**INDIAN INSTITUTE OF TECHNOLOGY KANPUR**

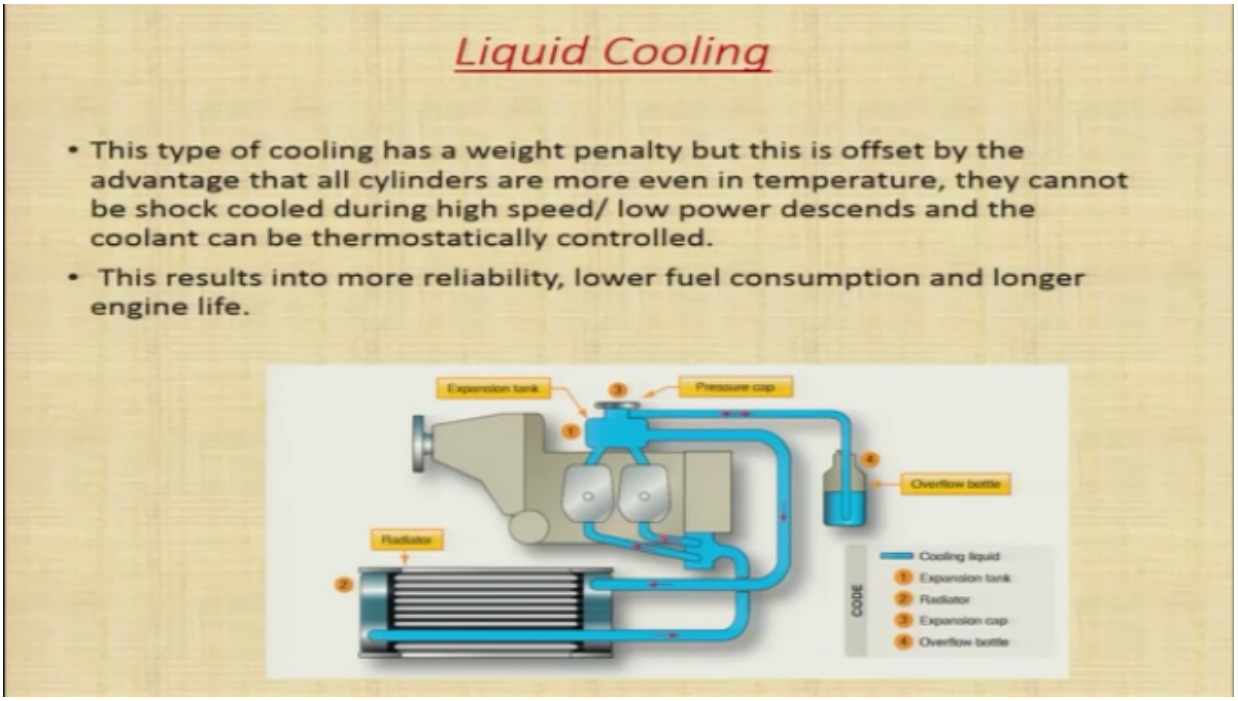
**NPTEL**

**NPTEL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING**

**Course Title**
**Aircraft Maintenance (Engines)**

**Lecture - 12**
**Exhaust Systems**

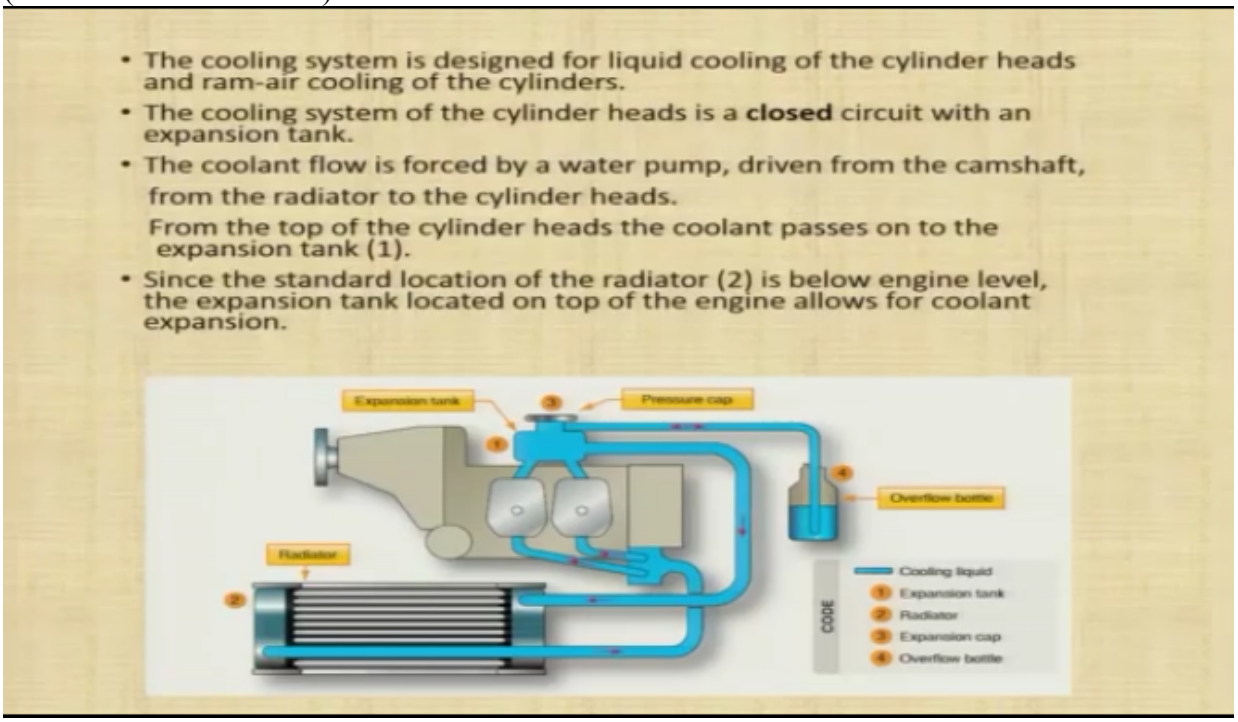
**By**
**Prof. A.K Ghosh & Mr. Vipul Mathur**
**Department of Aerospace Engineering**
**IIT Kanpur**




So this liquid cooling this has its own set of advantages, disadvantages as we know that every system has its own advantages and disadvantages, this liquid cooling also has its advantages and disadvantages, that disadvantage is that it has weight penalty because you have more number of parts, you have more number of parts responsible for liquid cooling, so it adds to weight, but this penalty is offset by advantage that all the cylinders are more even in temperature, your all the cylinders are more evenly cooled, they cannot be shock cooled during high speed or low power descends as well as the case in your air cooling, they cannot be shock cooled during high speed and low power descends and the coolant can be thermostatically controlled.

So the coolant is thermostatically controlled you do not get shock cooling and all the cylinders are evenly controlled, so you have more number of advantages, this results into more reliability, lower fuel consumption and longer engine life, so these advantages they provide you more reliability, they lower your fuel consumption and provide longer engine life.

(Refer Slide Time: 01:35)



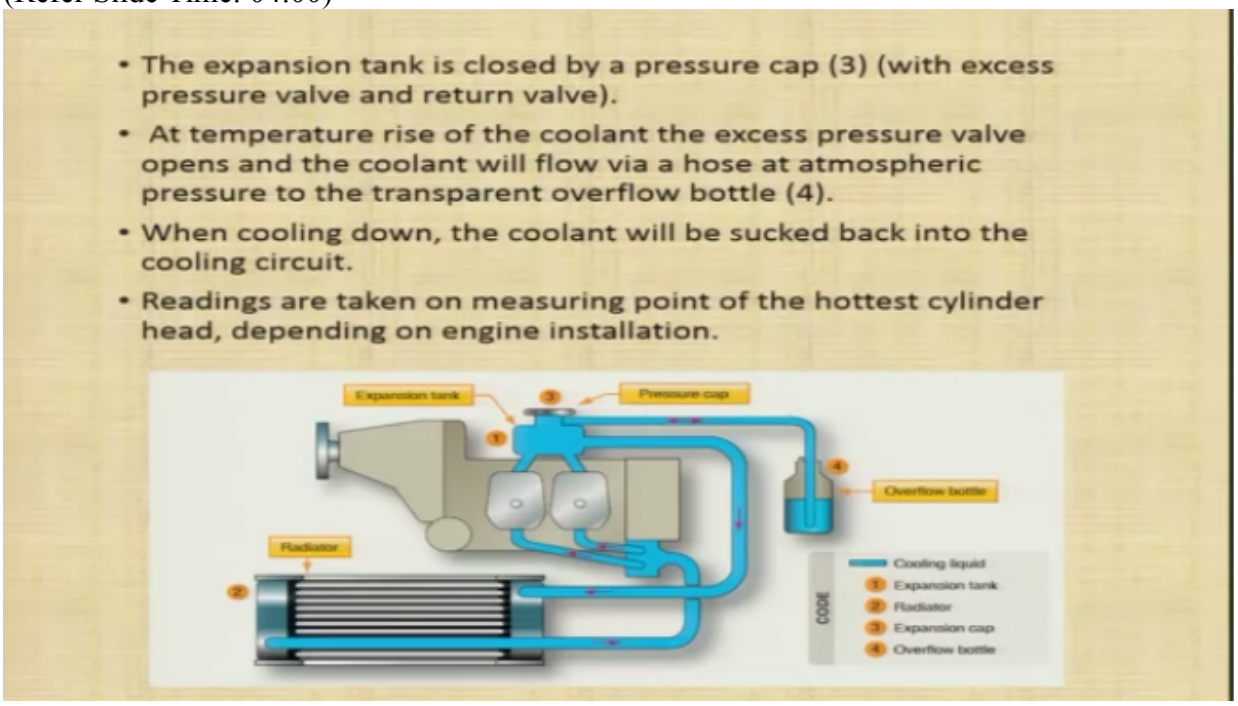

The cooling system is designed for liquid cooling of the cylinder heads and ram-air cooling of the cylinders, so you can see this is a combination of air cooling and liquid cooling, so this cooling system this is providing liquid cooling for the cylinder heads and ram-air cooling for the cylinders.

The cooling system of the cylinder head is a closed circuit with an expansion tank, now you can see in the diagram there is a schematic diagram here, you can see this is your radiator, then this is your water pump here you can see this is your water pump, then these are your cylinders, this is your expansion tank, on top of the expansion tank you have the pressure cap and then you have the overflow bottle, so this cooling system of the cylinder heads is a closed circuit within expansion tank, so with an expansion tank this system is working, the coolant flow is forced by a water pump, now this water pump is forcing the coolant from the cylinder head, so this water pump, this is forcing the coolant from the radiator to the cylinder heads, and this water pump is being driven by the camshaft, by the engine camshaft, so this water pump is been driven by the engine camshaft and this water pump is forcing the liquid, the coolant from the radiator, so you can see this, this coolant is moving out of the radiator and to the water pump is going to the cylinders, from the top of the cylinder heads the coolant passes on to the expansion tank.

Now this coolant is taken from the radiator, this water pump is pushing this liquid coolant from the radiator and providing it to the cylinder heads. From the cylinder heads the coolant is passing to the expansion tank, now since the standard location of the radiator is below engine

level, now this radiator is on the lower side, on the lower level, that expansion tank located on top of the engine allows for coolant expansion, so this expansion tank allows for coolant expansion.

(Refer Slide Time: 04:00)




The expansion tank is closed by a pressure cap, now we have seen that this expansion tank is a closed by a pressure cap, you have a cap here which is a pressure cap, this pressure cap has an excess pressure valve and a return valve, so this cap, this is an excess pressure valve and a return valve.

At temperature rise of the coolant the excess pressure valve opens, so when the temperature of the coolant increases, now since the coolant is coming from the radiator via the water pump, it is going to the cylinder heads, from the cylinder heads it is extracting the heat and going to the expansion tank.

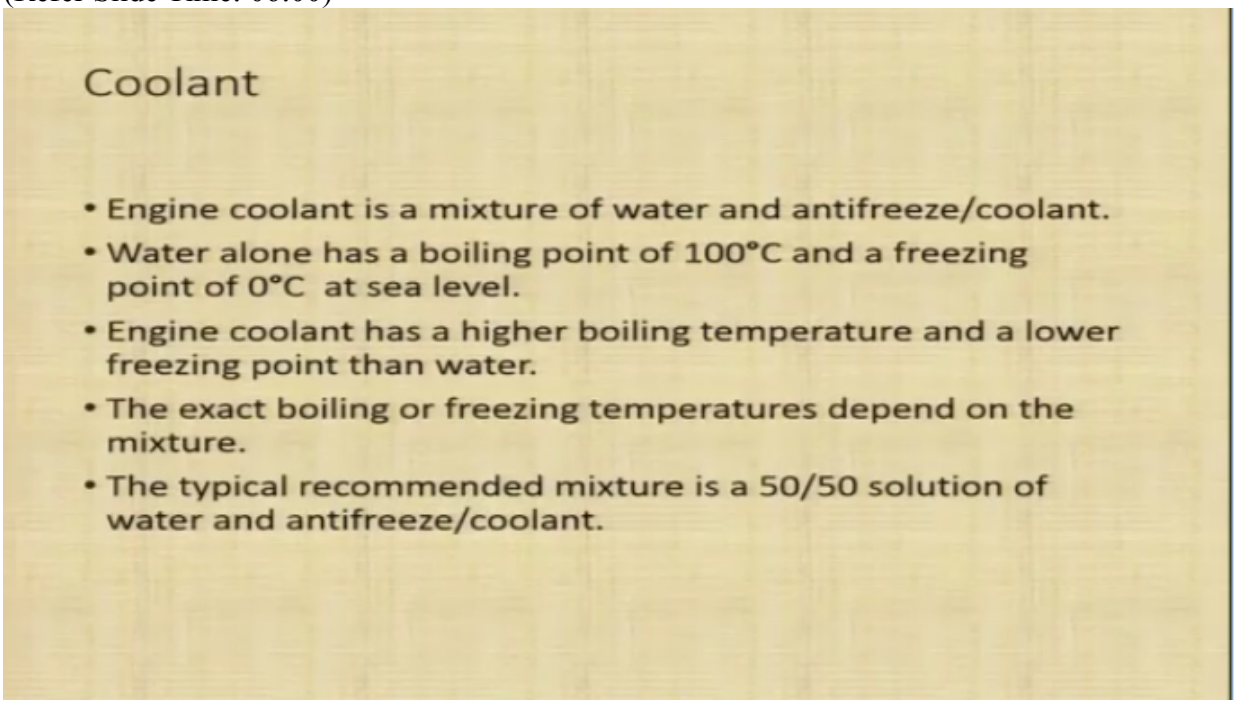
Now with the heat the coolant temperature has increased and because of the increase temperature of the coolant, the excess pressure valve in this pressure cap this opens, and the coolant will flow via a hose at atmospheric pressure to the transparent overflow bottle.

So now this excess pressure valve will open because of the increase temperature of the coolant, it will flow through this hose to the transparent overflow bottle.

Now when cooling down, now when the temperature reduces the coolant will be sucked back into the cooling circuit, now as the temperature reduces that coolant goes back into the system, so we have seen earlier also that the cylinder head temperature is measured at the hottest cylinder head depending on the ingenious solution but some of the modern engines they are being equipped with cylinder head, temperature sensors on all the cylinders so that we have the

CST measurement for each cylinder, so this was about a combination cooling, air cooling and liquid cooling, this is the diagram this shows how the cylinder heads are being liquid cooled.

(Refer Slide Time: 06:00)

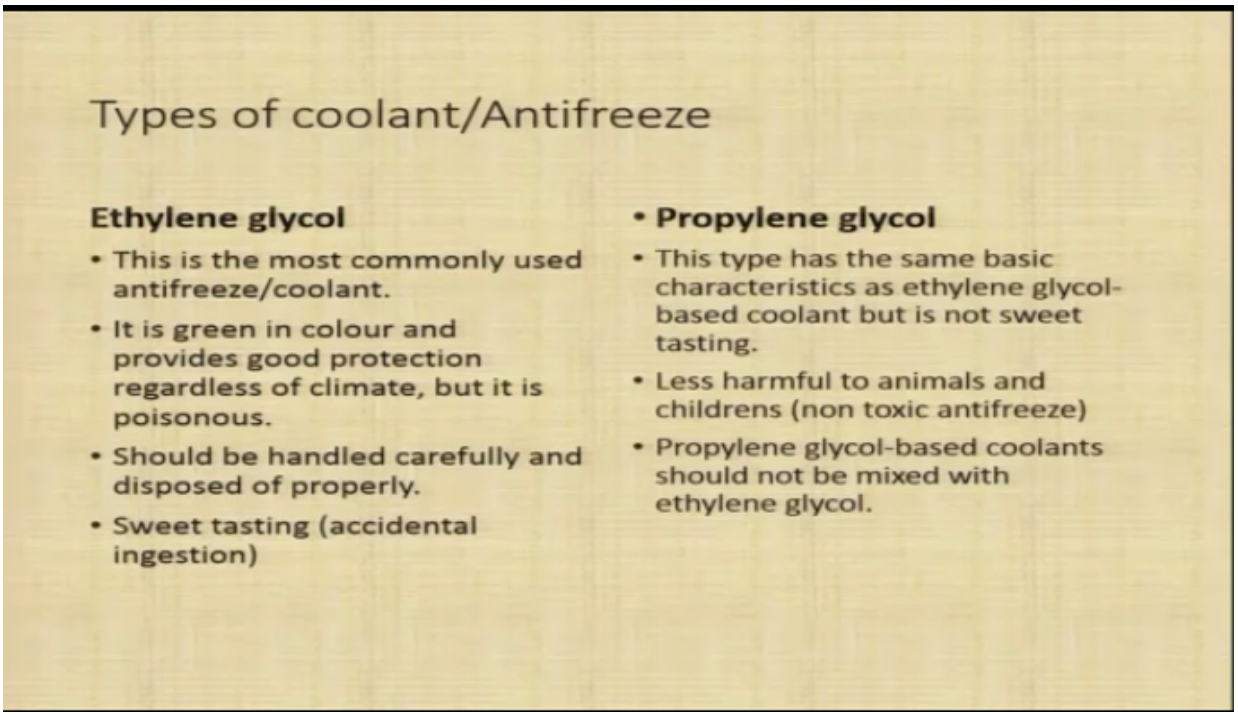



Now in the liquid cooling we are using a coolant, we mentioned just now that we are using the coolant, what is that coolant? Engine coolant is a mixture of water and antifreeze coolant, so it is a mixture of water and antifreeze coolant, water alone has a boiling point of 100 degree centigrade and a freezing point of 0 degree centigrade at sea level.

Engine coolant has a higher boiling temperature and a lower freezing point than water, so the advantage of engine coolant is that it has a higher boiling temperature and a lower freezing temperature as compared to water.

The exact boiling or freezing temperatures depends on the mixture. The typical recommended mixture is a 50/50 solution of water and antifreeze coolant, so in case if are supposed to mix the coolant with water to look ideal combination, a typical combination is 50/50 solution of 50% water, and 50% antifreeze coolant.

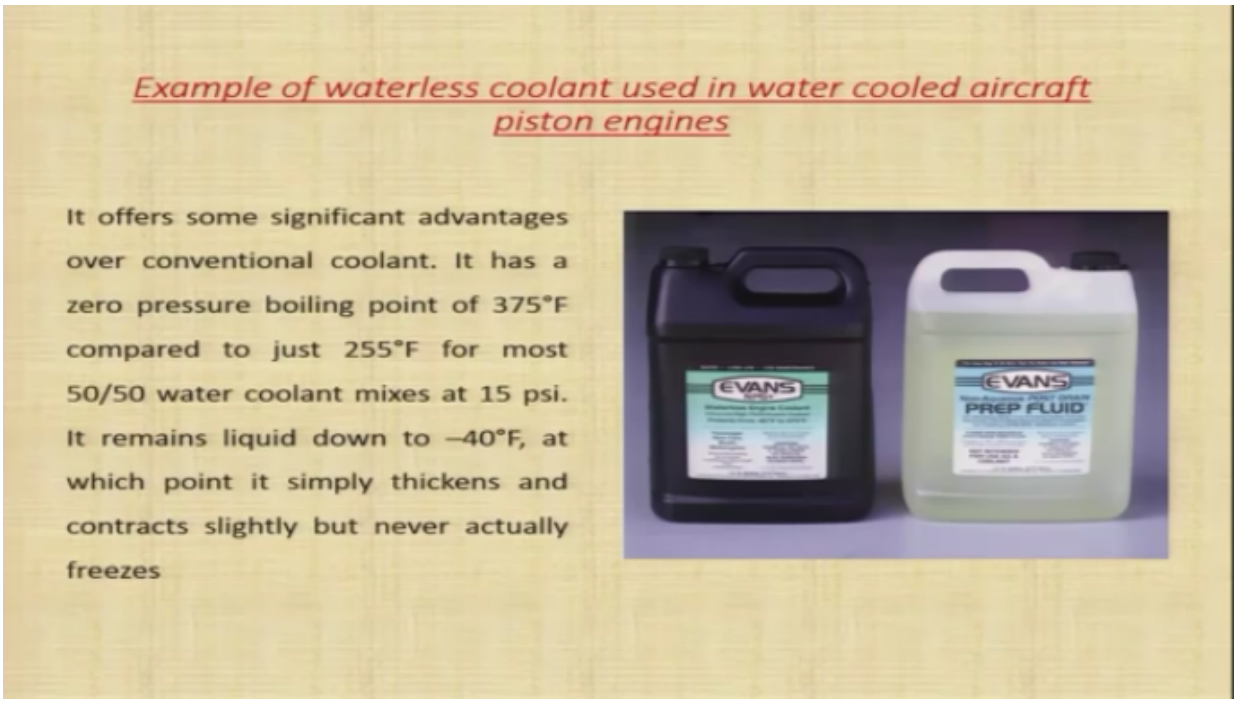
(Refer Slide Time: 07:02)




Now what are the types of coolants being used? Let us see there are two types, one is ethylene glycol and another is propylene glycol, coming to ethylene glycol this is the most commonly used antifreeze coolant, it is green in colour and provides good protection regardless of climate, but it is poisonous, so it provides good climate, good production, but it is poisonous, it should be handled carefully and disposed of properly.

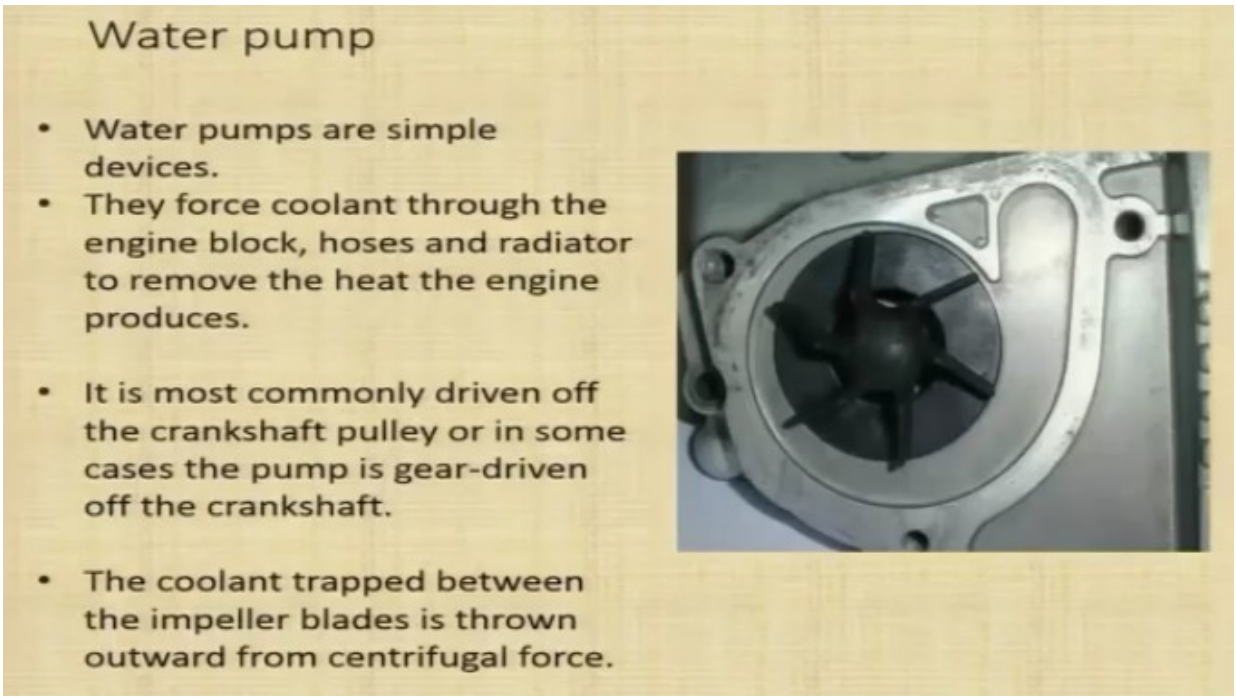
Propylene glycol, this type has the same characteristics as ethylene glycol but is not sweet in taste, it is less harmful to animals and childrens. Propylene glycol-based coolants should not be mixed with ethylene glycol, but in aviation in aircraft engines the most common used coolant is ethylene glycol.

(Refer Slide Time: 07:54)




Now here in the picture you can see some example of water less coolant used in water cooled aircraft piston engines, so there are coolants in the market where we are not supposed to mix water, they are all water less coolant and it offers some significant advantages over conventional coolant, it has a zero pressure boiling point of 375 degrees Fahrenheit compared to just 255 degrees Fahrenheit for most 50/50 water coolant mixes at 15 PSI, it remains liquid down to -40 degrees Fahrenheit at which point, it simply thickens and contracts slightly but never actually freezes, so you can see some of the advantages mentioned here were waterless coolants which are being used, these type of coolants are being widely used in the engine, here you don't have to mix them but water and they are all water less coolant and we just have to use them directly, they have much lower freezing points and better operating characteristics.

(Refer Slide Time: 08:54)




In the liquid cooling we mentioned about the water pump, this water pump was directing the coolant from the radiator to the engine cylinder head, so let us see what is a water pump, it is a simple device, it forces coolant through the engine block or the radiator, hoses to remove the heat the engine produces.

It is most commonly driven off the crankshaft pulley or in some cases the pump is gear driven off the crankshaft and in one of the example we have seen that the water pump was driven by the camshaft.

The coolant trapped between the impeller blades is thrown outward from the centrifugal force, here in the figure you can see the impeller blades, these are your impeller blades, the coolant trapped between these impeller blades is thrown outward from the centrifugal force.

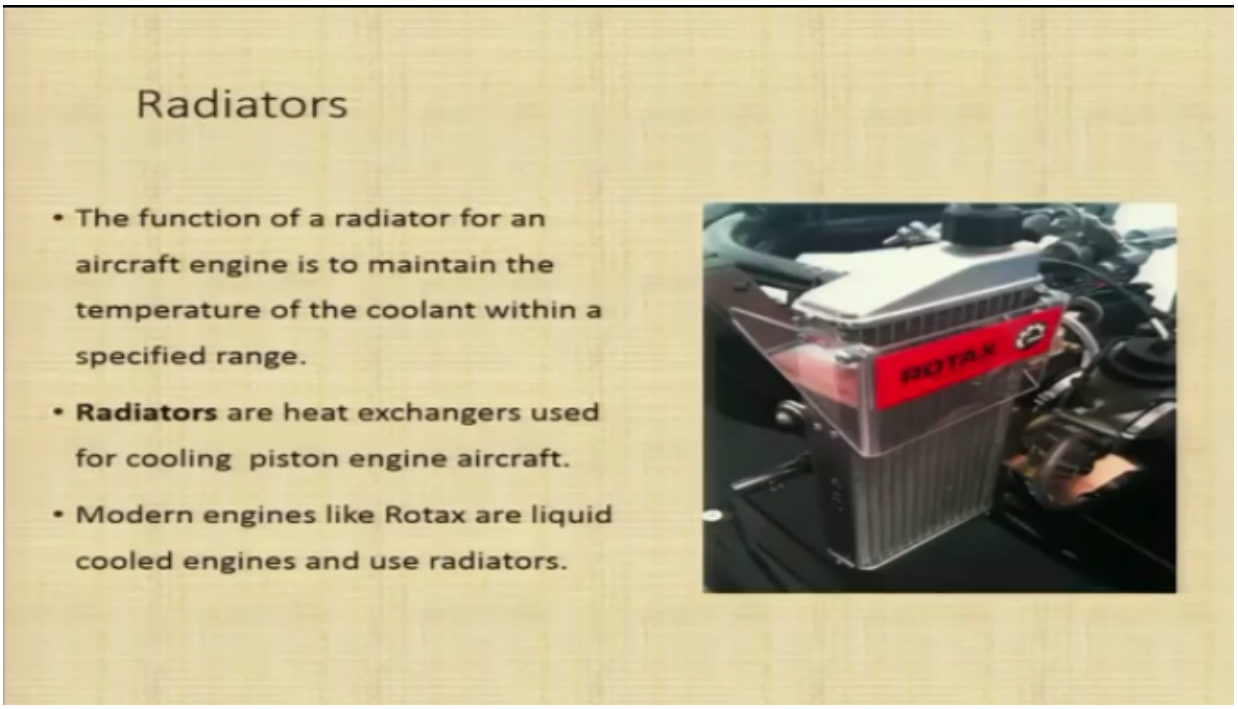
(Refer Slide Time: 09:55)

- A suction (vacuum) is created in the center area of the pump housing.
- Coolant is drawn from the radiator via the radiator hose into the water pump.
- The coolant is then circulated through the engine where it picks up heat from the combustion process and then is sent back into the radiator where the heat is transferred to outside air.

A suction of vacuum is created in the center area of the pump housing, so a suction is created in the center area of the pump housing, cooling is drawn from the radiator via the radiator hose into the water pump, so because of this suction in the center portion of the pump the coolant is drawn from the radiator into the pump.

The coolant is then circulated through the engine where it picks up heat from the combustion process and then is sent back into the radiator where the heat is transferred to the outside air, so we have seen in the diagram, in the schematic diagram of the liquid cooling, the coolant is circulated through the engine, it picks up the heat from the combustion process and the coolant is first sent through the expansion tank to the overflow bottle and once the temperature comes down the coolant is again sent back to the radiator, and the outside air extracts the left over heat from the coolant.

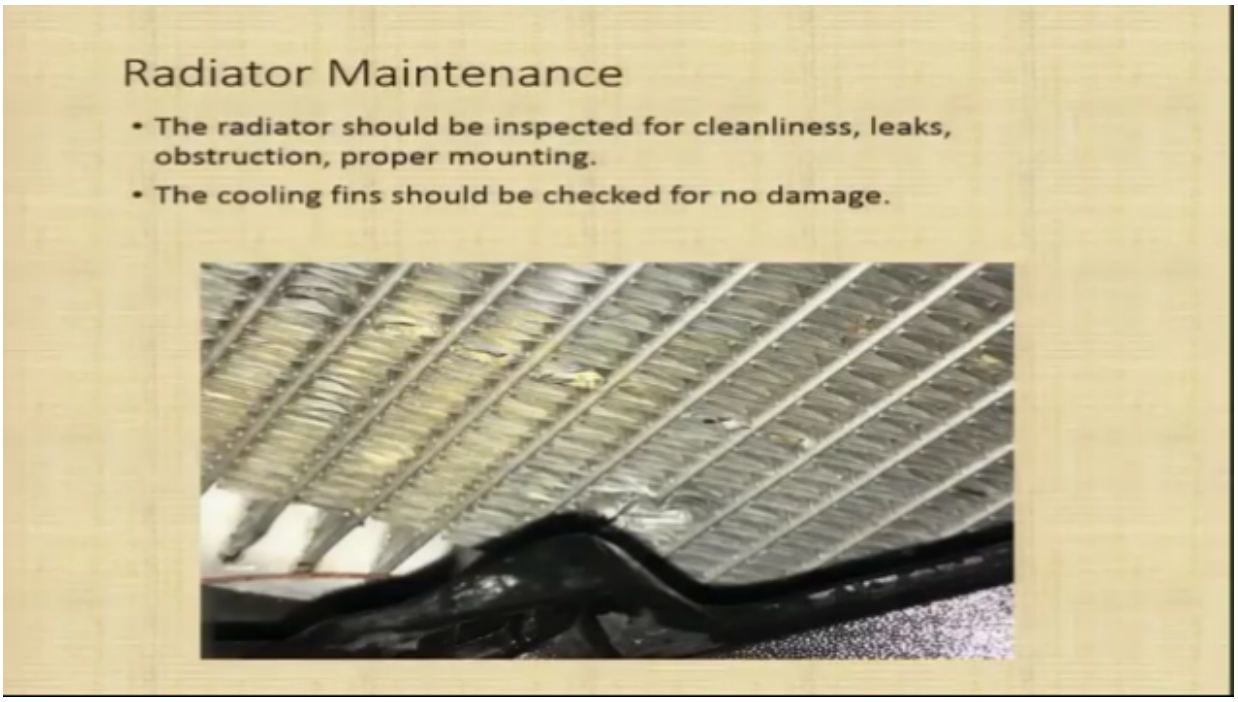
(Refer Slide Time: 10:58)




We have also seen the radiators, so a radiator in one of the engines is shown here in the diagram, the function of the radiator for an aircraft engine is to maintain the temperature of the coolant within a specified range, so we have to maintain the temperature of the coolant in the specified range, so the radiator helps in doing so.

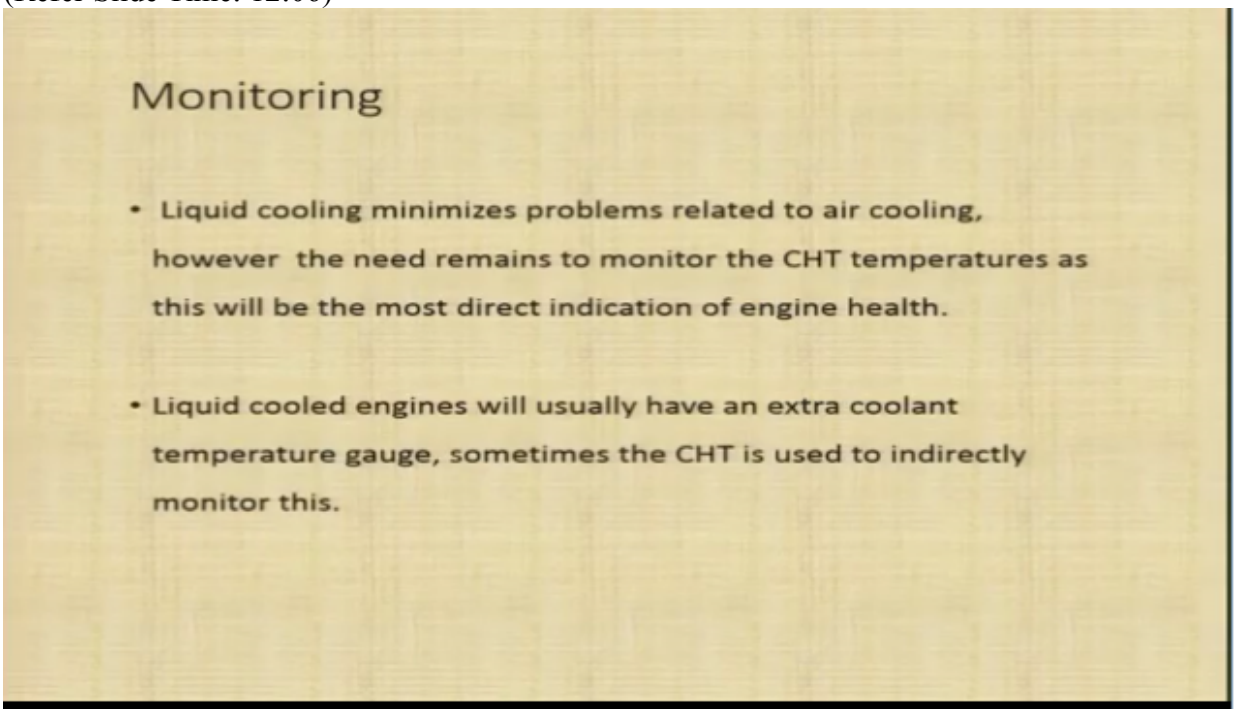
Radiators they are heat exchangers used for cooling piston engine aircrafts, and modern engines like Rotax are liquid engines and are using radiators, so we will see in our videos, we will see the Rotax engines also we will see the radiators on the aircraft.

(Refer Slide Time: 11:34)




Now the radiators we need to do some inspections, some maintenance on the radiators, there should be inspected for cleanliness, leaks, obstructions and proper mounting. The cooling fins should be checked for no damage, you can see the fins of the radiator here, you can see some damages also in the fins, so we need to check that there is no such damage on the fins, there is no leakage in the radiator, there is no obstruction in the cooling fins and the radiator is properly mounted.

(Refer Slide Time: 12:06)



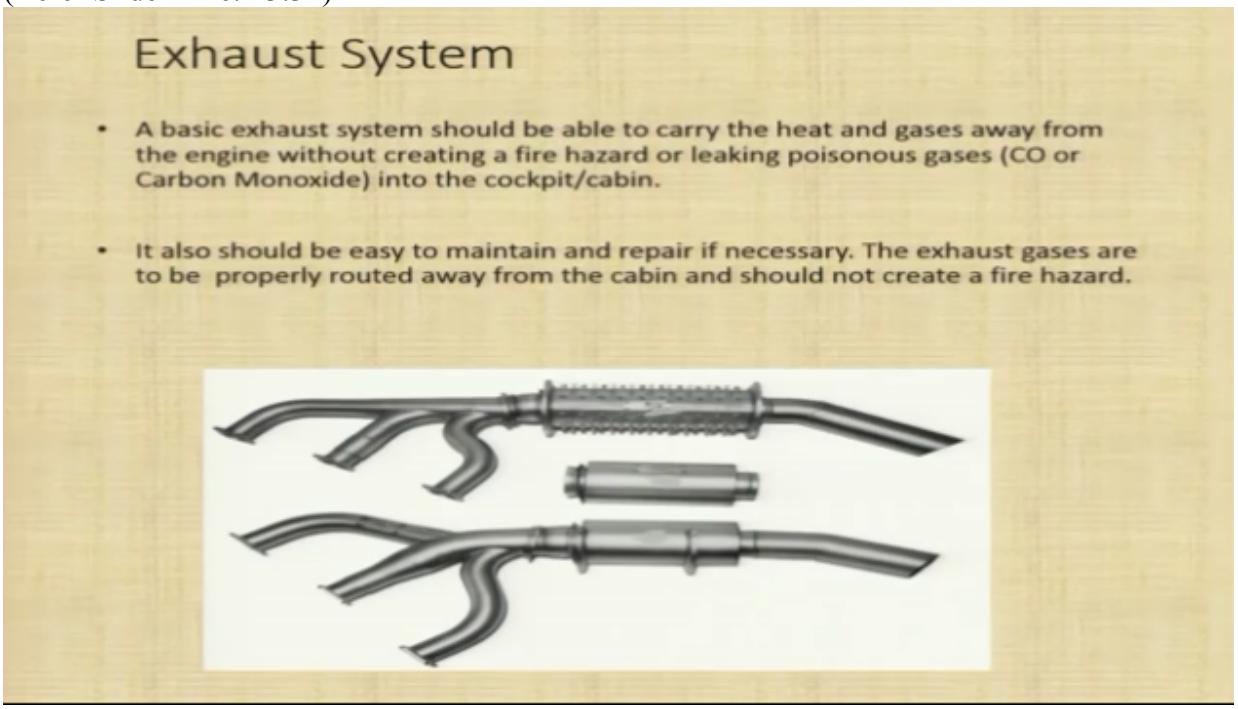
Monitoring, liquid cooling minimizes problems related to air cooling, however the need remains to monitor the CHT temperatures as this will be the most direct indication of engine health.

We've seen what air cooling is, we have seen what is liquid cooling and liquid cooling this minimizes lot of problems that air cooling had, but still we need to monitor the cylinder head temperatures of the cylinders as this will be the direct indication of our engine health.

Liquid cooled engines will usually have an extra coolant temperature gauge, sometimes the CHT is used to indirectly monitor this, so in case of liquid cooling we will also have an additional gauge like the coolant temperature gauge or the water temperature gauge which will give us the temperature of the coolant in addition to the cylinder head temperature, gauge being used in all over the engines.

So our next system is exhaust system, the fuel air mixture which is burning inside the engine cylinders is to be exhausted, the exhaust gases are to be exhausted out of the system, how the exhaust gases are being rooted out of the system, out of the engine is shown in this system, let us see what is all exhaust system about.

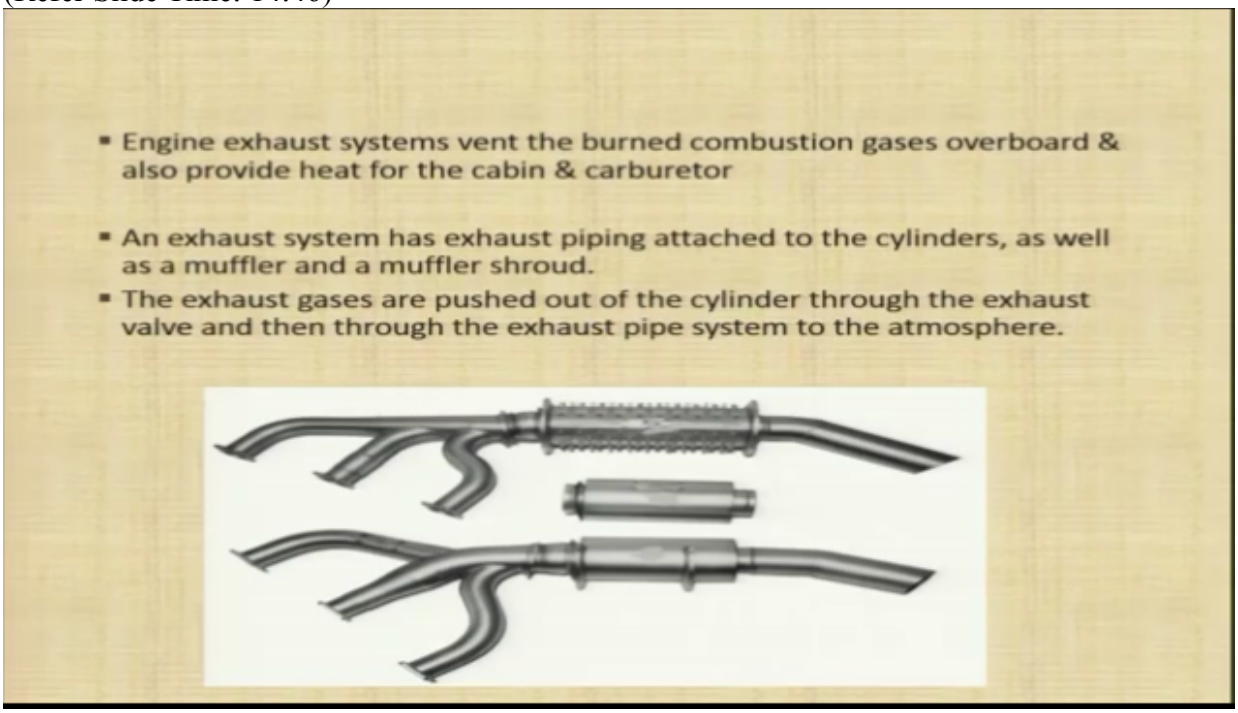
(Refer Slide Time: 13:34)




A basic exhaust system should be able to carry the heat and gases away from the engine without creating a fire hazard or leaking poisonous gases into the cockpit or the cabin, so the basic purpose of the exhaust system is to carry the heat and gases away from the engine, so that they do not become a fired hazard or the poisonous gases carbon monoxides specially, they do not leak into the cabin or the cockpit, so the exhaust system this will carry the heat and gases away from the engine.

It also should be easy to maintain and repair if necessary, so the system should be repaired and maintained easily, the exhaust gases are to be properly routed away from the cabin and should not create a fire hazard, so the routing of the exhaust gases they should be properly routed and they should not pose a fire hazard.

(Refer Slide Time: 14:46)

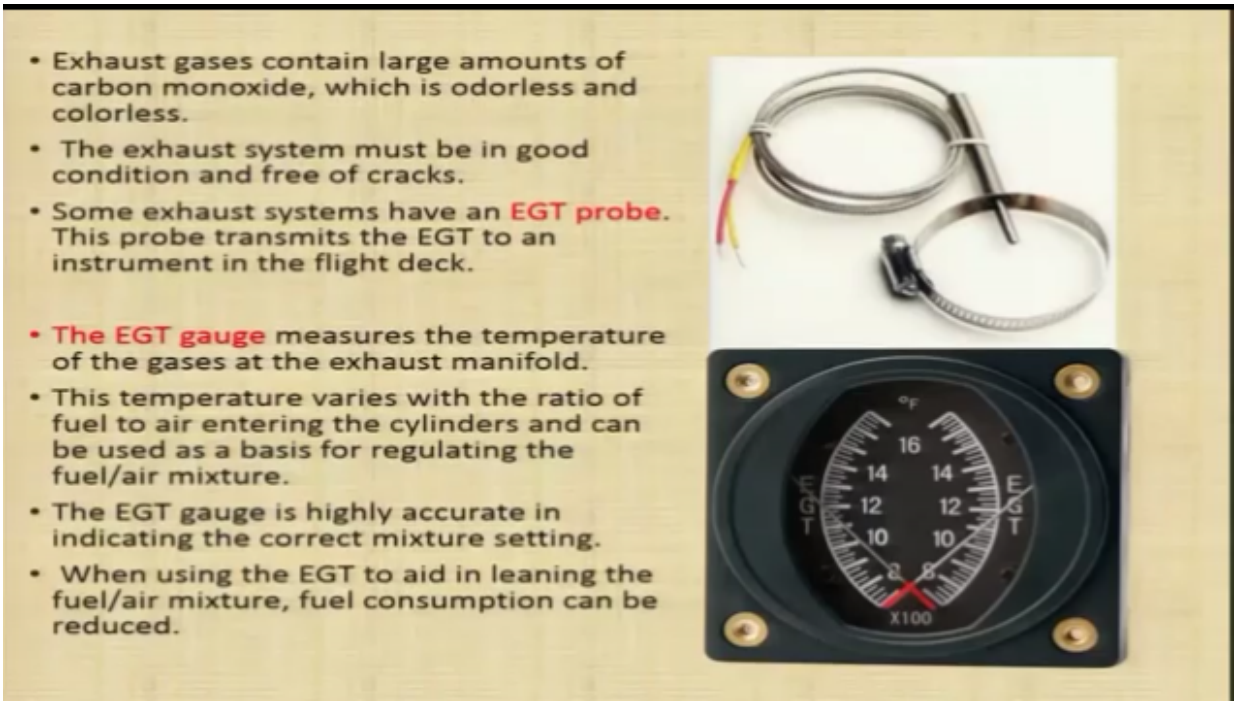



Engine exhaust systems vent the burned combustion gases overboard and also provide heat for the cabin and carburetor, so the exhaust system they do not only vent out the burned combustion gases but they also provide heat for cabin and carburetor for providing cabin heating, for providing carbon heating for the carburetor or the fuel metering system

An exhaust system has exhaust piping attached to the cylinders, as well as a muffler and a muffler shroud, so we will see in the diagrams that the cylinders they are all having exhaust piping attached to that, and you have a muffler and a muffler shroud, you can see here in this diagram, these are your exhaust pipes, this is your exhaust pipe from where the exhaust gases are going out, these tubes you can see they are connected to each engine cylinder where exhaust port of the cylinder and from there the exhaust gases are coming here, this is your muffler here and this is your muffler shroud, so this muffler shroud covers this muffler like this, and the exhaust gases are routed through this pipe and they are sent out of the engine.

The exhaust gases are pushed out of the cylinder through the exhaust valve and then through the exhaust pipe system to the atmosphere.

(Refer Slide Time: 16:20)




Exhaust gases contain large amounts of carbon monoxide which is odorless and colorless, we see that, we have seen earlier also that exhaust gases they have large amounts of carbon monoxide gas which is colorless and odorless.

The exhaust system must be in good condition and free of cracks, we will see what are the inspections to be done on the exhaust system, we will see how to maintain the exhaust system and the system should be in good condition and should be free of cracks.

Some exhaust systems have and EGT probe, the EGT is your exhaust gas temperature and some exhaust system they should have a exhaust gas temperature probe, you can see here in the diagram this is your probe for the exhaust gas temperature, this is your temperature sensor which senses the temperature of the exhaust gases.

This probe transmits the EGT to an instrument in the flight deck, this probe will transmit the exhaust gas temperature to a gauge in the cockpit. EGT gauge measures the temperature of the gases at the exhaust manifold, so this EGT gauge will measure the temperature of the exhaust gases in the exhaust manifold.

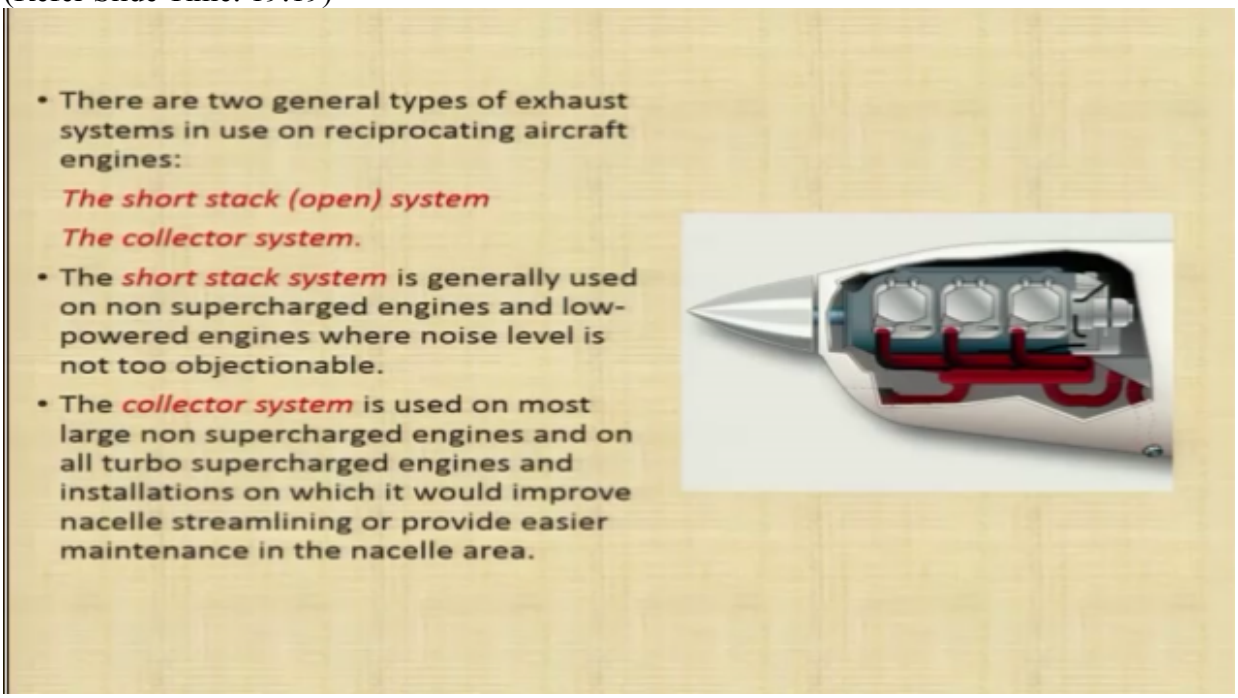
This temperature varies with the ratio of fuel to air entering the cylinders and can be used as a basis for regulating the fuel air mixture, so the temperature of the exhaust gases it varies with the ratio of fuel to air which is entering the cylinders and it can also become a basis for regulating the fuel air mixture, so we will see in our fuel system chapter that what a fuel air mixture is all about, we will see how we can vary the ratio of fuel and air mixture and what are the effects of having different ratios.

The EGT gauge is highly accurate in indicating the correct mixture setting, so you can see here this is the exhaust gas temperature gauge and this is your exhaust gas temperature probe, here this is the sensor which measures the temperature of the exhaust gases in the exhaust manifold,

from here this sensor picks up the temperature and transmits it to this gauge and from this gauge in the cockpit we can see what the temperature of the exhaust gases is.

When using the EGT to aid in leaning the fuel air mixture, fuel consumption can be reduced, so in this slide we have tried to show you that the fuel air mixture can also be adjusted, can also be correctly set while using a exhaust gas temperature gauge, so exhaust gas temperature is also an important parameter which we will see in the fuel system chapter also.

(Refer Slide Time: 19:19)

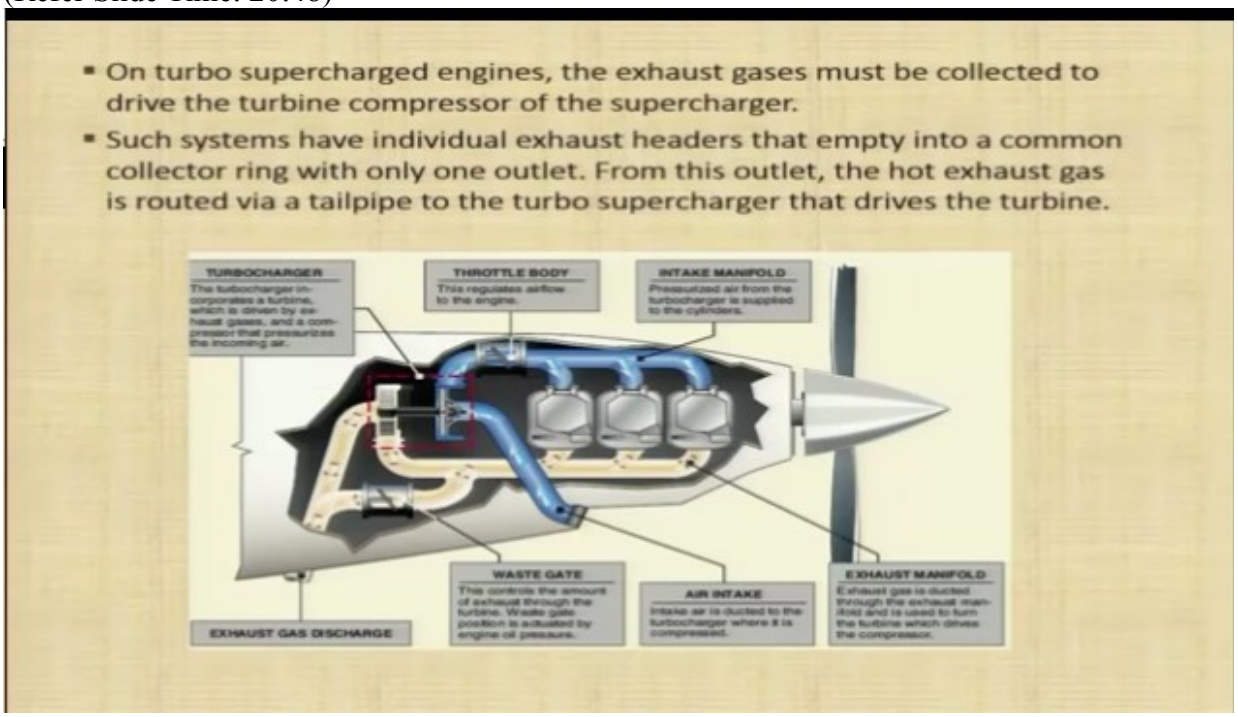



There are two general types of exhaust systems in use on reciprocating aircraft engines, so the reciprocating engines basically two types of systems, two types of exhaust systems are being used, the short stack system and the collector system.

The short stack system is generally used on non-supercharged engines and low-powered engines where noise level is not too objectionable, so the short stack system is mainly used on non-supercharge engines basically naturally escalated engines and low powered engines where noise level is not too objectionable.

The collector system is used on most large non-supercharged engines and on all turbo supercharged engines and installations on which it would improve nacelle streamlining or provide easier maintenance in the nacelle area, so the collector system is basically used on high powered engines, and also on turbo supercharged engines where nacelle streamlining or provide or easier maintenance of the nacelle area is provided, this is used on most large non supercharged engines and on all turbo supercharged engines, and installations on which it would improve nacelle streamlining or provide easier maintenance in the nacelle area, so this collector system is basically being used on high powered engines, non-supercharged engines or turbo supercharged engines.

(Refer Slide Time: 20:48)

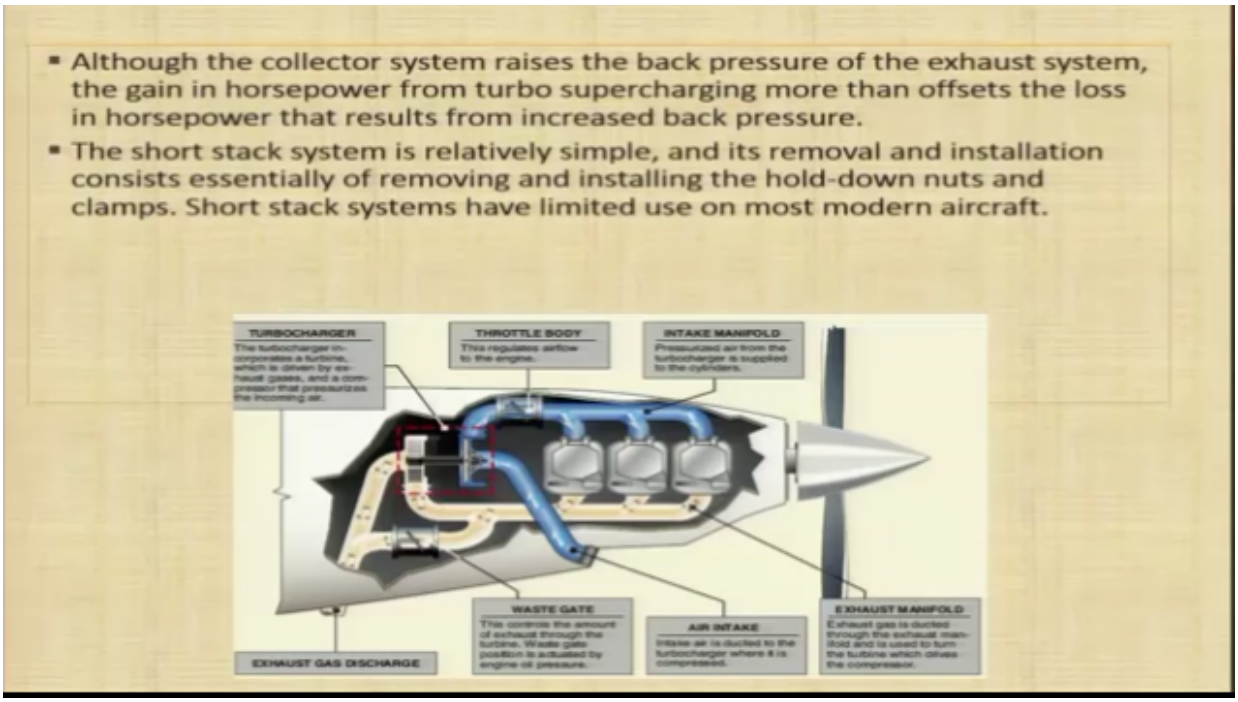



On turbo supercharged engines the exhaust gases must be collected to drive the turbine compressor of the supercharger, so we have seen in our earlier chapter in case of turbo charges the exhaust gases are being used to guide the turbine of the turbo charger, so on turbo supercharged engines the exhaust gases they must be collected to drive the turbine and compressor of the supercharger.

Such systems have individual exhaust headers that empty into a common collector ring with only one outlet, from this outlet, the hot exhaust gas is routed via a tailpipe to the turbo supercharger that drives the turbine, so here in the diagram you can see this is your turbo charger here, this is your throttle body, this is your intake manifold, this is your exhaust manifold, here from each cylinder you can see the exhaust gases are coming out, these are your exhaust gases and the exhaust gases they are driving the turbine of the turbo charger, and after driving the turbine of the turbo charger the exhaust gases are being routed out through the exhaust gas discharged pipe.

Here you can see, you can see the exhaust gases coming out from each cylinder going into the turbo charger to drive the turbine of the turbo charger, after driving the turbine of the turbo supercharger the exhaust gases are being exhausted out of the engine, such systems have individual exhaust header which empty into a common collector ring with only outlet, from this outlet the hot exhaust gas is routed via tailpipe to the turbo supercharger then drives the turbine.

(Refer Slide Time: 22:38)

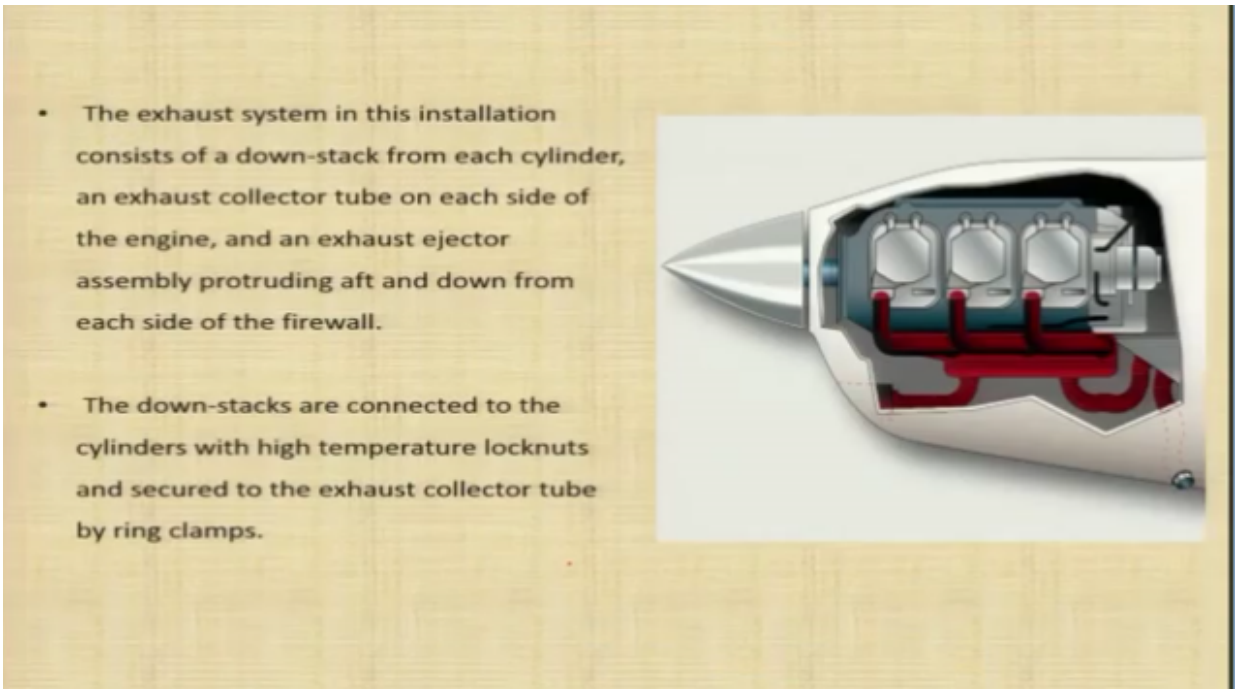



Although the collector system raises the back pressure of the exhaust system, so gain in horsepower from turbo supercharging more than offsets the loss in horsepower that results from increased back pressure, now this collector system this raises the back pressure of the exhaust system, this is one disadvantage where the exhaust or the collector system raises the back pressure of the exhaust system, but the gain in horsepower from turbo supercharging is offsets this loss in horsepower that is due to the increased back pressure.

Now the increased back pressure results in lowering of power on the engine, but the turbo supercharger increases the power and this increase of super charger power offsets the loss of power due to back pressure in the exhaust because of the collector system.

The short stack system is relatively simple, and its removal and installation consists essentially of removing and installing the hold-down nuts and clamps, so this short stack system this is very simple and the removal and installation is just removing and installing the hold down nuts and clamps. These short stack systems have limited use on most modern aircrafts.

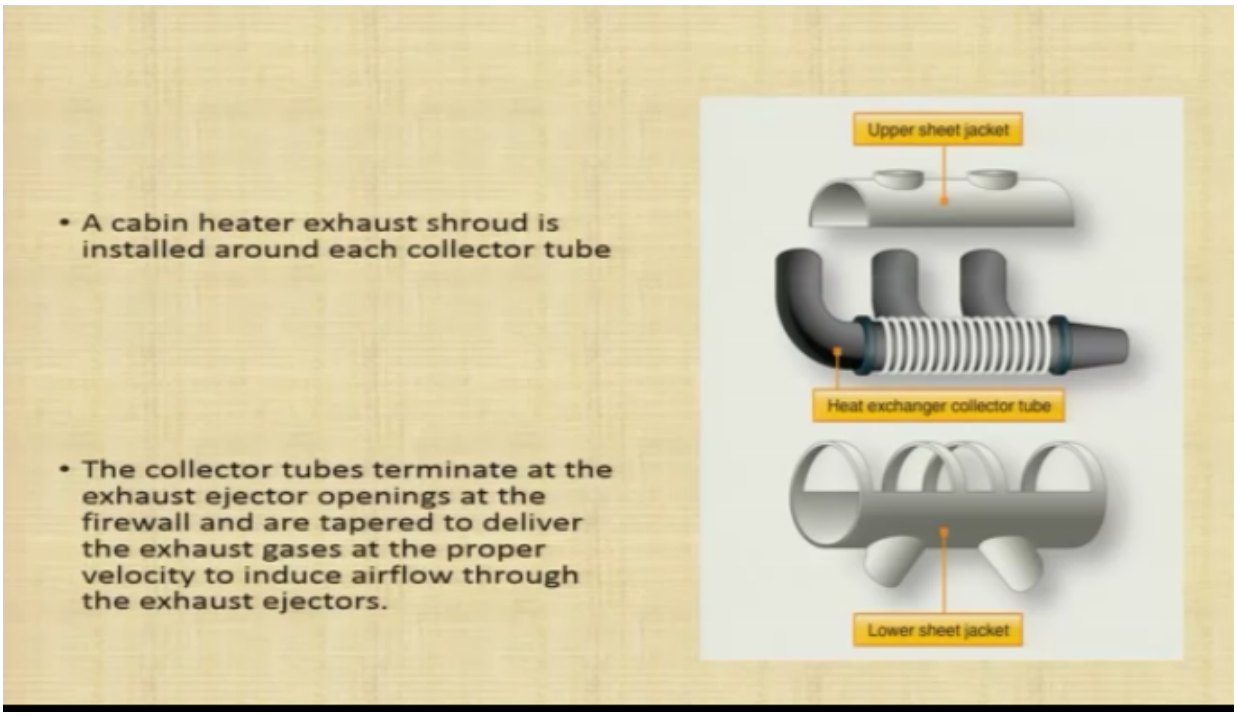
(Refer Slide Time: 24:02)




The exhaust system in this installation consists of a down stack from each cylinder, so in the figure you can see you have down-sack from each cylinder, and exhaust collector tube, you have a exhaust collector tube on each side of the engine, so each side of the engine you have this tube, and an exhaust ejector assembly, from here you have an exhaust ejector assembly protruding aft and down from each side of the firewall, so you have the exhaust tubes coming out from the each cylinders collecting and then finally being sent out of the engine.

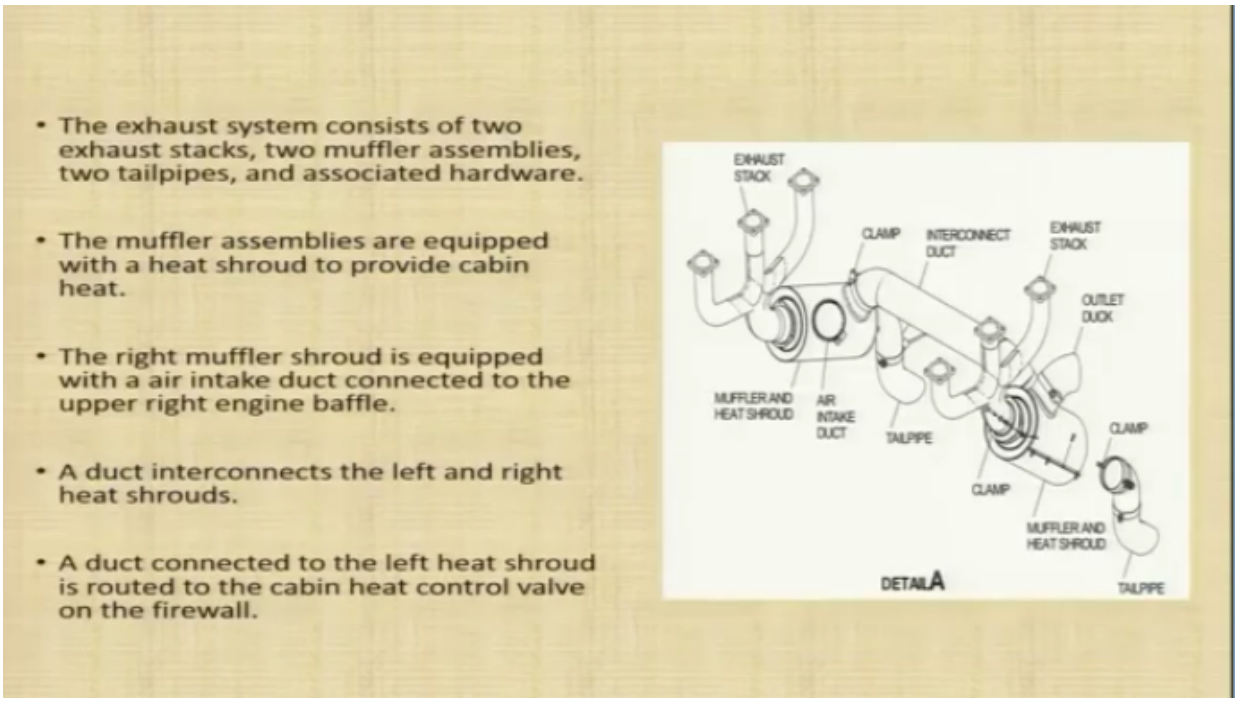
The down stacks are connected to the cylinders with high temperature locknuts and secured to the exhaust collector tube by ring clamps, so these down-stacks they are connected to the cylinders by locknuts which are high very temperature locknuts and a secured to the exhaust collector tube by using ring clamps.

(Refer Slide Time: 24:53)




So here in the figure you can see this is your heat exchanger collector tube, and this is your upper sheet jacket, and here you can see this is your lower sheet jacket, so this jacket, this covers this collector tube and this cabin heater exhaust shroud is installed around each collector tube, so this shroud is around each collector tube, the collector tubes terminates at the exhaust ejector openings at the firewall and are tapered to deliver the exhaust gases at the proper velocity to induce airflow through the exhaust ejectors, so you can see here these tubes they are tapered to delivered the exhaust gases at the proper velocity to induce airflow through the exhaust ejectors.

(Refer Slide Time: 25:41)




Here in the figure you can see one exhaust system, this is basically the exhaust system of one of our aircrafts Cessna-206 which we will see in one of our videos, we can see in the figure these are your exhaust stacks, this is for one side, this is probably for the left side, and this is the exhaust stack for the right side of the cylinders, so three cylinders we have on the right side, three cylinders on the left side, total 6 cylinders, and these stacks they are connected to the exhaust port of the cylinders, so if this is your right side this is for cylinder number 1, 3 and 5 and this is for cylinder number 2, 4 and 6, so all the exhaust ports of the cylinders are connected to the exhaust stacks.

These exhaust stacks they are connected by means of an interconnect duct, so you can see here this is your interconnect duct, this is connecting the two exhaust stacks, and here you can see this is your muffler, this side you have one muffler and this side you have another muffler.

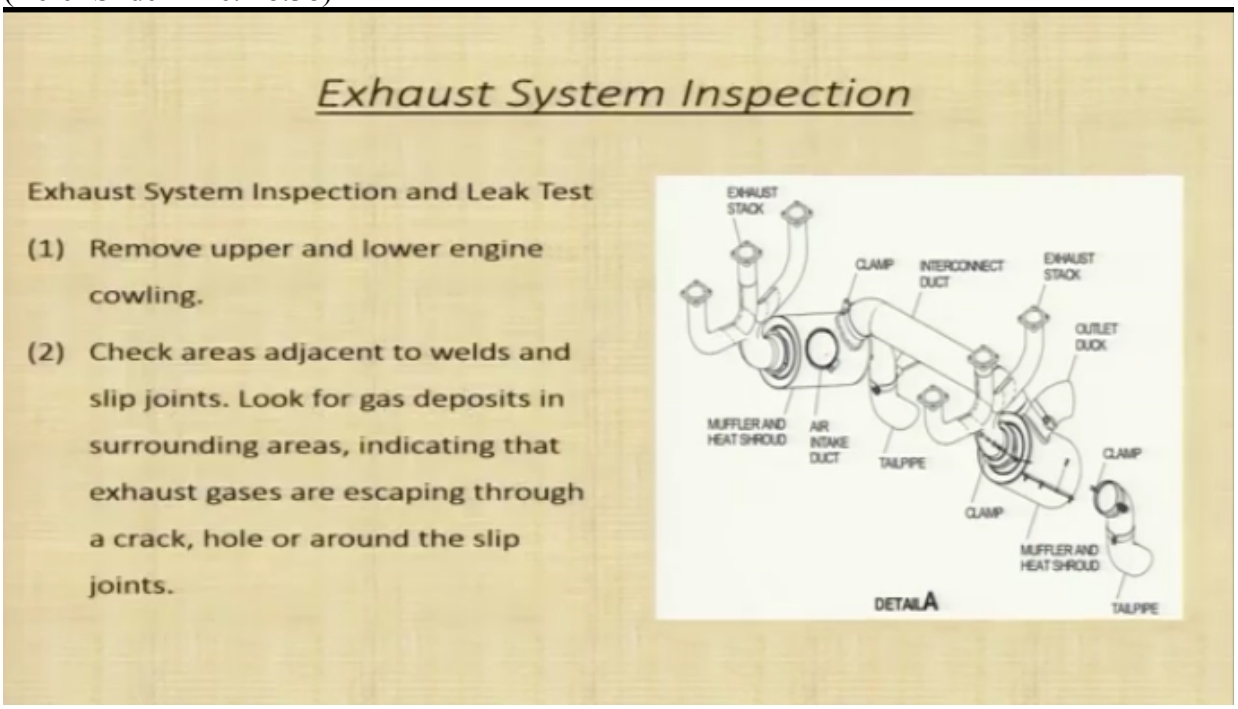
Then here you have your tailpipe, and this is your tailpipe through which the exhaust gases are going out, and one of the muffler you have the air intake duct, so let us see what the system is? The exhaust system consists of two exhaust stacks, so these are your exhaust stacks this is one exhaust stack and this is another exhaust stack, two muffler assemblies, these are two muffler assemblies this is one muffler assembly and this is another muffler assembly, two tailpipes, this is one tailpipe and this is another tailpipe, and associated hardware and the hardware is like nuts, clamps, etcetera.

The muffler assemblies are equipped with the heat shroud to provide cabin heat, so on top of the mufflers you can see you have heat shrouds to provide cabin heat, so these mufflers they are provided with the heat shroud to provide cabin heat.

The right muffler shroud is equipped with a air intake duct, so this right muffler shroud this is provided with an air intake duct connected to the upper right engine baffle, so this is connected to the upper right engine baffle.

A duct interconnects the left and right each shrouds, these duct disconnects your left and right heat shrouds, a duct connected to the left heat shroud, a duct connected the left heat shroud is routed to the cabin heat control valve on the firewall, so this there is one duct which is connected to the cabin heat control valve in the firewall and this is the duct in one of the muffler you have an air opening which is connected to the upper right engine baffle.

(Refer Slide Time: 28:38)




Now let us see what are the inspections to be carried out on the exhaust system, there are certain inspections, there are certain leak test which have to be carried out on the system, in order to do these inspections you have to first remove your upper and lower cowlings, then check areas adjacent to welds and slip joints, so you have the welds here on the exhaust, you have the welds you need to check the areas around the weld and the slip joint.

Look for gas deposits in the surrounding areas, we need to check for the welds, we need to check for the leaks, we need to check for gas deposits in these joints and in the adjoining areas which indicate that exhaust gases are escaping through a crack, hole or around the slip joints.

In case if we find any gas deposit then that indicates your exhaust gas is leaking through that hole, through that crack or around the slip joints.

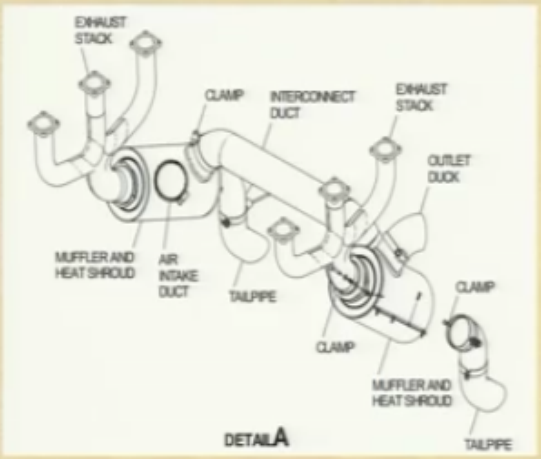
(Refer Slide Time: 29:41)

3 After visual inspection an air leak check should be made on the system as follows:

(a) Attach the pressure side of an industrial vacuum cleaner to the tailpipe opening, using a rubber plug to effect a seal as required.

*NOTE: The inside of vacuum cleaner hose should be free of any contamination that might be blown into the engine exhaust system.*

(b) With vacuum cleaner operating, all joints in the exhaust system may be checked manually by feel, or by using a soap and water solution and watching for bubbles. Forming of bubbles is considered acceptable; if bubbles are blown away, system is not considered acceptable.




After visual inspection an air leak check should be made on the system, so after inspecting it visually we also need to do an air leak test, attach the pressure side of an industrial vacuum cleaner to the tailpipe opening, using a rubber plug to effect a seal as required, so we can use a pressure side of the vacuum cleaner to the crane opening using a rubber plug so that a seal is formed, the inside of the vacuum cleaner hose should be free of any contamination that might be blown into the engine exhaust system, so we need to ensure that our vacuum cleaner hose and everything is free of any contamination, so that no contamination is blown into the engine exhaust system.

With vacuum cleaner operating, all joints in the exhaust system may be checked manually by feel, or by using a soap and water solution and watching for bubbles, so all once we are providing pressure in the system it is all sealed we need to check all the, we need to check all the joints by using a soap and water solution and watching for bubbles or we can also manually feel it. Forming of bubbles is considered acceptable, if bubbles are blown away system is not considered acceptable, so when the bubbles are formed that system is considered acceptable but in case bubbles are been blown away then your system is not considered acceptable.

(Refer Slide Time: 31:20)

(c) Repeat procedure for opposite exhaust.

(4) Where a surface is not accessible for a visual inspection, or for a more positive test, the following procedure may be used:

(a) Remove exhaust stack assemblies.

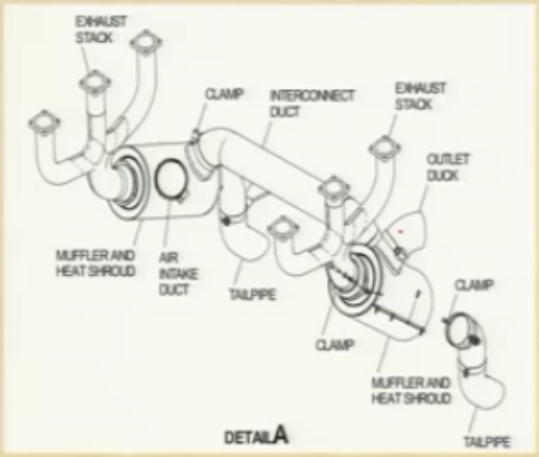
(b) Remove heat shrouds from mufflers.

(c) Use rubber expansion plugs to seal openings.

(d) Using a manometer or gage, apply approximately 1.5 PSI (three inches of mercury) (10.3 kPa) air pressure while each stack assembly is submerged in water. Any leaks will appear as bubbles and can be readily detected.

(e) Exhaust stacks found defective must be replaced before the next flight.

(5) Install exhaust system and perform inspection in step (3).




So this procedure should be checked for both the exhaust port, this system also and for another system also, where a surface is not accessible for a visual inspection, or for a more positive test the following procedure maybe used, so where there might be surfaces which are not accessible for the dual inspection, in that case we need to use the following procedure.

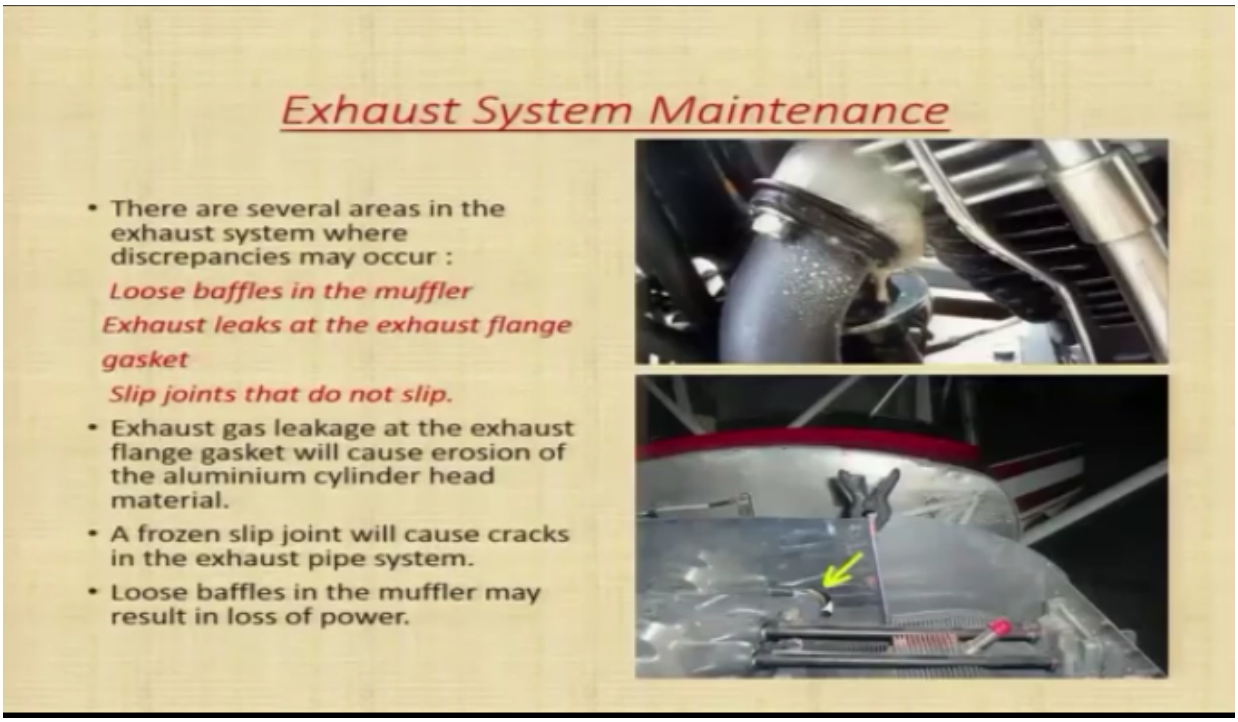
Remove the exhaust stack assemblies, we need to remove the exhaust stack assemblies, remove heat shrouds from the mufflers, we need to remove these exhaust stack assemblies, we need to remove the heat shrouds from the mufflers and use rubber expansion plugs to seal the openings.

Using a manometer or gage apply approximately 1.5 PSI air pressure, while each stack assembly is submerged in water, so with each stack assembly submerged in water and 1.5 PSI pressure applied, the complete systems sealed it is submerged in water, any leaks which will appear as bubbles and can be readily detected, so any leaks can be detected as any leak in the system will form bubbles.

Exhaust stacks found defective must be replaced before the next flight, so in case if you find any defect in the exhaust system it should be either repaired or replaced before the next flight.

Install exhaust system and perform inspection as in step 3, so after performing the leak test the exhaust system is again installed back and the system, the inspection mentioned in point number 3 that is the visual inspection that should again be carried out.

(Refer Slide Time: 33:04)



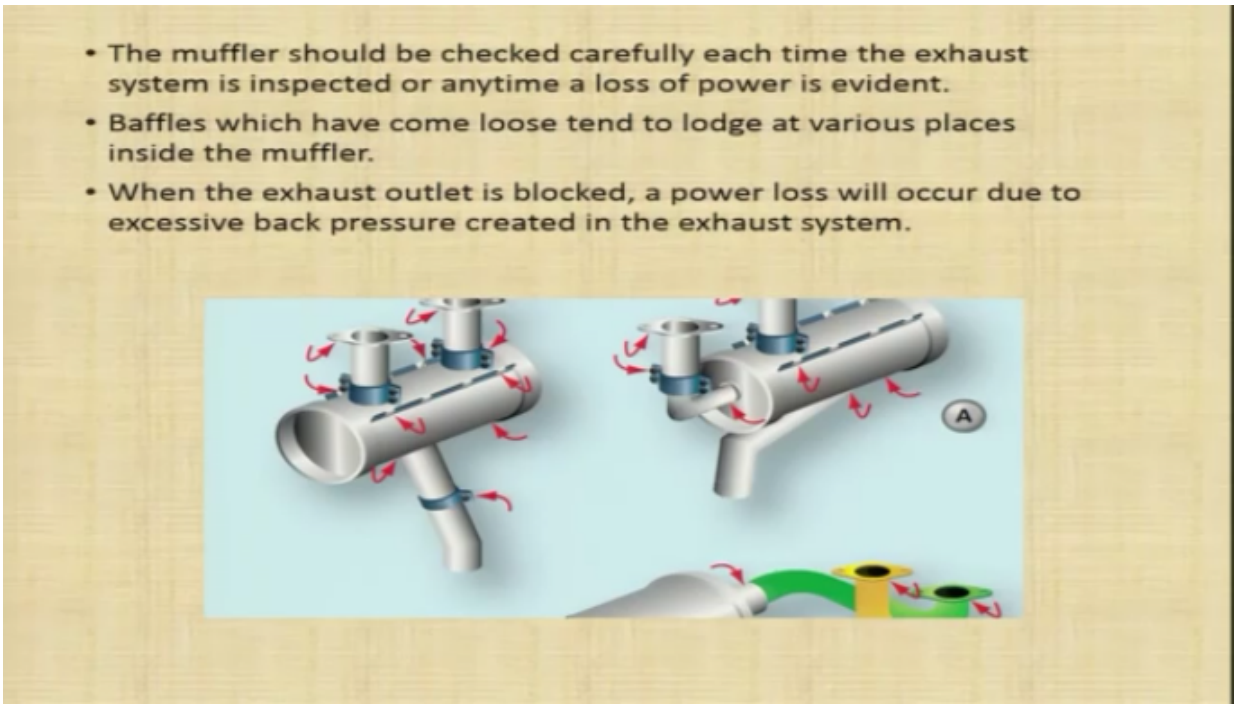

Now coming to exhaust system maintenance, what are the maintenance actions we do on the exhaust system? There are several areas in the exhaust system where discrepancies may occur, so there are various systems, various areas in the exhaust system where discrepancies will may occur, that is loose baffles in the muffler, you may have loose baffles in the muffler, exhaust leaks at the exhaust flange gasket, so here you can see in this diagram this is your exhaust disconnected to the cylinder, to the exhaust port of the cylinder, this is your exhaust manifold and you may have leaks here in the system, and slip joints that do not slip, so you may have discrepancies, you may have leaks in the exhaust flange gasket and exhaust flange gasket, you may have slip joints which do not slip, you may have loose baffles in the muffler.

Exhaust gas leakage at the exhaust flange gasket will cause erosion of the aluminum cylinder head material, so here you can see in case if there is any leakage from this exhaust manifold from the exhaust port then this will cause erosion of the aluminum cylinder head mater, so hence this cylinder is made of aluminum, so this gas leakage will cause erosion of the aluminum cylinder head.

A frozen slip joint will cause cracks in the exhaust pipe system, now in case if your slip joints are frozen, if there is no movement between the slip joints then it will cause crack in the exhaust pipe system.

Loose baffles in the muffler may result in loss of power, now in case if the baffles in the muffler are loose that will also result in loss of power, so we need to be careful about the loose baffles in the muffler which may result in loss of power, we must be careful about the leaks at the exhaust flange, gasket and we also need to be careful about the slip joints that do not slip as this may cause breaking of the exhaust pipe.

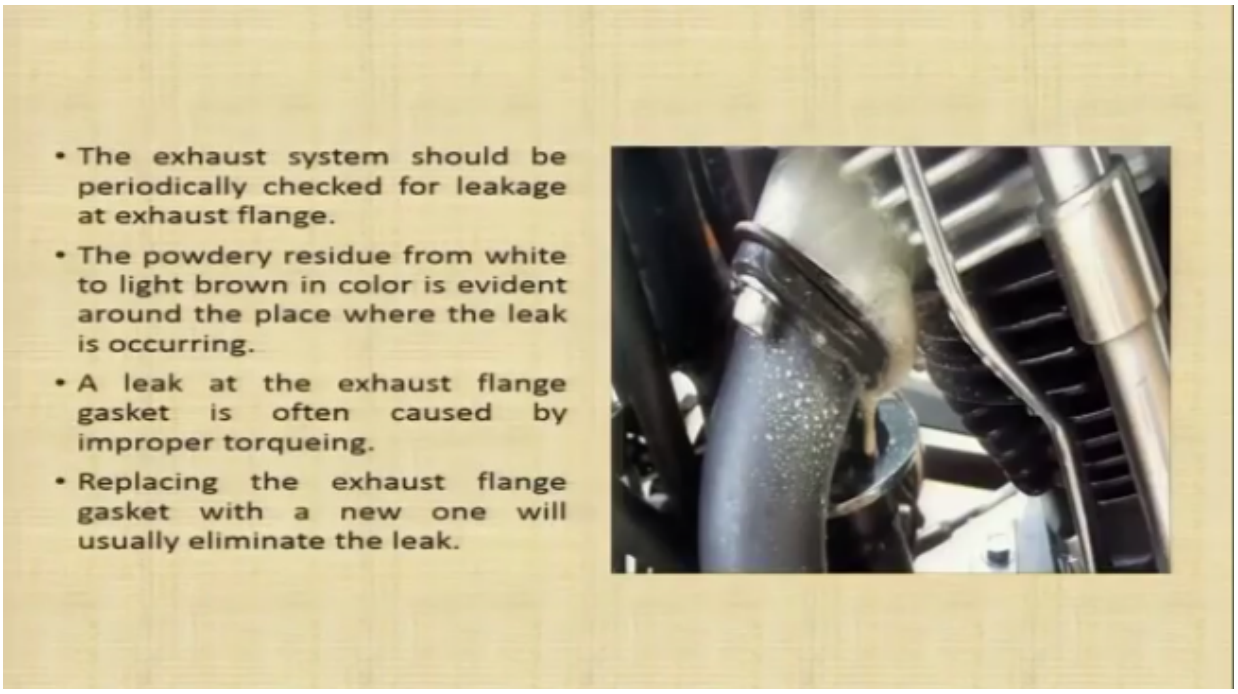
(Refer Slide Time: 35:18)




The muffler should be checked carefully each time the exhaust system is inspected or anytime a loss of power is evident, so muffler should be carefully inspected or anytime when we observe loss of power the muffler should be very carefully inspected.

Baffles which have come loose tend to lodge at various places inside the muffler, now inside the muffler in case if the baffles have or loose they can lodge at various places inside the muffler, then the exhaust outlet is blocked, in case the exhaust outlet is blocked a power loss will occur due to excessive back pressure created in the exhaust system, so in case if you are exhaust outlet is blocked there will be excessive back pressure in the exhaust system which will result in loss of power, so we need to be careful about the loss baffles in the exhaust muffler.

(Refer Slide Time: 36:20)

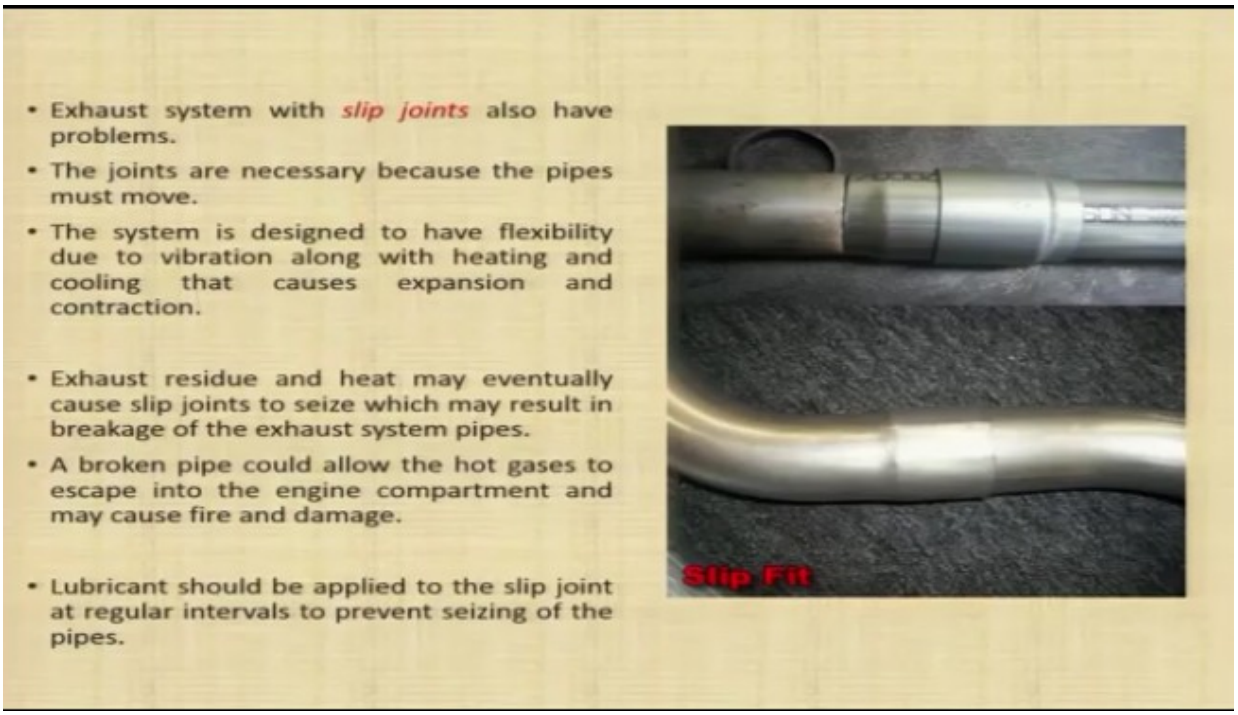



The exhaust system should be periodically checked for leakage at exhaust flange, you can see here this is the picture we are trying to do a soap test here, and you can see we are observing some bubbles and some leakage here, so the exhaust system should be periodically checked for leakage at exhaust flange, the powdery residue from white to light brown in color is evident around the place where the leak is occurring. So you can see here some powdery deposit, some white to light brown in color, powdery deposit which indicates that there is a leakage around the place.

A leak at the exhaust flange gasket is often caused by improper torqueing, so generally we have observed that the leak in this exhaust flange area is mainly due to the improper torqueing of these hold-down nuts, so these hold-down nuts should be properly torqued, in case if they are not torqued they may result in leakage through these exhaust flanges.

Replacing the exhaust flange gasket with a new one will usually eliminate the leak, so in case if you are observing any leak the best thing to do is to replace the gasket the exhaust flange gasket and this will usually eliminate the leak, and the hold down nuts should be properly torqued.

(Refer Slide Time: 37:41)




Exhaust system with slip joints also have problems, now here in the diagram you can see these are your slip joints, and these slip joints also have the set of problems, the joints are necessary because the pipes must move, so these joints are necessary so that the pipes are able to move the system is designed to have flexibility due to vibration along with heating and cooling that causes expansion and contractions.

So these slip joints are designed so that the system has got flexibility due to vibration, due to heating and cooling because of which expansion and contraction of the metal is taking place, so flexibility is required.

In case if these slip joints they do not, they freeze then there is no movement in the slip joints then this will result in crack in the exhaust pipes.

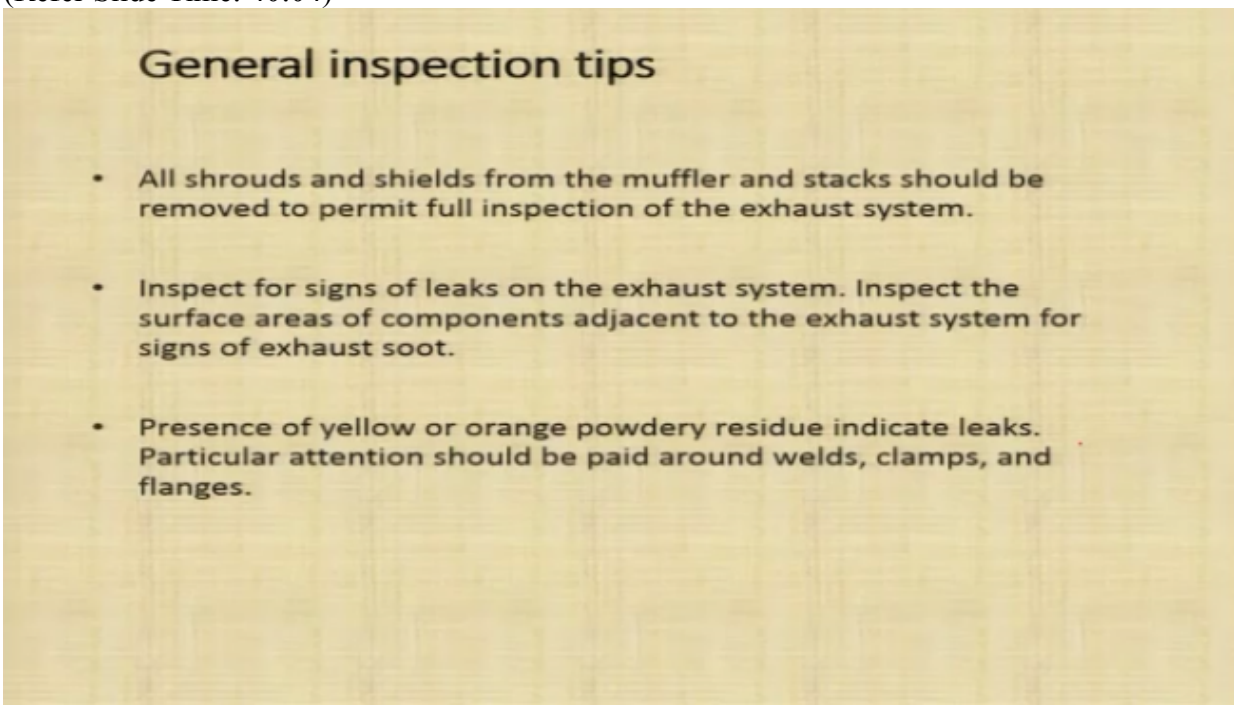
Exhaust reside and heat may eventually cause slip joints to seize which may result in breakage of the exhaust system pipes, so exhaust residue and heat can result in slip joints to seize, there will be no movement and it can result in breakage of the exhaust system pipes.

A broken pipe could allow the hot gases to escape into the engine compartment and may cause fire and damage, so in case if your exhaust pipe is broken then it will allow the exhaust gases to leak in the engine compartment and can finally cause fire and damage.

Lubricant should be applied to the slip joint at regular intervals to prevent seizing of the pipes, so it is very essential to apply lubricant at the slip joints, so as to prevent seizing of the pipes, so here in the figure you have seen these are your slip joints, these slip joints some movement is required, the system is designed to have flexibility because of vibration and contraction and expansion of the metal due to heating and cooling, so that in case if these joints freeze then there is no movement and the exhaust pipes may break, and once the exhaust pipes are broken it

can result in leakage of the exhaust gases in the engine compartment and can cause fire and damage.

(Refer Slide Time: 40:04)

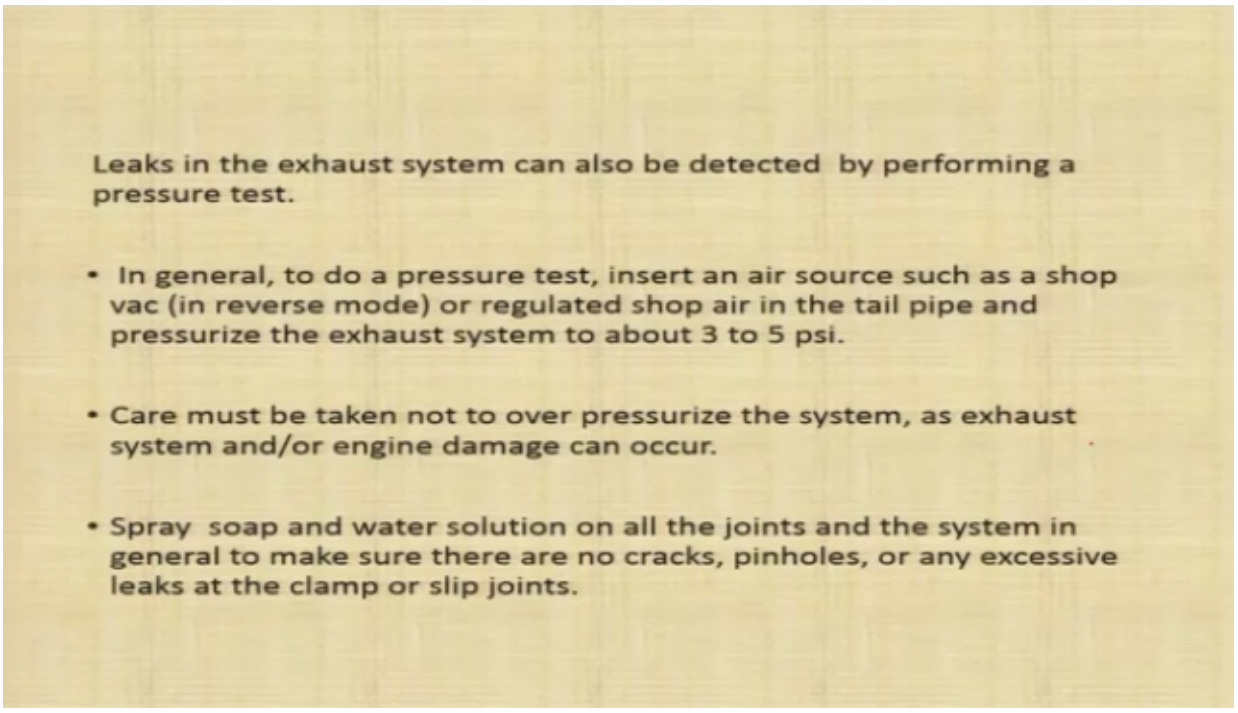



Now let us see about the general inspection on the exhaust system, all shrouds and shields from the muffler and stacks should be removed to permit full inspection of the exhaust system, so in order to carry out the full inspection a detailed inspection of the exhaust system, so the all the shrouds and shields from the muffler and the stacks they should be removed, they should be opened.

Inspect for signs of leaks on the exhaust system, so the important thing to be observed on the exhaust system is sign of leaks, inspect the surface areas of components adjacent to the exhaust system for signs of exhaust soot, so in addition to the exhaust system itself we also need to inspect the adjacent areas, areas adjacent to the exhaust system for any sign of exhaust soot, and any sign of leakage in the exhaust system.

Presence of yellow or orange powdery residue indicate leaks, now in case if we observe from yellow or orange powder kind of residue that indicates leakage in the area, particular attention should be paid around welds, clamps and flanges, so we need to pay particular attention around the welding portion, the welded parts, the clamps and the flanges, we need to observe that there are no residue, no powder residue indications around these areas.

(Refer Slide Time: 41:34)

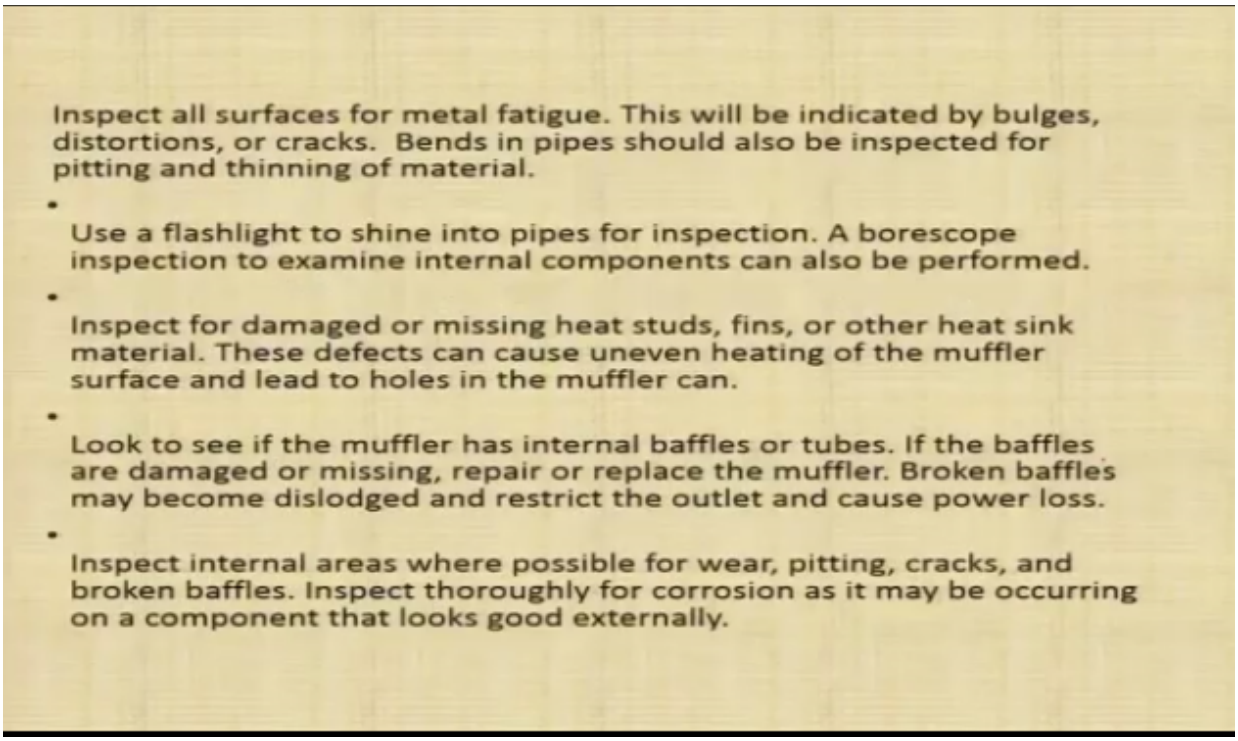



Leaks in the exhaust system can also be detected by performing a pressure test, we have seen earlier that how the pressure test was done, so apart from the visual inspections or leak test can also be done to detect if there is any leakage in the system.

In general to do a pressure test, insert an air source such as a shop vacuum in reverse mode or regulated shop air in the tail pipe and pressurize the exhaust system to about 3 to 5 PSI, we have seen in our earlier slide how we have done the exhaust pressure test, similarly we give a pressures of air pressure of 3 PSI to 5 PSI, we sealed the complete system and we need to check by means of soap and water solution or by submerging the exhaust system in the water to see if there are any bubbles in the system, if there are any leaks in the system.

Care must be taken not to over pressurize the system as exhaust system or an engine damaged can occur. Spray soap and water solution on all the joints and the system in general to make sure there are no cracks, pinholes, or any excessive leaks at the clamps or slip joints, so as I had just now mentioned that soap and water solution on all the joints can be swayed and the system in general to make sure that there are no cracks, no pinholes, or excessive leaks at the clamps or the slip joints.

(Refer Slide Time: 43:06)




Inspect all surfaces for metal fatigue, so the complete system all the surfaces they should be checked for metal fatigue, this will be indicated by bulges, distortions or cracks, so metal fatigue will be indicated by cracks, by bulges, or distortions on the surface. Bends in pipes should also be inspected for pitting and thinning of material. So all the pipe bends they should be very minutely observed, they should be minutely observed, they should be minutely inspected for pitting or thinning of the material.

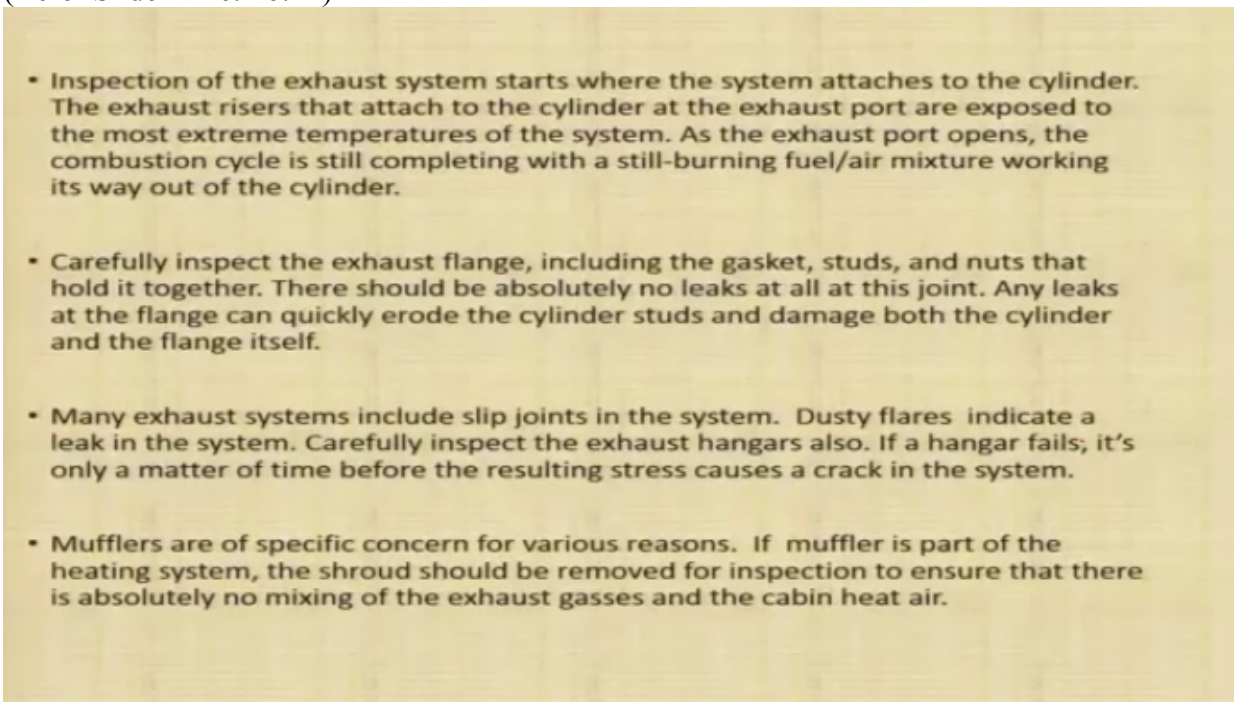
Use a flashlight to shine into pipes for inspection, so in order to carry out the thorough inspection we can use a flashlight to shine into the pipes so that a proper visual inspection can be carried out, a borescope inspection to examine internal components can also be performed, so internal inspection can also be done through a borescope inspection.

Inspect for damaged or missing heat studs, fins, or other heat sink material, so in the exhaust system we also need to inspect the damaged or missing heat studs, we need to check the fins, the cylinder fins and other heat sink material. These defects can cause uneven heating of the muffler surface and lead to holes in the muffler can, so any kind of damage, any kind of defect can lead to uneven heating of the muffler surface and can also result in holes.

Look to see if the muffler has internal baffles or tubes, if the baffles are damaged or missing repair or replace the muffler, so the muffler internal portion is also to be inspected, the baffles they should not be broken, broken baffles may become dislodged and restrict the outlet and cause power loss, as we have seen earlier that in case if your exhaust outlet is blocked then there will be excessive exhaust back pressure and finally it may result in power loss, so in case if the baffles are broken in the muffler they will become dislodged and restrict the outlet and cause power loss.

Inspect internal areas where possible for wear, pitting, cracks, and broken baffles, so the internal portion, the internal portion of the exhaust system should also be carefully inspected to see if there is any wear, if there is any pitting, if there are any cracks or there are any broken baffles, so the internal areas should also be carefully inspected apart from the external area. Inspect thoroughly for corrosion as it may be occurring on a component that looks good externally, so the components externally might be good looking they may be, there might not be any problem apparently if we see them externally, but internally they may be corroded, so we also need to inspect them thoroughly for corrosion as it may be occurring on a component inside.

(Refer Slide Time: 46:22)




Inspection of the exhaust system starts where the system attaches to the cylinder, so now the exhaust system when it is connected to the cylinder exhaust port, so the exhaust the system inspection starts right from that point. The exhaust risers that attach to the cylinder at the exhaust port are exposed to the most extreme temperatures of the system, so these exhaust risers they are exposed to the most extreme temperatures of the engine because the exhaust gases are directly coming from the exhaust port into these areas.

As the exhaust port opens, the combustion cycle is still completing with the still burning fuel air mixture working its way out of the cylinder, so we have seen in our previous chapters, we have seen in the auto cycle also in the auto cycle explosion also that as the exhaust port opens the combustion cycle is still completing, it is not yet complete, it is still completing with a still burning air mixture which is working it's way out of the cylinder.

Carefully inspect the exhaust flange, including the gasket, studs, and nuts that hold it together, so this area is to be inspected very thoroughly we need to check the exhaust flange, we need to inspect the exhaust flange we need to inspect that gasket, and the studs, and the nuts that hold the exhaust tubes, the exhaust stacks to the exhaust port on the cylinder. There should be

absolutely no leaks at all at this joint, so this area this joint should be leak proof, leak free and there should not be any leak at this point.

Any leaks at the flange can quickly erode the cylinders studs and damage both the cylinder and the flange itself, we have seen in our earlier slide also that any leakage at this point will erode the aluminum cylinder and will cause damage to the cylinder studs and cylinder and the flange itself.

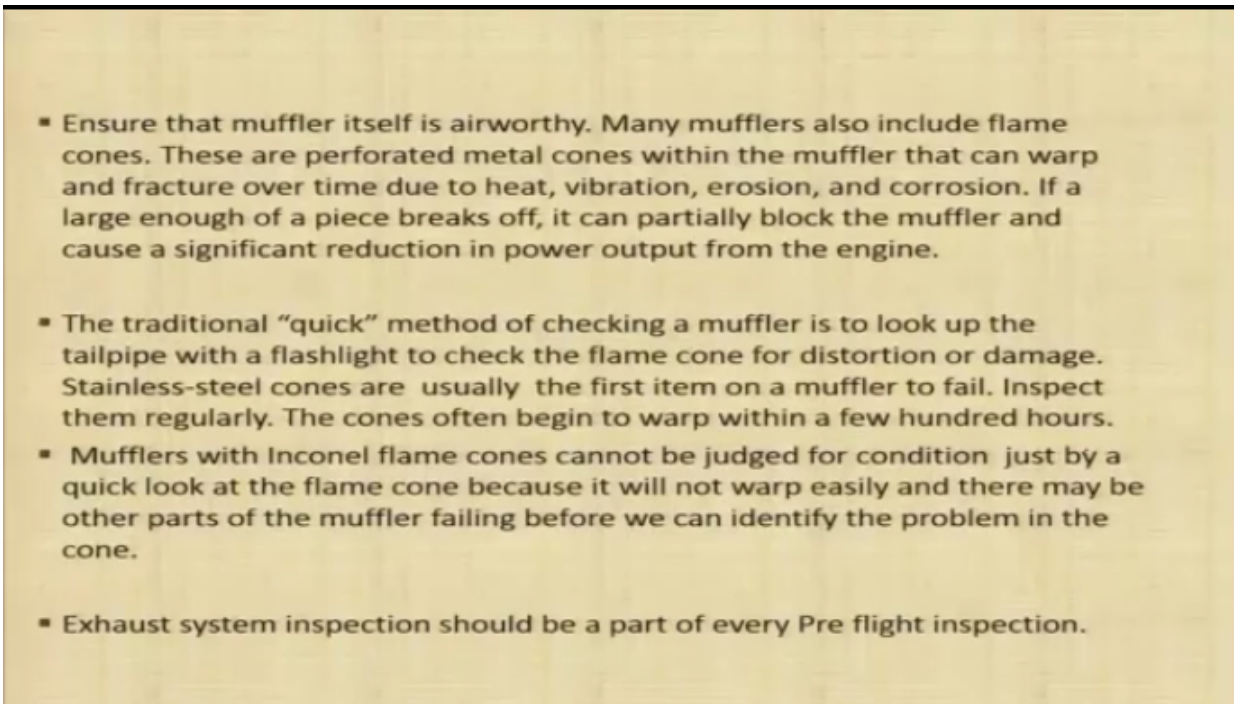
Many exhaust systems include slip joints in the system, so we have seen what a slip joint is, many exhaust systems have slip joints, the joints these slip joints they are designed to have flexibility, we need to inspect these joints very carefully, dusty flares indicate a leak in the system.

Now along the joints of the adjacent area of the joint if we observe some dusty flares that indicates a leak in the system carefully inspect the exhaust angles also, if a hanger fails it's only a matter of time before the resulting stress causes a crack in the system, so all these exhaust tubes they need to be inspected thoroughly any leakage in the system will very soon result in a crack in the system.

Mufflers are of specific concerned for various reasons, a mufflers they are a very important part of the exhaust system we need to inspect them thoroughly if muffler is part of the heating system the shroud should be removed for inspection to ensure that there is absolutely no mixing of the exhaust gases and the cabin heat air.

Now in case if the muffler is being used as part of the cabin heating system or as part of other heating system, the muffler shroud, the shroud over the muffler it should be removed for inspection and it should be ensured that the exhaust gases and the cabin heat air are not mixing together and everything in the muffler is working satisfactorily.

(Refer Slide Time: 50:26)




Ensure that muffler itself is airworthy, many mufflers also include flame cones, these are perforated metal cones within the muffler that can warp and fracture over time due to heat, vibration, erosion, and corrosion, so now we need to ensure that the mufflers itself they are airworthy, some of the mufflers they have metal cons and these are perforated metal cones and they can work and fracture overtime due to heat, vibration, erosion and corrosion. If a large enough of a piece breaks off, it can partially block the muffler and cause a significant reduction in power output from the engine, so we all know that in case if there is an obstruction in the exhaust then it can result in loss of power from the engine, so if a large enough of a piece breaks off it can partially block the muffler and cause a significant reduction in power output from the engine.

Now the traditional quick method of checking a muffler is to look up the tailpipe with a flashlight to check the flame cone for distortion or damage, now the common method in the field which is being done to carry out the inspection of the muffler is to look up the tailpipe with a flashing light to check that the flame cone is free of distortion or damage.

Stainless steel cones are usually the first item on a muffler to fail, so generally in a muffler the first items to fail are the stainless steel cones, we need to inspect them regularly the cones often begin to warp within a few hundred hours, so these cones we need to be very carefully inspected and need to inspected very regularly.

Mufflers with Inconel flame cones cannot be judged for condition just by a quick look at the flame cone, because it will not warp easily and there may be other parts of the muffler failing before we can identify the problem in the cone, so Inconel flame muffler cones they cannot be judged for condition where easily by just by looking at them because it will not warp easily and there may be other parts also in the exhaust system and the muffler which can fail, which are failing before we can identify the problem in the cone.

So the exhaust system this needs to be thoroughly inspected for cracks, for leaks, for corrosion, for vibration and any breakage, so and it should be very thoroughly inspected in fact the exhaust system inspection should be a part of every preflight inspection and any observation, any leakage indication should be taken very seriously and we need to take appropriate action in a, in appropriate way as per the guidelines of the manufacturer in the proper time, so the exhaust system should be thoroughly inspected for all the cracks, for all the vibrations, erosions, corrosions, leakage, we need to inspect the exhaust system as per the manufacturers recommendation at proper intervals as per the guidelines of the manufacturer, and in fact in every preflight inspection the exhaust system should be carefully inspected, so this was all about the exhaust system, we will look for another system, we will look on the aircraft about the exhaust system, we will look various exhaust systems on various aircrafts. Thank you.

**Acknowledgement**
**Ministry of Human Resource & Development**

**Prof. Satyaki Roy**
**Co-coordinator, IIT Kanpur**

**NPTEL Team**
**Sanjay Pal**
**Bharat Lal**
**Ashish Singh**
**Badal Pradhan**
**Tapobrata Das**
**K. K. Mishra**
**Ashutosh Gairola**
**Puneet Kumar Bajpai**
**Bhadro Rao**
**Shikha Gupta**
**Aradhana Singh Rajawat**
**Sweta**
**Nipa Sikdar**
**Anupam Mishra**
**Ram Chandra**
**Manoj Shrivastava**
**Dilip Tripathi**
**Padam Shukla**
**Sharwan K Verma**
**Sanjay Mishra**
**Shubham Rawat**
**Santosh Nayak**
**Praduyman Singh Chauhan**
**Mahendra Singh Rawat**
**Tushar Srivastava**
**Uzair Siddiqui**

**Lalty Dutta**
**Murali Krishnan**
**Ganesh Rana**
**Ajay Kanaujia**
**Ashwani Srivastava**
**M.L. Benerjee**

**an IIT Kanpur Production**