Table of Contents

Executive Summary

Oceans and waterways can be extremely dangerous places for boats operate in. High seas and strong currents have been the cause of many accidents in the boating industry over hundreds of years. Therefore during the design process, a vessel must be designed to safely operate in a certain ocean areas. Some ocean expanses have much higher sea states compared to others. It is therefore necessary to predict the response of your vessel to the waves in the certain region it will operate, thus making sure your vessel will survive the forces and motions induced from the wave. Certain safety criteria have been constructed by the IMO for safe operation of the vessel. Vessels all around the world must adhere to these standards. The FTV Bluefin has been given a new seaway to operate in. An analysis has be done to see whether the vessel will meet the IMO criteria. The results show that for most headings, periods and wave heights the vessel will pass the criteria, however for some certain conditions the vessel will fail.

Introduction

The Bluefin is a purpose built fisheries training vessel owned and operated by the AMC. The proposal is for the vessel to operate in a new coastal environment between the months of March, April and May. The vessel must be tested to see if and where it will pass the given criteria. Wave data has been given for the ocean region. The criteria has been given for motions at the bridge which is located 25 metres forward of Station 0 and 11.6 metres above the baseline. The criteria requires that the bridge must have a maximum RMS absolute vertical acceleration due to heave of less than $2m/s^2$, and also a maximum RMS lateral acceleration less due to roll less than $1m/s^2$ The results shall indicate which set of headings, speeds and wave heights will make the vessel unsafe to operate on. A recommendation can then be made for where and what sea states the Bluefin will be able to operate in. Table 1 shows the principle particulars of the vessel while Figure 1 depicts a CAD of the vessel.

Table 1 – Principle Particulars of the Bluefin

Length overall (m)	34.5
Length between perpendiculars (m)	30.1
Beam (m)	10
Draught (m)	3.91
Cruising speed (knots)	10
Vertical centre of gravity above baseline (m)	5.1

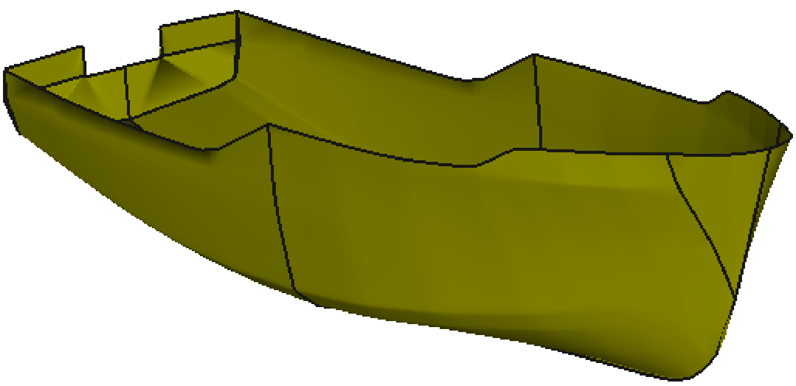

Figure 1 – CAD of the FTV Bluefin's hull

Procedure

How is the Response in Regular Waves Predicted

A vessel can respond in 6 different ways when encountering waves. They are surge, sway, and heave (which are translation movements in the x,y and z axis respectively) and roll, pitch and yaw (which are rotations about the x,y and z axis respectively). Figure 2 depicts the coordinate system used in Seakeeper.

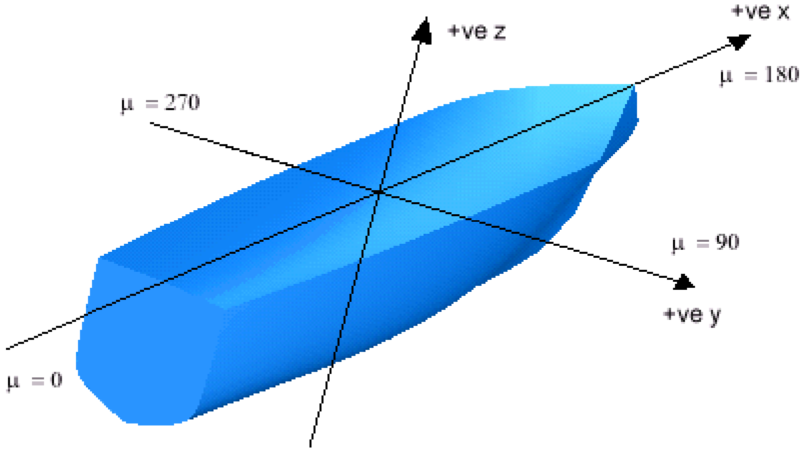

Figure 2 - Seakeeper coordinate system

When analysing the response in a wave the vessel, the heave, pitch and roll of the vessel can be compared to the oscillatory motion of a mass on a spring. However the vessel also experiences two other factors which are a forcing function and damping. Therefore the vessel's reaction can be very accurately calculated using the spring-mass damper theory (Duffy, 2012). The vessels motions can then be expressed using formulas. The general equation of motions for heave, pitch and roll are given in Equations 1,2 and 3 respectively.

$$a\ddot{z} + b\dot{z} + cz = F_0 cos\omega_e t \quad \textbf{(1)}$$

$$a\ddot{\theta} + b\dot{\theta} + c\theta = M_0 cos\omega_e t \quad \textbf{(2)}$$

$$a\ddot{\emptyset} + b\dot{\emptyset} + c\emptyset = M_0 cos\omega_e t \quad \textbf{(3)}$$

How are the Added Mass Coefficients Predicted

Duffy (2012) defines added mass as the product of the body acceleration and a quantity having the same dimension as the mass. The added mass is an inertial force term which is found in different ways for heave, pitch and roll. For heave the inertial force term can be written as

$$(m + a_z)\frac{d^2z}{dt^2} \quad \textbf{(4)}$$

where a_z is the added mass in heave.

a_z is the summation of the added mass for all the 2D strips along the length of the vessel and can be found using Equation 5.

$$a_z = \frac{\rho\pi}{2}\int_{-\frac{L}{2}}^{\frac{L}{2}} Cy^2(x)dx \quad \textbf{(5)}$$

C is a product of the added mass for a 2D strip (section) of the vessel. This is given in Equation 6.

$$a_n = C\frac{\rho\pi B_n^2}{8} \quad \textbf{(6)}$$

a_z (added mass coefficient) may now be calculated for heave. In pitch the inertia force is given by:

$$a = I_{yy} + \delta I_{yy} \quad \textbf{(7)}$$

where δI_{yy} is the added mass moment of inertia and is found using Equation 8.

$$\delta I_{yy} = \int_{-\frac{L}{2}}^{\frac{L}{2}} a_n x^2 dx \quad \textbf{(8)}$$

The added mass for each strip 'a_n' is found using the same equation as in heave and x is the distance of each strip for the longitudinal centre of gravity.

The added mass moment of inertia for roll is usually found through experiments of from analytical expressions (Duffy, 2012). It has been found through numerous experiments that the added mass moment of inertia for rolling as about 20% of the mass moment of inertia of the actual ship (Bhattacharyya, 1978).

How are the Damping and Restoring Coefficients Predicted

The damping coefficient 'b' and restoring coefficients 'c' are predicted in different ways for heave, pitch and roll.

Heave:

The damping coefficient for heave is directly related to the wave amplitude (Grim, 1959). 'b_n' is given by Equation 9.

$$\boldsymbol{b_n = \frac{\rho g \bar{A}^2}{\omega_e^2}} \quad \textbf{(9)}$$

where ω_e is the encounter frequency and

$$\bar{A} = \frac{\zeta_a}{z_a} = \frac{\textit{Amplitude of the radiated wave}}{\textit{Amplitdue of the heaving motion}} \quad \textbf{(10)}$$

b_n is the damping force on one strip along the vessel. To find the total damping coefficient 'b' we sum the each individual value of b_n.

$$b_{heave} = \int_{-\frac{L}{2}}^{\frac{L}{2}} b_n dx \quad \textbf{(11)}$$

The restoring force in heave is just the additional buoyancy due to the draft increasing due to movement of the vessel. This is given simply by:

$$c = \rho g A_{wp} \quad \textbf{(12)}$$

Pitch:
The damping pitch moment coefficient is found the same way as the damping coefficient in heave. Once b_n is found the total damping coefficient can be found by summing all the values for each individual strip along the vessel.

$$b_{pitch} = \int_{-\frac{L}{2}}^{\frac{L}{2}} b_n x^2 dx \quad \textbf{(13)}$$

The restoring coefficient for pitch can be assumed to vary linearly with θ and is given by Equation 14

$$c = \rho g \nabla \overline{GM_L} = \Delta \overline{GM_L} \quad \textbf{(14)}$$

Roll:
Bhattacharyya (1978) provides a method to predict the damping coefficient in roll and is given in Equation 15

$$b_n = \frac{\rho g^2}{\omega_e^3} \left(\frac{B_n}{2}\right)^2 \bar{A}_\emptyset^2 \quad \textbf{(15)}$$

where $\bar{A}_\emptyset$ is defined as:

$$\bar{A}_\emptyset = d_\emptyset \left(\frac{\omega_e^2 B_n}{2g}\right)^2 \quad \textbf{(16)}$$

Using the strip theory the total damping coefficient can then be found by summing together all the b_n along the vessel

$$b = \int b_n dx \quad \textbf{(17)}$$

The roll restoring moment is just the transverse righting moment and for small angles of roll can be written as:

$$\boldsymbol{c = \Delta \overline{GM}_T} \quad \textbf{(18)}$$

and for large angles of roll the formula changes to:

$$\boldsymbol{c = \Delta \overline{GM}_T \sin\theta}$$
(19)

How is the Response in Irregular Waves Predicted

Once the response in regular waves have been predicted, the response of the vessel in irregular is fairly straightforward. There are six steps stated below:

Step 1:
A suitable wave spectrum is chosen for the required seaway. If a wave spectrum is not available it can be predicted using a suitable standard wave spectrum formulation.

Step 2:
Change the wave frequency in the wave spectrum to encounter frequency as they will be different using Equation 20

$$\boldsymbol{\omega_e = \omega_w - \frac{v\omega_w^2}{g} cos\mu} \quad \textbf{(20)}$$

Step 3:
Obtain the response of the vessel in regular waves, and then find the transfer function. This is found by dividing by the wave amplitude and then plotted against encounter frequency.

Step 4:
The plot obtained in Step 3 is the squared on the y-axis, resulting in a plot known as the response amplitude operator (RAO).

Step 5:
Multiply the ordinates of the RAO with the ordinates of the encounter wave spectrum which will result in the motion amplitude spectrum. The Equations 21, 22 and 23 show how is it done for heave, pitch and roll respectively.

For heave:

$$\boldsymbol{S_z(\omega_e) = S_\zeta(\omega_e)\left[\frac{z_a}{\zeta_a}\right]^2} \quad \textbf{(21)}$$

For pitch:

$$S_\theta(\omega_e) = S_\zeta(\omega_e)\left[\frac{\theta_a}{\zeta_a}\right]^2 \quad \textbf{(22)}$$

For roll:

$$S_\emptyset(\omega_e) = S_\zeta(\omega_e)\left[\frac{\emptyset_a}{\zeta_a}\right]^2 \quad \textbf{(23)}$$

Step 6:
The motion spectrum can then provide information about the ship motion the same way a wave spectrum can be used to obtain information about waves.

Limitations

Seakeeper is an accurate seakeeping program to an extent. There are certain limitations in the programming. Firstly the mapping of the vessel is done through Lewis Sections. Lewis sections are a conformal mapping technique. This technique can be inaccurate when the vessels sections are very wide or deep and have a low sectional area. Areas where this may occur include sections of the vessel which have a skeg, rudder or a keel. Therefore in the analysis it is quite common to remove this part of the vessel to produce more accurate results. Other main limitations of the conformal mapping technique are that the mappings always cross the axes at 90 degrees, and the sections are always continuous, therefore chines may be rounded off.

Secondly the vessel is analysed using strip theory. The basic method behind strip theory is that the vessel can be divided into a series of 2D strips for which the hydrodynamic properties of the vessel can be predicted. All these strips are then integrated over the hull which gives the total vessel motions. There are many limitations and assumptions to the strip theory. Lloyd states that linear strip theory makes the following assumptions:

- The fluid is inviscid – viscous damping is ignored, (In fact the damping factor which the user enters for roll should include viscous roll damping, which is the primary source of damping for roll.)
- The ship is slender (i.e. the length is much greater than the beam or the draft, and the beam is much less than the wave length).
- The hull is rigid so that no flexure of the structure occurs.
- The speed is moderate so there is no appreciable planing lift.
- The motions are small (or at least linear with wave amplitude).
- The ship hull sections are wall-sided.
- The water depth is much greater than the wave length so that deep water wave approximations may be applied.
- The presence of the hull has no effect on the waves (Froude-Krilov hypothesis.)

As well as these assumptions Boyd (1995) states possible effects that may cause the strip theory to become inaccurate:

- Emergence or submergence of the bow or stern.
- Flare (non-wall sidedness) of the hull at the waterplane.
- Submergence of the bow or stern overhangs in a vessel.
- Three dimensional flow effects and flow interaction in a longitudinal direction along the hull including dynamic lift at speed.

Other times when the Strip theory may be deemed unreliable is in following seas. This is because the motions of the vessel are much less linear, therefore not fitting the spring mass damper theory accurately. Studies have shown that Seakeeper is most reliable between head seas (180 degrees) to bow-quartering seas (135 degrees and 215 degrees). Consequently, for headings outside of this range, more testing should be undertaken for reliable results.

One final limitation of the strip theory is that it is generally only applied at lower Froude numbers. At higher Froude numbers approaching 0.8 Seakeeper is likely to over-estimate the motions of vessels in the planing regime.

While there are many ways in which the Strip Theory and Lewis Sections may be inaccurate, they usually provide enough precision to be deemed worthy of ship analysis.

Seakeeper Input Parameters

For the analysis to run in Seakeeper, parameters must be entered into the program first. The parameters are described below .

- **Vessel sections and mapping points**. The more sections the vessel is divided into and the more mapping points which are used give a greater accuracy for the shape of the vessel. For the calculations the vessel was divided into 30 sections using 10 mapping points for each section. This number will give a sufficient amount of accuracy for the analysis of the vessel. The skeg was removed from the analysis as it vastly complicates the mapping of the hull. The mapping of the hull is done through lewis sections, which basically change the shape of the hull into a similar semi-circle. As you can imagine a pointy skeg will complicate the mapping a semi-circle greatly. As removing the skeg does not change the results in heave and pitch it is considered to be accurate. However for roll, the removal of the skeg will increase the accelerations, therefore assumptions must be made for how much damping to the roll a skeg would create.
- **Type of Vessel** (either a monohull or a catamaran). As the Bluefin is a monohull, the monohull selection was chosen.
- **Mass distribution**. The Pitch and Roll gyradius are not given for this assignment, therefore the help file suggests that inputting a percentage of length and beam will give accurate results. For the pitch gyradius, 25% of the LOA was used. For the roll gyradius 35% of the BOA was used. The VCG of the vessel was given as 5.1 metres.
- **Damping factors**. In the help file it was suggested that damping factors should be left the same without an in depth knowledge of how to calculate them. Therefore the pitch damping was left at 0 and the roll damping was left at 0.075
- **Environment** (Salt water or Fresh Water). As the vessel is operating in salt water, a density of 1025 kg/m^3 was chosen
- **Frequency range**. The frequency range decides for how many frequencies will be analysed when calculating the RAO's. For the analysis, 30 different frequencies were used. This number was chosen as it provided a sufficient range of frequencies to analyse the motions of the vessel.
- **Method**. Three methods must be chosen. Firstly transom terms were chosen to be used. As the vessel operates with a transom, using transom terms will give a more accurate result. However this provides a problem when using the strip theory. Choosing to incorporate transom terms with increase the heave and pitch damping. Secondly the method for added resistance must be chosen. The method chosen was the Salvesen method. This method is suggested to be more accurate for a wider range of hull shapes and was therefore used. Thirdly a wave force method must be chosen. Arbitrary wave heading was chosen as we are analysing the vessel from all different headings, thus head seas approximation will be inaccurate for many of the headings.

Global Wave Statistics Online

BMT Fluid Mech

Location | Season & Direction | Wind | Wave Scatter | Extreme Waves | Wave Persistence | Help

Wave Scatter Table

Worldwide Database , Sea Area 101, Mar - May , ALL DIRECTIONS

Sig Hgt (m)		2	30	128	249	267	183	90	35	11	3	Obs 1000
> 14												
13 to 14												
12 to 13												1
11 to 12												1
10 to 11								1				2
9 to 10						1	1	1	1			4
8 to 9						1	2	2	1	1		8
7 to 8					1	3	4	4	2	1		16
6 to 7					3	7	9	7	4	1		32
5 to 6				1	7	16	19	13	6	2	1	65
4 to 5				4	19	36	33	19	8	2	1	122
3 to 4			1	13	46	65	49	23	7	2		205
2 to 3			4	35	83	85	47	16	4	1		276
1 to 2		1	14	58	79	50	18	4	1			224
0 to 1		2	10	17	10	3	1					43
	< 4	4 ~ 5	5 ~ 6	6 ~ 7	7 ~ 8	8 ~ 9	9 ~ 10	10 ~ 11	11 ~ 12	12 ~ 13	> 13	
	Zero Crossing Period (s)											

Figure 3 - Wave measurements for proposed coastal operational zone for the months of March – May (Global Wave Statistics Online)

Table 2 - Wave Heights and Zero Crossing Periods

Significant Wave Height (m)	Zero Crossing Period (s)	Significant Wave Height (m)	Zero Crossing Period (s)
3.5	5.5	**4.5**	6.5
	6.5		7.5
	7.5		8.5
	8.5		9.5
	9.5		10.5
	10.5		11.5
	11.5		12.5
	12.5		13.5

The values in Table 2 show the wave spectra data that was inputted into Seakeeper. This data was chosen from the data given in Figure 3. As the analysis was for the operation area with significant wave heights from 3-5 metres, results were calculated for both 3.5 metres and 4.5 metres. From these two significant wave heights each zero crossing period must be entered. In the proposed operation area 3.5 and 4.5 metre waves have a variety of different zero crossing periods. In order to calculate results for all these periods they must be all entered into Seakeeper. For a wave of significant height 3.5 metres zero crossing periods ranged between 5.5 and 12.5 seconds while with a significant wave height of 4.5 metres the zero crossing periods ranged from 6.5 to 13.5 seconds.

Results

The results from Seakeeper come in a polar plot. Examples of polar plots are shown in Figures 4 and 5. The polar plot shows how the FTV Bluefin will respond according to the heading of the vessel and speed it is travelling. For the FTV Bluefin to pass the requirements it must have a maximum RMS absolute vertical acceleration at the bridge due to heave of less than $2m/s^2$, and also a maximum RMS lateral acceleration at the bridge less due to roll less than $1m/s^2$. The results in Tables 3 to 8 show at which heading and speed the FTV Bluefin will pass and fail this certain set of criteria. Passing is denoted by a ‘Y’ (yes) and failing is denoted by an ‘N’ (no).

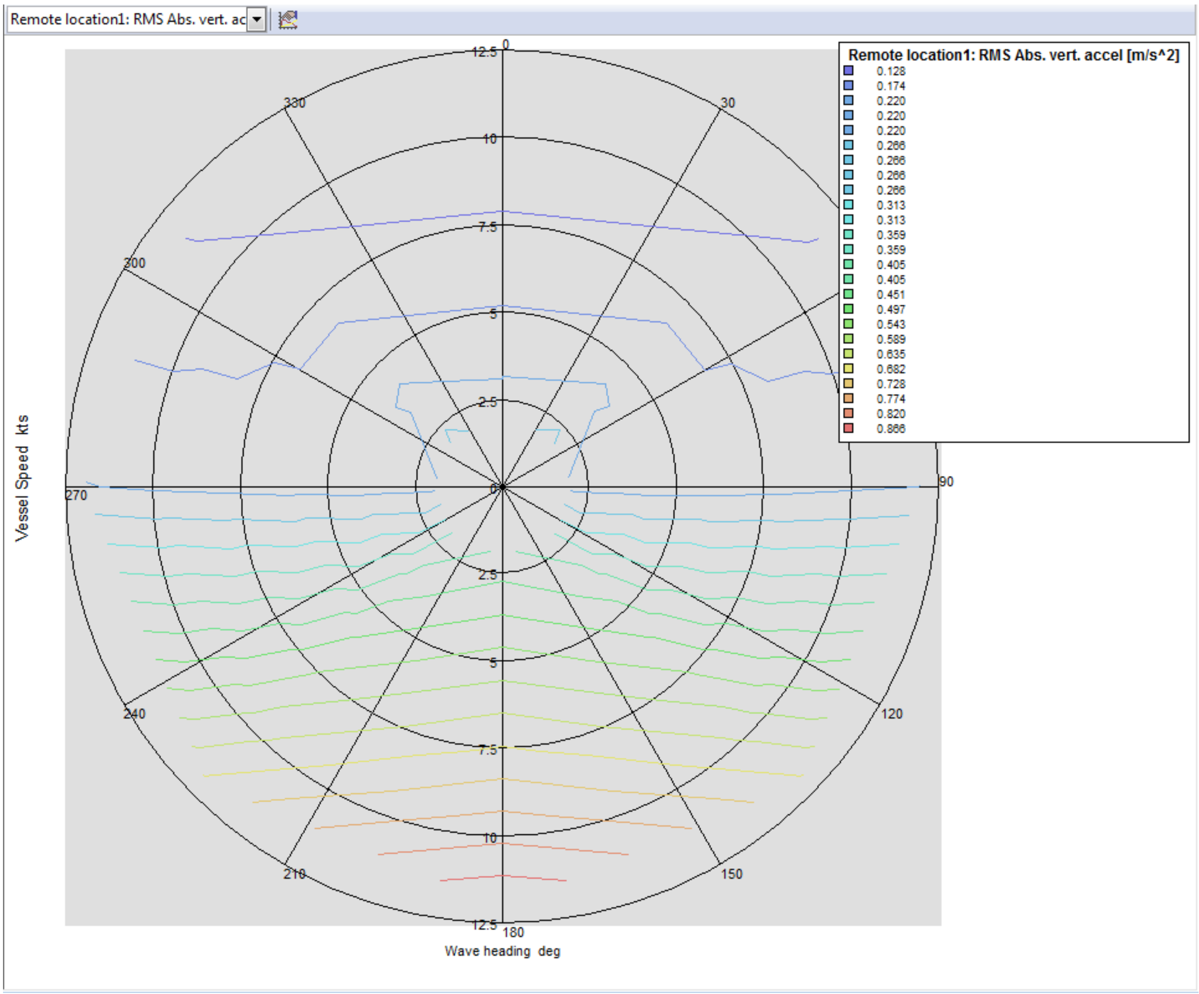

Figure 4 – Example of a polar plot for heave at zero crossing period of 12.5 seconds and a significant wave height of 3.5 metres

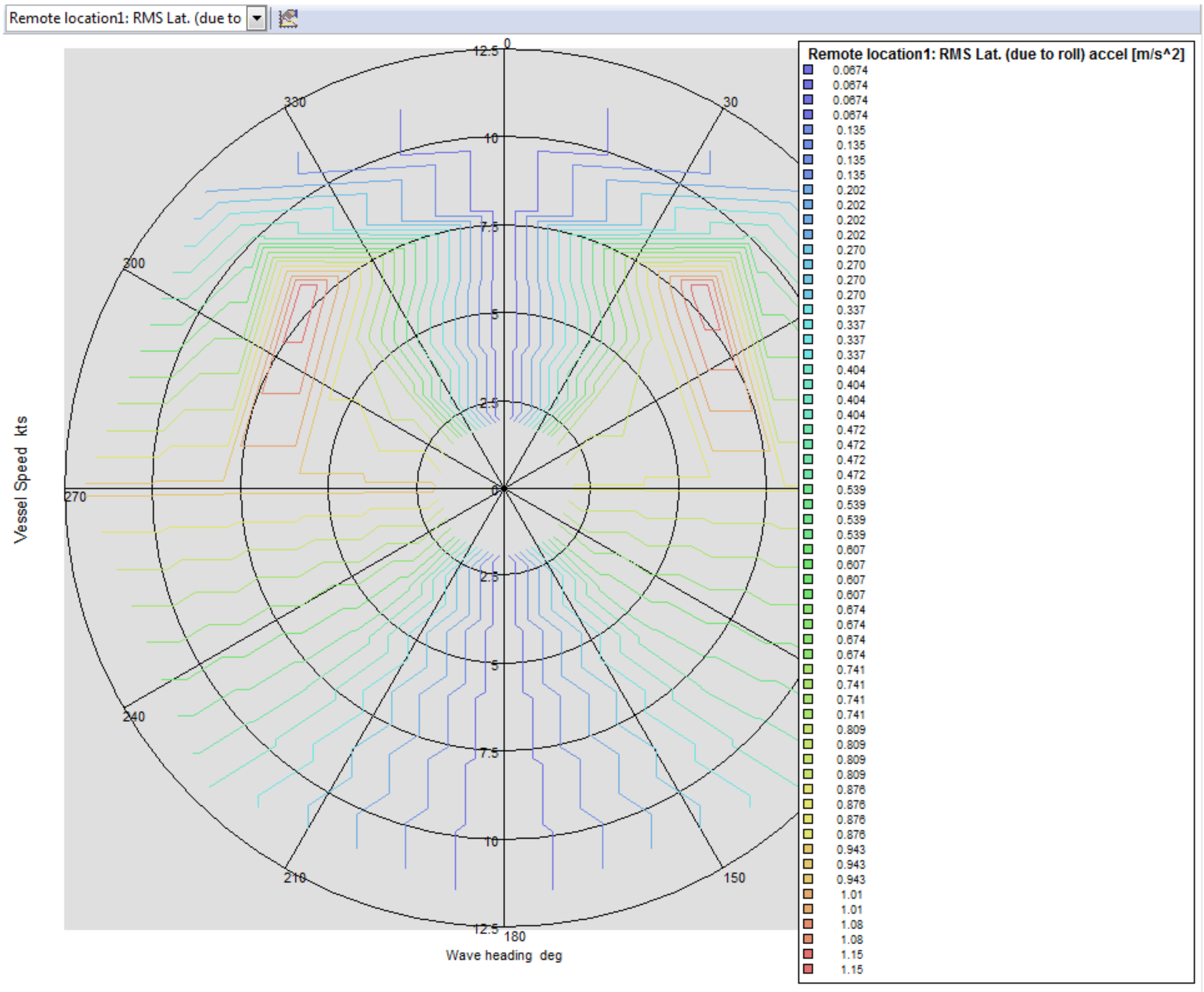

Figure 5 – Example of polar plot for roll with a zero crossing period of 6.5 seconds and a significant wave height of 3.5 metres

Significant Wave Height of 3.5 metres

Table 3 – Table depicting whether vessel will pass or fail criteria at different headings and speed with the wave data of zero crossing period of 5.5 seconds and significant wave height of 3.5 metres.

ZCP = 5.5s SWH = 3.5m

Speeds (kts)	2		4		6		8		10		12	
Heading (deg)	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
90	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
135	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y
180	Y	Y	N	Y	N	Y	N	Y	N	Y	N	Y
225	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y
270	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
315	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N

360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 4 - Wave data of zero crossing period of 6.5 seconds at a significant wave height of 3.5 metres.

ZCP = 6.5s SWH = 3.5m

Speeds (kts)	**2**		**4**		**6**		**8**		**10**		**12**	
Heading (deg)	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
90	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
135	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y
180	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
225	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y
270	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
315	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 5 - Wave data of zero crossing period of 7.5 seconds at a significant wave height of 3.5 metres.

ZCP = 7.5s SWH = 3.5m

Speeds (kts)	**2**		**4**		**6**		**8**		**10**		**12**	
Heading (deg)	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**	**Heave**	**Roll**
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
90	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
135	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
180	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
225	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
270	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
315	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

For waves with zero crossing periods greater than 7.5 seconds and a significant wave height of 3.5 metres the vessel will pass the criteria at all headings for both heave and roll.

Significant Wave Height of 4.5 meters

Table 6 - Table depicting whether vessel will pass or fail criteria at different headings and speed with the wave data of zero crossing period of 6.5 seconds and significant wave height of 4.5 metres.

T = 6.5s **SWH = 4.5m**

Speeds (kts)	2		4		6		8		10		12	
Heading (deg)	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	N	Y	N	Y	N	Y	N	Y	Y	Y	Y
90	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
135	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
180	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
225	Y	Y	Y	Y	N	Y	N	Y	N	Y	N	Y
270	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
315	Y	N	Y	N	Y	N	Y	N	Y	Y	Y	Y
360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 7 - Wave data of zero crossing period of 7.5 seconds at a significant wave height of 4.5 metres.

T = 7.5s **SWH = 4.5m**

Speeds (kts)	2		4		6		8		10		12	
Heading (deg)	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y	Y
90	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y	Y
135	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y
180	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	Y
225	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y
270	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y	Y
315	Y	Y	Y	N	Y	N	Y	N	Y	Y	Y	Y
360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Table 8 - Wave data of zero crossing period of 8.5 seconds at a significant wave height of 4.5 metres.

T = 8.5s **SWH = 4.5m**

Speeds (kts)	2		4		6		8		10		12	
Heading (deg)	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll	Heave	Roll
0	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
45	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
90	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
135	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
180	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y
225	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
270	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
315	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

360	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

For waves with zero crossing periods greater than 8.5 seconds and a significant wave height of 4.5 metres the vessel will pass the criteria at all headings for both heave and roll.

Discussion

By studying the results in Figures 4 and 5 and Tables 3 to 8 it can be seen that there are certain headings that will be worse for heave, and certain headings that will be worse for roll. The headings that will be the worst for heave are following seas, or headings (180 degrees). This is because the vessel's hull is not strategically designed to minimise heave from this direction. As the stern of the FTV Bluefin is relatively 'full', the moment produced by a change in bouyancy in following seas will be quite large compared to the moment produced with head seas as the bow is quite slim, therefore the bouyancy force will not be as large. Thus the accelerations from following seas will be much larger than the accelerations in head seas. The headings that will be worst for roll will be bow-quartering to beam seas (45-90 degrees and 270-315 degrees). Bow quartering seas will be the worst as seen in Figure.. as the roll response will be amplified by a pitch motion as well. However in beam seas the theoretically should be no pitch therefore no coupling will occur. The roll response in beam and following seas will be much less as there will be much less surface area for the wave to hit, thus causing little to no moment about the x-axis to cause acceleration (roll).

The results also show that as the zero crossing period decreases so do the motions of the vessel. This will be because with a longer wave period, the wave will be less steep and therefore creating a smaller buoyancy moment on the vessel which causes the vessel to accelerate. However comparing Table 5 and 7 it can be seen as the wave height increases the vessels motion response will also increase. Therefore the vessel may pass the criteria at a certain heading in 3.5 metres waves however would fail in 4.5 metre waves. Thus when deciding if the vessel is safe to operate in this area, the worst condition must be tested. For this case the worse condition would be significant wave height of 4.5 metres. By knowing this we can then determine where the vessel will be safe to operate. Tables 3 to 8 show that there are not too many circumstances when the heading, wave height and wave period match up so that the vessel will fail. Therefore it could be said that the vessel would be able to operate in this ocean expanse as long as it was careful during larger seas.

The remaining polar plots are given in Appendix A and by closely examining these a more accurate determination of where and when the vessel would be able to operate would be possible.

Recommendations

I would recommend that the FTV Bluefin would be able to operate in this new coastal environment. There are some headings, wave heights and wave periods that it would not pass the IMO criteria, however with special attention paid to when these circumstances would occur, the vessel would able to safely do its work. While saying this, to be on the safe side some damping devices for heave and roll may be looked into, however without research and experiments it is incorrect to assume that these would help the FTV Bluefin to dampen it's motions.

References

Bhattacharyya, R., *Dynamics of Marine Vehicles,* John Wiley and Sons, New York, 1978.

Boyd, J.C.M. 1995. *Analysis of Non-Linear Vessel Motions Using Modified Linear Strip Theory*. MSc Thesis, Curtin University of Technology.

Duffy, J., *Lecture Notes,* Australian Maritime College, 2012

Grim, O., Die Schwingungen von Schvimmenden, Zwei-dimensionalen *Korpern,* HSVA Report 1171, 1959

Lewis, E. (Ed.), *Principles of Naval Architecture,* SNAME, New York, 1990

Lloyd, A.R.J.M., *Seakeeping, Ship behaviou in Rough Weather,* 2nd Edition, 1998