

9. CONTROL DEVICES

9.1 Active and passive control devices

All control devices could be divided in two main categories: active and passive.

Active control devices: are devices actively fed by external energy.

Passive control devices: are devices absorbing energy from ship speed and propeller race.

Active	Passive
Thrusters; active rudders; azimuthing propellers; Voith-Schneider propellers	rudders; stopping shields; fins;

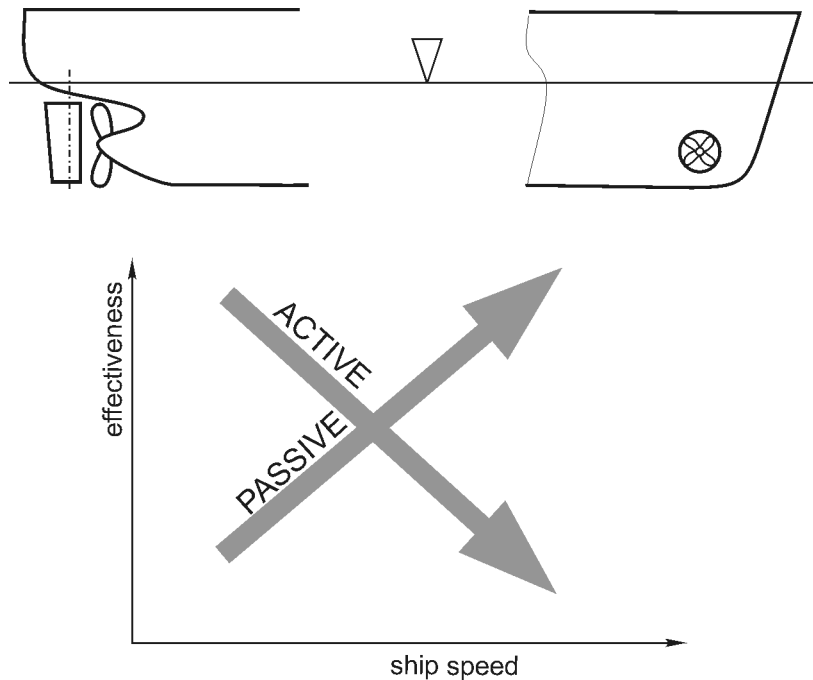


Fig. 9-1

Application: effectiveness of active control devices generally is reduced with increasing ship speed; effectiveness of passive control devices is increasing with ship speed.

9.2 Characteristics of rudder profiles

Rudders are the most common control devices. Rudder is a profiled foil or flat plane which is developing lift when inclined to the flow. Profile (or flat plane) when at an angle δ to oncoming flow develops lift and drag force. Lift causes turning moment of the ship, drag causes reduction of speed. Both depend on rudder deflection angle

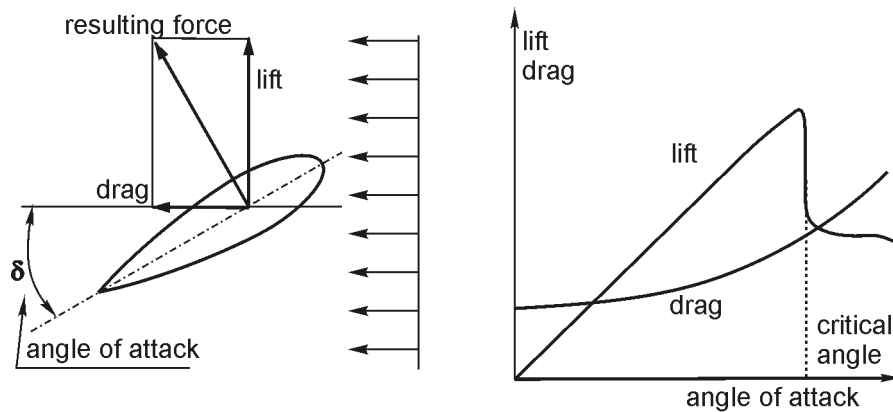


Fig. 9-2

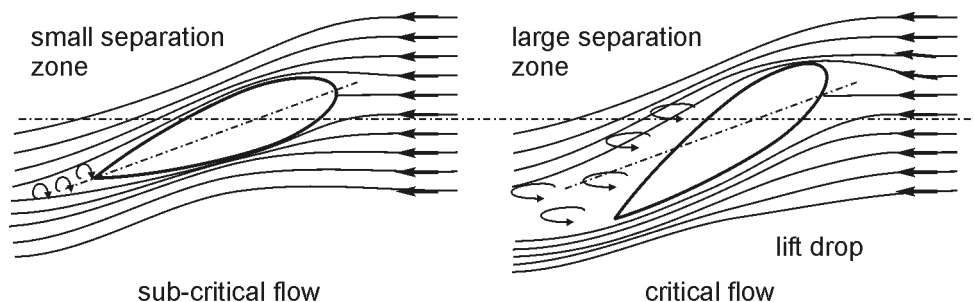


Fig. 9-3 Explanation of the stalling phenomenon at critical angle

Rudder is more effective if the lift developed is larger. The ratio of drag/lift is also important and it has to be as small as possible.

Rudder effectiveness depends upon:

- profile (form, thickness)
- aspect ratio
- rudder outline
- rudder location
- special features (flaps, foils etc.)

9.3 Rudder effectiveness

9.3.1 Profile

All modern rudders have cross-section in the form of a symmetric airfoil profile. Some older ships are fitted with the flat plate rudder. Profile is better than flat plate as it is seen from the table below where values of lift and drag coefficients and their ratio are compared:

rudder angle [deg]	plate rudder			NACA 0015 Profile		
	C_L	C_D	C_D/C_L	C_L	C_D	C_D/C_L
10	0.323	0.132	0.409	0.289	0.042	0.145
20	0.654	0.311	0.437	0.622	0.135	0.217
30	0.915	0.593	0.648	0.926	0.320	0.346
40	1.000	0.873	0.673	0.685	0.605	0.883

Providing almost the same values of lift coefficients profile offers much lower values of drag/lift coefficients. Difference between various profiled used for rudders is not very large, but thickness has some effect.

9.3.2 Aspect ratio

Aspect ratio affects rate of change of lift coefficient with rudder angle and also affects the critical angle

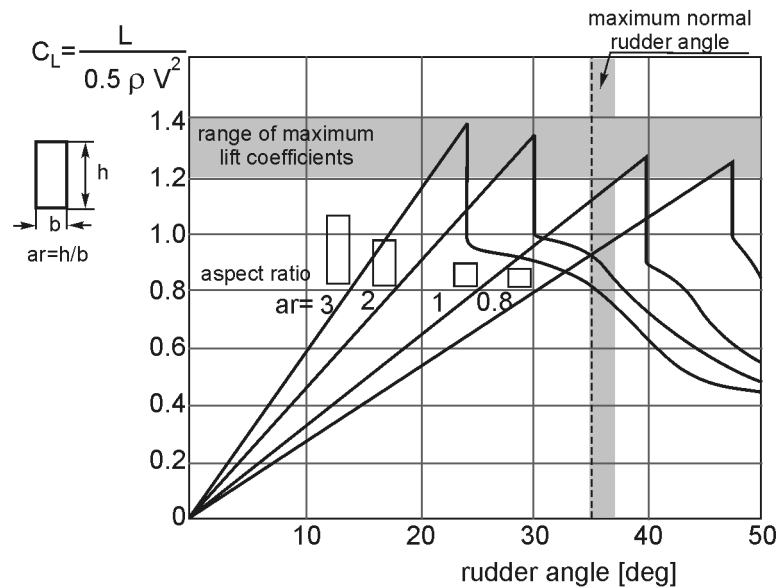


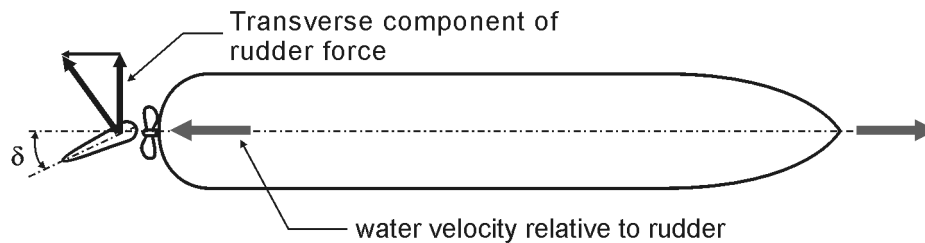
Fig. 9-4

9.3.3 Rudder outline

Rudder outline has small effect on profile characteristics. Outline could be rectangular, trapezoidal, rounded edges, etc.

9.4 Rudder force

Rudder force depends on the angle of rudder relative to the water velocity. When the ship is moving on the straight course, this angle is approximately equal to the rudder angle (Fig.2-9).



δ - rudder angle = angle of attack

Fig. 9-5

When the ship makes a turn, the direction of water velocity at the position of the rudder does not coincide with the plane of symmetry of the ship.

The angle of attack of the rudder is reduced and is equal to the angle of rudder minus drift angle at the position of the rudder.

(Drift angle at the position of the rudder is the angle between tangent to the ship's path at the rudder position and plane of symmetry of the ship).

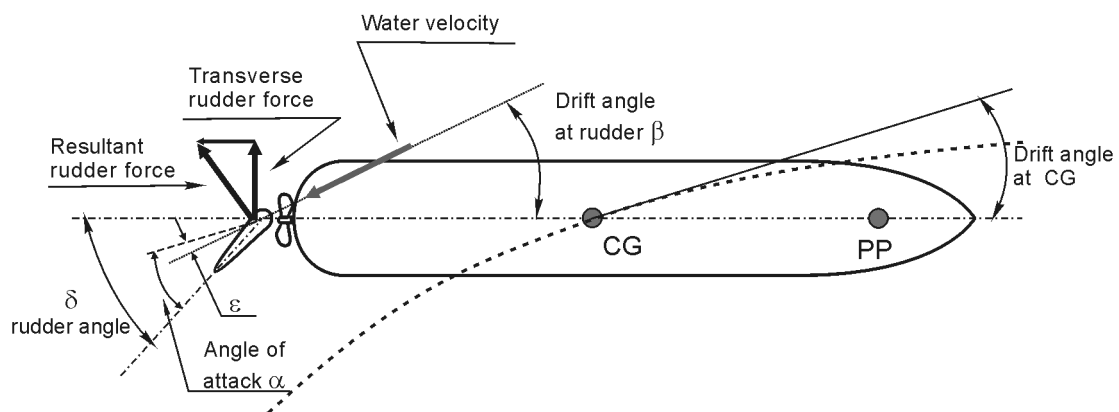


Fig. 9-6

In fact, the so-called flow straightening effect due to propeller slipstream, diminishes influence of the drift angle. Finally :

$$\alpha = \delta - \beta + \varepsilon$$

α effective rudder angle

δ effective rudder angle

β drift angle

ε flow straightening effect

9.5 Effect of ship's wake and propeller race on rudder performance.

Rudder is located behind the hull and in the propeller slip stream. This is important from the point of view of the lift force of the rudder.

$$\text{Lift } L = C_L \cdot \frac{1}{2} \rho V^2 S$$

9.5.1 Effect of wake:

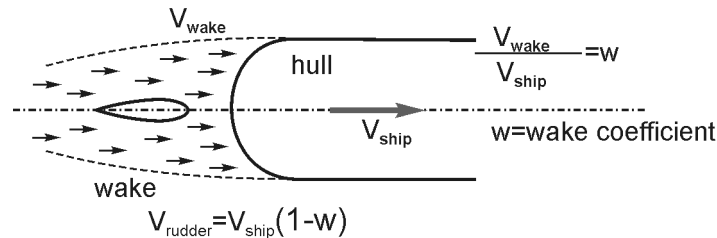


Fig. 9-7

Velocity of flow in the wake is considerably lower than ship speed - lift force is reduced!

9.5.2 Effect of propeller slipstream (race)

When the rudder is located behind the propeller, it is in the propeller slipstream where the flow is accelerated

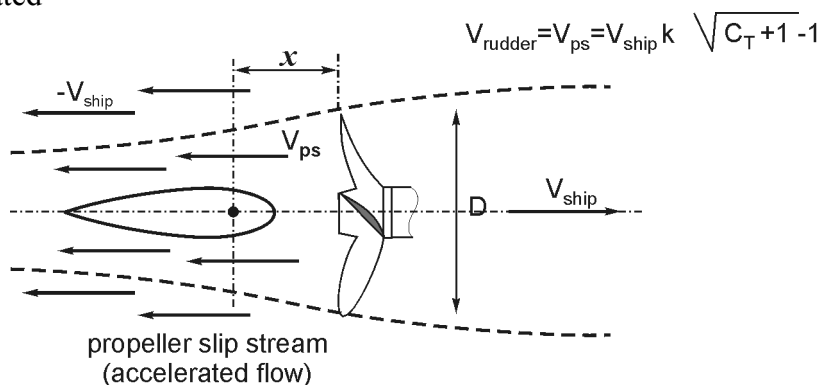


Fig. 9-8

Velocity in the propeller slipstream depends on the propeller thrust Load coefficient C_T and on the distance x between propeller and rudder. This is taken into account by the coefficient k in the above formula:

x/D	0	0.25	0.50	0.75	1.0
k	0.50	0.79	0.88	0.94	0.96

Wake effect and effect of propeller slipstream act in opposite directions.

$W = 0.1 \sim 0.3$ depending of the fullness of the hull. Velocity in the propeller slipstream $V_{ps} = 1.2 \sim 1.5 V_{SHIP}$, that means that this effect is stronger. If propeller is not working, the effectiveness of rudder is very small. At rest, if propeller is kicked ahead the lift force of rudder is large.

In twin-screw ships, rudders positioned behind propellers are effective. If there is one rudder in the plane of symmetry, it is much less effective.

9.6 Rudder in the propeller slipstream in ahead and astern condition

The sketches show how rudder develops lift in different situations during manoeuvring with the propeller in ahead and astern position

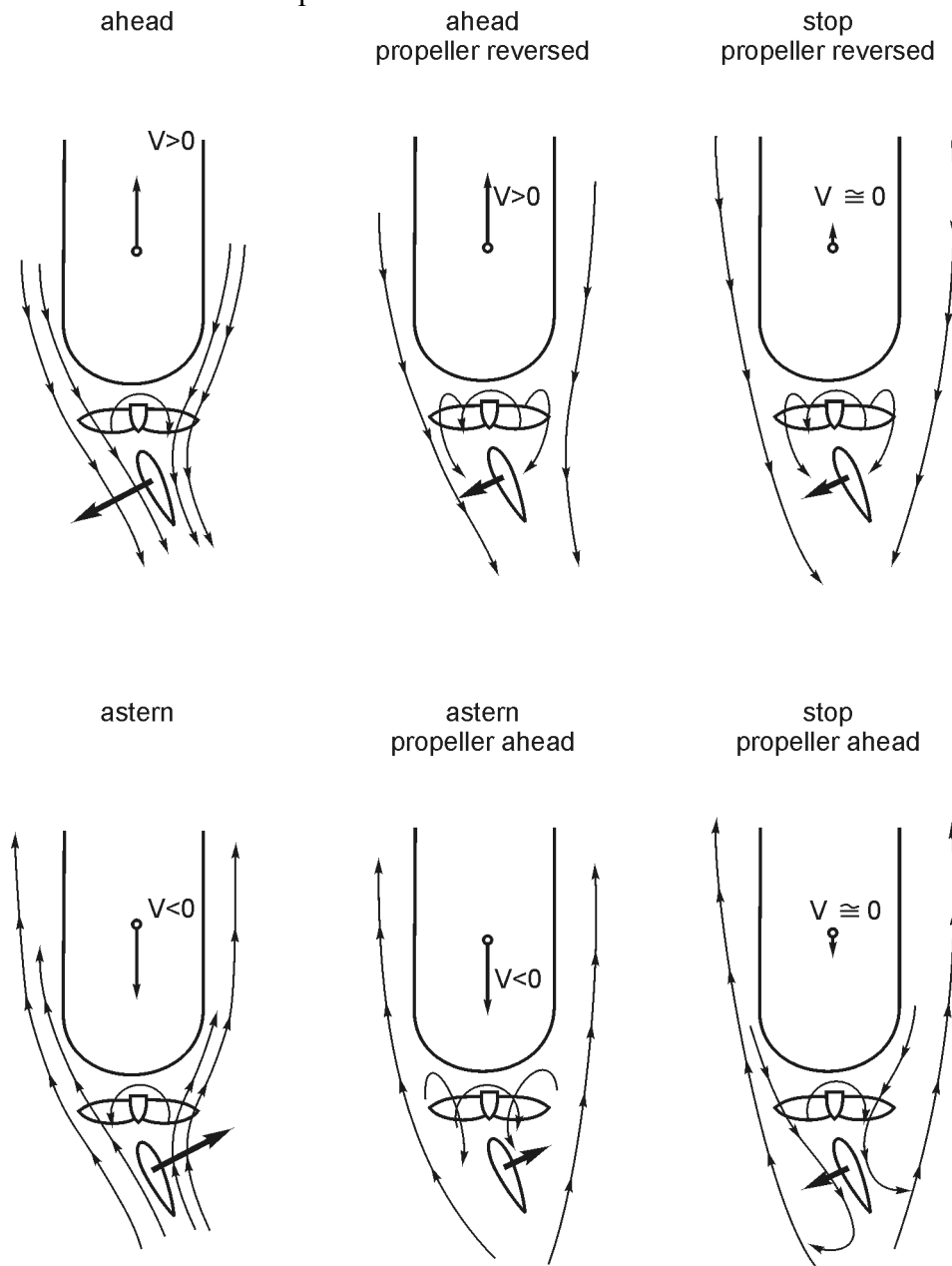


Fig. 9-9

9.7 Different ways to develop lift - Special rudders

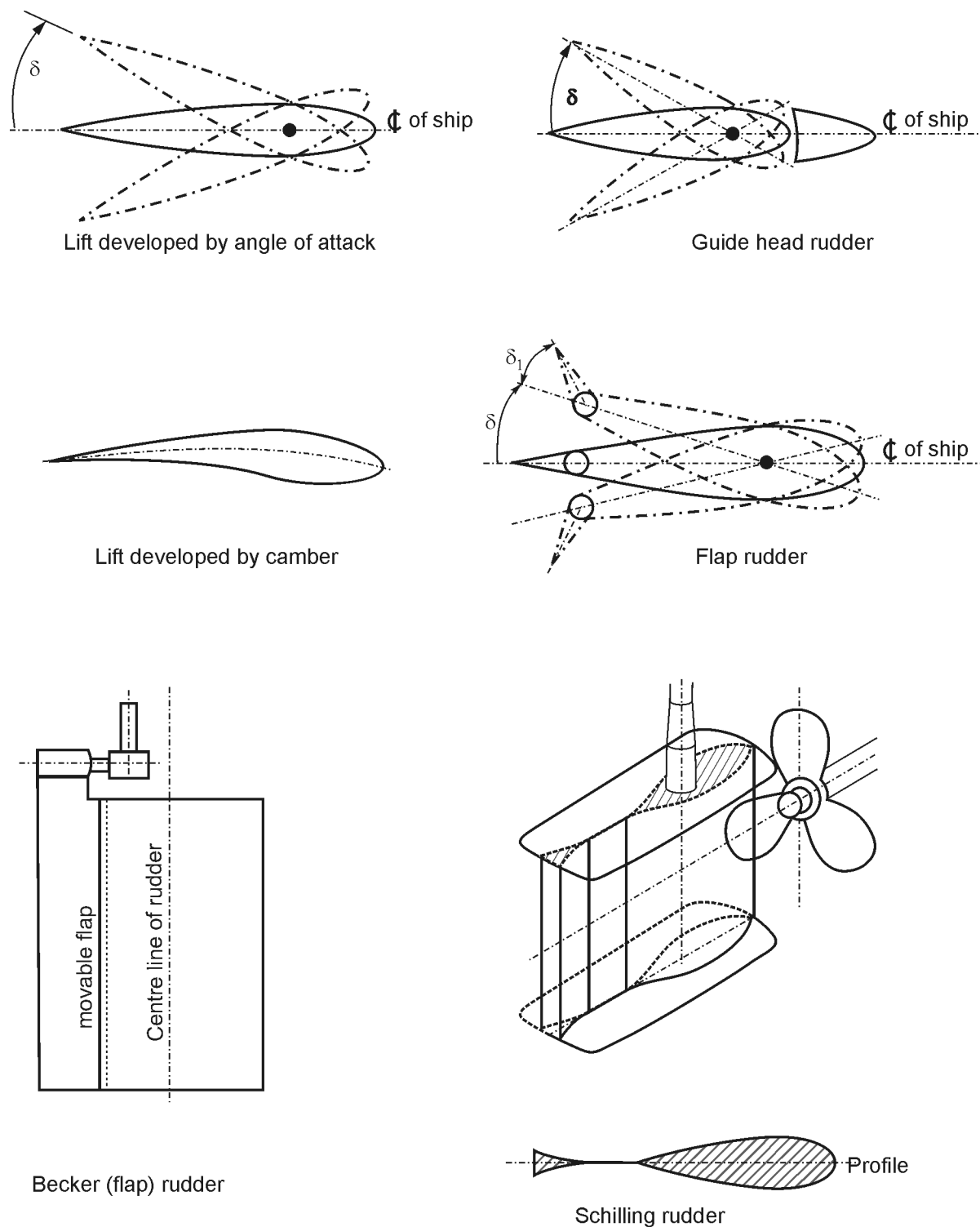


Fig. 9-10

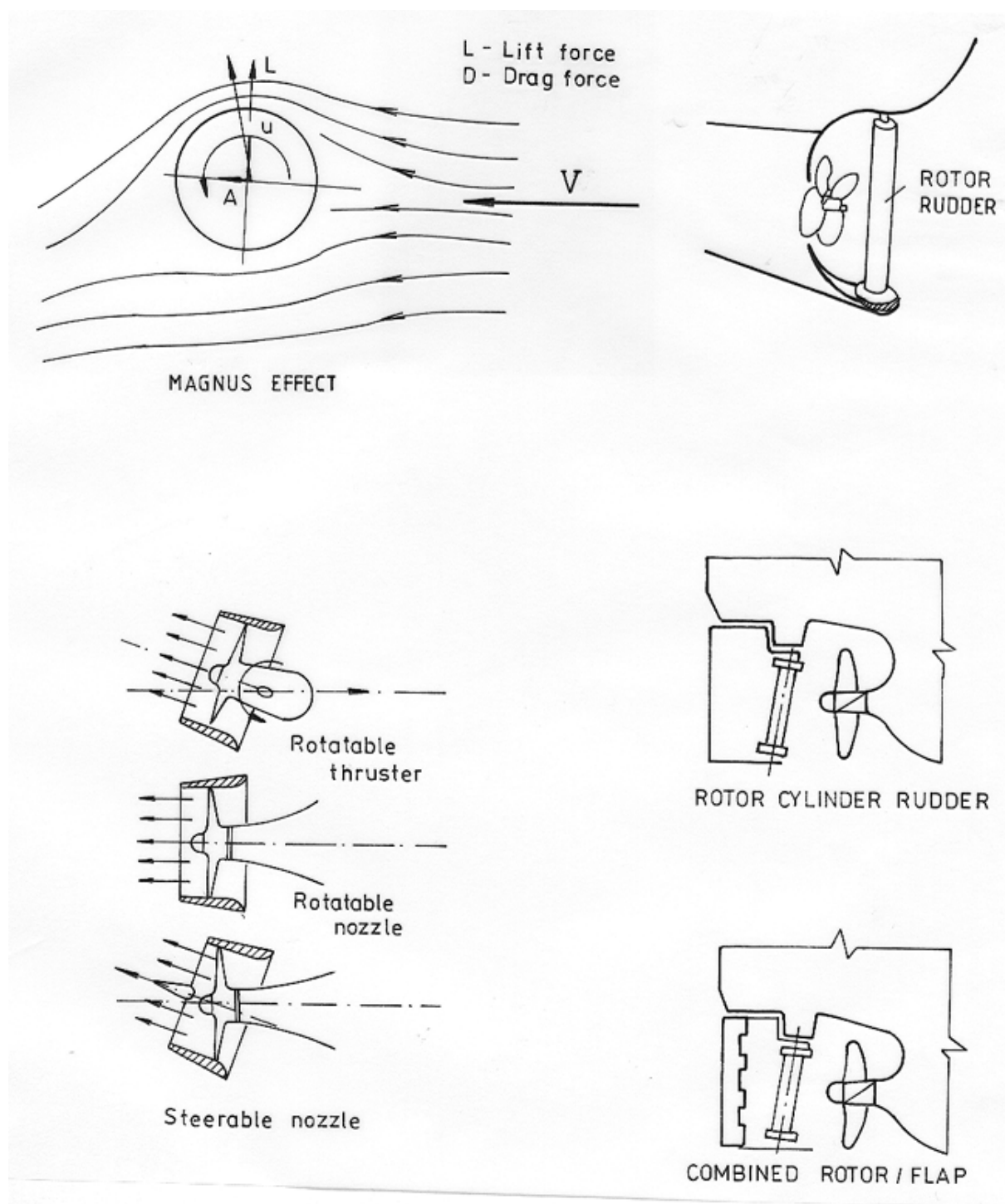


Fig. 9-11

9.8 Special rudders characteristics

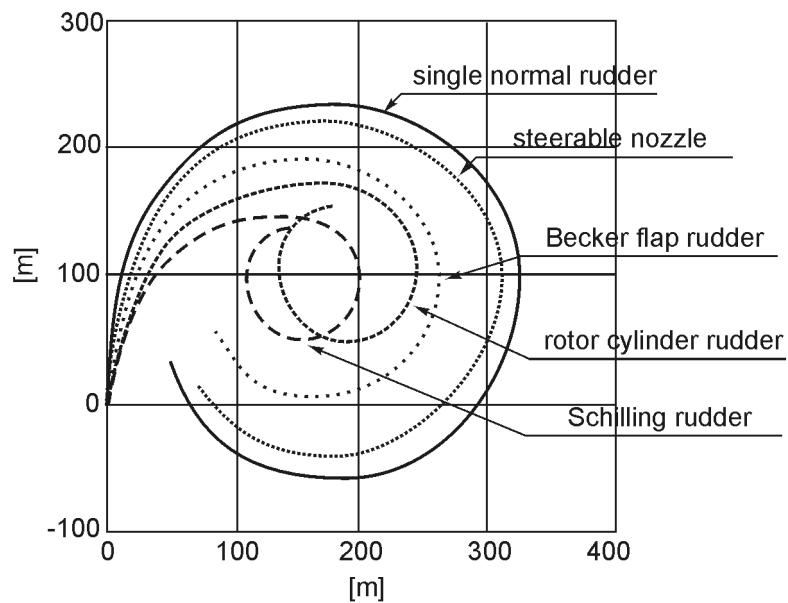


Fig. 9-12 Comparison of turning circles

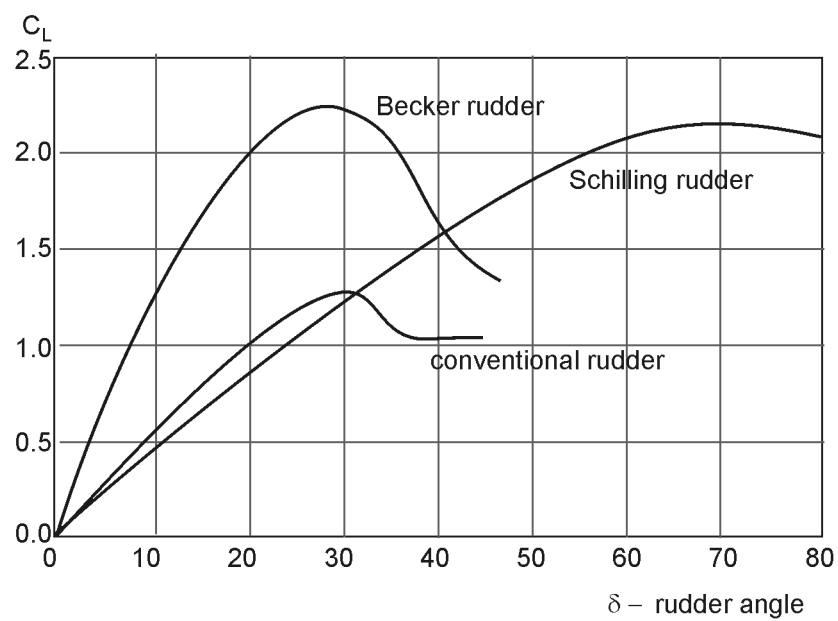


Fig. 9-13 Comparison of lift characteristics

9.9 Active control devices: Thrusters

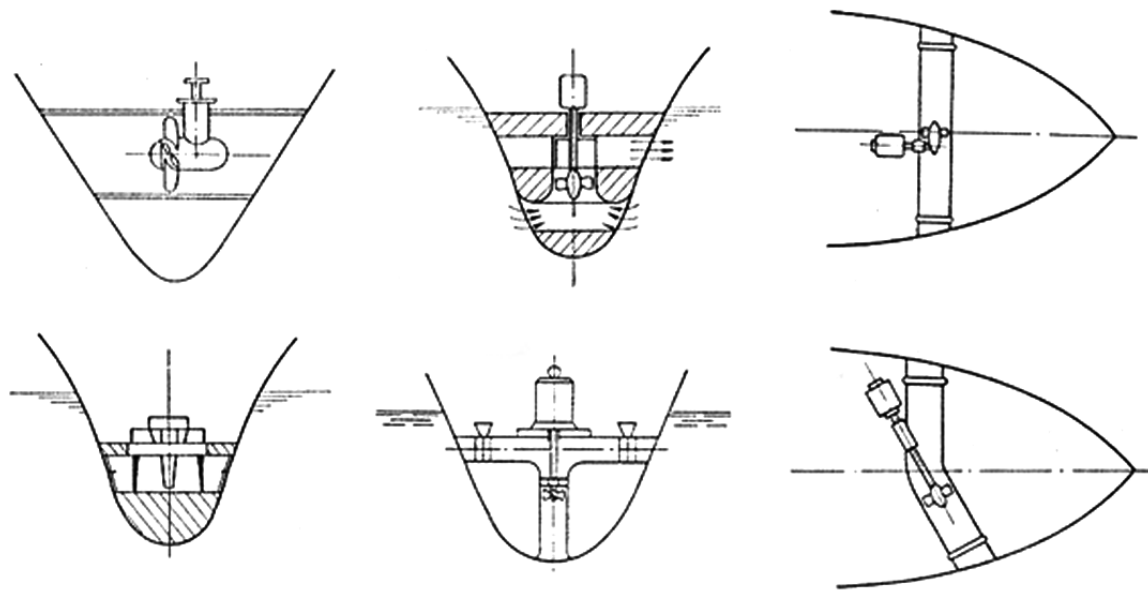
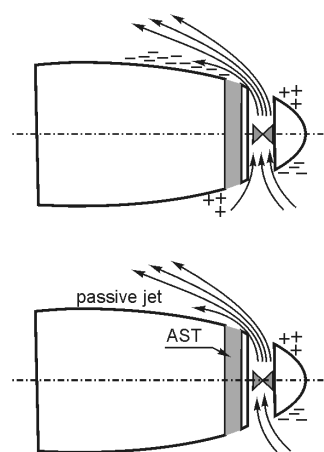


Fig. 9-14 Thruster types



Sketch showing direction of active and passive flow through thruster without and with AST

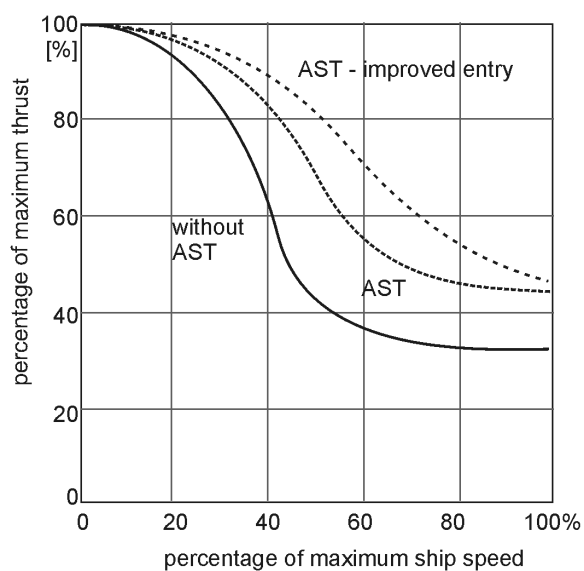


Fig. 9-15 Transverse thruster with and without Anti Suction Tunnel (AST)

9.10 Thruster forces

Thrusters create forces perpendicular to the plane of symmetry of the ship.

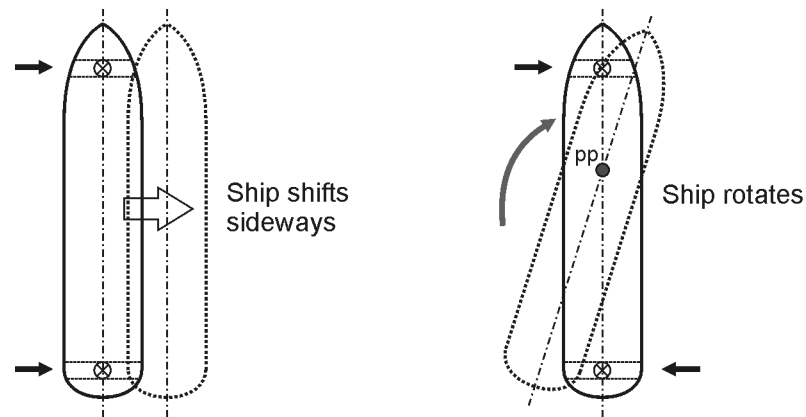


Fig. 9-16

Effectiveness of thrusters depends on whether the ship is moving ahead or astern.

Example: bow thrusters are more effective when ship is moving astern.

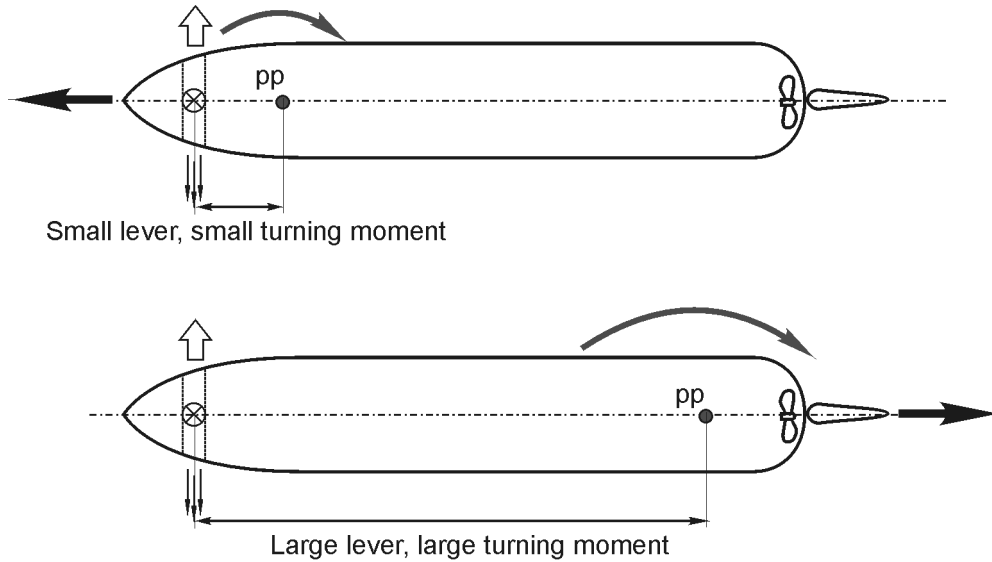


Fig. 9-17

9.11 Differences in rudder and thrusters action

Very slow speed – swing to starboard

At the very slow speed the effect of using starboard rudder results in shift of the centre of gravity to port, then swing to starboard. The position of pivot point is in bow quarters. When using bow thrusters the pivot point is in the stern quarters and the centre of gravity moves to starboard (fig.2-13)

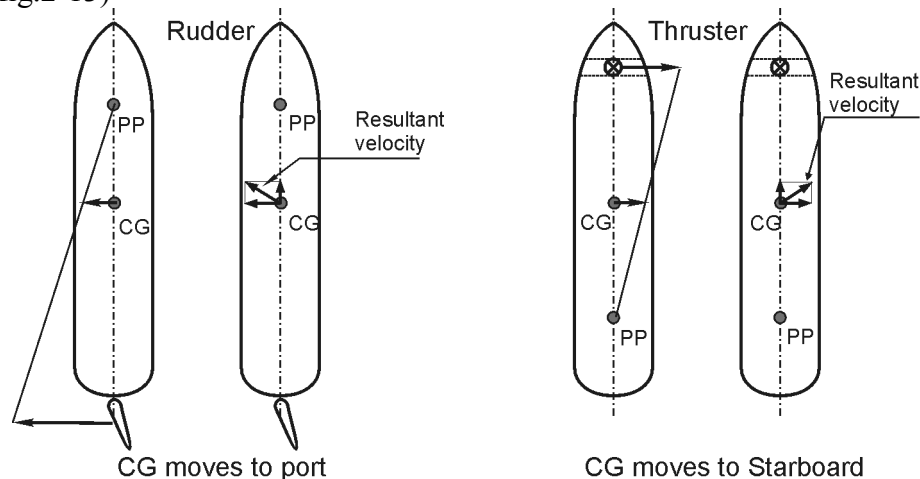


Fig. 9-18

At speed – swing to starboard

At speed, the bow thrusters force may have an opposite effect on the centre of gravity, moving it away from the swing when the pivot point comes between the resultant bow thrusters force and the centre of gravity. However, the bow is meeting very strong underwater resistance, leaving a small resultant force to push the bow over and to move the stern against the lateral resistance abaft the pivot point. The bow thrusters force is exerted to close to the centre of lateral resistance and in comparison with the resistance, is too small to have noticeable effect. In addition, the water rushing past tunnel aperture reduces thrust of the bow thrusters (fig.2-14).

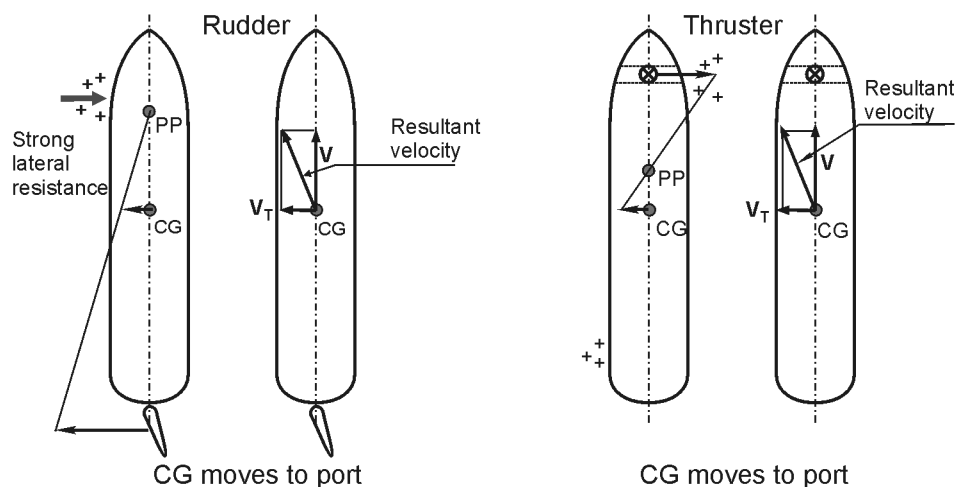


Fig. 9-19

9.12 Lateral motion using rudder and bow thrusters

9.12.1 Lateral motion to port

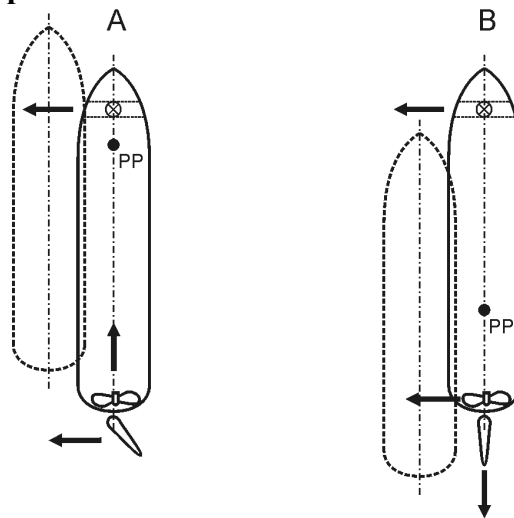


Fig. 9-20

1. With short kicks ahead, full starboard rudder, right handed propeller. Moderate amount of thrust of the bow thrusters to port to compensate swing to starboard. (Fig.2.15)
2. With astern power. Transverse thrust of the propeller pushing stern to port. Moderate thrust of the bow thruster to port to compensate possible swing.

9.12.2 Lateral motion to starboard

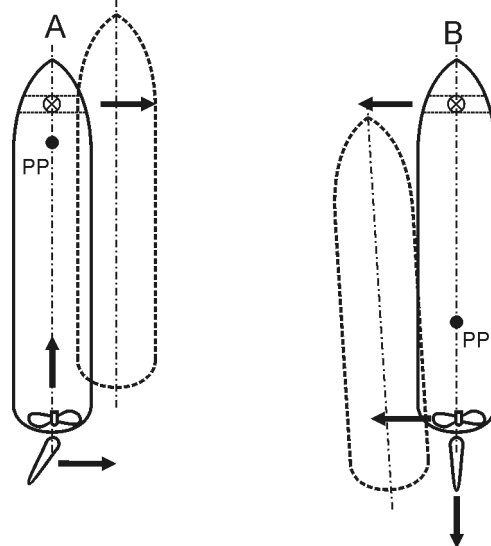


Fig. 9-21

- A. With short kicks ahead, full port rudder and use of bow thrusters to starboard no problems in lateral motion to starboard.

With astern power, there might be problems as shown (fig. 2.16). The bow is likely to swing to starboard because of the transverse thrust of the propeller to port. To control this thrust of the right-handed propeller bow thruster force to port is used. This, together with transverse thrust of the propeller may cause unintentional lateral motion to port, which, if much power is used, might be of considerable magnitude.