

7 STANDARD MANEUVERING TESTS

This section describes some of the typical maneuvering tests which are performed on full-scale vessels, to assess stability and performance.

7.1 Dieudonné Spiral

1. Achieve steady speed and direction for one minute. No changes in speed setting are made after this point.
2. Turn rudder quickly by 15° , and keep it there until steady yaw rate is maintained for one minute.
3. Reduce rudder angle by 5° , and keep it there until steady yaw rate is maintained for one minute.
4. Repeat in decrements of -5° , to -15° .
5. Proceed back up to 15° .

The Dieudonné maneuver has the vessel path following a growing spiral, and then a contracting spiral in the opposite direction. The test reveals if the vessel has a memory effect, manifested as a hysteresis in yaw rate r . For example, suppose that the first 15° rudder deflection causes the vessel to turn right, but that the yaw rate at zero rudder, on the way negative, is still to the right. The vessel has gotten "stuck" here, and will require a negative rudder action to pull out of the turn. But if the corrective action causes the vessel to turn left at all, the same memory effect may occur. It is easy to see that the rudder in this case has to be used excessively driving the vessel back and forth. We say that the vessel is unstable, and clearly a poor design.

7.2 Zig-Zag Maneuver

1. With zero rudder, achieve steady speed for one minute.
2. Deflect the rudder to 20° , and hold until the vessel turns 20° .
3. Deflect the rudder to -20° , and hold until the vessel turns to -20° with respect to the starting heading.
4. Repeat.

This maneuver establishes several important characteristics of the yaw response. These are: the response time (time to reach a given heading), the yaw overshoot (amount the vessel exceeds $\pm 20^\circ$ when the rudder has turned the other way), and the total period for the 20° oscillations. Of course, similar tests can be made with different rudder angles and different threshold vessel headings.

7.3 Circle Maneuver

From a steady speed, zero yaw rate condition, the rudder is moved to a new setting. The vessel responds by turning in a circle. After steady state is reached again, parameters of interest are the turning diameter, the drift angle β , the speed loss, and the angle of heel ψ .

7.3.1 Drift Angle

The drift angle is the equivalent to angle of attack for lifting surfaces, and describes how the vessel "skids" during a turn. If the turning circle has radius R (measured from the vessel origin), then the speed *tangential* to the circle is $U = rR$. The vessel-reference velocity components are thus $u = U \cos \beta$ and $v = -U \sin \beta$. A line along the vessel centerline reaches closest to the true center of the turning circle at a point termed the *turning center*. At this location, which may or may not exist on the physical vessel, there is no apparent lateral velocity, and it appears to an observer there that the vessel turns about this point.

7.3.2 Speed Loss

Speed loss occurs primarily because of drag induced by the drift angle. A vessel which drifts very little may have very little speed loss.

7.3.3 Heel Angle

Heel during turning occurs as a result of the intrinsic coupling of sway, yaw, and roll caused by the center of gravity. In a surface vessel, the fluid forces act below the waterline, but the center of gravity is near the waterline or above. When the rudder is first deflected, inertial terms dominate (Phase 1) and the sway equation is

$$(m - Y_{\dot{\delta}})\dot{v} - (Y_r - m x_{CG})\dot{r} = Y_{\delta}\delta. \quad (89)$$

The coefficients for \dot{r} are quite small, and thus the vessel first rolls to starboard (positive) for a positive rudder action.

When steady turning conditions are reached (Phase 3), hydrodynamic forces equalize the centrifugal force $mU r$ and the rudder force $Y_{\delta}\delta$. The sway equation is

$$-Y_{\dot{v}}v + (mU - Y_r)r = Y_{\delta}\delta, \quad (90)$$

with Y_r small, $v < 0$ when $r > 0$ for most vessels, and $|Y_{\dot{v}}v| > |Y_{\delta}\delta|$. Because the centrifugal force acts above the waterline, the vessel ultimately rolls to port (negative) for a positive rudder action. The transition between the inertially-dominated and steady-turning regimes includes an overshoot: in the above formulas, the vessel overshoots the final port roll angle as the vessel slows. From the sway equation, we see that if the rudder is straightened out at this point, the roll will momentarily be even worse!

In summary, the vessel rolls into the turn initially, but then out of the turn in the steady state.

7.3.4 Heeling in Submarines with Sails

Submarines typically roll into a turn during all phases. Unlike surface vessels, which have the rigid mass center above the center of fluid forcing, submarines have the mass center below the rudder action point, and additionally feel the effects of a large sail above both. The inertial equation

$$(m - Y_{\dot{\delta}})\dot{v} - (Y_r - m x_{CG})\dot{r} = Y_{\delta}\delta \quad (91)$$

is dominated by $m\dot{v}$ (acting low), $-Y_{\dot{v}}\dot{v}$ (acting high), and $Y_{\delta}\delta$ (intermediate). Because $|Y_{\dot{v}}\dot{v}| > m$, the vessel rolls under the sail, the keel out of the turn. In the steady state,

$$-Y_{\dot{v}}v + (mU - Y_r)r = Y_{\delta}\delta. \quad (92)$$

The drift angle β keeps the $Y_{\dot{v}}$ -force, acting high, toward the center of the turn, and again centrifugal force $mU r$ causes the bottom of the submarine to move out of the turn. Hence, the roll angle of a submarine with a sail is always into the turn, both initially and in the steady state. The heel angle declines as the speed of the submarine drops.