AMCS
AMC SEARCH
Commercial arm of the Australian Maritime College

Vessel Wave Wake Study

relevant to the

Speed and Behaviour Management Strategy

for the

Gold Coast Waterways Authority

Report 16/M/03(C)

29 August 2016

Technical Report

Title: Vessel Wave Wake Study relevant to the Speed and Behaviour Management Strategy	
Client:	Gold Coast Waterways Authority
Client Representative:	Brian McRae, Manager (Strategy)
Project Manager:	Associate Professor Gregor Macfarlane
Author:	Associate Professor Gregor Macfarlane
Date:	29 August 2016
Number of pages:	12 (including cover)
Classification:	Commercial-in-Confidence
Report Number:	AMC Search 16/M/03(C) – *for public release*
Project No:	16/M/03
Distribution List:	**Project Manager (sign)** Gregor Macfarlane
Gold Coast Waterways Authority	**AMC Search CEO (sign)** Dean Cook

- This report is prepared solely for the use of the Gold Coast Waterways Authority. No responsibility to any third party shall be accepted, as the report will not be prepared, and shall not be intended for any other purpose.
- The Gold Coast Waterways Authority acknowledges that it is, and will continue to be, solely responsible for making management decisions and functions when implementing any advice or recommendations in this report.
- We believe the report is accurate and precise, but no warranty is given for the accuracy or reliability of information given from the Gold Coast Waterways Authority that may affect the outcome in actual conditions.
- You should be aware of the fact that no matter how accurate and precise the Australian Maritime College is in the preparation of its modelling, there can be no guarantee, given the multitude of variables which may affect the outcome, that the result of modelling will be replicated in actual conditions and vessels.

Vessel Wave Wake Study

relevant to the

Speed and Behaviour Management Strategy

CONTENTS

NOMENCLATURE and ABBREVIATIONS

E	wave energy (for each wavelength, per unit width of wave crest) (J/m)
H	wave height (m)
T	wave period (s)
u	vessel speed (m/s)
g	acceleration due to gravity (taken as 9.81 m/s)
ρ	water density (kg/m^3)
L	waterline length of vessel (m)
LOA	overall length of vessel (m)
y	lateral distance between vessel sailing line and measurement point (m)
h	water depth (m)
AMC	Australian Maritime College (University of Tasmania)
GCWA	Gold Coast Waterways Authority
GIS	Geographic Information System
PAX	Passengers

Vessel Wave Wake Study

relevant to the

Speed and Behaviour Management Strategy

1 INTRODUCTION

At the request of Brian McRae, Manager (Strategy), with the Gold Coast Waterways Authority (GCWA), Associate Professor Gregor Macfarlane of the Australian Maritime College (AMC) was engaged as a consultant to provide specialist advice on vessel wave wake (commonly referred to as 'wash') in respect to GCWA's Speed and Behaviour Management Strategy (Reference 1), including the accompanying interactive map (Reference 2).

This work primarily involved the following tasks:

(1) Provision of specialist advice and feedback on the draft Proposed Response to the Speed Limits Review - February 2016 (Reference 3) and the Speed and Behaviour Management Strategy - June 2016 (Reference 1). This work is presented in AMC Search Report 16/M/03 (A): 13 April 2016 (Reference 4) and emails exchanged between Brian McRae and Gregor Macfarlane.

(2) Perform a study which provides scientific justification for the selection of appropriate vessel length and speed limits for the Red and Yellow Zones. This has been achieved using wash data acquired from both full scale trials on a variety of relevant vessels and predictions from an empirical tool that has been developed over the past 20 years specifically for this purpose. This work is presented in Section 2 of this AMC Search Report.

(3) Provision of additional background information on wakeboarding and advice on its management. This is also presented in this report (Section 3).

(4) Based on the issues and information covered in the three dot points above, comment on the proposed changes to speed limits described in References 1, 2 and 3 (provided in emails between Brian McRae and Gregor Macfarlane).

2 VESSEL WAVE WAKE STUDY

<u>Background and Methodology</u>

The initial AMC review of the Proposed Response to the Speed Limits Review (Reference 4), which led to the Speed and Behaviour Management Strategy (Reference 1), noted that there was currently little or no explanation on how the vessel length and speed restrictions proposed for the revised Yellow Zone were determined. It was agreed that the Strategy would benefit by including a justification, based on accepted scientific knowledge, for selecting the proposed vessel length (6.5m) and speed (25-knot) restrictions for this zone. Similar comments apply to the application of 6-knots as the speed limit for the Red Zone.

The present study has generated plots of both the wave height and energy that are indicative of those likely to be generated by a variety of typical water craft that regularly use Gold Coast waterways. This has been used in combination with appropriate criteria for assessing vessel generated waves on sheltered waterways to identify suitable vessel length and speed restrictions. The study has considered typical vessels and conditions expected in the areas of concern, particularly the Coomera and Nerang Rivers (including nominal river width, depth, fetch and bank angle/type).

The vessel wave wake data (wave height and energy) used and presented in this study has been acquired from two primary sources: (1) pre-existing full scale experiments performed by the Author on many recreational and small commercial vessels over the past 15 years, and (2) predictions from a dedicated vessel wave wake software package developed by the Author. Further details are provided later in this report and in References 5 to 8.

Wave Wake Analysis

When assessing the waves generated by marine vessels it is important to note the following:

- All marine vessels generate a wave pattern that consists of many waves of varying height and period (wavelength).
- The wave pattern generated by a vessel is largely independent of vessel form, but it is greatly affected by water depth, degree of lateral restriction and vessel speed. In general, there are four distinctly different types of wave pattern: sub-critical, trans-critical, critical and super-critical. The type of wave pattern created by a vessel depends solely on the combination of vessel speed and water depth beneath the vessel.
- Quantifying the wave profile by the characteristics of a single wave is inadequate, particularly when the vessel is operating in shallow water depths (where longer period waves are often generated). The assessment methodology recommended by AMC is to identify and quantify the three most significant waves in a wave train. This ensures that the waves possessing the greatest height, longest period and highest energy are always identified and assessed. The complex nature and number of variables that influence vessel wave patterns means that there are occasions when all three (greatest height, period and energy) are represented by one, two or three individual waves.
- Although all three key waves have been considered in the present study, to avoid confusion just a single wave is presented in the plots provided – these represent the worst case.
- Both the height and period of each of these three waves are of equal importance.
- Wave energy is proportional to the square of the wave height and square of the wave period, so any change in either height or period will result in a significant change in wave energy (Equation 1).

$$E = \frac{\rho g^2 H^2 T^2}{16\pi} \quad \text{(Eq. 1)}$$

- Wave height can be significantly affected by hull design, but wave period is largely unaffected. For example, two vessels of same length but significantly different displacement will generate waves of similar period, but the height of the heavier vessel's waves will be greater, and hence be more energetic.

- Wave height will decay with increasing lateral distance from the sailing line of the vessel. Wave period remains approximately constant over lateral distance.
- A vessels slenderness ratio (waterline length divided by the inverse cube of its displaced volume) is an excellent indicator of the waves generated by surface vessels (Equation 2). When aiming to minimise vessel wave wake issues it is accepted practice to maximise the slenderness ratio - that is, make the vessels as long and light as practical.

$$\text{Slenderness Ratio} = \frac{Waterline\ Length}{(Displaced\ Volume)^{1/3}} \qquad \text{(Eq. 2)}$$

- Wave period, although largely unaffected by changes to hull form, is heavily dependent upon both vessel speed and water depth.
- Naval architects and maritime engineers traditionally non-dimensionalise vessel speed using the length Froude number, Fr_L (Equation 3). Because water depth plays such a crucial role in the characteristics of the waves generated, it is also very important to consider the non-dimensional relationship between vessel speed and water depth, the depth Froude number, Fr_h (Equation 4).

Length Froude number (Eq. 3)

$$Fr_L = \frac{u}{\sqrt{gL}}$$

Depth Froude number (Eq.4)

$$Fr_h = \frac{u}{\sqrt{gh}}$$

- All vessels typically generate the largest waves when they travel at or around their displacement hull speed, which equates to length Froude numbers of $0.4 \le Fr_L \le 0.5$).
- A depth Froude number of 1.0 is termed the critical speed and speeds leading up to this critical speed are sometimes referred to as trans-critical speeds (approximately $0.75 \le Fr_h \le 1.0$). In this region, both the period and angle of the leading divergent waves rapidly increase, making this a speed range to avoid, if practical.
- Potentially the worst case in regards to generating damaging or dangerous waves will occur when a vessel operates within both of these unfavourable zones at the same time.

<u>AMC *Wave Wake Predictor*</u>

Predictions of wave wake characteristics were made using the AMC's *Wave Wake Predictor*, an empirical tool developed following analysis of data from a comprehensive series of scale model experiments on a wide range of vessel types operating in various shallow and deep water depths. The database used to develop this prediction tool is arguably the world's largest collection of model and full scale vessel wave wake experiments, all performed using stringent and standardised procedures. The tool has been validated against many series of full scale trials data and is well suited to provide indicative values of wave height and energy for the marine craft of interest in this study. Further details on the prediction tool and its validation can be found in References 5 to 8.

The development of the prediction tool had the benefit of performing all experiments within controlled conditions thus ensuring wave profiles were acquired at a steady state and at multiple known lateral locations (typically a minimum of six up to 12 locations). This allowed each of the key waves to be monitored as the waves dispersed and propagated away from the vessel sailing line, through the near and medium fields then into the far field. Not only does this method provide more certainty that each of the three key waves will be clearly identified, but it also allows both the wave decay rate and propagation angle to be accurately measured (in addition to their height and period).

Generic Vessel Details

In order to investigate suitable limits for the proposed Yellow Zone, the previously covered methods have been used to provide wave wake data for a range of typical watercraft that frequently use Gold Coast waterways. The basic details of each vessel are provided in Table 1.

The primary aims of this study are to (a) highlight just how dramatically vessel wave wake (wash) characteristics change with vessel size and speed, and (b) to identify rational limits for vessel speed and/or vessel size for the Red and Yellow Zones. Given the large number of variables that affect vessel wave wake it is not practical to be too precise in such a study, thus the characteristics of the various "generic" watercraft need only be nominal. To ensure consistency when comparing data, the values for water depth and lateral distance have been kept constant at approximately 6m and 23m respectively. Similar general trends would result for different values of water depth and lateral distance.

Table 1: Details of generic vessels

No.	**Generic Vessel Description**	**Length - Overall** (m)	**Length – Waterline** (m)	**Displacement** (kg)
1	Personal Watercraft (Jetski)	3.2	2.7	450
2	Aluminium Runabout (2 PAX)	4.6	3.9	800
3	Aluminium Runabout (3 PAX)	5.2	4.5	1,000
4	Ski Boat - Small (2 PAX)	5.4	4.5	1,000
5	Ski Boat - Large (2 PAX)	6.3	5.3	1,500
6	Aluminium Runabout (4 PAX)	6.4	5.4	1,500
7	Aluminium Runabout (5 PAX)	7.8	6.8	2,500
8	Sports Motor Cruiser	11.5	10.6	7,500

Results

The height of the maximum wave for the various generic vessels listed in Table 1 are plotted as a function of vessel speed in Figure 1. As can be seen, the form of the curve is generally similar for all vessels in that wave height initially increases as speed increases above 4 knots, reaches a peak and then gradually decreases. The speed at which the peak occurs is influenced by the length of each vessel – which is related to the length Froude number (i.e. the peak occurs at a higher speed for longer vessels). As can also be seen, peak wave height generally increases with an increase in vessel size.

It is generally accepted that wave energy is a better quantity for determining acceptable wash than wave height, as it is a function of both wave height and period. The energy of the maximum wave is plotted as a function of vessel speed in Figure 2.

The results shown in Figures 1 and 2 support the proposed maximum speed limit of 6 knots for all vessels operating in Red Zones. As can be seen in Figure 2, at these slow speeds (between 5 and 8 knots) there is a very steep increase in wave energy for all vessels. For example, the wave energy at 6 knots is approximately double that at 5 knots, but at 7 knots it is typically doubled again (four times greater than at 5 knots).

A separate vessel wash study investigated nominal wave energy limits designed to minimise bank erosion of typical rivers in south-east Queensland, and proposed a limit of approximately 180 J/m for moderately sensitive shorelines (Reference 9). This limit is shown in Figure 2, which suggests all generic vessels (just) meet this criterion at a speed of 6 knots. For comparison, the recommended wave energy limit for more sensitive shorelines (60 J/m) is also shown in Figure 2 – in such cases there is an argument that vessel speed should be limited to just 5 knots.

For the Yellow Zone, there is strong justification from the results presented in Figure 2 that larger vessels (in excess of 6.5m) should continue to observe the 6-knot speed limit to avoid generating unacceptably energetic waves (at any speed in excess of 6 knots). These results also clearly demonstrate the need for smaller craft to minimise operation at ‘intermediate’ speeds (6 to 15 knots) – if they don’t, their waves can easily exceed the nominal acceptable limit of 180 J/m. This confirms the proposal that operators of small craft be encouraged to “get up on the plane” (speeds around 20-25 knots) to minimise wave generation.

It is reiterated that the data presented here is deliberately general in nature – it is extremely impractical to consider every variable that influences the characteristics of vessel-generated waves, thus the primary aim is to provide indicative data from which rational waterway management decisions can be made. It may be worth noting that the Author has recently commenced an (independent) research program that aims to further investigate vessel wash in the slow speed range of 4 to 10 knots, where wave characteristics are known to change dramatically. This study may also consider various river bank types and the effect of lateral distance between the banks and the vessels’ sailing line.

3 WAKEBOARDING

Specific mention of additional complexities from wakeboarding activities, as opposed to water skiing, were raised in the initial feedback on the draft Proposed Response to the Speed Limits Review (Reference 4).

There are some fundamental differences between these activities, especially when wakeboarders take deliberate steps to increase the height/energy of their vessel-generated waves to enhance this activity, making it potentially more controversial than ‘traditional’ water skiing activities. Commonly adopted methods for increasing vessel waves for this purpose include: operating at intermediate displacement speeds, increasing stern-down running trim angles and/or increasing displacement (either statically through the addition of weight, or dynamically by the addition of hydrofoils underneath the tow vessel). Wave wake height becomes an important factor when undertaking this activity, as well as wave steepness. The waves closest to the vessel will always be the highest and steepest, but there is a practical limit as to how close the wakeboarder can manoeuvre from the tow vessel.

Wakeboarding is a popular and growing sport and provision should be made to accommodate this activity. However, wakeboarding activities are not recommended in narrow waterways possessing sensitive shorelines and are more suited to more open areas having increased fetch, which are higher energy environments that are generally bounded by shorelines that are more resistant to incident wave energy. As a result, it is becoming commonplace to provide dedicated locations for these activities to occur. It is recommended that consideration be given to addressing this topic within the *Strategy* – for example, stating that such activities/actions may be best confined to designated water skiing areas and prohibited from Yellow Zones.

As it currently stands, water skiing is permitted within Yellow Zones, thus it is assumed that wakeboarders are also permitted to use these zones (provided vessels are less than 6.5m long). It is further assumed that they are permitted to: (a) operate at the 'optimum' speed to maximise wash – generally around 8-14 knots (depending on water depth, vessel length and any dynamic method to increase displacement), and (b) modify a vessel such that wash is amplified. This runs against one of the primary aims of the Yellow Zone, which is to avoid wash issues by restricting those craft capable of creating damaging wash and encouraging small craft to operate at higher planing speeds. As shown in Figure 2, there is the high probability that these waves will significantly exceed levels that are considered sustainable when these operations occur close to shorelines that are susceptible to wave erosion.

It may be necessary to request users of Yellow Zones minimise water skiing / wakeboarding activities at 'slow' speeds (say below 20 knots), while clearly stating that the intention is to avoid generation of excessive wash, thus inferring that wakeboarding at 'optimal' speeds for wave generation is not permitted. An alternative approach would be to simply state that wakeboarding is not permitted in Red and Yellow Zones, thus confining them to other designated water skiing areas and Green Zones.

REFERENCES

1) Gold Coast Waterways Authority, Speed and Behaviour Management Strategy, June 2016.
2) Gold Coast Waterways Authority, GIS maps "Speed Limits Review_No aerial photos", accessed in QGIS V2.14.2, provided by Brian McRae 4th May 2016.
3) Gold Coast Waterways Authority, Proposed Response to the Speed Limits Review, February 2016.
4) Macfarlane G.J., Review of the Gold Coast Waterways Authority's Proposed Response to the Speed Limits Review, AMC Search Report No. 16/M/03(A), 13 April 2016.
5) Macfarlane, G.J., *Marine vessel wave wake: focus on vessel operations within sheltered waterways*, Doctor of Philosophy Thesis, Australian Maritime College, University of Tasmania, June 2012.
6) Macfarlane, G.J., Bose, N. and Duffy, J.T., Wave wake: focus on vessel operations within sheltered waterways, *Proceedings of the Society of Naval Architects and Marine Engineers (SNAME) 2012 Annual Meeting*, 24-26 October 2012.
7) Macfarlane, G.J., Correlation of prototype and model scale wave wake characteristics of a catamaran, *SNAME Marine Technology*, Volume 46, Number 1, January 2009.
8) Macfarlane, G.J., Correlation of prototype and model wave wake characteristics at low Froude numbers, *Transactions of the Royal Institution of Naval Arctitects (RINA), Part A2, International Journal of Maritime Engineering*, 2006.
9) Macfarlane, G.J. and Cox, G., 2003, 'Vessel wash impacts on bank erosion - Noosa River (between Lakes Cootharaba and Cooroibah) and Brisbane River (Kookaburra Park to the Bremer River junction)', Refereed report for the Moreton Bay Waterways and Catchments Partnership, AMC Search Ltd report 01/G/18.

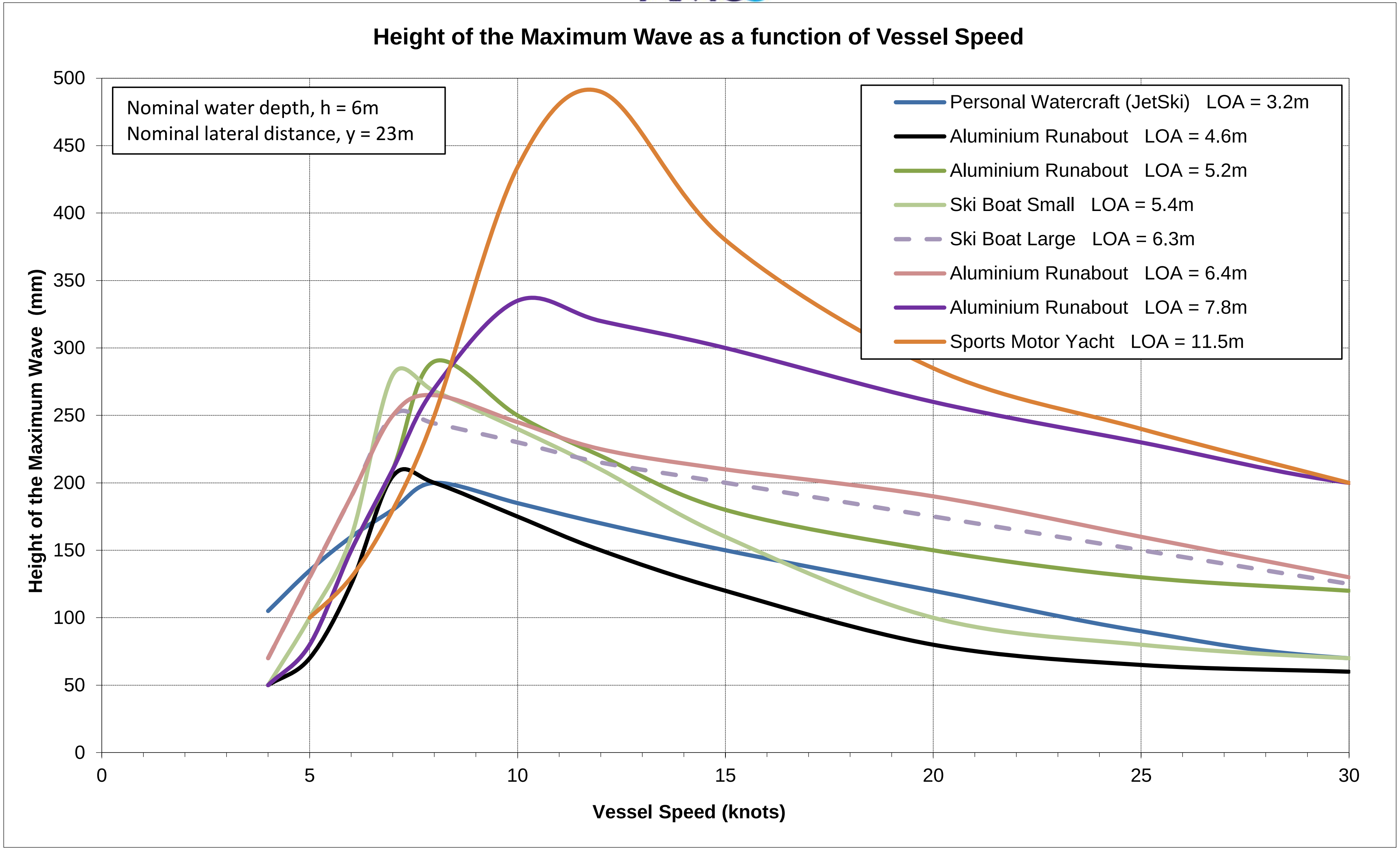

Figure 1: Height of the maximum wave as a function of vessel speed for multiple generic vessel types

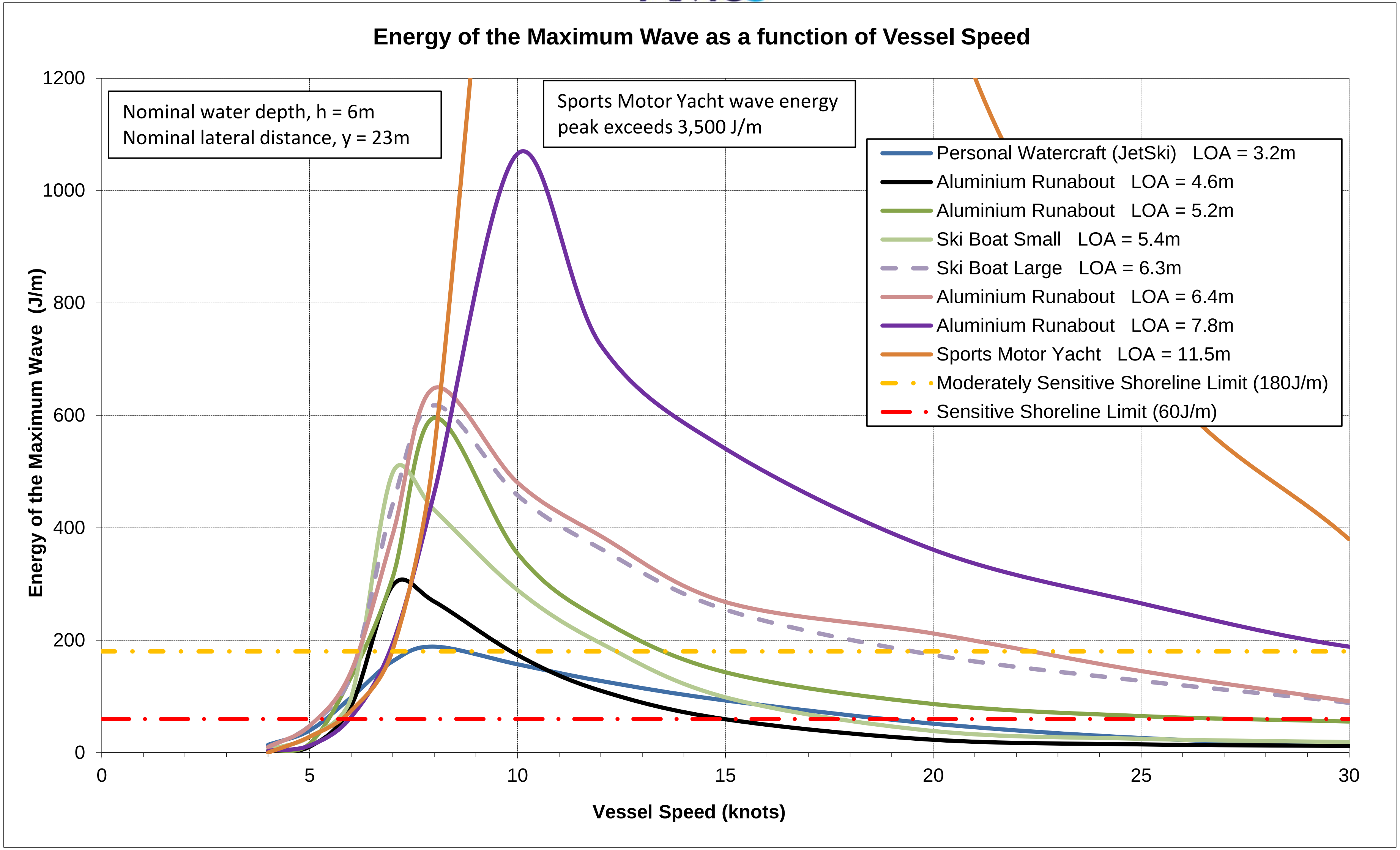

Figure 2: Energy of the maximum wave as a function of vessel speed for multiple generic vessel types