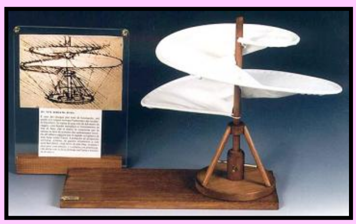
Advanced Propulsion System
GEM 423E

Week 1: Historical Development of the Screw propeller

Dr. Ali Can Takinacı
Associate Professor
in
The Faculty of Naval Architecture and Ocean Engineering
34469
Maslak – Istanbul – Turkey

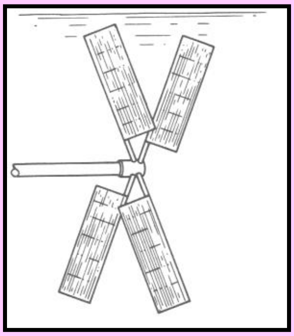
- Archimedes (287-212 BC) & Leonardo da Vinci (1452-1519 AC) made initial thoughts on screw propulsion.

Archimedes invented his “Archimedean Screw Pumps” to irrigate the field of Syracuse in Sicily.



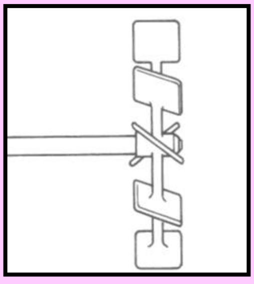
Air propeller model. One of the best known drawings of Leonardo, this precursor of the helicopter has a central metal frame propeller covered with linen. Power was to be supplied by men, or by a spring, to rotate the propeller and create lift. **Dimension:** cm. 40x27x27

- Toogood and Hayes of Britain claimed patent for using helical surfaces (Archimedean screws) as a propeller in 1661.
- Hooke, the English physicist suggested to use Archimedean screw for ship propulsion in 1683.



- Some years later in 1752 the Academie des Sciences in Paris offered a series of prizes for research related in naval architecture. Bernoulli won a prize with a propeller wheel.

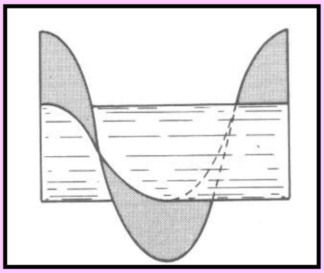
Daniel Bernoulli 1700-1782



Bernoulli's propeller wheel

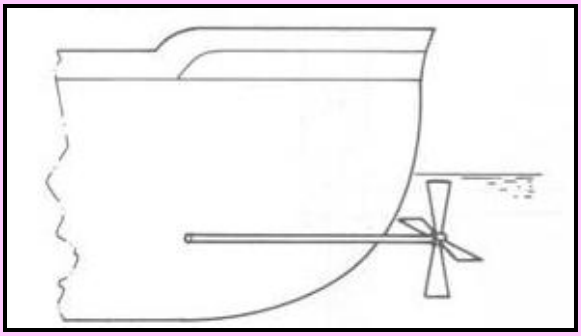
- He intended to be driven by a Newcomer steam-engine.
- With this arrangement, he calculated that a particular ship could be propelled at just under 2.5 knots by the application of some 20-25 HP.
- Opinion, however, was still divided as the most suitable propulsor configuration, as indeed it was to be for many years to come.

- The French mathematician Paucton, working about the same time as Bernoulli, suggested a different approach which was based on the Archimedean screw



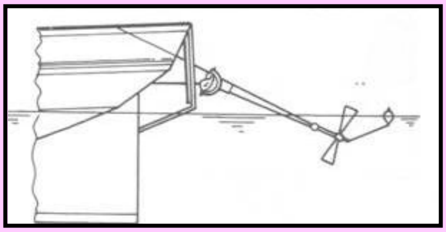
Archimedean screw of Paucton

- Joseph Bramah in England proposed an arrangement for a screw propeller located at the stern of a vessel in 1785.



Bramah's screw propeller design

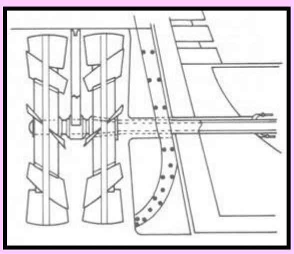
- Edward Shorter used a variation of Brahma's idea to assist sailing vessels.
- The shaft was designed to pass into vessel's hull above the waterline.
- He managed to propel a deeply loaded ship at a speed of 1.5 mph in calm condition.
- But no further application of Shorter 's propeller was recorded



Shorter's propulsion system

- Colonel John Stevens, who was a lawyer in the USA experimented with screw propulsion in the year following Shorter 's proposal.
- He built a 25 ft long boat into which he installed a rotary steam engine and coupled this directly to a four-bladed propeller.
- The blades were flat iron plates riveted to forgings which formed a "spider-like" boss attachment to the shaft.
- He later replaced the rotary engine with a steam engine of the Watt type an managed to attain a steady cruising speed of 4-8 mph.
- However he was not impressed with the overall performance of his craft and decided to turn his attention and energies to other means of marine propulsion

- John Ericsson designed and patented in 1836 a propulsion system comprising two contra-rotating propeller wheels.
- The wheels were not dissimilar in outline to Bernoulli's earlier proposal.
- Each wheel comprised eight short, wide blades of helical configuration mounted on a blade ring with the blades tied at their tips by a peripheral strap.

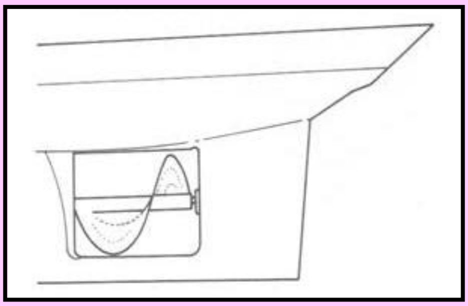


- He constructed a 45 ft vessel named “*Francis B. Ogden*”.
- Trials were conducted on the Thames in the presence of representative from the admiralty.
- The vessel was observed to be capable of a speed of some 10 mph.
- The admiralty expressed “disappointment” with the result of the trial.
- It was said that one reason was their concern over a vessel’s ability to steer reliably when propelled from the stern.

- Following this rebuff Ericsson left England for the USA in 1843.
- He designed the US Navy’s first screw propelled vessel, the *Princeton.*
- It has been suggested that by this time the US merchant marine had some 41 screw propelled vessels in operation

- The British Admiralty modified their view of screw propulsion shortly after Ericsson's trials due to the work of an English farmer, Francis Petit Smith, who was later knighted for his efforts.
- Smith enjoyed making models boats, and testing them on o pond on his farm in Middlesex.
- From one such model which was propelled by an Archimedean screw he was insufficiently encouraged to build 6 ton prototype boat powered by 6 h.p. steam engine to which he fitted a wooden Archimedean screw of two turns.

- The vessel underwent trials on the Paddington Canal in 1837.
- The propeller was damaged during the trials and about half of it broke off whereupon the vessel immediately increased her speed.

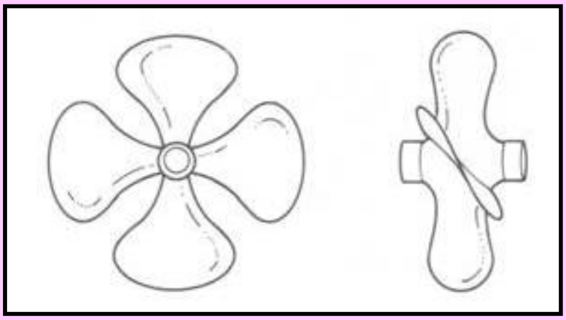


- Smith recognized the implications of this accident and modified the propeller accordingly.
- In the trials on the Thames, the vessel reached a speed of some 7 mph.
- The navy's response to these trials was sufficiently encouraging to motivate Smith into constructing a larger ship of 237 tons displacement which he called *Archimedes*.
- The vessel was built in 1839, had a length of 125 ft.
- She powered by two 45 hp engines and fitted with single turn Archimedean screw (5 ft 9 in in diameter, 5 ft in length)

- In the meantime, the *Archimedes* was lent to Brunel, who fitted her with a series of propeller having different forms.
- The result of Brunel's trials with this vessel was that the design of the *Great Britain* which was originally intended for paddle propulsion, was adapted for screw propulsion.
- The general form of the propeller adopted by Brunel for the *Great Britain* did not follow the Smith design but was similar to that proposed by Ericsson, except that in the case of the *Great Britain* the propeller was not of the contra-rotating.

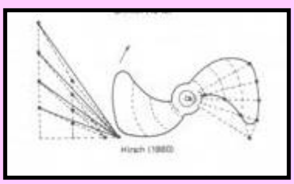
- Concurrent with these developments other inventors had introduced novel features into propeller design.
- Renie in 1839 had proposed increase in pitch from forward to aft of the blade, three-bladed helices and the use of skewback in the design.
- Taylor and Napier in 1840 experimented with tandem propellers, some of which were partially submerged.
- Also by 1842 the windmill propeller fitted to the French mail boat *Napoleon*.

- This propeller is particularly interesting since it was developed to its final form a series of model tests in which diameter, pitch, blade area and blade number were all varied.



- *HMS Rattler* was a sloop of 800 tons and was powered by a steam-engine of about 200 HP.
- Subsequently, she ran a race against her paddle half-sister, *HMS Polyphemus*.
- By January 1845 some thirty-two different propeller designs had been tested.
- The best of these propellers was designed by Smith and propelled the ship at a speed of about 9 knots.
- This propeller was a a two-bladed design, had a diameter of 10 ft 1 in, a pitch of 11 ft and weighed 1.68 tones.

- In 1860 Hirch patented a propeller having both variable chordal pitch (today’s camber) and variable radial pitch; as an additional feature this propeller also possessed a considerable amount of forward skew on the blades.

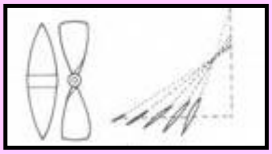


- Thornycroft in 1873 designed a propeller with restricted camber in the mid-span regions of the blade and also combined this with a backward curvature of the blades in an attempt to suppress tangential flow.

- Other developments worthy of note in the context of this introductory review are those by Mangin, Zeise and Taylor.
- Mangin in 1851 attempted to increase the thrust of a propeller by dividing the blades radially into two portions.


Mangin (1851)

- Zeise carried the ideas of the development of the radial pitch distribution a stage further in 1886.
- He increased the pitch of the inner sections of the blade in an attempt to make better use of the inner part of the blades.



- The latter part of the 19th century also saw the introduction of theoretical methods which attempted to explain the action of the screw propeller.
- In 1880-1970 the basic shape of propellers remained unchanged .
- In 1970-1990's fuel crisis and environmental effects (low noise and vibrations) had an impact on propeller shape and stern configurations as well as the developments of unconventional propellers

Part II. Modern Propulsion Systems

Fixed Pitch Propellers

- The fixed pitch propeller has traditionally formed the basis of propeller production over the years in either its *mono block* or *built-up* forms.
- The mono block propellers is commonly used today.
- But the built-up propeller, whose blades are cast separately from the boss and the bolted to it after machining, is rarely used.

- Mono block propellers form the major proportion of propellers today and cover a broad spectrum of design types and sizes, ranging from those weighing only a few kilogram's for use on small power-boats to those destined for large tankers and bulk carriers which can weigh around 80-85 tones an perhaps require the simultaneous casting of some 120 tones of metal in order to produce for casting.

Materials

- For larger propellers, over 300 mm in diameter, the non-ferrous materials predominate: high tensile brass, and the manganese and nickel-aluminium bronzes (nicalium) are the most favoured types of materials.
- For small propellers, use is frequently made of materials such as the polymers, aluminium and nylon.

Choice of Blade Number

- Blade numbers generally range from two to seven.
- In some naval applications, where consideration of radiated noise become important, blade numbers may be greater.

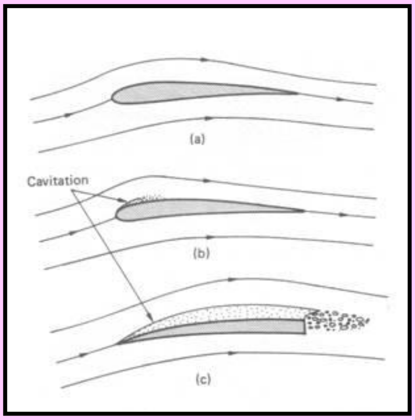
- For merchant vessels, 4, 5 and 6 blades are generally favoured.
- Many tugs and fishing vessels frequently used 3-bladed designs.
- Small work or pleasure power-boats 2- and 3-bladed propellers tend to predominate.

Operation Regimes - Cavitation

- For some, high speed craft where both the advance and rotational speeds are high and the propeller immersion is low, a point is reached where it is not possible to control the effects of cavitation acceptably within the other constraints of the propeller design.

- To overcome this problem the blade sections are permitted to fully cavitate, so that the cavity developed on the back of the blade extends beyond the trailing edge and collapses into the wake of the blades in the slipstream.

- Such propellers are termed *supercavitating propellers* and frequently find application on high-speed naval and pleasure craft.



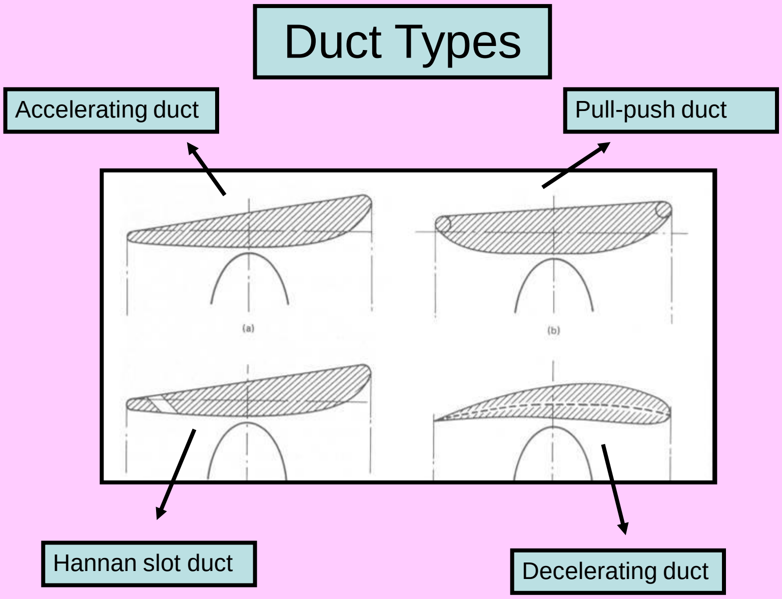
- When the design condition dictates a specific hydrodynamic loading together with a very susceptible cavitation environment, typified by a low cavitation number, there comes a point when even the supercavitating propeller will not perform satisfactorily.
- For example:
  - Tip immersion is so small.
  - Air is drawn from the surface.

- Such propeller are termed *surface-piercing propellers,*
- Their design immersion (free surface – shaft center) can be reduced to zero.
- Propeller operates half in half out of water.
- The pressure face remains fully wetted and the suction side is fully *ventilated* or *dry*.

This is an analogus operating regime to the supercavitating propeller, bu in this case the blade surface suction pressure is at athmospheric condition and not the vapour pressure of water.

Ducted Propeller

- Ducted propellers comprimise two principal components:
  - An annular duct having an aerofoil cross section;
  - The propeller;



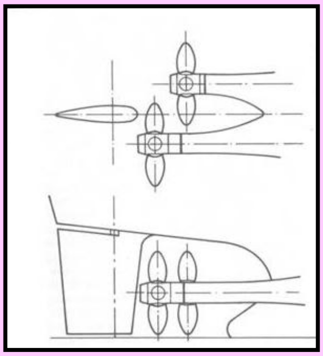
Contra-rotating Propellers

- The contra-rotating propeller, principle, comprising two coaxial propellers sited one behind the other and rotating in opposite directions.

- Contra-rotating propulsion systems have the hydrodynamic advantage of recovering part of the slipstream rotational energy.
- This is lost to a conventional single screw system.
- They posses a capability for balancing the torque reaction from the propulsor which is an important matter for torpedo and other similar propulsion systems.

Overlapping Propellers

- This is again a two-propeller concept.
- The propellers are not mounted coaxially but are each located on separate shaft system such that the distance between the shaft center lines is less than the diameter of the propellers.

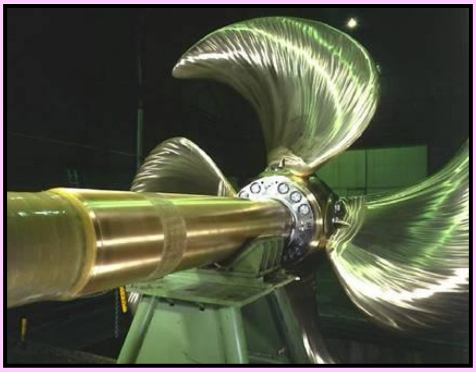


- Design problems.
  - The direction of propeller rotation
  - The distance between shafts
  - The longitudinal clearance between the propellers
  - The stern shape
- There are only partial answers to these questions.
  - The best rotation direction is outward, relative to the top-dead-center position
  - The distance between shaft lies in the region of 0.5 to 0.8D

Controllable Pitch Propellers - CPP

- There is only one operational variable in fixed pitch propeller which is rotational speed.
- But the CP propeller provide an extra degree of freedom in its ability to change blade pitch.

- Some propulsion applications, particularly those involving shaft driven generator, the shaft speed is held constant, thus reducing the number of operating variables to one.



- The CP has much more complex structure the FP alternative.

- But, they offer some advantages. Some of them
  - Manoeuvring
  - Fine control of thrust
  - Constant shaft speed operation

- Large diameter of hub may cause a hydrodynamic problem

Hub/Diameter ratios

FP Propellers	CP Propellers
0.16D-0.25D	0.24D-0.32D

- SCHOTTEL controllable-pitch propellers are propulsion systems that can be used with almost any type of vessel.
- The power spectrum ranges from 600 kW to 30,000 kW, with propeller sizes varying between approximately 1.5 to 8.0 metres.
- Advanced calculation methods allow the controllable-pitch propeller systems to be optimally adapted to the vessel’s hull form, thereby maximizing efficiency and minimizing noise generation.

PROPELLERS - What is the difference between "controllable", "variable" and "progressive" pitch, and what effect does each have on efficiency?

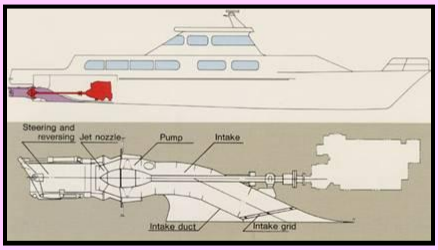
- Controllable and variable pitch are often confused with each other.
- Controllable pitch is when the propeller blades are allowed to rotate on the hub.
- This means that the helm can control the pitch angle, changing it to meet varying operational needs - such as when a trawler changes from towing (lower pitch) to top speed (higher pitch). It is important to note that it is the pitch angle that changes.

- Why? Because once you rotate the blade, you no longer have the same pitch from root to tip - causing a slight loss of efficiency as compared to a fixed-pitch propeller.
- This loss, however, is more than overcome by being able to use more than one pitch to begin with.
- Variable pitch refers to the distribution of pitch from root to tip (as introduced above). Because water is slower near the hub (principally due to frictional effects of the shafting and boss structure), reducing the pitch in this region can improve cavitation, but more importantly it can greatly reduce root cavitation in highly-loaded propellers.

- Reducing the pitch at the tip - called "off-loading" the tip - reduces the tip vortex energy that contributes to cavitation and noise.
- Progressive pitch is a term used by some for the camber that is in a blade.
- Think of the local pitch at the leading edge "progressing" to a higher pitch at the trailing edge. Cambered blades typically have a bit more efficiency and less cavitation, but they are harder and more expensive to manufacturer.
- Ref: http://www.hydrocompinc.com/news/news19.htm

Waterjet Propulsion

- WJ propulsion has found considerably application in recent years on wide variety of small high-speed craft; however their application to larger craft is growing rapidly.

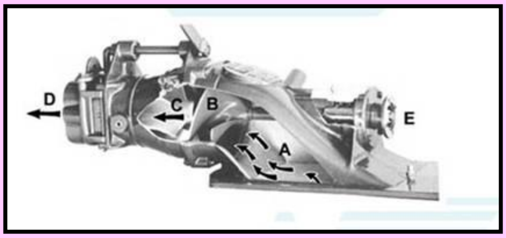


How a Waterjet Works ?

- A waterjet generates propulsive thrust from the reaction created when water is forced in a rearward direction.
- It works in relation to Newton's Third Law of Motion - "every action has an equal and opposite reaction".
- A good example of this is the recoil felt on the shoulder when firing a rifle, or the thrust felt when holding a powerful fire hose.

- Put simply, the discharge of a high velocity jet stream generates a reaction force in the opposite direction, which is transferred through the body of the jet unit to the craft's hull, propelling it forward.
- In a boat hull the jet unit is mounted inboard in the aft section.
- Water enters the jet unit intake on the bottom of the boat, at boat speed, and is accelerated through the jet unit and discharged through the transom at a very high velocity.

- The picture shows where water enters the jet unit via the Intake (A). The pumping unit, which includes the Impeller (B) and Stator (C), increases the pressure, or "head", of the flow.
- This high pressure flow is discharged at the nozzle (D) as a high velocity jet stream. The driveshaft attaches at the coupling (E) to turn the impeller.



- Steering is achieved by changing the direction of the stream of water as it leaves the jet unit.
- Pointing the jet stream one way forces the stern of the boat in the opposite direction which puts the vessel into a turn.

- Reverse is achieved by lowering an astern deflector into the jet stream after it leaves the nozzle.
- This reverses the direction of the force generated by the jet stream, forward and down, to keep the boat stationary or propel it in the astern direction.

How a Waterjet Works ? - Video

Waterjet Advantages

- Waterjet propulsion has many advantages over other forms of marine propulsion, such as stern drives, outboard motors, shafted propellers and surface drives.
- These advantages include

Excellent Maneuverability

- Precise steering control at all speeds
- "Zero Speed" steering effect provides 360° thrusting ability for docking and holding stationary.
- Sideways movement possible with multiple jet installations.
- High efficiency astern thrust with "power-braking" ability at speed

- **High efficiency**
  - Propulsive coefficients as good or higher than the best propeller systems achievable at medium to high planning speeds
- **Low drag and shallow draft**
  - Absence of underwater appendages reduces hull resistance shallow draught - Jet intake is flush with hull bottom to afford minimum draught.

- **Low maintenance**
  - No protruding propulsion gear eliminates impact damage or snags
  - Minimum downtime and simple maintenance routines
- **Smooth and quiet**
  - No hull vibration, no torque effect and no high speed cavitation gives maximum comfort levels on board
  - Low underwater acoustic signature
- **Total safety**
  - No exposed propeller for complete safety around people in the water

- **Maximum engine life**
  - Jet unit impeller is finely matched to engine power
  - Power absorption is the same regardless of boat speed
  - No possibility of engine overload under any conditions
- **Simplicity**
  - Single packaged module
  - No heavy and expensive gearbox required for many installations.
  - Simple driveline from engine to jet coupling
- **Easy installation**
  - Complete factory tested package, ready to bolt in
  - No difficult engine alignment problems

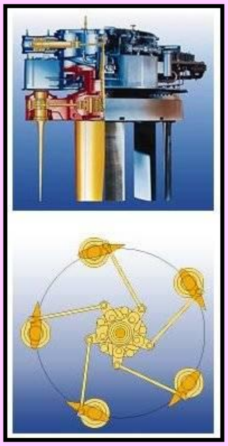
- **Superior cavitation resistance**
  - Pump design offers up to 25% more thrust than other waterjets between 0 and 20 knots.
  - Manoeuvrability at low speeds and acceleration to high speeds are superior.
- **Precise steering control**
  - Jet steering nozzle minimises thrust loss when steering.
  - No central dead band provides higher course-keeping efficiency and higher overall boat speeds.

Cycloidal Propellers

- The cycloidal, or vertical axis propellers, basically comprise a set of vertically mounted vanes, six or eight in number, which rotate on a disc mounted in a horizontal plane.
- The vanes are constrained to move their spindle axis relative to the rotating disc in a predetermined way by a governing mechanical linkage.
- Types of vertical axis propellers:
  - The Kirsten-Boeing Propeller
  - The Voith-Schenider Propeller

- The Voith-Schenider Propeller
  - Precise and steeples thrust variation in X and Y-coordinates within 360 degrees with constant direction of rotation and constant and variable revolutions.

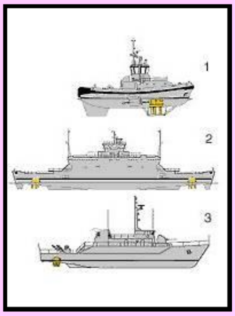
- The ideal controllable pitch propeller:
  - precise
  - safe
  - quick
  - reliable



- The Voith-Schneider Propeller with its own specific characteristics provides every vessel so equipped maximum manoeuvrability, safety, efficiency and reliability.

- Main applications: on Voith Water Tractors for towing, shiphandling, escort duties for salvage, fire-fighting, oil-skimming and off-shore operations, on ferries and on mine hunting vessels.

- By intelligent propeller arrangement, types of ships can be produced to the highest standards of marine technology which offer the optimum adaptation to their special operating conditions, e.g.:
  - Voith Water Tractors(1)
  - double-ended ferries(2)
  - passenger ships
  - floating cranes
  - mine hunters(3)
  - buoy layers
  - oil-skimming vessels

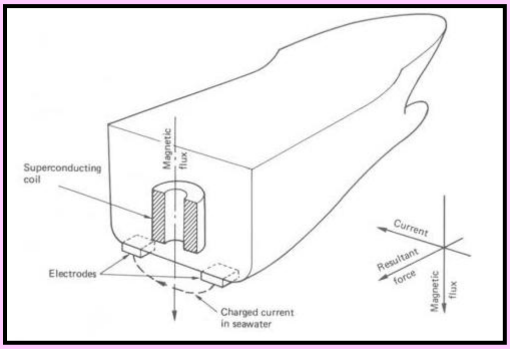


Paddle Wheels

- It is a predator of screw propulsion system.
- Used largely on lakes and river services or where limited draughts are encountered.

Superconducting Electric Propulsion (Magnetohydrodynamics – MHD)

- The system provides ship propulsion without the aid of either propellers or paddles.
- The fundamental principal of electromagnetic propulsion is that of interaction between a fixed coil inside the ship and an electric current is passed through the sea water from electrodes in the bottom of the ship.
- A force is produced orthogonal to the magnetic field and to the current as a result of Fleming's right-hand rule.
- It provides noise and vibration free hydrodynamic propulsion so that it is found some applications in navy vessels.
- One of the major problems in this propulsion system is the difficulty to maintain superconducting coil zero resistance property, which is required, to be kept at the temperature of liquid helium (-268 °C).



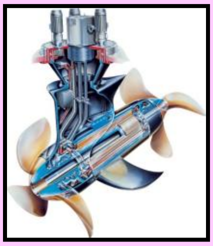
Working principal of MHD (Superconducting Electric Propulsion)

Azimuth Podded Propulsion

- It provides propellers with high manoeuvrability, high efficiency, low noise and less cavitation
- Today, the major users of pod units have been cruise liner operators.

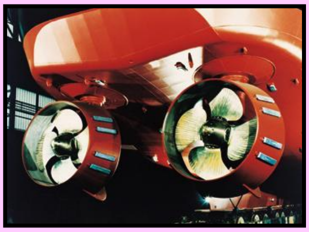
- The introduction of pod propulsion, which will allow the propulsion unit to be placed without considering any shaft arrangements or space for machinery will, of course, give the naval architect many new opportunities to design the 'ultimate hullform'.

- Pod drives in twin propeller version are particularly suitable for the market sectors RoPax, double-ended ferries, supply vessels, tankers, container ships and yachts.
- For the offshore industry, pods with single propellers in nozzles are part of the new development



Rudder Propeller

- Rudder propeller is combined propulsion and steering systems rated at up to 6000 kW, which convert the engine power into optimum thrust.
- As the underwater components can be steered through 360 degrees, the full propulsive power can also be used for manoeuvring and dynamic positioning of the ship.
- Maximum manoeuvrability, optimum efficiency, economical operation, space-saving installation and simple maintenance - these are just a few of the outstanding features of this robust and reliable propulsion concept, which has proved its worth under tropical and arctic conditions in vessels of all kinds all over the globe.

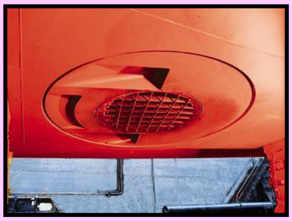


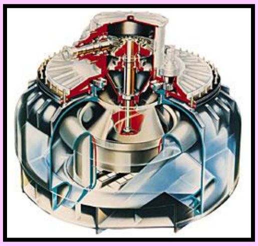
Twin Propeller

- The SCHOTTEL Twin-Propeller (STP) is the successful optimization of the complete Rudder propeller system with an efficiency up to 20% higher.
- It is the ideal means of propulsion for all vessels in the medium speed range.
- Two propellers mounted on a common shaft and rotating in the same direction, with guide fins integrated into the complete system, result in a host of advantages, including high reliability due to the straightforward construction with a small number of moving parts, reduction of the propeller diameter without penalising the efficiency, lower fuel costs and low maintenance requirements.

Pump Jet

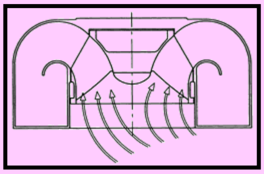
- The SCHOTTEL Pump-Jet (SPJ) operates on the principle of a centrifugal pump.
- An impeller sucks in water from under the hull and forces it into a pump housing. The outlet nozzles are fitted in the bottom plate, making it possible for the jet to be installed in a flat-bottomed hull too.
- With a compact design, low loss of buoyancy and low suction effect, Pump-Jets with power ratings up to 3500 kW develop a high thrust even in extremely shallow water and over a wide speed range. Like all SCHOTTEL products, they are distinguished by their excellent manoeuvring properties - as propulsion units for inland and coasting vessels or as independent manoeuvring and standby systems for seagoing ships.



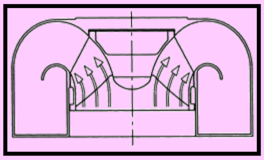


Pump-Jet / Operating principle

An impeller sucks in water through the intake funnel, a protective grid in the bottom plate preventing foreign bodies from entering the Pump-Jet.

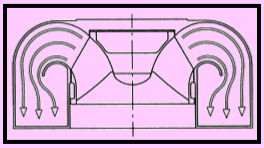


The impeller forces the energized water into a diffuser, as a result of which kinetic energy is converted into pressure energy.

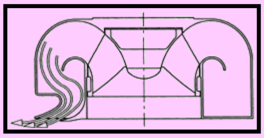


Pump-Jet / Operating principle 2

This energy transformation process is continued in the diffuser, and the water is collected in the pressure casing.



The water is finally expelled through the outlet nozzles at an angle of 15°, and thrust is generated which can be steered through 360°.



Pump-Jet / Applications – Main Propulsion

Double-ended ferry
(1.40 m draught),
2 x SPJ 132 (505 kW each)
Shipyard: McTay Marine Ltd.,
United Kingdom
Owner: Caledonian MacBrayne,
United Kingdom .

Smaller standard vessel
(1.64 m draught),
2 x SPJ 82 (370 kW each)
Shipyard: Danyard Aalborg AS,
Denmark
Owner: Royal Danish Navy

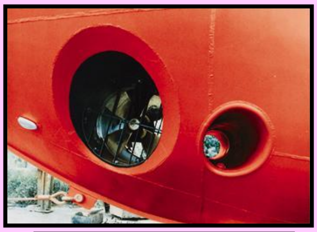
Pump-Jet / Applications – Auxiliary Propulsion

Ro-Ro-vessel
(8.40 m draught),
2 x SPJ 220 (850 kW each)
Owner: DFDS AS, Denmark

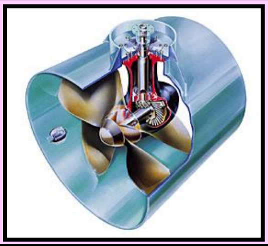
Paddle-wheel steamer
1 x SPJ 57 (195 kW)
Conversion yard: Scheepswerf en Maschinefabrik De Biesbosch-Dordrecht BV, The Netherlands
Owner: Köln-Düsseldorfer Deutsche Rheinschiffahrt AG, Germany

Transverse Thruster

SCHOTTEL Transverse Thrusters (STT) are built on the basis of the tried-and-tested underwater gearboxes of Rudder propellers. We supply standard Transverse Thrusters with FP or CP propellers rated at up to 3400 kW.



SCHOTTEL offers optimized solutions even for special applications in which extremely low noise generation is required.



Transverse Thruster - Applications

19.500-dwt-Chemical product tanker
Main Propulsion: 1 x SSP 7 (5.1 MW)
Auxiliary: 1 x STT 550 (620 kW)
Shipyard: Shanghai Edwards Shipyard, PR China
Owner: Donsøtank Reederi AB, Sweden

Car/passenger ferry
2 x STT 170 (260 kW each)
Shipyard: Ørskov Staalskibsværft AS, Denmark
Owner: Samsø Linien, Denmark