1. Introduction

Pivot point of the ship turning is defined in seafarers publications more or less accurately as follows.

Pivot point is the point which trace the turning curve of a ship.It is located in the fore section of the ship, aftwards of the stem at 1/6-1/3 of ship’s length [3].

Although not intended, some publications may give the impression that the pivot point moves right aft with sternway.This is clearly not correct and can sometimes be misleading. It should also be stressed that other factors such as acceleration, shape of hull and speed may all affect the position of the pivot point [24].

The pivot point is defined also: *that position aboard the vessel* about which the ship rotates when turning.*In conventional vessels, the pivot point was approximately one third (1/3) of the ship’s length, measured from forward, when moving ahead.*

…It should be noted that when the vessel goes to anchor the pivot point moves right forward and effectivelly holds the bow in one position.Any forces acting on the hull, such as from wind or current, would cause the vessel to move about the hawse pipe position [14].

The phenomenon of pivot point existence in ship manoeuvring is well known to navigators, though there is unclearly statement regarding qualitatively and quantitatively its location on a ship during various modes of operation. The available literature on ship manoeuvring and handling does not cover all aspects of pivot point in a systematic way [7].

The pivot point (PP) is the point in diametrical plan of the vessel or in the prolongation of this plan, around which the vessel swings on the tajectory which she describes.This trajectory can be a circle arch with its own center of rotation on the traject (momentary center of rotation).From PP, fore and aft of the vessel can be seen swinging with the same angular speed, even if PP is out of ship’s shape.

PP (or tactical point of turning) is located in the point of intersection between ship’s diametrical plan and the perpendicular from momentary center of rotation.In PP, ship’s tangential speed on the trajectory is ship’s speed recorded on board.

PP is important for ships’ operators because it gives some indications regarding equilibrum of the forces acting on the vessel, by its indication regarding space swept during turning and by posibility to predict ship’s orientation.

If PP is not close to *1/2L*, when space swept by the vessel is $\pi L^2/4$ and it is located fore or aft, necessary space for turning is 4 times larger (π^2).

2. Movements of a vessel, Water Resistance and Pivot Point

The most important movements for ship’s handling are (fig.1):

1. Longitudinal, fore-aft, along axis X-X’;
2. Transversal, starboard-port,along axis Y-Y’;
3. Swinging to starboard or to port.

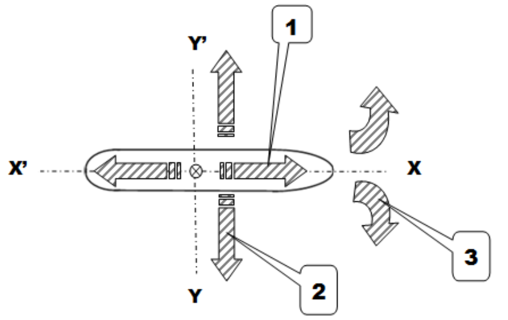


Figure 1. 3 degree of freedom of a vessel

To find PP position we will simplify the factors which affect ship's handling to the mechanical phisics although the hydrodynamic effects have a considerable importance.

During straight fore ward movement, water-resistance force is applied right on the stem, somewhere at mid draft, depending of bow shape (classic or bulbous).In the same time it is recorded high pressure in front and around the bow (fig.2).

Same judgment works for straight astern movement simplifying and do not considering influence of the propeller and rudder. Shape of underwater hull is

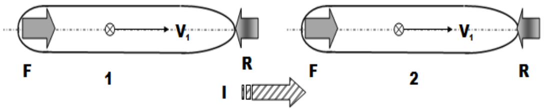


Figure 2. Longitudinal movement of a vessel

very important for high pressure repartition.

As soon as, during movement ahead or astern, due to one of controlled or uncontrolled horizontal forces acting on the vessel, ship starts to turn and she will expose to the water flow another section, larger than going straight along fore-aft axis X-X', the pick of water-resistance and pressure will shift from axe X-X' to the geometrical center of underwater hull section area perpendicular on the new direction of the movement. The maximum of the ship's section which can be exposed to the water flow is her vertical longitudinal section for a lateral movement (drift; sway) on transversal axis Y-Y'.

The direction of the water-resistance *(R),* could be anywhere between longitudinal axis, X-X' and transversal axis, Y-Y'.

Depending of the direction of the movement, the vessel's speed, hull shape, trim and heel, the application point of the water-resistance force will be in different points along the vessel, changind continously during complex movement of the vessel.

To analyze the influence of horizontal forces applied on the vessel (steering force, propeller force, lateral thrusters, tugs or pushers, wind and currents) and reducing phenomenon to classical mechanics, we have to report these forces to the water-resistance force or high pressure in the area where it acts.This force will be present as long as vessel is floating and moving. The arm lever of these forces is distance between their supports and Water-Resistance Force.

The action of a force or resultant of few forces acting on a stopped vessel can generate all three movements.For our purpose, the rotation and the sideway movement are considered. The rotation movement has a center of rotation which it is used to be call Pivot Point (PP).

The ship's PP is the place from where fore and aft extremities of the vessel are turning with the same angular speed. This does not mean that PP is inside of ship's shape in all situations.

Beside of PP, vessel's trajectory has its own center of curvature call Momentary Center of Rotation (i.e. center of turning circle).In fact all forces acting upon a vessel have, more or less, momentary effects in ship's dynamic movement.

3. Water Resistance and Pivot Point of a vessel stopped

Considering a stopped ship, without movement through the water and rudder mid ship's, we can find a point situated about at its mid length, from where if a tug will push with a force *F* (Fig.3), fore and aft extremities of the ship are moving with same speeds $V1= V2$. The force *F* is applied on the same support as water-resistance force *R*. Its center of application is Center of Water Resistance (CLR). Arm lever of *F* and *R* is zero.

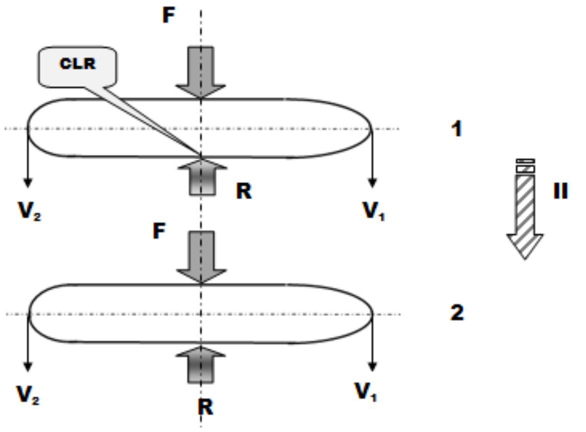


Figure 3. Lateral movement of a vessel

The ship will be translated from axis 1 to 2 (parallel axis). In this case there is not rotation, nor PP, or it is situated at infinity.

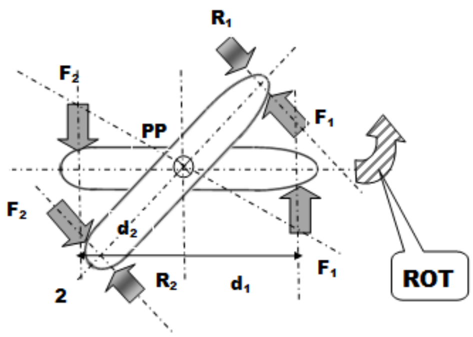


Figure 4. PP of a stopped rotational vessel

Considering 2 forces equals, parallels and of different sens, F_1 and F_2 acting at the extremities of a vessel (fig.4) with the condition $F_1xd_1= F_2xd_2$, $d_{1,2}$ measured from the vertical plan of CLR, the vessel will have a pure rotational movement (ROT) and its PP will be in the vertical plan of CLR around mid ship. Vessel is on even keel and no heel.

If one force is applied close to CLR but more to one side of the considered ship, let to say aft in respect with CLR (Fig.5), the arm lever of forces *F* and *R* will be "*d*" and the ship will record a side movement and a rotation (*V1>V2*). The longitudinal axis of 2 consecutive positions will be intersected in PP. If the ship would be anchored, PP would be where the anchor was dropped or where the cable will leave the bottom. In this case PP is outside of ship's shap.

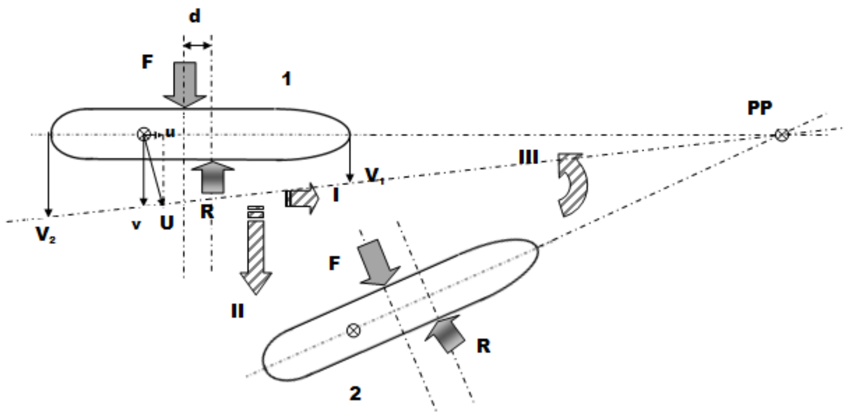


Figure 5. Pivot point of a stopped vessel

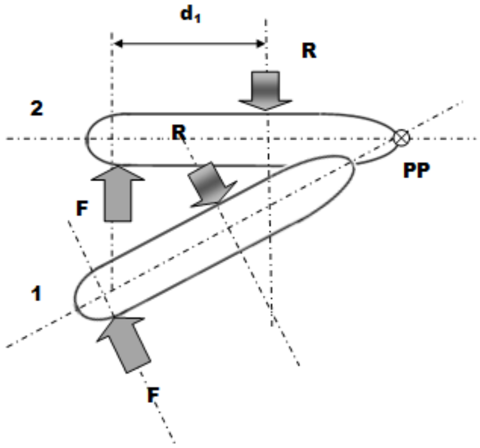


Figure 6. Pivot point on the bow

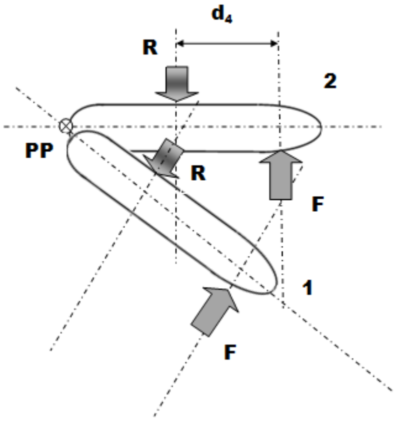
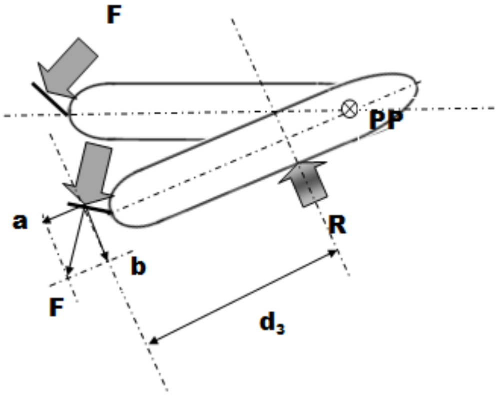


Figure 8. Pivot Point on stern



7. Pivot point in fore area

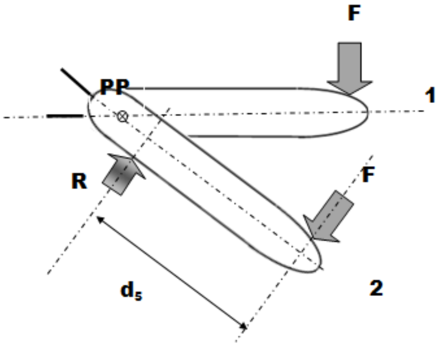


Figure 9. Pivot point in aft area

If the tug will push with force F closer to aft (Fig.6), the arm lever of *F* and *R* , $d_1 > d$ (from fig.5) and rotation of the ship will be faster ($V_1>>V_2$) and PP will be located inside of ship's shape closer to application point of *R* in ship fore part.

If the force *F* acting upon the vessel is situated extremly aft, let to say force is applied on the rudder (fig.7), $d_3 > d_1 > d$; position of PP will be more closer to *R*. The same phenomena is if force *F* is applied fore, bow thruster or tug (fig.8).PP will be situated aft; it can be even on the stern or in aft area(fig.8). During ship's manoeuvring all these forces are in dinamicaly relation.The position and magnitude of the water resistance and therefor of PP is continously change.

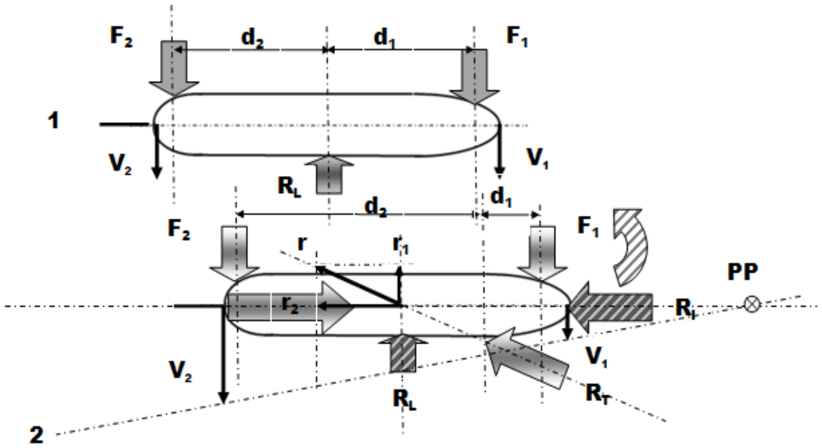


Figure 10. Pivot point of a vessel under propulssion

4. Water Resistance and Pivot Point of a moving vessel

If the ship will start to move ahead keeping her rudder mid ship's (fig.10,1'), due to lateral resistance R_L (drifting movement with speed $V_1=V_2;d_1=d_2$) and longitudinal resistance R_l (fore ward movement given by propulsion arrangements), it appears a resultant water resistance force R_T high, which has its application point fore ward. The result is a shift of *PP* fore ward in the direction of the movement. Arm levers of F_1 and F_2 reported to R_T are changing and $d_2 > d_1$.In consequence $V_2 >> V_1$; it means the vessel will turn more quickly. Even with a kick ahead, this increasing of rotation speed can be seen. This phenomenon is valid for astern movement if the tug or bow thruster acts fore ward.

Due to short distance between R_L application point and PP, in practice, ship handlers use to consider PP as reference point for R_L application point. In reality application point of R_L depend of underwater shape of the vessel.

PP is the result of composing water resistance of the vessel moving through the water and resultant of all other forces acting upon the vessel.

It is important not to overlook the fact that *we are considering only the ship's headway or sternway through the water, not over the ground*. If the vessel is stationary with respect to the shore, but is stemming and turning in the current, the PP will be forward, since the vessel has headway with respect to the water. Likewise, if she is tied to the dock, with a current from astern, the pivot point will be aft at the moment the lines are cast off and ship will start to turn.

It is clear that efficiency of bow thruster is lower during fore ward movement (fig. 11) and higher during aft ward movement (fig. 12).

Changing of arm lever of ship's thrusters is very well known by ship handlers which use it to increase efficiency of these controllable forces. If bow thruster is weak it is enough a kick astern to increase its arm lever and consequently its efficiency.

Obviously PP will exist only when the vessel is in turning movement and to predict its position is not easy in all cases.For a stabilised turning on calm sea without current, PP is situated fore or aft, function of sens of movement in fore or aft area as it is presented in the most of publications, at 1/5-1/3L from fore or aft.

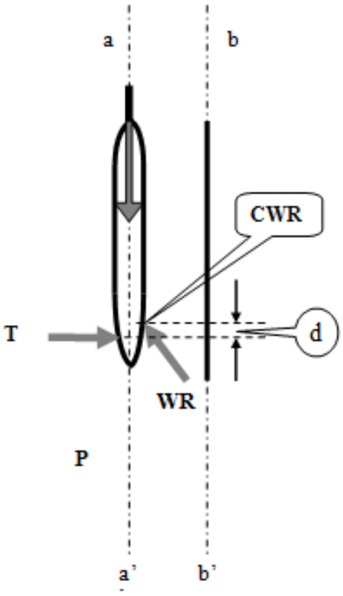


Figure 11. Low efficiency of bow thruster

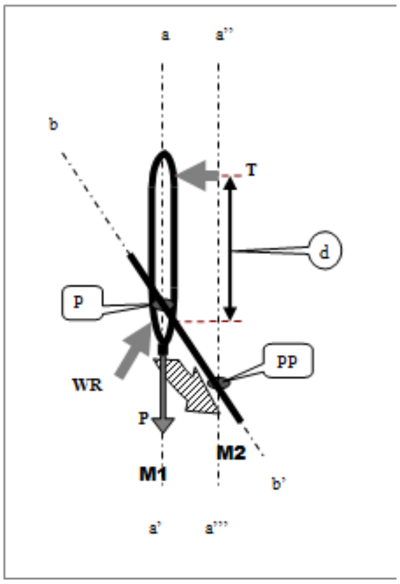
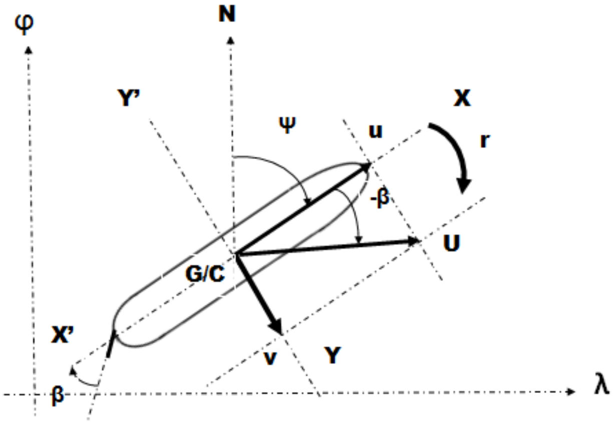
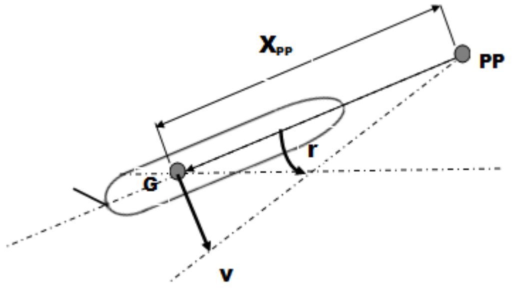


Figure 12. High efficiency of bow thruster



A



B.

Figure 13. Elements for Pivot Point definition
a. Movements and speeds in 3D of freedom
b. PP absissa

The position of PP (fig. 13) depend of the ratio of lateral movement (v) and rotational movement (r).In other words, PP is defined as a point at distance Xpp, measured from the center of gravity of the ship that satisfies the relationship [7]:

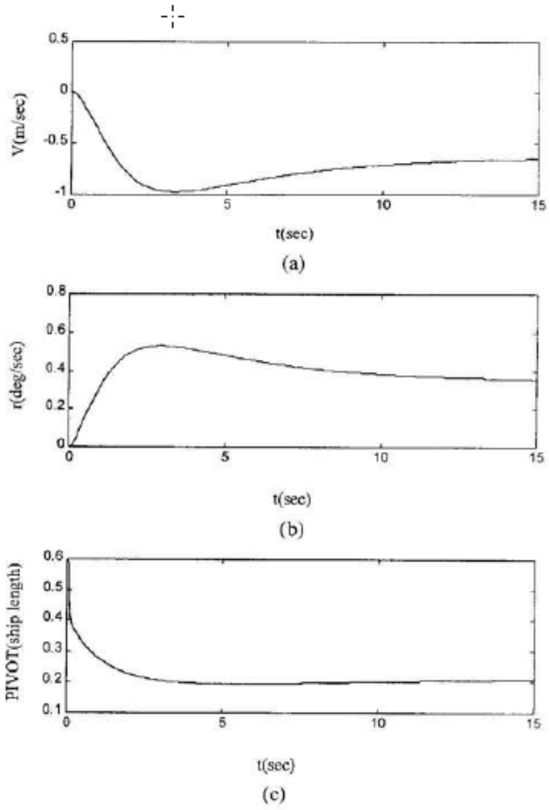
$$v + Xpp \bullet r = 0 \qquad (1)$$

Where:
v - is sway speed at the center of gravity of the ship;
r - is the yaw rate (known on ships as ROT – rate of turn).
It follows, from Eq.(1) that:

$$Xpp = -v/r \qquad (2)$$

Eq.(2) is ill defined when the yaw rate is zero, which corresponds to a straight line motion. When the vessel movies on a straight line ahead or astern or she is in a pure sway motion, it is reasonable to consider PP at infinity [7]. In other words saying, *when the vessel moves along axe X-X' or she drifts along axe Y-Y', there are not a PP and it is unfair to declare that PP is fore or aft function of direction of ship's movement, as it is used in present.*

Fig.14.a shows the measured sway speed, *v*, and 14.b the yaw rate, *r*, for a Very Large Crude Oil Carrier at 35 degrees rudder ,turning maneuver[4]. PP computed with Eq.(2) is shown in Fig. 14.c. It is observed that during 35 degrees turning maneuver, the PP moves from midship to about 1/5 ship length aft from the bowIn full-bodied ships, pivot point is closer to the bow, in slender ships farther from the bow.



(a)

(b)

(c)

Figure 14. v, r, and X_{PP} for turning circle manoeuvre in calm environment

Once ship starts to rotate under action of a force F (Fig.10), important masses of water move under and along her hull. Due to their inertia and ship's inertia, water movement will continue when action of F ceases and ship will continue to rotate.

To estimate effect of F it has to calculate its moment. Again, in practice ship handlers use to calculate this taking arm lever, d, between estimated PP and position of the tug or thruster. Explanation is clear although it is not correct. *PP can be appreciates by sight but R application point can not.*

5. Water Resistance, Pivot Point and particular effects

5.1 Coming into wind

An interesting effect against usual behavior of changing R application point is coming into wind.

To be more evident, we will consider a vessel with accommodation aft and a right hand propeller, rudder mid ship's, being in position along axis a-a' and just start moving astern (Fig. 15). The wind blows from starboard quarter.

Expectation, due to propeller transversal thrust and wind is movement $M1$, a turning and eventually drifting to port. Due to shifting of R application point aft, between wind force W and R appear a couple which will bring ship's stern in movement $M2$ on axis b-b' into the wind, up to a certain angle when d will become zero.
Opposite effect can be obtained if it will try to turn the vessel using the thruster situated at same level as R, in our case stern thruster.Its arm lever will be almost zero and the effect will be the drift of entire vessel only. In this case no PP.

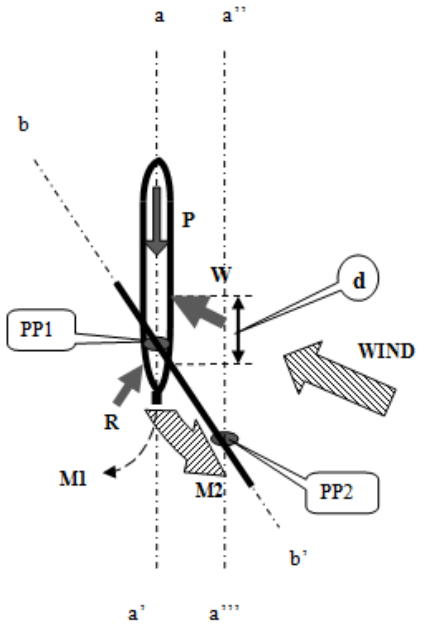


Figure 15. Wind effect upon a vessel with aft PP

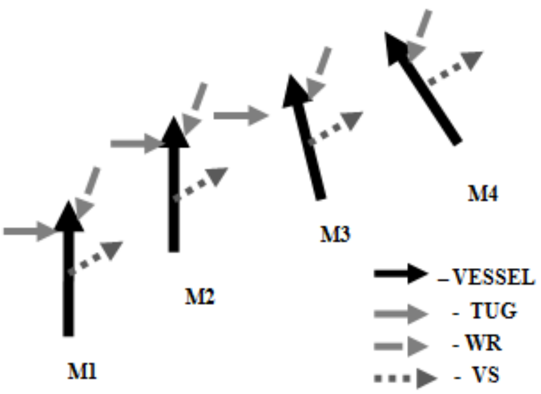


Figure 16. “Donkey-like” effect

5.2 “Donkey-like” effect

One of the most spectacular effect of application of an external force upon a vessel and getting an opposite result (donkey-like) is the movement of the vessel when a tug is acting on the support of water resistance force against it (fig.16).

In fig.16 it were represented only the speed vectors of the vessel and the tug. If the tug will start to push in position *M1* and vessel has an appreciable speed fore ward, it can not turn the vessel. She will drift and she will keep initial direction as in position *M2*. As soon as the tug will stop pushing in position *M3*, the vessel will start to turn towards the tug. She will continue to turn in the same direction a certain time as is shown in position *M4*.
Due to reduced arm lever between tug and water resistance, tug and vessel will drift and no rotation will be recorded.When the tug will stop and will leave the vessel in position *M1* (Fig.17), her center of gravity *G* will continue by inertia its drifting with speed *GI*. Due to arm lever *d* between *GI* and *WR*, it appears a couple which will start to turn the vessel towards the tug.

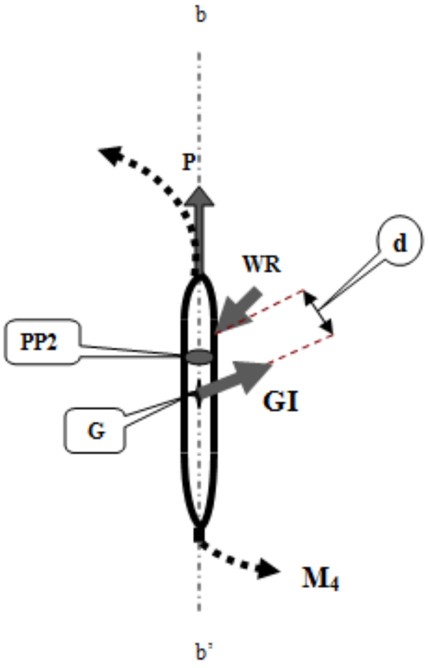


Figure 17. Forces responsible for “Donkey-like” effect

PP starts shifting from fore ward to mid ship PP2 (Fig.17).
The masses of water moved during action of the tug have their own inertia and will continue to generate a water flow directed to port quarter. In the same time, fore of the vessel is passing relatively undisturbed water which will keep the bow, amplifying the rotation.
The effects of water flow and pressures around the vessel and how they influences ship’s manoeuvre is still a possible subject of research.

5.3 Sideways manoeuvre - crabbing

An example of how ship handlers play with rotation and drift of the vessel is manoeuvre of sideways or “crabbing”, in our example a berthing on port quarter at an oil rig (Fig.18). We consider a vessel with limited bow-

thruster power. The thruster runs at constant speed.
To move the vessel sideways to oil rig, rudders (*Rd*) will be set hard starboard, starboard engine astern (P_1), port engine ahead (P_2) and bow-thruster to port at maxim power (*Tcst*). Usually stern sideway speed is greater than bow sideways speed, *M1>M2* (Fig.18a) and the vessel will come with aft part closer to berthing place.
Turning couple of propellers depend of their arm, *d*. In order to increase bow-thruster effect, it will increase P_1 and it will stop P_2 which it will reduce aft turning effect and it will give an astern movement of the vessel. Effect of astern speed will be a shift of center of water resistance and the pivot point in PP_2.
The arm lever of bow-thruster will increase, consequently its sideways effect and *M2a* become greater than *M1a*. The result will be astern movement for a while and a closer position of the bow to oil rig (Fig.18c). In this moment, it will be reduced starboard engine power and port engine will be set ahead at a greater rate than starboard. Vessel will start, finally, to move fore ward and the pivot point will take position PP_3. Arm lever of bow-thruster will be reduced and M1b>M2b. Playing in above described manner, rudders can be kept in the same position.

For a stopped vessel, starting the engine ahead and setting rudder hard to one side, during turning, PP position will shift quickly, in evolution phase, from a location close to Center of Gravity and mid of the vessel, to fore ward, keeping the position of 0.10-0.25 of length between perpendiculars (Lpp) from stem before stabilization state of turning. Time of PP setting is about half of turning stabilization time, respectively sideways speed and turning rate stabilization time. PP final position and time of stabilization depend of underwater shape. It is a particularity of each vessel or category of vessels.

6. Pivot point in current and swell

To see the effect of the current on position of PP (fig. 19) one can consider a ship with rudder at a certain angle to starboard, moving with speed through water *V,* recorded in her center of gravity *G*. Speed *V* can be decomposes longitudinally and transversally in *u* and *v*.The vessel swings around PP with angular speed *r*.PP, defined before, describes turning curve *T*, on which she moves with speed *V'*.The trajectory *T* has the momentary center of rotation *Ci*.It is considering the current *W* having oposite sense with ship's bow swinging sense.

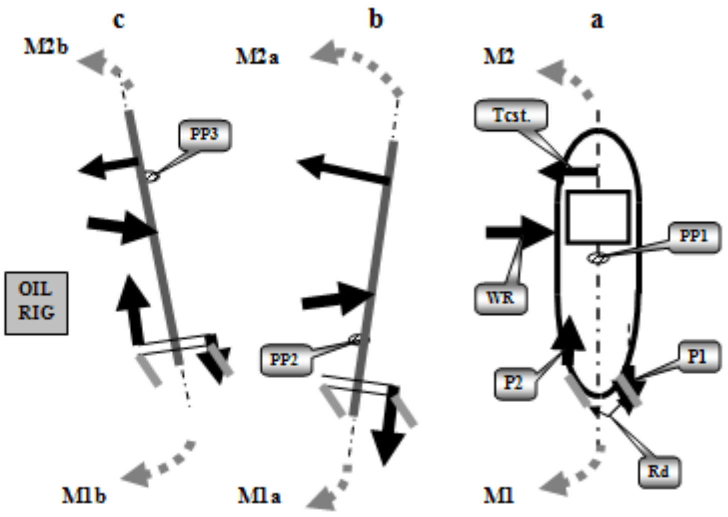


Figure 18. "Crabbing" using PP position

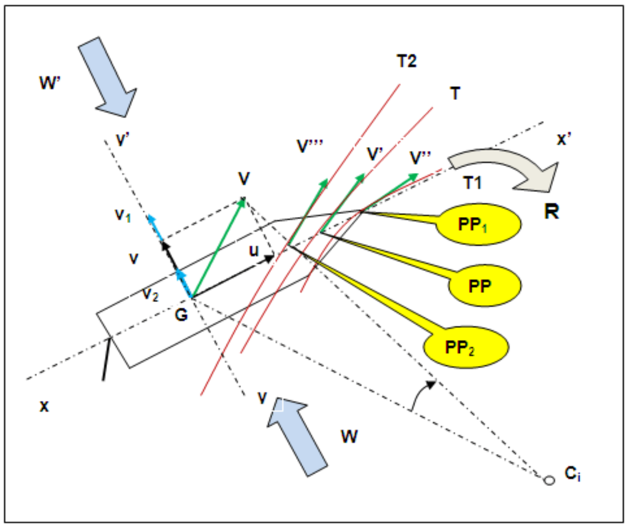


Figure 19. Changing of PP position in current

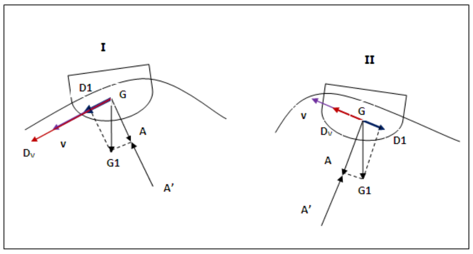


Figure 20. Swell effect upon swey speed

Acting on axis y-y', current speed will sum with sway speed v rezulting new sway speed v_1.To this new sway speed corespond a new PP_1, placed more forward ($Xp = -v/r < Xp_1 = -v_1/r$), which will moves along trajectory T_1 with speed *V''*.For the case of current of the same sense with bow swing speed (W'), sway speed will be reduced by current speed, resuting sway speed $v_2 < v$.New PP_2 will be located towards *G* and it will moves with speed *V''' on the trajectory* T_2 *(the momentary radius,* $RT_2 > RT > RT_1$*).*

To study the effect of the swell on the position of PP (fig.20-seeing from aft), we consider a vessel turning with sway speed *v*, having swinging sense to port.The swell comes from starboard.During rising and falling of the ship on swell wave, displacement force acting in G_1 will be decomposed in a plan parallel with floating plan, D_1 and in a plan perpendicular on floating plan, *A*, which is canceled by Archimedes buoyant force *A'*.
Depending of the slope of the swell wave on which is the vessel situated, the component D_1 will be composed with the sway speed *v*, resulting a new sway speed D_V.This new sway speed can be greater (fig.20.I) or smaller (fig.20.II) than old sway speed (between swell crests), depending of the sense of D_V which will be same or oposite with sway speed before arriving swell wave.Sway speed beeing involved in definition of PP position, it results that, during passing from one slope to the other of the swell wave, PP will have a "jump" in respect with its position before to arrive the swell wave.

7. PP and ship's inertia

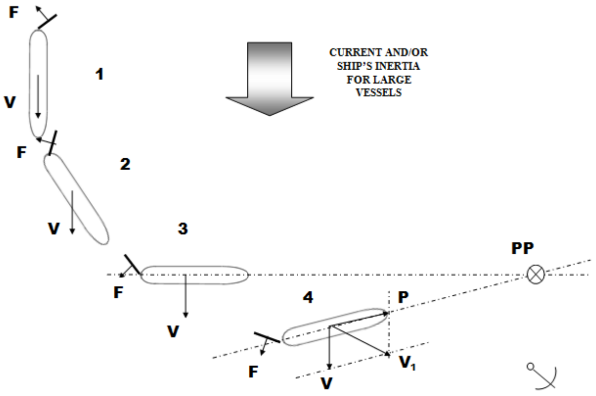


Figure 21. Influence of inertia and current on PP

During turning of large and heavy vessels despite of starting swinging, due to huge inertia, ship will continue movement on direction she had before to set rudder on certain angle and to appear rudder force *F* (fig. 21).The result of lateral movement will be a PP far fore ward.This has to keep in mind when it needs to anchor in a certain position.Starting engine will change direction of drifting but it will increase space swept by vessel.To reduce space of turning, it has to stop before turning point and to start swinging at altmost "zero" speed.Kicks of engine to amplify rotation could be usefull in this situation.

8. Experiments to find PP

Theory of PP is beautiful but it needs practice confirmation.To prove validity of PP theory it were performed few tests on a real vessel and on manoeuvring simulator on a virtual one.

To find PP position (fig.22) it has used bridge ships equipment, two marine portable GPS, watches and cameras. The two portable GPS were placed at fore and aft extremities of an offshore multipurpose vessel (fore GPS above of fore perpendicular). During ship evolution it were made movies fore and aft to record time and GPS screens and pictures with bridge navigation informations were taken at about each change of 10^0 of ship's heading. After extracting of data from movies and pictures, position of fore and aft GPS were represented with connected linear speed. Using principles of mechanics, at intersection of perpendiculars on these speeds it was found Instantaneous Centre of Rotation *Ci,* around which the movement of the vessel is producing .
$Sa\ GPSa\ Ci = Sf\ GPSf\ \ Ci = 90^0$.GPS tangential speeds (*Sa and Sf*) were decomposed on direction of ship's centre line (*Sfl and Sal*) and on a perpendicular on the centre line (*Sat and Sft*). Transversal components Sat and Sft gives swinging movement of the vessel.Joining transversal components of GPS speeds *Sat* and *Sft*, which correspond with angular rotation speed, at intersection with centre line it will be found the pivot point PP, as it is defined in ship's handling (as point from where fore and aft are rotating with same speed).

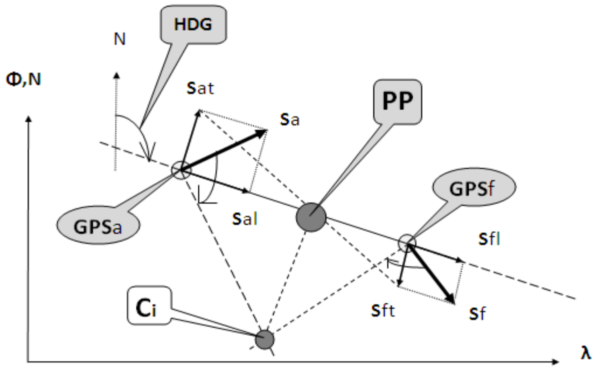


Figure 22. Method of finding PP position

The origin of pivot points measurements is fore perpendicular which in our case correspond with ship's stem.PP abscissa *Xpp,* are negative inside of ship's shape.PP position can be get also at intersection of diametrical plan (or center line) with a perpendicular from *Ci*.

There were performed few tests on real vessel and same tests on virtual ship (close as possible with particularities of real vessel), on Constanta Maritime University manoeuvring simulator.In this work we present a single test only due to limited space.Measurements done can be seen on figure 23.

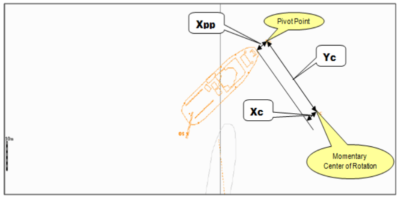


Figure 23. Coordinates of momentary center of rotation and PP as they are indicated by manoeuvring simulator.

The target of the test regarding PP was the evolution of its position in open sea, in real environment conditions and how this evolution can affect manoevring versus PP theory as it is presented in marine universities.Athough here it is presented a simple turning manoeuvre in open sea, the tests were performed in various conditions and their results are presented in a separate research report.Special attention was paid for current effect.

Abscissa PP *(Xpp)* was measured from fore perpendicular, where one GPS was placed and it is positive forward and negative aftward (it is a conventional notation).

Ordinate of momentary center of rotation *(Yc)* was measured from the diametral plan of the ship and its sign is positive when momentary center of rotation is on the side of rotation of ship's bow.

Angle *(Tc-Tw)* between ship's head and coming current (its direction, by navigation definition, is outgoing) has maximum value 180°, measured from the bow and being positive on the port side.

8.1 Vessels particularities

8.1.1 True vessel - Offshore Supply Vessel (SV)

L_{WL} = 56.37 m; B = 14.60 m; h = 5.50 m; d = 4.75 m;
D = 1500 tdw; 2 engines 2 x 1641 Kw; 2 fix propellers in Kort nozzles;
2 balanced rudders; Bow thruster = 5 mt; Max. speed = 13 knts; Height of eye = 15.25 m.

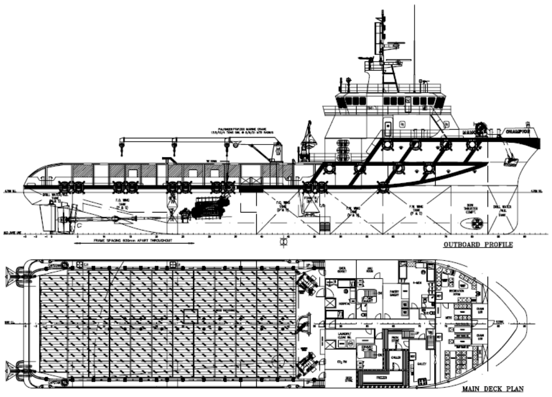


Figure 24. General plan of the reference vessel

8.1.2 Simulation vessel (OS_1)

General information

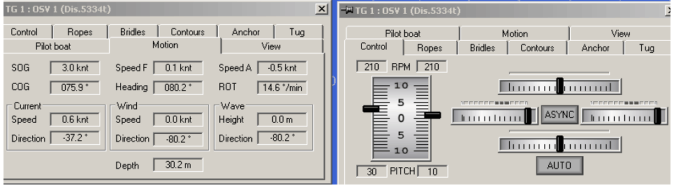
Vessel type	Harbour tug (Dis.469t)
Displacement	469.0 t
Max speed	13.6 knt

Dimensions

Length	35.7 m
Breadth	9.5 m
Bow draft	3.2 m
Stern draft	3.4 m
Height of eye	12 m

Type of engine	Slow Speed Diesel (1 x 1817 kW)
Type of propeller	CPP
Thruster bow	Yes
Thruster stern	None

Figure 25. Virtual vessel



SOG 3.0 knt
COG 075.9 °
Speed F 0.1 knt
Heading 080.2 °
Speed A -0.5 knt
ROT 14.6 °/min
Current
Speed 0.6 knt
Direction -37.2 °
Wind
Speed 0.0 knt
Direction -80.2 °
Wave
Height 0.0 m
Direction -80.2 °
Depth 30.2 m

210 RPM 210
30 PITCH 10

Figure 26. Controls and recording data during simulation

Abbreviations used in this work are:

Time - time of the record
HDG/Hdg - true course (through water)
Spd - true speed (through water)
COG - course over ground
SOG/Vt - speed over ground
Lat - latitude
Long - longitude
Xpp - abscissa PP from fore perpendicular (Ppv)
Yc - momentary center of rotation ordinate
Ci - momentary center of rotation
PP - pivot point

8.2 The tests

8.2.1 The test no.1 with reference vessel (SV) was a complete turning circle to starboard (fig.27), engine at minimum revolutions, in following conditions:

Rudder	35^0 starboard;
Staboard engine	676 rpm ahead;
Port engine	680 rpm ahead;
Bow thruster	stop
Total drift	321°/1,1 nd;
Apparent wind	0 nd;
Swell	220°/0,5-1 m/6-8 sec.
Remark	the boat landing on starboard

The results were recorded in table 1 from which were extracted the graphs presented in fig.28-32.

Variation of PP abscissa in respect with ship's head is presented in fig.28 and its variation in respect with the angle between ship's head and current in fig.29.

Analizing positions of PP (fig. 28) one can see that ship being all the time in ahead moving, PP approaches of stern and a good part of evolution it is out of the ship shape forward.Studing relation between PP position and incidence angle, ship-current (fig.29) one can observe that the highest values of the *Xpp*, positive or negative are placed to an angle of incidence between vessel and current of 70°-130°, the greatest positive value being recorded at 119,5° (tab.1), the highest negative at 90°-100° and the lowest values close to incidence angle 0° or 180°.This confirm mathematical definition of PP, when the current acts perpendicular on the vessel, drifting (sway) speed increases, value of the ratio *v/r* increases because angular speed of swinging does not record a proportional increasing.

From fig. 30 one can observe that the momentary centres of rotation (*Ci*) are grouped, this mean that the turning swepts little space although momentary centres ordinates are of quite high values (ship's trajectory is composed of large circle arches).

Momentary fluctuation, both for PP and Ci are induced, at the slow speed of the vessel, besides the current, by the swell too, this increasing or decreasing ship's sway or yaw rate.

Momentary centres of rotation abscissa were not recorded, theoreticaly being of the same value as PP abscissa although during their measurements, it was observed that these two kind of abscissa are not eguals, probably due to summoning of all errors of devices and graphic work precision.

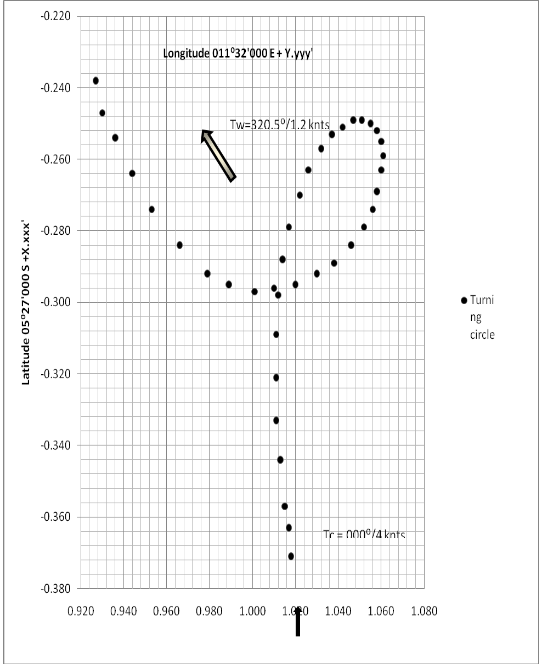


Figure 27. Ship's trajectory during the test

8.2.2 Test with virtual vessel (OS_1) was performed for the same conditions as for the real vessel.Unfortunately it was not found a virtual vessel with the same particularities as the referance vessel and difference between the two ships is very big $L_{SV} - L_{S1} = 21$ m, without considering that the vessel S1 has only one propeller but the vessel SV has two in nozzle.Against these differences, the results of the simulation (tab.2) confirm trajectory shape (fig.31).

To be more clear how position of PP is moving during the test in fig. 32 A-G were presented PP positions at different stages of evolution.One can be seen that at the beginning of test PP is fore ward out of ship's shape, the current increasing sway movement (fig.32A). Later, PP is aproaching to stem when vessel is faceing against current (fig. 32B), to approach to mid ship when vessel exposes port side to current and sway speed is decreasing (fig. 32C), it remaines in same position when current is from aft (fig.32D) and it goes fore ward as long as vessel exposes starboard side to current and her side speed is increasing (fig. 32E-G).

Table 1. Test data

NR	TIME			COMANDA (BRIDGE)					PROVA (FORE)				PUPA (AFT)		Xpp DE LA PROVA [m]	Yc [m]	Tc-Tw [ ]	ROT [/min]
		T	HDG	COG	LATITUDINE -05 27.000' +	LONGITUDINE 011 32.000' +	COG	SOG	LATITUDINE -05 27.000' +	LONGITUDINE 011 32.000' +	COG	SOG	LATITUDINE -05 27.000' +	LONGITUDINE 011 32.000' +				
A	15.58.53	00.16	2.0	2.0	-0.363	1.017	347	2.42	-0.356	1.018	337	2.52	-0.381	1.017	☐		41.0	
B	58.57	00.20	3.5	4.0	-0.357	1.015	353.0	2.42	-0.348	1.017	342	2.52	-0.327	1.002	39.59	106.73	42.5	24.0
1	6.00.20	1.42	71.0	69.6	-0.270	1.022	39.0	1.23	-0.267	1.033	13	1.85	-0.277	1.006	39.82	56.03	110.0	54.0
2	00.30	1.52	80.5	83.2	-0.263	1.026	46.0	1.18	-0.264	1.036	29	1.59	-0.267	1.010	66.21	96.31	119.5	60.0
3	00.40	2.02	91.0	90.0	-0.257	1.032	53.0	1.23	-0.258	1.042	31	1.75	-0.258	1.014	50.93	56.49	130.0	66.0
4	00.50	2.12	100.0	103.0	-0.253	1.037	65.0	0.98	-0.257	1.047	36	1.65	-0.251	1.021	37.50	37.97	139.0	54.0
5	6.01.00	2.22	110.0	107.8	-0.251	1.042	82.0	0.82	-0.256	1.053	48	1.49	-0.247	1.025	31.95	40.29	149.0	60.0
6	01.10	2.32	119.0	120.7	-0.249	1.047	90.0	0.67	-0.256	1.055	64	1.34	-0.241	1.030	30.56	61.58	158.0	54.0
7	01.20	2.42	130.0	129.5	-0.249	1.051	99.0	0.67	-0.258	1.059	54	1.54	-0.239	1.036	38.89	15.75	169.0	66.0
8	01.30	2.52	140.0	139.5	-0.250	1.055	146.0	0.72	-0.260	1.061	83	1.13	-0.238	1.042	-4.63	35.42	179.0	60.0
9	01.40	3.02	151.0	149.2	-0.252	1.058	170.0	0.93	-0.262	1.062	113	1.03	-0.237	1.047	-16.67	48.43	-170.0	66.0
10	01.50	3.12	162.0	151.0	-0.255	1.060	174.0	0.77	-0.264	1.066	121	1.03	-0.239	1.052	-12.04	50.47	-159.0	66.0
11	6.02.00	3.22	173.0	175.8	-0.259	1.061	192.0	0.72	-0.269	1.060	121	0.82	-0.243	1.058	-13.43	33.62	-148.0	66.0
12	02.10	3.30	180.0	187.3	-0.263	1.060	205.0	1.03	-0.274	1.058	149	1.03	-0.247	1.061	-26.39	51.40	-141.0	42.0
13	02.20	3.42	192.0	193.7	-0.269	1.058	216.0	1.08	-0.281	1.055	173	1.13	-0.253	1.062	-28.71	68.99	-129.0	72.0
14	02.30	3.52	201.0	212.0	-0.274	1.056	225.0	1.54	-0.284	1.052	187	1.44	-0.257	1.061	-37.04	77.79	-120.0	54.0
15	02.40	4.02	212.0	211.2	-0.279	1.052	234.0	1.65	-0.287	1.044	201	1.65	-0.263	1.059	-35.19	90.75	-109.0	66.0
16	02.50	4.12	221.0	222.0	-0.284	1.046	249.0	1.54	-0.291	1.038	209	1.18	-0.272	1.055	-43.06	72.93	-100.0	54.0
17	6.03.00	4.22	231.0	236.0	-0.289	1.038	258.0	1.59	-0.294	1.027	224	1.34	-0.280	1.048	-42.23	30.79	-90.0	60.0
18	03.10	4.32	242.0	242.4	-0.292	1.030	261.0	1.80	-0.298	1.019	228	1.75	-0.286	1.042	-31.95	91.77	-79.0	66.0
19	03.20	4.42	252.0	254.2	-0.295	1.020	269.0	1.85	-0.297	1.010	242	1.8	-0.290	1.035	-28.24	122.09	-69.0	60.0
20	03.30	4.52	262.0	264.2	-0.296	1.010	273.0	1.85	-0.297	0.999	247	0.93	-0.294	1.028	-30.56	117.98	-59.0	60.0
21	03.40	5.00	270.0	270.0	-0.297	1.001	282.0	2.00	-0.297	0.987	257	2.00	-0.297	1.015	-25.00	123.71	-51.0	48.0
22	03.50	5.12	284.0	280.0	-0.295	0.989	287.0	2.16	-0.291	0.977	262	2.37	-0.296	1.005	-2.78	129.18	-37.0	84.0
23	6.04.00	2.22	294.0	289.8	-0.292	0.979	301.0	2.21	-0.288	0.968	273	2.31	-0.297	0.993	-12.96	107.18	-27.0	60.0
24	04.10	2.32	300.0	298.8	-0.284	0.966	310.0	2.21	-0.279	0.957	281	2.37	-0.295	0.985	-9.26	105.56	-21.0	66.0
25	04.20	2.42	319.3	320.3	-0.274	0.953	317.0	2.26	-0.269	0.949	290	2.42	-0.291	0.967	4.63	101.40	-1.7	115.8
26	04.30	2.52	323.2	323.5	-0.264	0.944	320.0	2.21	-0.261	0.940	298	2.42	-0.284	0.957	7.64	130.57	2.2	24.0
27	04.40	3.02	337.5	337.5	-0.254	0.936	334.0	2.16	-0.250	0.934	308	2.42	-0.277	0.945	8.80	108.34	16.5	84.0
28	04.50	3.12	348.0	348.2	-0.247	0.930	339.0	2.06	-0.241	0.929	313	2.42	-0.269	0.935	19.45	101.17	27.0	66.0
29	6.05.00	3.22	357.0	357.5	-0.238	0.927	345.0	1.85	-0.233	0.927	317	2.42	-0.260	0.928	18.06	86.21	36.0	54.0

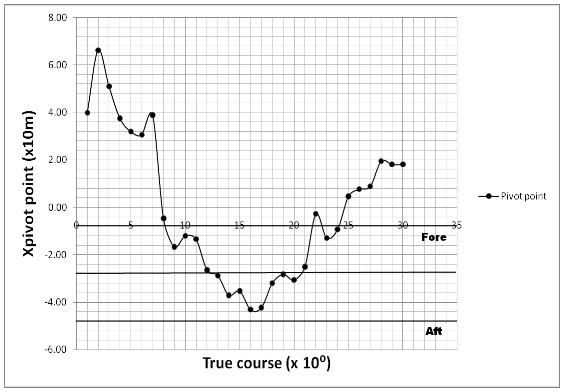


Figure 28. PP abscissa variation during the test

Position of PP in respect with angle between current and ship's head was presented in fig. 33.

The comparison between results of the test performed by real vessel and virtual vessel is not relevant because, in fact, they are two different vessels and analize of the results is in principle.

It has not to forget that the virtual vessel has not a boat landing as appendix and her results are not infuenced by a supplementary unsymmetrical resistance through water.

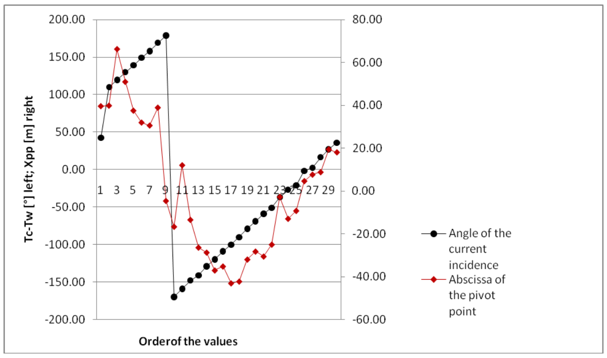


Figure 29. PP in respect with the current

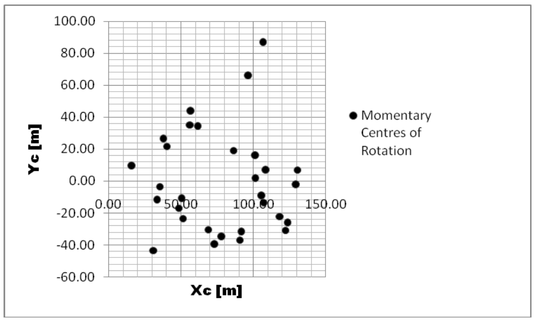
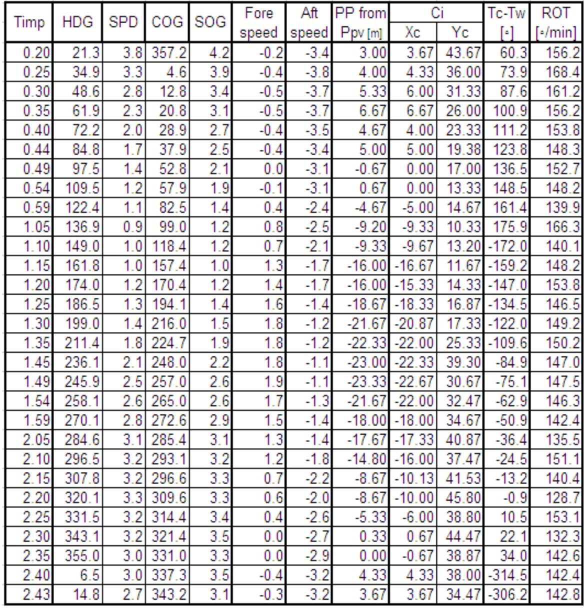


Figure 30. Momentary centres of rotation

Table 2 Simulator test data



Timp	HDG	SPD	COG	SOG	Fore speed	Aft speed	PP from Ppv [m]	Ci		Tc-Tw [°]	ROT [°/min]
								Xc	Yc		
0.20	21.3	3.8	357.2	4.2	-0.2	-3.4	3.00	3.67	43.67	60.3	156.2
0.25	34.9	3.3	4.6	3.9	-0.4	-3.8	4.00	4.33	36.00	73.9	168.4
0.30	48.6	2.8	12.8	3.4	-0.5	-3.7	5.33	6.00	31.33	87.6	161.2
0.35	61.9	2.3	20.8	3.1	-0.5	-3.7	6.67	6.67	26.00	100.9	156.2
0.40	72.2	2.0	28.9	2.7	-0.4	-3.5	4.67	4.00	23.33	111.2	153.8
0.44	84.8	1.7	37.9	2.5	-0.4	-3.4	5.00	5.00	19.38	123.8	148.3
0.49	97.5	1.4	52.8	2.1	0.0	-3.1	-0.67	0.00	17.00	136.5	152.7
0.54	109.5	1.2	57.9	1.9	-0.1	-3.1	0.67	0.00	13.33	148.5	148.2
0.59	122.4	1.1	82.5	1.4	0.4	-2.4	-4.67	-5.00	14.67	161.4	139.9
1.05	136.9	0.9	99.0	1.2	0.8	-2.5	-9.20	-9.33	10.33	175.9	166.3
1.10	149.0	1.0	118.4	1.2	0.7	-2.1	-9.33	-9.67	13.20	-172.0	140.1
1.15	161.8	1.0	157.4	1.0	1.3	-1.7	-16.00	-16.67	11.67	-159.2	148.2
1.20	174.0	1.2	170.4	1.2	1.4	-1.7	-16.00	-15.33	14.33	-147.0	153.8
1.25	186.5	1.3	194.1	1.4	1.6	-1.4	-18.67	-18.33	16.87	-134.5	146.5
1.30	199.0	1.4	216.0	1.5	1.8	-1.2	-21.67	-20.87	17.33	-122.0	149.2
1.35	211.4	1.8	224.7	1.9	1.8	-1.2	-22.33	-22.00	25.33	-109.6	150.2
1.45	236.1	2.1	248.0	2.2	1.8	-1.1	-23.00	-22.33	39.30	-84.9	147.0
1.49	245.9	2.5	257.0	2.6	1.9	-1.1	-23.33	-22.67	30.67	-75.1	147.5
1.54	258.1	2.6	265.0	2.6	1.7	-1.3	-21.67	-22.00	32.47	-62.9	146.3
1.59	270.1	2.8	272.6	2.9	1.5	-1.4	-18.00	-18.00	34.67	-50.9	142.4
2.05	284.6	3.1	285.4	3.1	1.3	-1.4	-17.67	-17.33	40.87	-36.4	135.5
2.10	296.5	3.2	293.1	3.2	1.2	-1.8	-14.80	-16.00	37.47	-24.5	151.1
2.15	307.8	3.2	296.6	3.3	0.7	-2.2	-8.67	-10.13	41.53	-13.2	140.4
2.20	320.1	3.3	309.6	3.3	0.6	-2.0	-8.67	-10.00	45.80	-0.9	128.7
2.25	331.5	3.2	314.4	3.4	0.4	-2.6	-5.33	-6.00	38.80	10.5	153.1
2.30	343.1	3.2	321.4	3.5	0.0	-2.7	0.33	0.67	44.47	22.1	132.3
2.35	355.0	3.0	331.0	3.3	0.0	-2.9	0.00	-0.67	38.87	34.0	142.6
2.40	6.5	3.0	337.3	3.5	-0.4	-3.2	4.33	4.33	38.00	-314.5	142.4
2.43	14.8	2.7	343.2	3.1	-0.3	-3.2	3.67	3.67	34.47	-306.2	142.8

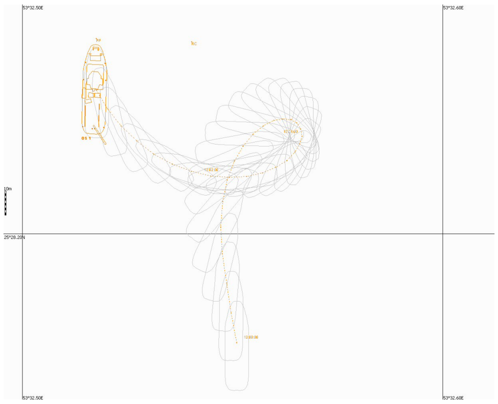
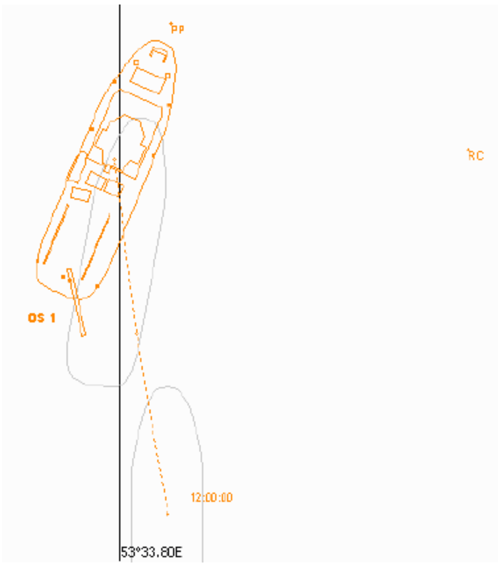
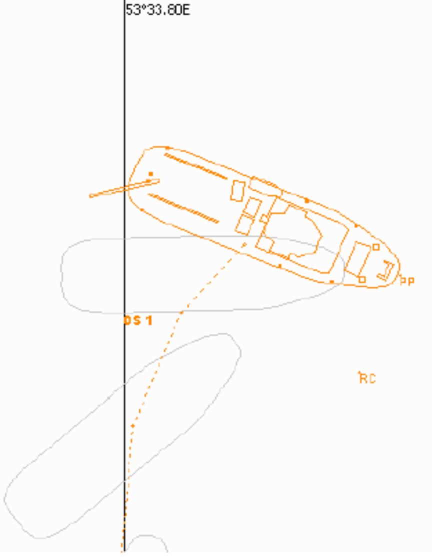


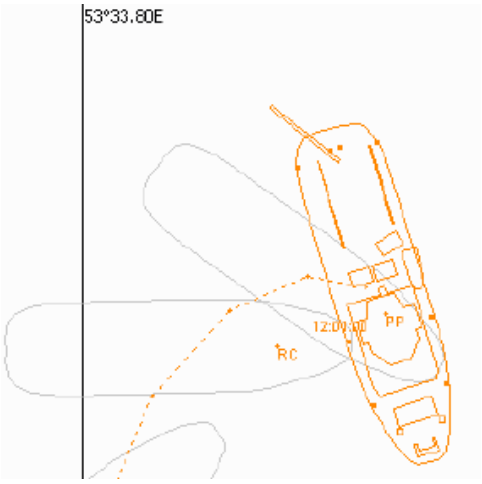
Figure 31. Trajectory of the virtual vessel OS1



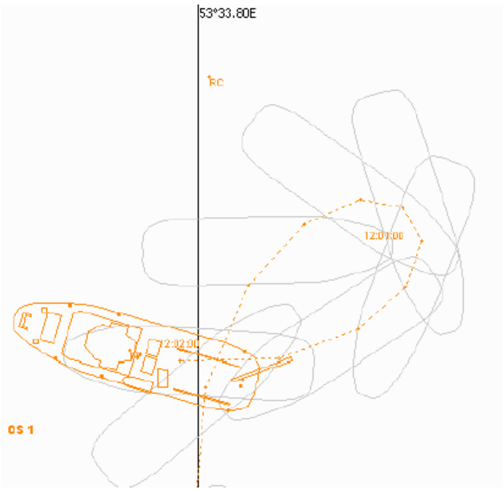
A


53°33.80E
PP
OS 1
RC

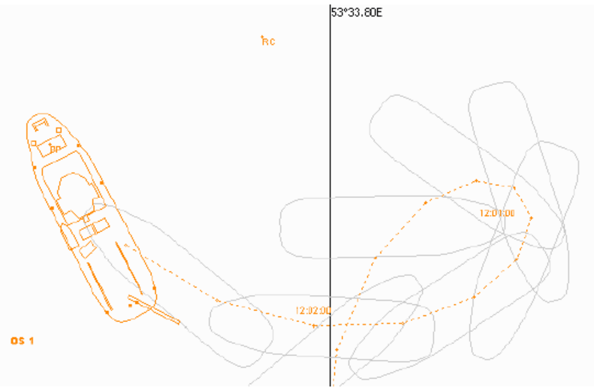
B


53°33.80E
12:01:00
PP
RC

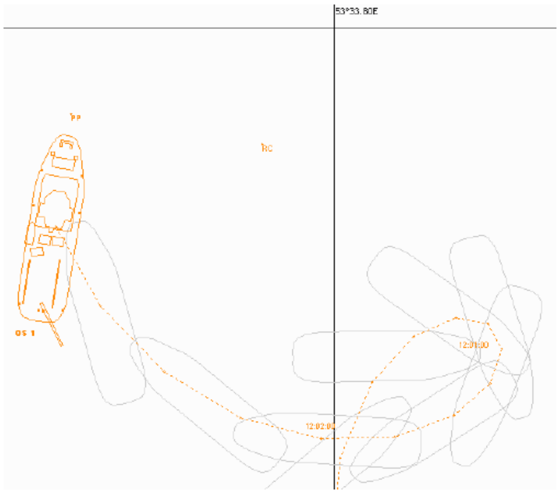
C


53°33.80E
RC
12:01:00
12:02:00
PP
OS 1

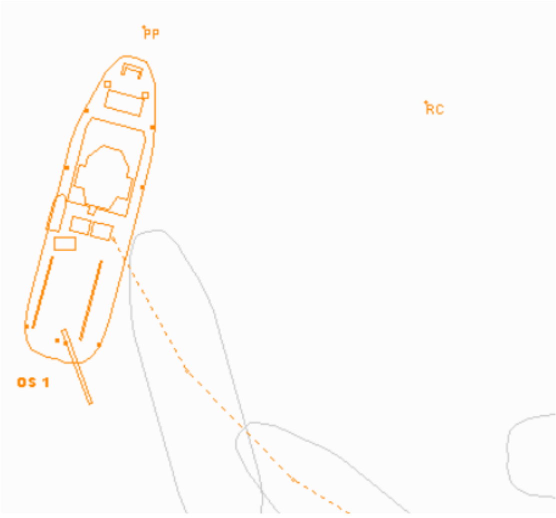
D


53°33.80E
RC
PP
12:01:00
12:02:00
OS 1

E



F



G

Figure 32 A-G. Pivot point position during simulation

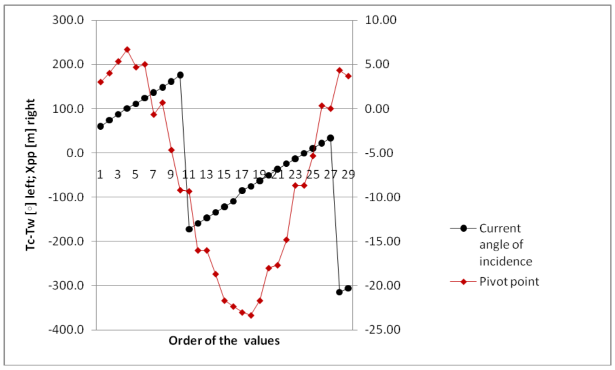


Figure 33. PP in respect with current influence

9. Conclusions

During documentation for this work it came out that there are a clearly discrepancy between shipbuilding research results and perception of ship operators training system about pivot point of the ship turning in different conditions.Theory of the pivot point is presented only for a stable turning in calm water and it is extended as each interpreter consider, below scientific level, although nowadays there are all facilities to find a complete statement of the question (manoeuvring simulators in large numbers).

Effect of controllable or uncontrollable forces upon a vessel is function of the arm lever between Water Resistance force and resultant of others forces.

If effect of the forces has a rotation motion, this rotation has a center, inside or outside of the ship's shape, function of ratio between rotation and sideways motion, call Pivot Point.

Position of Pivot Point depends of position of Water Resistance application point which is function of direction of movement, speed, environment conditions and ship's shape.

There are particular positions reported to Water Resistance application point where if a force is applied the effect upon a vessel is special.

The tests, among the others unpublished here, was performed with an important appendix fixed on the hull which it affected substantially the results of the tests. In the same time the tests clearly demonstrated the complexity of the factors which affect the evolution of the pivot point during real sea conditions manoeuvres against still waters manoeuvres and they show obviously that the pivot point can not be treated so simply as it is in the most works in training system of the seafarers, unchanged for more than hundred years.

It is clear that very offen the pivot point is located outside of the ship's shape and unknowing very well its position it is not proctically to try to calculate forces momentum which act on the vessel in respect with this point.The affirmations regarding moving of the pivot point up 1/5 or 1/4 L from bow has to be completed with specification that it is valid for a stabilized turning manoeuvre in water area with ideal conditions and it is not a general statement as it is understanding from the most works regarding the matter or completely wrong to assert that the pivot point is located in a certain place during streight way ahead or astern.

It was demonstrated, in special for low speed, huge influence of the current and the swell on the pivot point abscissa evolution.

Paraphrazing prof. Rayleigh who said: *"It happens not infrequently that results in the form of 'laws' are put forward as nobelties on the basis of elaborate experiments, which might have been predicted a priori after a few minutes consideration"*, we can say: *the results of the pivot point study which could be enunciated after a few minutes consideration, they needed experiments of which one was presented in this work and may be they will need more experiments on the ship models and manoeuvring simulators and may be even then it will not be sure that the complete theory of the pivot point will be assimilated by the seafarers training system.*

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