**FAAN TRAINING CENTER**

**ARFFS Training Unit**

**Aircraft Engines**

INTRODUCTION

Aero engines of various types constitute a major area of concern for the Airport Fire Service. Under normal circumstances they are exceptionally reliable. However, under abnormal conditions, where a failure occurs, or where personnel find themselves working in close proximity to them, they can present firefighters with considerable problems and severe hazards.

AIM

To introduce the participants to various types of aircraft engines and their associated hazards.

OBJECTIVES

At the end of this technical input and with detailed study of the Training Note the participants will be able to:

* State the various types of aircraft engines in use
* Name the materials used in construction and their fire hazards
* Explain how a Jet Engine works
* Explain the appropriate firefighting tactics and techniques
* State the safety measures to be followed by personnel when dealing with engine related fires.

The subject is dealt with under the following headings:

**ENGINE TYPES**

**Piston Engines**

* A brief understanding of how they work
* Fire hazards

**Jet Engines**

* A brief understanding of how they work.
* Fire hazards.

Engine Locations

Rear Mounted Engines

Auxiliary Power Units

Danger Areas

Tactics and Techniques

**PISTON ENGINES**

These engines can be sub-divided into three main categories:

1. In-line
2. Flat (horizontally opposed)
3. Radial

Aviation piston engines are similar to car engines and work by introducing a mixture of fuel vapour and air into a cylinder in the correct proportions, compressing this mixture with a piston, which is connected to a crankshaft and igniting it when the piston is near to the top of its stroke. The resulting explosion then drives the piston back down the cylinder producing power to turn the crankshaft.

They may be similar to a car engine but are in most cases larger and more powerful, usually with four, six or eight cylinders.

The front of the crankshaft drives through a reduction gearbox, which in turn drives, in most cases, a propeller. The rear end of the crankshaft drives accessories and may also drive a supercharger which increases the pressure at which air is supplied to the engine and allows the engine to continue to run efficiently when the aircraft is operating at high altitudes where the air is thinner. Alternatively there may be a turbocharger, i.e., a small turbine driven by the hot exhaust gases. The fuel used is normally aviation gasoline, AVGAS.

**In-line Engines**

These engines are very similar to car engines, where the cylinders are in a line, one behind the other. They may have any number between two and twelve cylinders arranged in this fashion. A variation of this type of design is the “V” engine such as the Rolls Royce Merlin, which is a V12 with six cylinders on either side of the V shaped engine block.

These engines are now rarely found on any aircraft other than historic or heritage types.



**Radial**

These engines were developed from the rotary engine in which the crankshaft remained stationary and the whole engine, cylinders and all, spun around driving the propeller. As engine RPM (revolutions per minute) increased with improvements in design and materials, this arrangement proved impractical, however a variation on this theme, where the cylinders remained still whilst driving a central crankshaft proved reliable, compact and powerful. The disadvantage of this configuration was its complexity, both in design and construction.



**Flat (Horizontally opposed)**

These engines are also very similar to certain types of car engines, such as the Porsche 911, which has a flat six, or the Ferrari Testarossa which has a flat twelve. But once again, in general they are larger and more powerful with four, six or eight cylinders, air-cooled and arranged in horizontally opposed pairs. In most cases, full use is made of the powerful stream of hot exhaust gases to drive turbochargers.



**FIRE HAZARDS - PISTON ENGINES**

The following list covers the most common fire hazards involving aircraft fitted with piston engines:

1. **Fuel Lines** - Exposed fuel lines under considerable pressure throughout the fuel supply system.
2. **Induction Systems** - Fuel mixtures under high pressures from turbo and superchargers.
3. **Carburettor** - Fuel under pressure
4. **Lubricant oil lines** - Lubricant oil under pressure.
5. **Exhaust** - Hot exhaust manifolds are one of the greatest hazards in an aircraft crash situation due to the likelihood of contact with hot lubricants or vaporising fuels. Exhaust systems will retain heat for considerable periods after extinguishment of fire.
6. **Accessory Section** - Electrical systems including alternators, regulators, general wiring and batteries are a ready source of ignition.
7. **Fuel** - AVGAS, as the most common fuel for piston engine aircraft.

**THE JET ENGINE**

Types:

1. Turbojet
2. Turbofan
3. Turboprop
4. Turboshaft - primary use helicopters

These are the four main types of jet engines. The first two, the turbojet and turbofan, are reaction engines, producing forward motion with the reaction from the jet thrust.

The turboprop and turboshaft operate on a different principle, where the energy in the gas flow is used to drive a large turbine which is connected to a propeller or power output shaft.

**The Turbojet**

The simplest and earliest form of gas turbine is used principally in high-speed aircraft, for example the Olympus 593 in Concorde. This type of engine passes all the air that it uses through the core of the engine.

**The Turbofan**

The turbofan is the most common type of gas turbine for aircraft propulsion systems. This type directs a proportion of the air through the core, where it is compressed, passed into the combustion section, where it is mixed with fuel, ignited and then passed through a turbine where a proportion of the power produced is returned to the compressor via the main shaft. However, the shaft also drives a fan of varying size, depending on the engine. This fan pushes cold air around the outside of the hot core of the engine, and can, in the case of large, high by-pass engines, contribute more than 50% of the thrust produced.

Examples are the Rolls Royce RB211 and Trent, high by-pass engines found on the Boeing 747 and 757, the Pratt & Witney JT8 D on the Boeing 737, 200 and DC 9, with a much lower by-pass ratio and the Adour on the Jaguar and Hawk, and the Rolls Royce RB 199 on the Tornado.

The Pegasus in the Harrier is a variation of the turbofan.

**The Turboprop**

The turboprop is essentially a turbojet with a large, high efficiency turbine which is designed to absorb all the energy remaining in the gas stream after sufficient has been removed to drive the compressor.

In practice, there is always a small amount of residual thrust in the exhaust gases. The power turbine drives the propeller through a reduction gearbox, usually at the front of the engine.

Examples of the turboprop are the Dart engine in the 748 and F-27 and the Tyne engine in the Transall C-160 and Atlantique.

**The Turboshaft** - usually found in helicopters

The Turboshaft is virtually a turboprop without a propeller, the power turbine being coupled to a reduction gearbox or directly to an output shaft.

As with the turboprop, the power turbine absorbs as much of the energy in the gas flow as possible and the residual thrust is very low.

Examples of the turboshaft are the Gem in the Lynx and the Gnome in the Sea King helicopters.

**LAYOUT OF THE JET ENGINE**

Turbofan Type Engine

The jet engine has three main sections:

1. Compressor
2. Combustion
3. Turbine

These three sections, on their own, are not the whole story. Without fuel, oil and electricity the engine cannot work. Therefore, fitted to the outer casing of the engine are various pumps and pipework, designed to deliver fuel and lubricating oils to the relevant parts of the engine, under pressure.

Additionally, the power produced by the engine is used to generate electricity for engine ignition and many other aircraft electrical systems, and hydraulic pressure for fight control, undercarriage and braking systems. There may also be components for providing air conditioning. Taken together, these various systems are referred to as the engine accessories.

To enable us to identify specific areas of fire risk we divide jet engines into five “Zones”.

* Compressor Zone One
* Combustion Zone Two
* Turbine (Exhaust) Zone Three
* Accessories Zone Four
* Reduction Gearbox Zone Five

**HOW DOES A JET ENGINE WORK?**

The jet engine is an internal combustion engine which, like all such engines, produces power by the controlled burning of fuel. The way it works is set out in the detailed descriptions of the five zones below.

**Compressor Section -Zone 1**

The compressor section consists of a series of close fitting rotating and static discs that are fitted with aerodynamically shaped blades. When the engine is working these blades draw air into the engine and compress it. In some engines this can be up to a pressure of 30 bar. The compressed air is then forced into the combustion section. The compressor is driven by a shaft that is connected to the turbine.

**Materials used within Zone 1**

Titanium alloy

Aluminium alloy

Composite materials

Steel

Nimonic alloys

**Combustion Section - Zone 2**

This is an annular steel flame tube or ring of tubes designed to achieve the most efficient combustion of the fuel/air mixture.

The combustion chamber has a number of burners to vaporise the fuel before mixing it with the compressed air.

Ignitors are provided to initiate combustion. Once combustion has commenced it becomes continuous for as long as fuel is fed into this section. With combustion established, there is a massive expansion of extremely hot gases, with a consequent huge increase in pressure. The design of the combuster then results in the gas moving into the turbine at very high speed.

**Materials used within Zone 2**

 Special nimonic alloys

Temperature within this zone can exceed 1800ºC

**Turbine Section - Zone 3**

The turbine, in common with the compressor, consists of one or more stages of alternate rotating and static discs. The high speed gas flow from the combustion section passes through the various turbine stages, causing it to spin. After this, it continues on out through the tail pipe as a powerful jet of hot gas, thrusting the engine which in turn moves the aircraft forward.

Because the turbine is connected to the compressor via a shaft, more air is drawn into the intake and the process carries on continuously.

**Materials used within Zone 3**

Titanium alloy

Nimonic alloy

Steel

Temperature within this zone 800ºC approx.

**Accessories Section - Zone 4**

Within this section we will find all the necessary components which are required to make the engine work.

1. Fuel Pumps

These pumps will deliver the fuel to the burners within the combustion section at high pressure. This pressure could be as high as 30 bar.

1. Hydraulic Pumps

These pumps will deliver hydraulic fluid to various sections of the aircraft at very high pressures. This pressure could be as high as 200 bar.

1. Gearbox (accessory)

This is designed to drive many different components within the engine and will contain lubricating oil.

1. Electrical Generators

These will provide power to electrical systems throughout the aircraft at fairly low voltage similar to the car alternator.

1. Heat Exchangers

These are fed with fuel from the fuel system which is then used to cool lubricating oil.

**Reduction Gearbox - Zone 5**

The reduction gearbox is used to reduce the rpm of the main shaft which in some turboprop engines could be as high as 40,000 rpm, down to a speed that is suitable for propellers. This would be in the range 2,500-4,000 rpm.

Materials used within Zone 5

**Aluminium alloy**

**Magnesium alloy**

**FIRE HAZARDS - JET ENGINES**

The main risk of fire occurring within jet engines will usually be associated with the accessory section, Zone 4.

As previously mentioned this zone contains:

Fuel Pumps

Fuel Lines

Hydraulic Pumps

Hydraulic Lines

Oil Pumps

Oil Lines

Gearbox (Accessory)

Electrical Generators

If any of these fuel pumps or fuel lines leak, the fuel or lubricants will be released in mist form under high pressures. Ignition from hot engine parts or electrical sparking could, under these circumstances, result in a fierce fire in this section.

It is protected by an inbuilt fire extinguishing system that can be operated by the flight deck crew, or on some aircraft, externally by ground crew of Fire Service personnel.

**Compressor Section - Zone 1**

This section could be affected by foreign object damage, e.g. bird strike, stones. This would cause the compressor blades to clash together violently, generating heat and combustible Titanium dust. However, any combustion in this section would most probably be a flash fire of short duration.

**Combustion Section - Zone Two**

This section is designed to operate at very high temperatures. However component failure within this section would result in a very persistent intense fire. If not dealt with quickly, **by isolating the fuel supply**, this intense combustion could very rapidly migrate into other areas of the engine.

**Turbine Section - Zone Three**

This is another section of the engine that is designed, from the word go, to withstand high temperatures. Fires in this section are generally caused by poor engine start procedures. Fuel can collect within the turbine/tailpipe area and burn, resulting in a running fuel fire from the rear of the engine.

**Reduction Gearbox - Zone five**

The main hazards with the reduction gearbox are lubricant oil and possibly the presence of combustible metals, i.e. magnesium alloy.

**ENGINE LOCATIONS**

The location of the engines can in itself reveal various problems for the fire crews.

**Rear Mounted Engines**

Deployment of appliances and fire crews

Height

Transfer of heat

Retention of heat

**Buried Engines**

Engines enclosed within the structure of the aircraft, such as Nimrod and most military fast jets like Tornado, F15 and Harrier, present particular problems:

Access

Heat transfer

Retention of heat

**Pylon Mounted**

In general, pylon mounted engines offer good access. When involved in a wheels up landing, fuel lines could be left open if the engine is torn away. Also, damage could occur to the internal wing fuel tanks of the aircraft.

In addition to engines for propulsion, very many aircraft are fitted with Auxiliary Power Units. Whilst being invaluable to aircraft operators and crews, they can present fire crews with difficult problems.

**Auxiliary Power Unit – APU**

This is a small turbine engine to supply electrical power to aircraft systems, i.e. air conditioning, lighting when the aircraft is on the ground with the main engines shut down.

It can be started in flight to provide power to the electrical systems in the event of normal power generation difficulties.

Power for main engine starting is made possible either by supplying electricity to a starter motor or air, bled off from the compressor, to operate a low pressure pneumatic starter.

Fire hazards associated with auxiliary power units parallel those of aircraft main engines.

The location of the auxiliary power unit can in itself be a problem as access will be difficult. They are located in various positions within the aircraft body, but most often are found within the tail section of the aircraft.

The auxiliary power unit can in itself be a problem as access will be difficult. They can be located in various positions within the aircraft, but most often are found within the tail cone of the aircraft.

They are protected by inbuilt fire extinguishing systems which can be operated from the flight deck or external methods. They also have automatic shutdown systems.

Station training must include location of external controls and methods of operation.

**GENERAL HAZARD AREAS**

These vary depending on the power of the engine fitted. **In general, stay away from aircraft engine intake and exhaust areas**. **Both of these areas have the capability to lift personnel off their feet and in one case, blow the person considerable distance, the other sees the person ingested into the engine**. It doesn’t take much imagination to foresee the results of such an event.

Reverse thrust mechanisms on jet engines are also an area of concern. In general, they consist of large individual components that when actuated, move very rapidly and with great force. Personnel should make every effort to familiarise themselves with the various types of mechanism that could be encountered.

Remember also, that propeller driven aircraft have lethal potential if not treated with caution. The chances of recovering from a propeller blade strike are extremely low.

All aircraft operators will issue you with safety charts regarding danger areas surrounding engines. If in doubt, stay away from engine intake and exhaust areas if engines are still running. Contact pilot to request shut down of engines.

**TACTICS AND TECHNIQUES**

The tactics and techniques required to successfully deal with a fire involving an aircraft engine will depend on a number of factors, such as:

* Aircraft type/size
* Engine type/size
* Position of engine
* Position of aircraft
* Weather conditions
* Equipment/media availability
* Number and experience of the crew

Although these engines are normally on a much smaller scale to large jet engines, they still present fire crews with danger and difficulty.

It will also depend on the section of the engine involved and the magnitude of the fire. For instance, a fire resulting from a component failure at a high power setting during take-off could quite easily see the whole engine core involved. In these circumstances, dual application of BCF and high volume water spray may be the required approach for a successful conclusion, on the other hand, if the problem consists of an ignited release of fuel due to a faulty pump in the accessory section, then access to this zone through fire access or maintenance panels and the application of BCF or CO2, may be the correct action. In all cases though, the circumstances will dictate the tactics used.

**Points to Consider**

* Positioning of appliances and crews so that monitors and side lines are able to cover, not only the immediate fire situation, but beyond, should the situation escalate.
* Light aircraft are very vulnerable to a rapid spread of fire into the cabin area from the engine bay. Speedy and positive action is required to ensure control of the situation.
* The characteristics associated with aviation fuels should be borne in mind and included in the general assessment of risk at such an incident.
* Fuel spillages will require a foam blanket for post fire security.
* BCF, CO2, and as an option, dry powder, can be applied directly into air intakes. Water spray should be considered for cooling with dual application, this is considered a proven method of dealing with this type of aircraft fire.

**REAR MOUNTED ENGINES**

These engines produce specific problems for firefighters.

In particular, positioning for such an incident can be difficult. Great care must be taken to ensure that escape chute deployment is not obstructed. This usually results in vehicles having to be positioned near the nose of the aircraft. With large aircraft, this can make the distance to the engines for monitor projection excessive. Additionally, when able to position on the rear, attention must be paid to potential drop areas in the event of structural collapse.

Due to the close proximity, or in some cases, the fact that the engine is contained within the rear fuselage, the potential for fire to spread into the cabin area is high. Therefore, an early entry into the aircraft to examine the interior for heat transfer is recommended.

If personnel are required to deploy media through fire or maintenance access panels, ladders may be necessary.

**AUXILIARY POWER UNIT FIRES (APU)**

In most cases, fires involving the APU are dealt with using the in-built fire extinguishing and shut down system. These systems can be operated by flight deck crew, ground crew or fire service using external controls. APU’s are often located in confined spaces, therefore consideration must be given for BA to be used by crews entering these areas.

Hazards and difficulties that firefighters may encounter whilst dealing with them are largely similar to those found during incidents with rear engine aircraft. However, in the event that the onboard system fails to deal with an APU fire, gaining access to it will probably be the most difficult part of the operation. With a large number of aircraft, firefighters can expect to need to get themselves and their equipment up to a height of 6 metres and more. This will necessitate the use of ladders or a stable platform of some kind, if available.

Once there, access to the inside of the APU housing will be your next problem. If the fire involves the core, then complimentary media and water spray may be effective, applied through the intake. However, if the fire is involving Zone 4 then some means of exposing the accessories needs to be found. Locating the catches and opening the covers may be an option, though the heat of the fire may have melted them beyond operation. If this is the case then serious consideration will need to be given to creating an opening using a suitable cutting tool. A drastic measure perhaps but better a ragged hole in an APU cover than a blackened heap of scrap aluminium on the ramp.

**ENGINE FIRE - SUMMARY**

Keep in mind the fact that this training note is a general guide to the understanding of how the various aircraft engines work and some of the tactics and techniques to deal rapidly with the problem you may face.

In order to deal effectively and successfully with an engine related incident, firefighters must, in the first place, ensure the safety of themselves and their colleagues. Safety must be established at the top of their priority list. Remember, one injured firefighter means probably three firefighters out of the team. Aircraft engines are dangerous.

The media, tactics and techniques required for any given engine will depend on the type of fire and the location within the engine or engine nacelle.