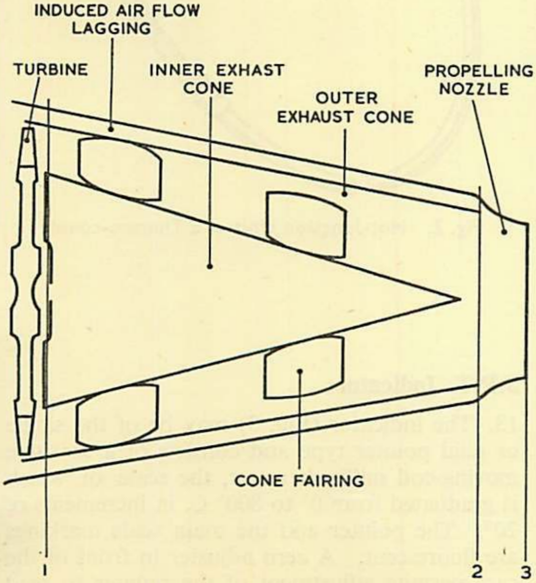

Fig. 1. Typical Jet Pipe and Propelling Nozzle.

3. The diameter of the nozzle is important. If it is too large the expansion is decreased and less thrust is obtained ; if the diameter is too small a back-pressure is set up, causing choking and a rise in turbine temperature, which is shown as an excessive jet-pipe temperature (j.p.t.).

4. The lengths of the jet pipe and nozzle affect engine efficiency. To achieve the optimum expansion through the nozzle, the gas flow can be accelerated gradually over a fairly large distance (long nozzle) or accelerated quickly over a short distance (short nozzle). In general the nozzle is kept short, since this has the effect of keeping the velocity of the gas flow in the jet pipe low (about 0·5M). The higher speeds resulting from a long nozzle cause frictional losses and a drop in efficiency. Tail pipe length determines the amount of frictional losses in the flow ; the shorter the pipe the smaller the loss. To obtain maximum efficiency from a given mass flow of gas, there is an optimum diameter for any tail pipe length.

Variable Area Jet-Pipe Nozzles

5. A large nozzle area is an advantage, in that it reduces the turbine back-pressure and results in easier starting. This advantage is of great importance in large engines where the power required to rotate the moving parts is a serious problem. An engine with a large nozzle area also accelerates to its idling speed much more quickly than it would with a small nozzle area when the turbine is working against a back-pressure. In general, ease of starting and maximum efficiency at low I.A.S. and thrust is ensured by having a large area jet nozzle.

6. When maximum thrust is required a reduced area nozzle gives best results. Consequently a variable area nozzle permits operation over a wider range of conditions and r.p.m. than is possible with a fixed area nozzle.

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7. **Turbo-Prop Engines.** With the turbo-prop engine, there is a distinct advantage in being able to adjust the velocity of the exhaust relative to the forward speed of the aircraft. If this can be done it is possible to avoid very high exhaust velocities with their inherently low propulsive efficiency, and to avoid too low an exhaust velocity which also causes a loss in power. A too low exhaust velocity means that not all the energy of the residual gas flow, after driving the propeller, is being used.

8. **Reheat.** When reheat is used the variable area nozzle is essential for maximum efficiency, because an increase in the area is necessary to cope with the increased rate of gas flow and to maintain a constant back-pressure on the turbine. Conversely, a smaller nozzle area is necessary for normal running if severe losses in thrust are to be avoided when reheat is not used. Variable area nozzles are usually of the two-*position* type, the area automatically increasing or decreasing as reheat is switched in or out.

Jet-Pipe Lagging

9. As a precaution against fire, and to assist in cooling the jet pipe, some type of lagging is generally provided. The pipe is wrapped in an insulating material such as asbestos blanket, or metal sheet foil with an air space between the foils. This type of lagging results in a jet-pipe temperature under the insulation of about 640° C. for a turbine inlet temperature of say 800° C. An airflow is usually passed over the lagging through the gap between it and the outer casing of the jet pipe. Cooling the jet pipe while reheat is used is described in Chapter 9.

Materials

10. The materials used in the manufacture of jet pipes are, in general, similar to those for combustion chambers, and are described in Chapter 4 of this section.

TEMPERATURE MEASUREMENT

Purpose

11. Thermometers, consisting of indicators and thermo-couples, are used on gas-turbine aircraft to measure the temperature of the exhaust gases, to ensure that the safe working temperature under various conditions is not exceeded.

Thermo-Couples

12. The thermometer operates on the principle of the thermo-couple, described in Part 2, Section 6, Chapter 3. Four hot junctions are normally placed in the gas stream in the tail pipe aft of the turbine, at 90° to each other. Each consists of two conductors, one of nickel-chromium and the other nickel-aluminium, mounted in a ceramic insulator which is housed in a protective metal sheath, as shown in Fig. 2. The sheath has a hole near its tip for the exhaust gases to enter the stagnation chamber. To reduce the gas velocity past the thermo-couple hot junction, which is in the stagnation chamber, and thus avoid an adiabatic temperature rise on impacting the thermo-couple, the exit (although diametrically opposite the entrance) is displaced 0·25 in. farther from the tip and has a smaller area. The gas is thus made to flow through a Z-shaped passage past the hot junction.

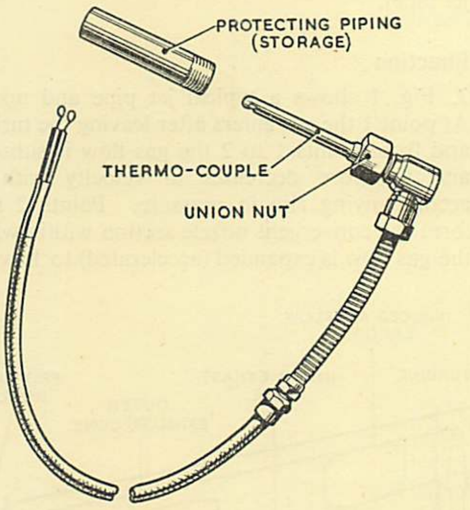

Fig. 2. Hot-Junction Unit of a Thermo-couple.

J.P.T. Indicators

13. The indicator (Fig. 3) may be of the single or dual pointer type and consists of a sensitive moving-coil millivolt meter, the scale of which is graduated from 0° to 800° C. in increments of 20°. The pointer and the main scale markings are fluorescent. A zero adjuster in front of the case permits adjustment of the pointer to read the ambient temperature of the instrument ; this

should be necessary only when a new instrument is fitted. The cold junction is located in the indicator, and is compensated for variations in temperature by a bi-metallic spiral which acts on the hair-spring controlling the pointer. The moving-coil resistance is also compensated for changes in ambient temperature.

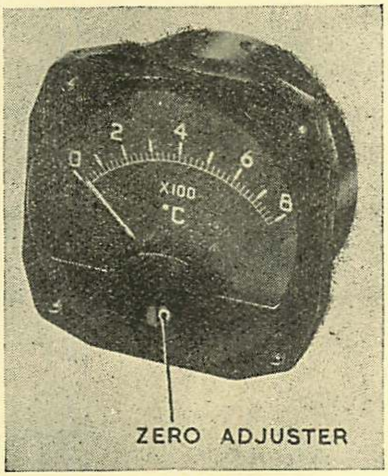

Fig. 3.
Jet-Pipe Temperature Indicator (0° to 800° C.).

TEMPERATURE CONTROL

Principles

14. Engine efficiency improves with increase of the gas temperature through the turbine and it is therefore desirable that the gas temperature should be as high as possible to extract the maximum power. At the same time, to prevent damage to vital parts, certain limits should not be exceeded. Temperature control involves the constant measurement of gas temperature so that when a preset limit is reached, the fuel flow is reduced to limit the temperature. The temperature used is that measured by the thermo-couples in the jet pipe.

Operation

15. The voltage generated by the thermo-couples at any temperature is fed into a *reference voltage unit*, which supplies a stabilized voltage equal to the voltage delivered by the thermo-couples when at the limiting temperature. The stabilized reference voltage can be adjusted to suit any particular installation and requirements, and is compensated for the changes in ambient temperature, which would otherwise vary the thermo-couple voltage. This compensation is automatic but the reference voltage is adjusted by a temperature selector.

16. **Temperature Limiting and Range Control.** The selector can be preset on the ground to prevent the j.p.t. from exceeding the maximum permissible, or it can be of a type that continually governs the j.p.t. to keep it at the optimum figure for any r.p.m. The first use is known as *temperature limiting control*, and the second use as *range control.*

17. The reference voltage unit, then, provides a preset, constant voltage and receives the varying voltages from the thermo-couples. These two values are compared and, if equal, the reference voltage is balanced and the output from the reference voltage unit is zero. If a difference exists between the two values, a signal is fed to an amplifier which gives an output only when the thermo-couple voltage is greater than the reference voltage. From the amplifier the output is led to a solenoid-operated valve which, by means of a hydraulic servo, controls the fuel flow to the burners.

18. To smooth out any tendency of the solenoid to hunt, which would cause continuous variations in the fuel supply leading to undesirable fluctuations of r.p.m. and thrust, a time lag is built into the amplifier to reduce its response.