An Introduction to Wake Active Manipulation

M C M Mackay* BEng AMRINA

** Senior Engineer, Frazer-Nash Consultancy*
* Corresponding Author. Email: M.Mackay@fnc.co.uk

Synopsis

The purpose of this paper is to introduce the concept of Wake Active Manipulation (WAM). This novel principle can be summarised as controlling wake profiles with the intention of producing useful effects outside of the normal propulsive efficiency gains. The use of which could assist the recovery of unmanned autonomous assets. Frazer-Nash assessed this concept through an analytical wake study of a vessel and appendage. The assessment summarised the ability to create a similar wake profile to what small craft utilise for 'wake surfing'. It was suggested that by utilising wake patterns in a similar fashion, a large mothership could assert a controlling or guiding force onto an approaching asset to assist recovery operations.

Keywords: Off-board asset, USV, wake, ship appendages, wake control, Launch and recovery, stern ramp, wake surfing.

1. Introduction

Ship design programmes will consider wake production when designing the hull-form, (Molland, 2008). This consideration tends to focus on the reduction of wake formations for the purpose of reducing wave-making resistance and or reducing a military vessel's signature profile. Wake Active Manipulation (WAM) wants to challenge this focus, and offer a reason to treat wake energy as a useful by-product that can be utilised for the benefit of vessel operations. In much the same way as the turbo in an engine recovering wasted energy from the exhaust to enhance capability, WAM suggests that the wasted energy within the wake field can be recovered or used to enhance the vessel's capabilities.

This paper will discuss the possible uses of the WAM principle as well as discussing a number of real world examples involving wake manipulation or control. The focus of Frazer-Nash Consultancy's assessment was to utilise WAM for launch and recovery of autonomous off board assets. Launch and recovery is recognised as being one of the blockers to widespread usage of autonomous vessels, and it was considered that the WAM principle would be capable of assisting this process and potentially enable greater use of these assets in the future.

Current wake changing techniques were considered, including aft end appendages, hull form design, trim and ballast techniques, as well as other innovations.

Following this, Frazer-Nash performed in house analysis of the basic principles behind the WAM idea, and commissioned an external assessment by Newcastle University. The internal assessment will be shown along with its findings within this paper.

Author's Biography
Michael Mackay is a Senior Engineer at Frazer-Nash Consultancy in Bristol, UK. Working towards chartership, he has a background in both Naval Architecture and Research and Development and has been involved in multiple, concept level ship designs, as well as work developing novel technology for the marine and defence industry.

https://doi.org/10.24868/issn.2515-818X.2020.014

2. Real World Examples

A key component of ship design is the generation of the hull form, the design criteria that drive this part of the design will vary between use cases. For a majority of vessels, the reduction of wave making resistance is considered and even prioritised. This is further explored throughout the life of a vessel, commonly achieved by the addition of appendages aimed at increasing transit efficiencies (J.D Van Manen, 1988). A current example of this would be the fitment of transom flaps onto a number of Type 23 frigates of the Royal Navy. These appendages were added for a number of improvements (Matthew. Williamson, 2007), among them was the reduction of wave making resistance through an increase in waterline length and reduction of wave effects off the transom. This case study can be seen to be replicated across a number of refit ships commonly for the purpose of efficiency gains.

A recent example of appendages used for propulsive gains is the ‘hull vane’ product. Simply put this is a spoiler for ships equipped with a foil profile to add lift and some apparent forward thrust to the vessel. A component of the benefits offered by the hull vane system is the reduction of transom produced wake. This is clearly demonstrated in CFD and real world examples (K. Uithof). A clear example of wake management that shows wake reduction could be visualised to do the opposite and create exaggerated wake if designed as such.

An example of the exaggeration of wake profiles can be seen in water sports, particularly ‘wake surfing’. This niche sport derives from wake boarding, but uses an exaggerated wake profile to allow the surfer to let go of the towrope and follow behind the speedboat surfing on the wave.

The wake surfing technique has shown the WAM principle in action in a working environment. Wake surfing is a technique in which the small craft is trimmed dramatically to the stern and port or starboard side to create an aggressive, one sided wake profile. The surfer following behind the small craft uses the tow rope to approach and ‘ride’ the exaggerated wake profile, allowing them to release the rope and surf behind the vessel unassisted.

Figure 1: A surfer riding the wake of a small craft unaided.

To achieve this, the speedboats deploy a number of wake effecting techniques, these include stern ballast, trim tabs, and side attached appendages. The result of which creates an exaggerated wake profile, at the expense of propulsive efficiency and speed. This sport shows a practical example of a vessel exaggerating or manipulating a wake profile.

3. Concept Breakdown

The following will cover the potential use cases for WAM as well as detail the use case Frazer-Nash has focussed on.

As suggested by Figure 1, the water sports industry could benefit from a developed WAM system. The potential to actively create wake focal points and move them around behind the transom could offer an exciting development to the sport offering the potential to form larger and more controlled wake profiles. This can extend to larger yachts, making it possible to have large moving wake zones off the back of superyachts, with effect being utilised for sport and enjoyment.

Use in the commercial marine sector was considered, with some potential to improve effectiveness of towed systems, however the focus on surface wake profiles left this as an option to explore later.

Frazer-Nash has significant experience in the assessment of naval signatures, and the potential for the WAM principle to be utilised in this sector was recognised. Given a hypothetical appendage arrangement capable of controlling the majority of developed wake profiles, it may be feasible to affect a vessel’s wake for the purpose of surface signature reduction or disguise. With current satellite technology capable of detecting and categorising profiles from space, the ability to minimise detectable wake would have operational benefits. In addition, a system capable of minimising wake could also produce a modified wake pattern that may be able to disguise the vessel as another.

For the context of the remainder of the paper, the focus of the WAM principle is on the launch and recovery of on-board assets, particularly with a stern ramp or dock. The use of unmanned surface vehicles (USV) is likely to become a leading tool in any navy's arsenal. A major factor to consider in deployment of USVs, is the difficulty in recovering assets without the use of an experienced coxswain. The complete reliance on autonomous or remote controlled technology adds risk to the deploying 'mothership'.

An industry response to this problem is to continue to develop the autonomous capacity of the USV, increasing the processing power and problem solving ability of each remote asset. This drive for 'human-like' control is progressing, however, until the technology reaches human level capabilities alternative recovery solutions could be developed.

Less intelligent autonomous assets are widely available, and still capable of performing in a multitude of scenarios. WAM offers the possibility to de-risk the use of these assets and subsequently produce a solution to unreliable recovery methods.

This forms the principle WAM will aim to address.

Hypothetically, if a 'mothership' has the ability to affect and control approaching USV's without mechanical connection, the ship user will likely be less adverse to the use of fully autonomous assets as they would have more control over how the USV is subsequently tethered and recovered. With the assumption that a series of appendages attached to the mothership can control the wake, field peaks and troughs, as well as utilising a stern ramp for launch and recovery operations.

4. Example Operating Scenarios

A system designed to assist the recovery of an un-manned asset could work as follows:

The approaching USV is detected off the transom, so the appendages create a flat approach into the wake field.

Once at an optimum distance the appendages create a wave trough at the location of the USV. This trough will capture and propel the approaching USV in a similar manner as a wake surfer behind a small craft. Once captured within this focal point the system will move the appendages to draw the focal point towards the transom, pulling the USV towards the stern ramp. When close to the transom and stern ramp, a trough is formed directly aft of the ramp to draw in and hold the USV at a fixed point of the back off the mothership. Once captured in the trough, the USV will remain stationary relative to the ramp, where lines can be attached to draw it up the stern ramp.

The wake field and interaction to two vessels is a complex system. There will be a significant number of variables and dependencies, two of which for example include Speed and Sea State.

- Speed

The speed and aspect ratio of the mothership will have a dramatic effect on the wake field. For Fr <~ 0.2 there is often almost no visible wake. With the transverse component becomes visible first (circular arcs spreading out behind the vessel) with the typical kelvin wakes at 19.5° becoming clearer above Fr ~ 0.3.Displacement hulls tend not to operate above Fr ~ 0.4 as the resistance becomes very large. There needs to be a balance between effectiveness of WAM and a controllable speed for the approaching USV to be capable of approaching and keeping up.

- Sea state

The effectiveness of WAM will need to be determined at varying sea states. A maximum sea state may need to be set, or possibly a control system that measures and accounts for the current sea state when making live adjustments to the system. Which could be determined after assessing the use ability in directional sea-state i.e. cross-seas.

5. Visualising WAM

The aim of this project was to validate the theory behind the WAM principle. This section will cover the analysis used to visualise the wake behind a large ship. To determine how wake profiles can be manipulated similarly to proven methods used by small boats in wake surfing.

This included looking at the following:

- Can wake profiles be controlled using appendages?
- Can focal zones be produced within the wake?
- Can these focal zones then be moved?

To assess these criteria, Frazer-Nash used a used an analytical method similar to that of Moisy & Rabaud (2018) to calculate the Kelvin wake generated by a moving pressure distribution. While limited by the 19.5° wake half angle typically seen from objects as varied as cargo ships, fishing vessels and ducks, there is considerable variation in the exact form of the wake produced. The wake from a rowing boat is very different to that from a cross-channel ferry, though the same physical principles underlie them both.

The frequencies of the waves excited on the water surface depend on the size, shape and speed of the vessel. Only those that couple well with the characteristic spectral shape of a Kelvin wake will be visible on the water surface, and the others will rapidly decay away. This coupling would be an important consideration in the design for any appendages intended for active wake management.

The analysis captures the excitation of the Kelvin waves by moving pressure distributions, and so allows us to model the interactions between the wakes from two different objects. For simplicity, in this example we considered the interactions between the wakes generated by two elliptical 2D Gaussian pressure distributions. The primary (representing the mothership) has a length to beam ratio of 6, typical of many vessels. The secondary (representing the WAM appendage) has the same dimensions, but is offset from the primary by one half-wavelength downstream along the wake.

In practice, geometrically the appendage will be far smaller. While it is typical to try to minimise the wake (and thus the wave making drag) of vessels, the appendage can be designed to produce as large a wake as possible. For simplicity, the two pressure distributions were modelled to have the same dimensions.

To demonstrate how the wake can be manipulated, the pressure of the secondary is varied from 0% to 95% of the primary pressure, with the results shown in (Figure 2). In practice this could be achieved by, for instance, varying the angle of attack of a hydrofoil shaped appendage. The top left image shows the wake field created due solely to the primary (secondary pressure set to 0% of primary), with a classic wake profile clearly visible. At 95%, (bottom), the upper wake arm has been almost completely removed, leaving almost flat water in the region of the upper wake arm. The intermediate stage (top right) shows how a smaller wake is formed behind the secondary, that could itself be used to help guide a USV into the trough behind the primary.

The longitudinal wavelength λ of the cusp waves that form the wake is determined solely by the forward speed of the vessel U, and is given by $\lambda = 2\pi U^2/g$. Hence, the typical wavelength of the wake from an appendage will be the same as the wavelength from the primary, allowing almost perfect cancellation between the two. This is true regardless of the size of the appendage.

The model was set up with a Fr of 0.35. Whilst this would reflect relatively high speed at vessel sizes around 100 meters, it was intended to show dramatic wake profiles and the ability to manipulate them.

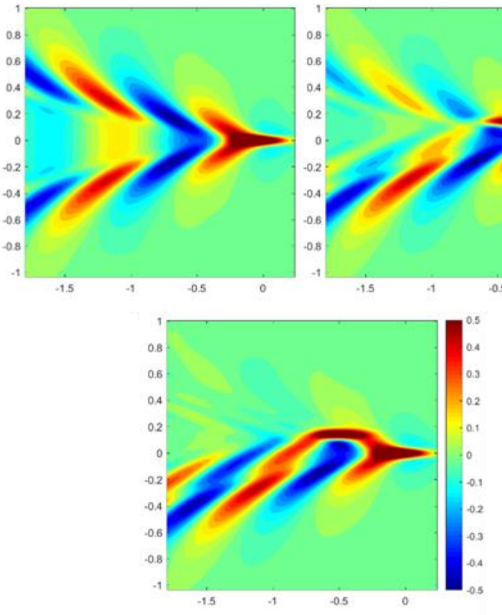

Figure 2: Wake manipulation showing how the upper arm can be almost entirely removed. Pressures on the secondary component are varied from 0% (top left), 47.5% (top right) and 95% (bottom) of the primary pressure.

6. Discussion

The results shown in Figure 2 show a distinct change in the standard wake profile similar to what is achieved in the sport of wake surfing. Although the analysis did not produce a specific focal point, it shows the ability to significantly alter the wake profile whilst moving at speed. Small craft use vessel trim and ballast, to port or starboard to create an offset wake pattern this creates a clean wave on one side and a rough more turbulent wave on the other.

In the instance shown in Figure 2 the port side wake arm is all but removed when the appendage is at 95% and significantly reduced at 47.5%. In practice this would represent a significant appendage in scale and force applied to it, however this shows a proof of concept and avenue for further work.

Using a single appendage, it is suggested that a channel could be created to aid a small craft's approach towards the stern of the main vessel.

Combining this with a hydrofoil off the transom similar to that shown in (K. Uithof) it could be possible to smooth out the wake flow behind the transom together creating a smooth transition from open sea to stern ramp. If this smooth transition field can then be replicated at higher speeds and more dramatic sea states then WAM would be a useful tool in the off board assets launch and recovery process.

Operationally, there are real benefits to simply being able to invert certain parts of the wake field. For example, vessels that utilise the stern ramp will face difficulties due to vessel pitching. This tends to be dependent on the sill depth on the stern ramp (Rubin. Sheinberg, 2003) as well as the size and stability of the mother vessel, and can lead to the small craft being pinned under the transom in extreme cases. The assessment shown in Figure 2 that using aft end appendages off the transom would create pressure fields that cancel out wake off the transom. If controlled actively with vessel pitching, it could be possible to create peaks and troughs just aft of the stern ramp to maintain sill depth regardless of mothership pitching. This will enable far safer stern ramp use and broaden the operational envelop of deployed assets.

One possible ambition of WAM is to create a system capable of detecting a small craft off the stern, preparing the wake profile accordingly to ease transition towards the stern ramp, then apply a guiding or 'surfing' force to the vessel to keep in on track. Then once close, control the transom wake to capture the asset just off the ramp to allow tethering.

7. Route to Exploitation

The following work will be needed to realise the potential of the concept:

- Comprehensive case study assessment

The aim of this study will depend on the user’s requirement. A focus on stern ramp operations for example would depend on the layout of the use vessel. A bespoke WAM assessment could be achieved using CFD.

- Tank Testing

Once the CFD tests are completed, and validated against a non-appended hull form. A model can be manufactured and tow tank testing performed to validate the CFD findings in the real world.

- Design of refit and new build system

A comprehensive design can then be produced for a system capable of controlling a vessels wake using a database of wake reactions built from the CFD and tank testing. This will need to include detailed structural design assessments due to the large forces at work on an appendage capable of dramatic wake changing affects.

- Retrofit demonstrator

Fit and install the WAM system onto a vessel to assess real world capabilities.

For all of the above work, consideration for effective speed ranges, sea state, and size ratios between the small craft and main vessel must be taken into account. This would provide acceptable operating envelopes depending on the system’s purpose.

8. Conclusions

The energy in a ship’s wake can be redirected and manipulated using appendages. The analytical assessment performed by the Frazer-Nash fluids team, shows the possibility of a large vessel controlling the wake profile similarly to a small craft. The principle of Wake Active Manipulation (WAM) offers a novel way to view a ship’s wake and suggests that the energy within can be harnessed to enhance the capability of the producing vessel.

Acknowledgements

- Newcastle University was approached to perform independent analysis on the WAM principle. The work is being undertaken by Dr Wetenhall and Ryan Abela, an MSc student within the marine technology department. They intend to run various CFD assessments on a frigate hull form to determine how appendages can move focal points within the wake profile. These would then be validated against towing tank tests. At the time of writing, the assessment has not been completed.
- Frazer-Nash Consultancy Fluids Group, Peter Cossins, and Christopher De Coninck
- Babcock Naval Concept Design Team.

References

F. Moisy, M. R. (2018). *Scaling of far-Field wake ngle of non-axisymmetric pressure disturbance* . University Paris-Sud.

J.D Van Manen, P. V. (1988). Resistance, Wave making resistance. In E. V. Lewis, *Principles of Naval Architecture* (pp. 15-27). Jersey: SNAME.

K. Uithof, P. v. (n.d.). *An update on the development of the hull vane.*

Matthew. Williamson, P. C. (2007). *Retrofit of Transom Flaps to RN Warships.* J.Nav.Eng 43(3).

Molland, A. F. (2008). *Ship design, construction and operation.* Anthony F. Molland: Butterworth-Heinemann.

Rubin. Sheinberg. (2003). *Stern boat deployment systems and operability.* San Francisco: World maritime technology conference.