Module BESTT MS6

Propulsion and Stability

AIM

It is beyond this course to consider the design decisions about boiler size, propeller dimensions or other design parameters of a steam powered vessel, but an understanding of the principles is valuable should a vessel with poor performance be presented: it will be much more straightforward to suggest causes. Similarly, students should be aware of the key areas where steam engineering overlaps with hull construction and have a working knowledge of what is appropriate and safe

INTRODUCTION

Regulatory frameworks

Stern gear

Propeller shafts and support

Paddle Wheels

Pitch, roll and boilers

Like all scientific and mechanical progress, a lot depends on 'trial and error'. Perhaps the classic example is Thomas Edison's search for the ideal carbon filament for his 'incandescent lightbulb'... nothing would last until, in desperation, he tried common sewing thread...

But steamboat and steamship development was no different. An idea would be tried, would show great promise, but it would not work 100% reliably, so operators would be wary of change and elect to stay with the first technology that had proved reliable, even if it was hopelessly out of date! Early paddle steamers used a variety of different engine designs. The 'side lever' – a form of upside-down beam engine persisted for many years, as did the oscillating engine, and up to the early 1950s, amazingly, there were still examples of each kind of engine in revenue earning service.

When Charles Parsons developed the steam turbine, he had to find ways of mating the high speed of the basic unit to the right speed for a propeller, and indeed he had to experiment with the right sort of propeller. If you look at his revolutionary *Turbinia* in Newcastle's 'Discovery' museum you'll see that she has a whole series of propellers on both prop shafts. Later, it was found the drive could be geared right down, but it was not until highly accurate, extremely large and heavy machine tools had been developed that could precisely cut the 'Vee' configuration gearing that was found most suitable. The gears enabled the huge power available at the turbine to drive a single prop on the end of a shaft turning at the kind of speed that would not 'cavitate' madly and would push the vessel along at the optimum speed. This was all very hard to calculate, much better to test and trial! If the gears were poorly machined the noise they made was untenable.

But maybe it is with boilers that we see how at a technical level trial and error was critical. Boilers that were essentially tanks full of water with a fire heating them up worked in the earliest days with very low pressures (2 -3psi). The very early ocean going ships fed their boilers with salt water so corrosion meant that a short life was guaranteed: for the boiler if not for the crew. When it was realised that higher pressures made for greater efficiency, the metallurgy was, at that point, just not there to support the demands.

These early 'box' type boilers were frequently built out of wrought iron plate, often described as 'iron mixed with dirt', to suit the shape of the hulls. Inevitably the masses of stays and plates and rivets necessary made the boilers nigh on impossible to clean properly. Joints were sealed with iron filings and urine or horse manure... and there are many stories of explosions. To be fair, these happened in steam plant on dry land too, but at sea, there were additional horrors to face.

Once material technologies – metallurgy - caught up with the ideas, life became safer for steam engineers – and indeed everyone aboard!

Even in modern steam launches, with a wealth of design information available, owners may experiment with different propellers (more correctly called screws) in order to optimise engine rpm, power delivery and performance.

The principles of steam power remain the same in locomotives, traction engines, stationary engines and steam vessels, however there are a few important facets in the marine application which must be understood. The stern tube on a screw vessel allows the propeller shaft to pass from inboard to outboard, and must operate so that there is not significant water ingress. The support of paddle wheels and the transmission of power to them has been covered in Unit MS 2 and so will not be repeated here. There will be fittings through the hull which similarly must be watertight. Finally there is the issue of stability of the vessel and correct dimensions to ensure all on board are safe in the expected conditions which the vessel is designed for.

Learning Outcomes

LO1:

Regulatory Framework

1. The Boat Safety Scheme
2. The Maritime and Coastguard Agency
3. Categories of waters
4. Passenger certificates

For smaller vessels, and those typically build or assembled by amateurs there are no specific regulations covering how boats are put together, and this can lead to some interesting innovation. The Canal and River Trust require all boats using their waterways to in order to prevent the risk of fires, explosion or pollution. Any vessel must be inspected by an examiner and a certificate of safety issued. In some locations, short term exemptions have been negotiated for steam launches, but the principles required are sensible and there are no reasons that the safety requirements should not be adhered to (e.g. fire extinguishers, secure electrical wiring etc.).

Passenger carrying or commercial vessels

Vessels under 24m in length which carry up to 12 passengers and/or undertake commercial work are required to comply with Maritime and Coastguard Agency (MCA) Codes of Practice which set out the structure of such vessels, the equipment they must carry, how they should be manned and the qualifications needed for manning them.

Vessels over 24m in length which proceed to seawards of Categorised Water Limits (as defined in the MCA's MSN 1776) must comply with the relevant STCW and Maritime & Coastguard Agency requirements whether they are used for commercial or private purposes

Local Authorities and other bodies responsible for defined areas of operation may impose requirements on vessels used for commercial work and/or which carry up to 12 passengers.

All vessels carrying more than 12 passengers must have a Passenger Certificate issued by the MCA. A passenger is defined in law as anyone over the age of one not engaged as a member of the vessel's crew. There are seven categories of Passenger Certificate ranging from Class I for unlimited international voyages (liners) through to Class VIA (small domestic passenger vessels) for short voyages to remote islands.

The most commonly encountered Passenger Certificates for smaller passenger vessels are Class IV which are valid on Category D Waters (estuaries), Class V which are valid on Categories A, B & C Waters (canals, lakes, lochs or rivers) and Class VI which are restricted to daylight hours and summer only and are available for any of the above plus short voyages to sea not more than 3 miles from the shore or more than 15 miles from the point of departure.

All sea-going ships with an engine power greater than 330KW are required to carry an engineer or engineers with Standards for Training, Certification and Watch keeping (STCW) Certificates of Competency issued by the MCA of the appropriate grade according to the size of the vessel and the nature of her service.

All vessels carrying passengers or engaged in commercial work with an engine size of under 330KW should carry an engineer or engineers passed out as competent for the roles they undertake by the vessel's owner. This includes, for example, passenger vessels like *Kingswear Castle,* which has MCA Passenger Certificates for carrying up to 235 passengers on the River Dart, and *Sir Walter Scott* which has MCA Passenger Certificates for carrying up to 245 passengers on Loch Katrine.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO1 1	The Boat Safety scheme	Describe the locations where a Boat Safety Scheme Certificate is required	Classroom	
LO1 2	The Maritime and Coastguard Agency	Describe which vessels must comply with the MCA Codes	Classroom	
LO1 3	Categorised Waters	List the categorised waters	Classroom	
LO1 4	STCW Certification	Explain why STCW Certification is compulsory on sea-going ships	Classroom	

Learning Outcomes

LO2:

From Engine to movement

1. Flexible couplings
2. Bearings
3. The stern tube
4. The propeller shaft
5. Propellers or screws
6. Paddle Wheels
7. Rudders
8. The skeg
9. Anodes

Flexible coupling

It is conventional to fit a flexible coupling between the engine and the propeller shaft on small boats, and especially on wooden boats. This will usually consist of an arrangement of two parallel metal plates with a flexible material between. The plates will be connected to the shafts using keyed connections, or in smaller applications, a taper-locking or even grub screwed flange. This should be checked for security and wear periodically.

Support bearings

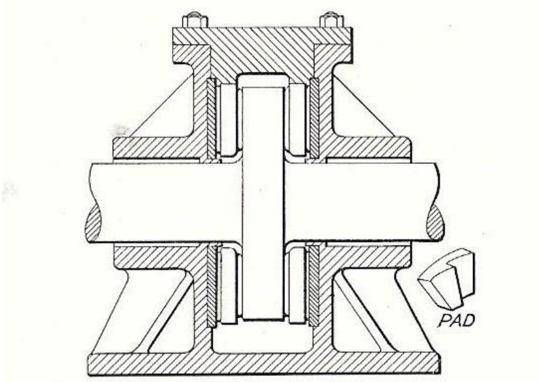
The propeller shaft will need to be supported at intervals if there is more than 1 metre protruding from the stern tube. There are ways to calculate correct spacing of shaft support bearings but a useful rule of thumb for checking is that the interval between shaft supports should not be more than 40x the shaft diameter. In many applications there will be no need for these supports but a narrowboat may well have several metres of driveshaft to support. These support bearings should be checked for wear and corrosion regularly: the environment of the bilge space is continuously damp and these bearings will require regular lubrication for corrosion control

Thrust Bearing

The thrust which is generated by the screw needs to be transferred to the hull and not place longitudinal loads on the engine. To achieve this a Thrust Bearing is fixed to the shaft in some secure manner and also fixed firmly to a rigid frame attached firmly to the hull. Again, this is subject to the highly corrosive atmosphere of the bilge. The thrust bearing must be capable of dealing with loads in both directions. Is the bearing is becoming worn this may become noticeable through excessive play, or by a constant rumbling when under power.

Some engines for launches are designed to incorporate a thrust block, but to exploit this feature the propeller shaft should not have a flexible coupling between engine and screw which can introduce alignment issues and not allow for any flexion of the hull.

Ships will often have a thrust bearing of the "Michel Type" as illustrated which is partially oil filled.



A collar is fitted to the propeller shaft; within the Michel Type thrust bearing kidney shaped pads are fitted in such a way to self-lubricate and transfer the thrust from the ship's screw to the ship's structure.

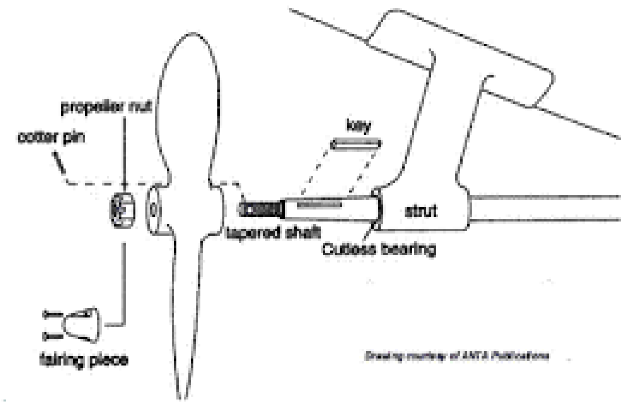
Smaller launches may simply have a deep grove roller bearing which is held to the shaft with a pair of grub screws (ideally into indents on the shaft).

Stern tube

During the construction of the ships/boat hull provision is made for a hole to be formed from the hull interior to the water side of the hull through the rear (stern) of the hull. This hole is normally referred to as the stern tube.

In single shafted vessels it would be normal for the stern tube to be positioned amidships passing through the hull in line with the keel.

For twin screwed vessels the stern tubes would be positioned either side of the keel positioned to allow for greatest propeller efficiency. These stern tubes normally require the shaft and its propeller to be supported by Strut bearings.



It should be noted that angling of the propeller shaft will cause a loss of power that the propeller should be able to create and so decrease the vessel's efficiency.

Angle of shaft	Propeller Performance Loss
3 Degrees	0·14%
10 Degrees	1·52%
15 Degrees	3·41%

Whilst these losses of performance figures may seem low it should be remembered that cost in fuel over extended operating periods would be great.

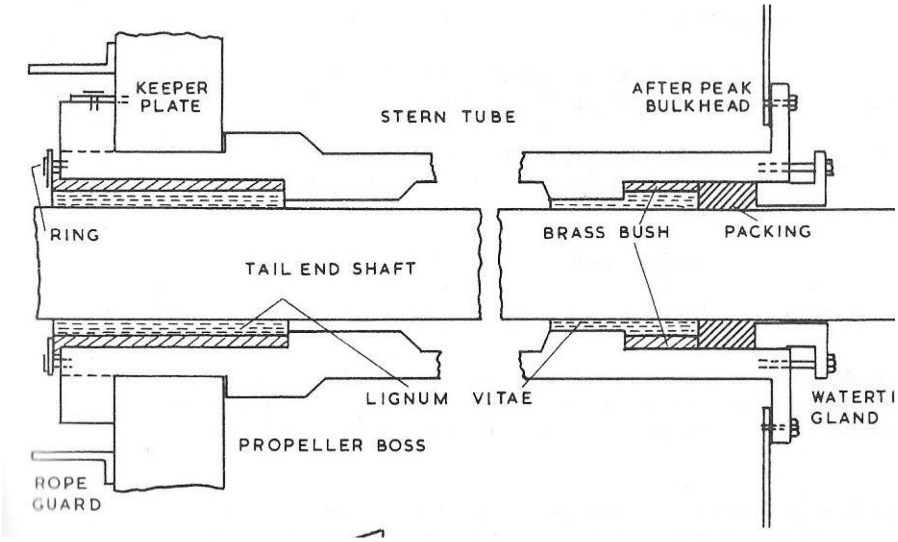
On the inboard side, the propeller shaft passes through a gland stuffing box. This is the watertight segment. The gland stuffing does not need to be compressed strongly as the pressures it is resisting are very small compared with those on the piston rods of an engine. The stuffing box will usually have a grease port – this will often have a grease reservoir which may have a screw-down plunger: the maintenance regime may require half a turn at the end of each day. The propeller shaft then travels through a water filled void and though the water lubricated cutlass bearing. During on-shore maintenance the water inlet ports should be checked for blockages of marine life or accumulated debris.

Inboard outboard

Stern tubes are fitted primarily to provide a bearing for the propeller shaft which is normally referred to as the Tail End Shaft. The bearings situated at either end of this tube are substantial as forces exerted here are great and ever changing from the force of the propeller to the forces exerted by changing sea or water conditions.

Traditionally the tail end shaft passed through the stern tube being supported at the propeller end by long staithe type bearings originally made of end grain wood (lignum vitae). This material was often in later years changed from wood to various composite type materials (particularly for lower shaft powers). The naturally occurring heavier than water timber lignum vitae has become a rare material difficult to source.

The stern tube then extended on with a dead space until reaching another lignum bearing. The lignum staithes are then backed by a brass liner before the start of a water tight gland through which the tail shaft passes before being attached to the propeller shaft. The water tight seal or gland was traditionally cotton mutton fat and graphite combination which was not pleasant to work with.



This type of stern tube is mainly confined to vintage vessels and has in recent years gone out of favour being replaced by oil lubricated patent stern tubes.

Note that a rope guard is fitted to try and stop rope or other fouling items becoming wrapped around the shaft and so causing damage and delay.

The propeller shaft

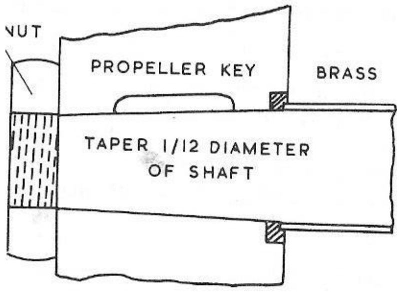
The propeller shaft will usually be made of high grade stainless steel and should not suffer corrosion but it may be subject to wear at both the cutlass bearing and surprisingly the gland point. Periodically the shaft should be removed from the vessel and inspected for wear. Obviously this will need to be done with the boat out of the water, and is usually achieved by withdrawing the shaft outwards.

The screw (propeller)

The propeller will usually be a bronze alloy and will suffer corrosion, especially in salt water. There should be anodes present in some way to reduce this. The propeller should be inspected for pitting while the boat is out of the water and may be polished to improve efficiency.

There are a number of ways to attach a propeller to the shaft.

1-**Tapered with key –** this system is where the propeller is fitted to the shaft and then pushed into position and locked with a nut.



2- **Tapered with no key –** Key ways were always a problem causing cracks about the key way ends which were instrumental in a number of propellers being lost at sea.

It should be noted with tapered propeller fitment it is very important to ensure that the shaft and propeller taper fit was correct. If the propeller is to be removed from the shaft it is suggested that heat is applied to expand the propeller boss slightly, and then use a 'puller' rather than a hammer to free the boss from the shaft.

3- **Parallel no key hydraulic interference fit**. This where the propeller is fitted with a sleeve that under hydraulic pressure will allow the propeller to be positioned on the shaft then fixed by dropping the pressure. This will only be seen on larger vessels.

Paddle Wheels

Paddle wheels have been used for the propulsion of ships and boats from the earliest times powered times. The first recorded trial of a steam driven paddle driven boat was in 1698 by Papin and Leilbnita with a Savory Engine being used for the trial.

It should be noted that the positioning of paddle wheels particularly on side mounted setups is critical and has in early days caused a number of paddle steamers to fail with regard to efficient or optimum power transmission and hence speed. Paddle wheels should be positioned such that the contacts the water at the wave's maximum height on the steamer's hull. A rough guide to the position of side wheeled paddles is for the wheels is to position them 2/3 of the hull length back from the vessel's bow.

There are number of different types of paddle wheeled vessel

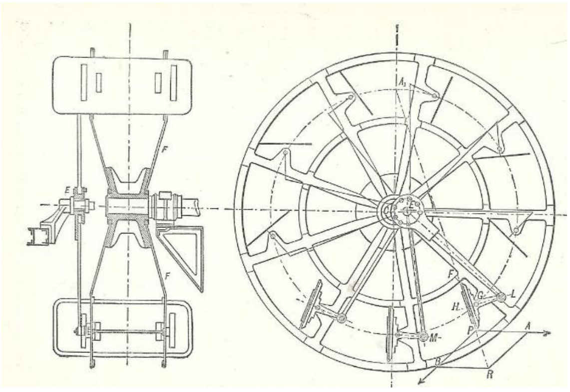
1-**Stern wheeler** – Commonly associated with Mississippi River Boats. This where one large wheel is fitted across the stern of the vessel and directly driven by connecting rods from a single main engine. A useful form of drive for river boats operating in variable depth of water.

2-**Side Wheeler** - Whilst mentioning the stern wheelers it should be mentioned that particularly in America another form of river boat was employed known as the Side Wheeler which was a normal river boat but instead of being fitted with one engine and one paddle wheel is fitted with two independent engines (one Port one starboard) driving side mounted independent paddle wheels. This type of propulsion unit is good for river and or shallow water operation only.

3-**Radial Paddle Wheels –**This is the simplest and least expensive form of side wheel in use. The wheel consists of a cast iron hub fitted with radial arms which extend to outer steel rings. Flat boards are then fixed parallel to the ends of the arms. These boards known as floats are securely fixed and transmit the engine's power to drive the ship in the required direction.

These simple paddle wheels are not particularly efficient with energy by spent after the power part of the stroke purely agitating the water to no good effect. So, to increase efficiency and lower costs a different form of wheel was introduced.

4-**Feathering Paddle Wheel –**



This type of wheel whilst looking similar to the radial paddle wheel is very different being a huge advance in the technology of the time when in 1877 Henry Williams was granted the patent.

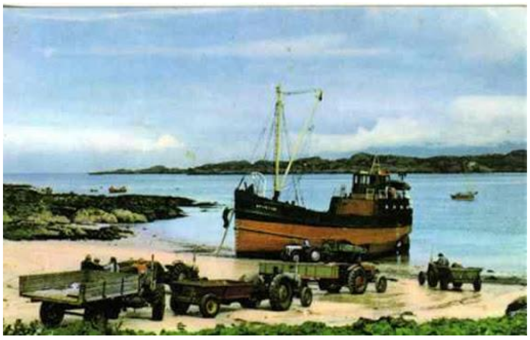
In this form of paddle wheel the boards or floats enter the water at 90° then turn being held as near as possible to this angle during the power part of the stroke. The boards are then moved into what is known as the feathering position when not providing power so as to cause as little resistance to the vessels motion as possible.

It should be noted that commercial paddle steamers have both paddles joined for safety reasons, with no means of independent operation. The Admiralty however operated diesel electric paddle tugs for many years with independent paddles with no reported problems.

Rudders

During maintenance the mounting points for the rudder should be inspected for wear. Similarly any links which take the controls from a remote operating location to the tiller. The rudder may also suffer damage from debris kicked by the screw whilst running. Poor manoeuvring may be improved by adjustments to the rudder, and students may wish to research balance rudders (https://www.marineinsight.com/naval-architecture/types-rudders-used-ships/) and schilling rudders.

The Skeg



The skeg's principal purpose is to provide protection for the screw from underwater obstructions or even limited protection should the vessel run aground. In some boats the skeg is in line with the keel, and this is essential if the vessel is expected to 'take the bottom' because it works on tidal waters. The VIC boats where designed to be beached on a falling tide so that they could be unloaded in remote locations without the need for a quay.

Lake or riverboats may have their screws mounted significantly below the keel line in order to improve efficiency because the screw can work in 'clean water' not affected by the turbulence of the hull shape. This makes the screw particularly vulnerable.

Anodes

Metals will corrode when in contact with water, but it is possible to reduce this by attaching 'anodes' to metal components which are below the water. This can be to protect the entire ship if it is steel, or just the metal parts extending from a wood or fibreglass hull. The anodes are made of zinc (for saltwater) or magnesium (freshwater) and they will gradually corrode and diminish in size over time – hence the term 'sacrificial anode'. They will require periodic replacement if they are to work correctly. Do not be fooled into leaving them in place until they completely disappear to get your money's worth – they might appear intact but be relatively ineffective if the bulk of the material is just zinc oxide.

Any metal component requires an electrical connection to the anode and this may be seen as wires running through the bilges to connect external anodes to the prop shaft, skin fittings to bronze strainer inlets, or the keel condenser. Ring anodes are also available which may be fixed directly to the shaft adjacent to the screw.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO2 1	Flexible Coupling	Assess prop-shaft flexible coupling for security and wear	Workshop	
LO2 2	Thrust bearing	Identify the location of the thrust bearing on the drive train; inspect and lubricate	Workshop	
LO2 3	Propeller shaft	Withdraw a propeller shaft from the stern tube, assess wear with callipers at several points. Replace and reseal	Workshop	
LO2 4	Stern gear	Inspect screw, skeg, rudder & tiller for corrosion and wear	Workshop	
LO2 5	Paddle Wheels	Describe the arrangements of paddle wheels and explain feathering	Classroom	
LO2 6	Anodes	Inspect anodes if present and replace as necessary	Workshop	

Learning Outcomes

LO3:

Steam plant in boats

1. Factors effecting stability
2. Boilers in boats
3. Pollution

There is a great deal of science surrounding the principles of stable floating in boats and ships, and there are substantial compromises around speed, efficiency and stability. In the most simplified way, a narrow hull will travel quickly through the water with the least resistance, however this hull shape will be very susceptible to rolling. Most leisure steam vessels are relatively sleek, to offset the relatively low power output of the engines and also because slim launches are aesthetically elegant. This gives many smaller boats the increased likelihood of being 'tippy'.

Whilst all vessels must expect a bit of roly-poly do be aware that too much of that can have a seriously harmful effect on a boiler particularly if it so severe that there is a danger that heating surfaces on the boiler tubes or furnace crown may be momentarily uncovered as water slurps about inside the boiler. It is for this reason that the heating surfaces in marine boilers are generally proportionately lower in the boiler than on similar land-based plants.

For example, the paddle steamer *Britannia* (1896 – 1955) which worked in the Atlantic swells of the Bristol Channel got through no less than four boilers in her career of sixty years. By contrast the *Consul,* ex *Duke of Devonshire* (1896 – 1968) which worked in the altogether gentler waters of Torbay and the South Coast was scrapped with her original boiler still in place.

To attempt to make a boat as stable as possible for any given hull profile, it is desirable to keep the centre of mass as low as possible. In practical terms, this means the engine, boiler, fuel, and water reserves need to be as low in the hull as is practicable. This introduces several problems: fuel and water need to be raised up to feed the boiler, the engine could potentially be affected by bilge water, and possibly the most significant – the hull needs to be protected from the heat of the boiler.

Both wooden and fibreglass boats are vulnerable to both radiated and conducted heat below and adjacent to the boiler. There are many tales of steam launch owners spotting smoke rising from below the boiler rather than from the funnel, and having to react quickly to avert disaster. Therefore it is important that the area around and below the boiler is regularly inspected for signs of scorching or damage, and that any heat-resisting structures (such as reflective stainless steel sheets, or ceramic fibre insulation) remain intact, undamaged and fit for purpose.

Each fitting out is unique, but in all cased the boiler will be firmly secured to load-bearing members which are fitted to the hull. The fixings and structural members are all susceptible to corrosion and so these should be inspected regularly. This will be particularly important if the vessel is used on salt water which may enter the bilges and attack steel fittings. Heat can be transmitted well through metals, and so any scorching may also be evident around structural members, and also in timber or bulkheads adjacent to the smoke side of the boiler.

The smoke from funnels may attract disapproving glances because of the perception of pollution and as already discussed, smoke should be kept to a minimum Great care should also be given to liquid pollution from steam vessels. The lubrication system of most steam engines is classified as a 'total loss' lubrication system. Basically this means that the oil applied to bearings and links will eventually drip off the engine and go somewhere else. It is very important that this somewhere else is not a river, lake, or the sea. It is normal good practice that there will be a drip-tray or sump under the engine which will collect the oil, plus condensed water from the engine and/or rain if it is an open boat.

The oil collected in the sump tray should be disposed of appropriately – whether withdrawn with a syringe and collected for recycling, or passed through an oil-scavenging cloth for responsible disposal. Additionally, the bilges of the vessel could have oil scavenging 'bilge socks' floating in them to collect any drips which manage to escape. There are also a number of commercially available filter/collection systems which clean the water flowing from a bilge pump and the filters in these should be checked routinely to make sure they are in full working order and not blocked of full.

LO	Objective	Assessment Criteria	Delivery	Date achieved and Supervisors signature
LO3 1	Stability	Explain why the heavy parts of the vessel's machinery should be as low as possible	Classroom	
LO3 2	Heat Transfer	Examine areas around a boiler for signs of excessive heat transfer	Workshop	
LO3 3	Pollution	Explain how oil pollution may enter the waterway or sea	Classroom	
LO3 4	Pollution prevention	Assess the systems in place for preventing oil contamination from a vessel	Workshop	

BESTT Marine steam maintenance and repair Module MS6

Assessment Record for: Training Centre: Year:

LO1	1	2	3	4		
Supervisor Initials and date when completed						
LO2	1	2	3	4	5	6
Supervisor Initials and date when completed						
LO3	1	2	3	4		
Supervisor Initials and date when completed						