A REVOLUTIONARY RIDE CONTROL SYSTEM FOR MULTI-HULL HIGH SPEED MARINE VESSELS

A. J. Robertson and R. Monk, Nauti-Craft Pty Ltd, Australia

SUMMARY

In all traditional multi-hull design, the hulls are an integral part of the whole vessel, inputs received are “felt” or resolved by everything. This paper presents a fundamental change in the way marine vessels can be designed so that they can be driven safely and comfortably at high speed. This new approach isolates the hulls from the super structure using a sophisticated suspension system with automotive heritage. The shape and design of the hulls provides the first response to inputs from the surface, similar to the tyres on a wheel and the suspension system provides the second response. The system proposed is a passive, reactive system and is overwhelmingly driven by the inputs received by each of the hulls. The vessel shares the loads across the hull contact surfaces providing a uniquely stable platform to apply suspension engineering technologies and techniques to optimise the “ride and handling” or the seakeeping and safety of the vessel.

1. INTRODUCTION

The Nauti-Craft concept is to resiliently suspend the superstructure above the hulls. An interconnected suspension system is fundamentally designed such that it operates passively and the different translational and rotational movements can be individually tuned. Being able to “mode-decouple” provides the designer many options to optimise performance. For example, a slamming situation could be designed to be “handled” by articulating and pitching the hulls. The systems proposed also operate passively, at rest or on a mooring and the action of the hulls provide much more stability as well as power generation opportunities.

2. EXISTING RIDE CONTROL SYSTEMS FOR MARINE VESSELS

As technical people from an automotive background the science and art of Naval Architecture is understood to be the design of the number and shape of the hull(s) and of any ride control systems such as trim foils and gyroscopes. Hull design considerations include (but are not limited to) the purpose of the vessel, its operating requirements and sea states. These deliver the design of the hull, expected hull resistance, the propulsion system(s), other associated systems and expected performance levels. Typically, the initial analysis and design is focused on smooth and flat water conditions, with investigation of differing sea-states being considered after initial flat water analysis is complete. This approach has led to a variety of innovative adaptations to existing fixed hull configurations, which can have various limitations:

- CATAMARAN & SWATH – Catamarans generally have a major issue with slamming conditions. Also have a fixed, high natural frequency in roll and high torsional loads.

- WAVE PIERCING VSV’S (Very Slender Vessel’s) – Larger VSV’s operate efficiently up to their design conditions and sea-states, but once exceeded experience significant pitching, slamming and increased load conditions. Smaller VSV’s have challenging packaging considerations.

- TRIM FOILS (and other active fins) – Hydrodynamic in operation, so ineffective when stationary.

- GYROSCOPES – Have weight, packaging, control and energy requirements.

- PLANING HULLS – Typically and traditionally suitable to smaller vessels and friendly sea-states.

3. AN AUTOMOTIVE APPROACH TO RIDE CONTROL IN THE OCEAN

The ocean provides extreme conditions for any form of transport. It is also one of the oldest means of moving people and goods in both small and large amounts. The automotive industry is still in its infancy when compared to the marine industry, with developments beyond the cart having only been around from the early 19th century. Since that time, the auto industry has seen amazing developments, especially in the area of ride control and durability.

The core idea in a nautical suspension system is to be able to separate the part (i.e. a hull, pod or ski) that interfaces with the water from the superstructure, which contains people, goods, equipment etc. Once these are separated there is an opportunity to provide isolation, which can include compliance, damping and control, and to provide further tune-able items to improve and even optimise ride and handling characteristics (or in nautical terms – sea-keeping and safety).

Current comparisons to an auto application could include;
• Extreme off-road racing (Dakar rally-raid, Baja 1000 off-road race)
• World Rally Championships
• Truck racing
• Consumer 4WD applications (where intelligent stiffness and damping systems have been employed).
• Military applications with extreme weights, loads, durability and reliability requirements
• F1, active systems

4. SOPHISTICATED SUSPENSION SYSTEMS

There has been a gradual but steady progression in the functionality and complexity of vehicle suspension systems:

• Un-sprung cart – could utilise a pivoting axle to accommodate uneven surfaces.
• Metal springs (from leaf to coil and torsion) and dampers (friction to hydraulic).
• Linking interface areas, i.e. roll stabilisers.
• Passive options – such as progressive spring rates and height control (using air springs or hydro-pneumatic rams).
• Cross linked systems – such as left to right, air or hydraulic interconnections.
• Partially active systems – such as active roll stabiliser control and active control of switchable interconnections or damping.
• Fully active systems powering four independent wheel rams to control the force at each independent point of support, which is inefficient and requires incredibly fast response, leading to high power consumption.
• Passive reactive interconnected systems which utilise mechanical and/or hydraulic interconnections between all four points of support to provide different stiffness and/or damping between the four different modes of suspension (much as a roll stabiliser bar provides different stiffness in the roll or bounce mode for two wheels).

The number of modes possible in a suspension system is generally dependent on the number of independent points that the body is effectively supported upon. For example, on land, a motorcycle has two points of support and two suspension displacement modes – heave (vertical bounce) and pitch. A tricycle has three points of support and three suspension displacement modes (roll, heave and pitch) and a four-wheeled vehicle have four suspension displacement modes (warp, roll, heave and pitch).

However in marine applications, as the surface engaging part is a hull rather than a wheel, an additional torque is present due to the longitudinal distribution of the forces supporting the hull in the water. So in the case of a catamaran, if both hulls are suspended to permit heave and pitch relative to the superstructure, then the suspension would have four modes of displacement (warp, roll, heave and pitch). Note that if both hulls are suspended to permit only heave with respect to the superstructure, it would have two modes of suspension displacement (roll and heave), but that would also require resolving the additional torque due to the longitudinal distribution of the forces supporting the hull in the water.

5. SUSPENSION MODE DESCRIPTIONS

As noted above, the number of possible modes of displacement of a suspension system is primarily dependent on the number of independent points of support of the body above the hulls or similar water engaging parts and is also dependent on the locating geometry, which defines the degrees of freedom of each part. In this paper, consideration has only been given to suspension systems for vessels having a body supported by four independent supports such as a Quadmaran having four independent hulls with respective suspension supports to the body, or a Catamaran having two independent hulls, each having independent forward and rearward supports to the body. Consequently, the four supports (e.g. front left, front right, back right and back left) provide the following four possible suspension modes, the first three being illustrated in Figure 1.
Figure 1: Pitch, Warp and Roll Suspension Modes for a Quadmaran Nauti-Craft Vessel

- **PITCH** – the front pair of supports move in one vertical direction and the back pair of supports move in the opposite vertical direction (e.g. front left and front right supports compress, and back left and back right supports extend).

- **WARP** – one diagonal pair of supports move in one vertical direction and the other diagonal pair of supports move in the opposite vertical direction (e.g. front right and back left supports compress, and front left and back right supports extend).

- **ROLL** – the left pair of supports move in one vertical direction and the right pair of supports move in the opposite vertical direction (e.g. front left and back left compress, and front right and back right extend).

- **HEAVE** – all four supports move in a common vertical direction (either all extending or all compressing).

6. THE NAUTI-CRAFT MARINE SUSPENSION SYSTEM

To enable the suspension system to operate, the water interfacing parts (hulls, pods or skis) need to be separated from the superstructure. While there must be some swept volume that remains clear to permit the motion of the hulls relative to the superstructure, there can be many advantages which offset the loss of useable space.

The interconnected systems of the Nauti-Craft marine suspension provide a passive reactive support of the vessel superstructure. The low warp stiffness reduces the change in torsional loads into the superstructure, while the ability to independently tune roll and pitch stiffness rates removes traditional compromises in the ride of the vessel. This reduces the stress on the superstructure and on its contents (people, cargo and components) for a given sea state of vessel speed, with corresponding gains in operational expenditure.

The primarily passive mode of operation of the system minimises the power required when compared to any active platform stabilisation technologies and continues to provide sea-keeping benefits from its mode decoupling operation when the vessel is stationary unlike hydro-dynamic ride control systems. The various wave induced displacements of the suspension system can even be used to generate power.

Active enhancements can be provided, from control of damping to vessel attitude control. The active controllers can for example utilise a sky-hook algorithm to minimise motion of the superstructure. Active and passive versions of the suspension system are both compatible with other controlled systems such as gyroscopes and personnel transfer gangways.

Nauti-Craft suspension systems are suitable for a wide variety of applications, for example planing or displacement water craft and vessels with two or more hulls, pods or skis.

7. DETAILED SYSTEM REVIEW, OPERATION AND BENEFITS

Figure 2 shows a simple catamaran system configuration; the Nauti-Craft suspension system is “driven” by the inputs received by each of the hulls. In this catamaran version the body is supported above each hull by independent forward and rearward hydraulic rams, the hydraulic rams are interconnected to provide decoupling between the various modes of motion involving vertical displacement between the hulls and the superstructure, ie. roll, pitch, heave and warp modes. This “mode-decoupling” enables the vessel to share the loads across the hull contact surfaces providing a uniquely stable platform to apply suspension engineering technologies and techniques to optimise the “ride and handling” or the seakeeping and safety of the vessel.

In roll, a conventional catamaran design typically provides a much higher natural frequency than a monohull. The “mode-decoupling” functionality of the Nauti-Craft suspension not only permits the roll natural frequency of a quadmaran, trimaran or catamaran to be reduced, but also allows the roll characteristics to be adjusted. For example, the roll stiffness can be adjusted in dependence on load and/or sea state and roll attitude adjustments can be made according to conditions. These roll attitude adjustments can be performed as a trim of the roll attitude over a period of multiple wave
cycles and/or as a high speed real-time active adjustment of the roll attitude providing compensation for wave induced roll motions and minimising the roll of the body of the vessel.

In pitch, not only can the stiffness and attitude be varied as discussed in relation to roll, but hydraulic fluid can be transferred to minimise the pitch of the body using the energy from the wave inputs. For example, when the forward part of the hulls encounter a wave front and are displaced upwards, the fluid displaced from the front rams can be directed to extend the rear rams, keeping the vessel body relatively level. As the wave front passes through to the rearward part of the hulls, the hydraulic fluid can be allowed to transfer back in the reverse direction to cause the front rams to extend, the rear rams to compress and the body to remain relatively level. Additionally the individual hulls can pitch to maintain engagement with the water surface without any such hull pitch directly affecting the pitch attitude of the superstructure. In a quadmaran configuration the extra degree of freedom in the pitch mode for individual hulls provides an opportunity to substantially and actively adjust the longitudinal centre of gravity of each of the hulls – this adjustment can significantly reduce hump speed and provide for smaller propulsion requirements to achieve planing and / or semi-planing speeds.

In heave, as with roll and pitch, the stiffness can be adjusted to avoid motion sickness frequencies and this can be done automatically in dependence on speed, sea state and applied loads. In some configurations of the suspension, the heave of the superstructure can additionally be actively controlled.

In warp, when the forward part of one hull and the rearward part of the other hull are located in troughs between waves and the opposite ends of the hulls are located on crests of waves, hydraulic fluid is displaced around the interconnections between the rams to balance the forces between the hulls. This ensures that during pure warp motions, the distribution of loads between the hulls is maintained at substantially the same level as when the vessel is on calm flat water. There are many advantages to such a low warp stiffness characteristic, including:

- significantly reduced torsional loads into the superstructure.
- improved ability to plane with planing hulls, especially over uneven water
- improved planing performance over uneven water.
- significantly improved level attitude of the superstructure.

The spring and damper rates can be independently controlled in all modes and can be adjusted to avoid motion sickness frequencies in addition to providing control of the motions of the deck and minimising accelerations.

In use, the advantage of “mode-decoupling” is that all the above modes operate simultaneously (i.e. not in a limited, sequential manner), so for example, in a slamming situation the suspension system can use a combination of the pitch and warp functionality described above to absorb the wave input, improving the continuity of contact between the hulls and the water while still maintaining roll stability, with any
vertical displacement being damped by heave damping. The interconnected suspension system is designed such that it operates substantially passively and the stiffness and damping of some or each of the roll, pitch, heave and warp modes can be individually tuned. Being able to “mode-decouple” provides the designer with many options to optimise performance. The systems proposed operate passively when under way, or when on a mooring or when driven against a structure such that the superstructure and deck remains more stable than the deck of any conventional vessel – see Figure 3.

Figure 3 demonstrates the motion reduction provided by the Nauti-Craft Quad prototype over a Boston Conquest. It shows the highest and lowest point of both vessels over a 30 second period, taken from a mooring shot towards the later half of a Nauti-Craft video (see video here). Although the Nauti-Craft prototype was 8.5 meters long overall, the suspended portion was only 6 meters long compared to an overall hull length of 7 meters for the Boston Conquest. The maximum displacement (lightweight plus deadweight tonnage) of the Quad is 2600 kg compared to 3280 kg for the Boston. The displacement is reduced by a factor of approximately 5 by the Nauti-Craft suspension system, despite the weights and lengths of the crafts being within approximately 20%.

Figure 3: “Comparison of the Vertical Movement of the Nauti-Craft Prototype and a Conventional Monohull when on a Mooring”

All motions including sway and surge of the deck and superstructure are reduced when compared to a conventional monohull or catamaran of similar size as the suspension system absorbs wave inputs, at least in part by relative motion between the hulls.

Figure 4: “Nauti-Craft Quadmaran Concept for Servicing Power Generation Unit”
As noted above, the Nauti-Craft suspension can be enhanced by control of stiffness or position (attitude) in any or each suspension mode. This can be performed using a “sky-hook” type control algorithm which is widely applied to automobile suspension control, wherein the sprung mass (body or deck and superstructure) acceleration is measured along with the relative displacement between the body and the hulls. In minimising the absolute accelerations transmitted to the body through the suspension system, the resonant peak of the body mass can be reduced and a good ride quality can be achieved. Other active control strategies can be employed and although active control of the vessel suspension system does not limit the use of other equipment such as actively controlled personnel transfer gangways, the two control systems can be integrated or at least exchange predicted load and acceleration data.

Due to the efficiency of the passive reactive core suspension system, it can be undesirable from a power consumption, complexity and robustness perspective to provide fully active control. However the benefits provided by the passive system can be further enhanced using (a low frequency) control of stiffness to adjust the natural frequency in any mode in dependence on loading condition or sea state. Similarly stiffness, attitude and/or damping can be adjusted in the roll mode to adjust the suspension when the vessel is subject to a beam wind for example.

Nauti-Craft has developed, built, filmed and tested a number of full size prototypes. Figure 6 is a photo of the high speed Quadmaran on test in the Indian Ocean near Cape Naturaliste. The measured top speed of this prototype was 39.5 knots.
For propulsion the prototype contained 2 by 215 horsepower, 1494cc Seadoo RXT supercharged jet ski’s as the rear pods, the seat and control interface had been removed with suspension mounting points and a double wishbone suspension control mechanism added to the ski’s. Moulds of the rear ski’s were taken to produce “Dummy” ski’s for the front pods with a similar suspension configuration. Each of the pods had a vertical travel of plus 500mm and minus 500mm. The overall length of the vessel was 8.5m and an overall width of 5.0m. The tested weight of the vessel (as shown) was 2300kg.

Testing and filming of the vessel was undertaken using a Boston Whaler as a chase and support vessel and a helicopter for stable on the run shots. Figures 7 to 9 show back to back footage of the 2 vessels encountering swells as they go around Cape Naturaliste. The Boston Whaler is 7.6m in length and weighs 2900kg (as shown).

The Nauti-Craft quadmaran was fitted with vertical accelerometers on each pod and a “g” box firmly mounted to the centre of the superstructure, these sensors were all connected to a National Instrument Compact DAQ USB, with Labview running on Windows XP as the data collection software. The vessel was tested at a number of speeds and in a number of directions relative to the sea and swell direction. The effect of the suspension system when the Nauti-Craft Quad is in motion can be seen in Figure 10, showing vertical acceleration spectrums of the chassis or deck of the quad and of one of the front hulls. The data was taken while the Nauti-Craft Quad was planing over the sea at an angle to the waves which demonstrates the benefits of the suspension system in the warp mode.
Figure 7, 8, 9: “Nauti-Craft Quadmaran 8m Prototype Compared to a Conventional Monohull”
10. CONCLUSIONS
The Nauti-Craft suspension system improves the ability of a multi-hulled vessel to maintain a good speed in rough sea states. In such situations the comfort is also improved through reduced body motions. The interconnections of the system provide a passive reactive, mode decoupling operation which (unlike many vessel ride control systems) is just as effective when stationary as at speed.

One example of an extreme application is transfer vessels for marine stations such as energy extraction or generation platforms at sea which require the ability to transport personnel and equipment at a reasonable speed and then provide a stable platform for transfer. The N-C systems are compatible with existing active systems such as active gangway systems. Similarly the military can require operation in extreme conditions, requiring high speeds in rough seas without significantly reducing the operational capacity of the crew and equipment being transported.

The Nauti-Craft suspension system can significantly reduce (and in moderate sea states eliminate) slamming, reducing the resulting damaging peak accelerations. It also permits vessels to ride over swell rather than piercing through it. These features improve operational safety and fuel consumption.

N-C systems are also suited to many recreational and commercial applications in the 6 to 36 metre vessel categories of both displacement and planing operation.

11. ACKNOWLEDGEMENTS
Chris Heyring as the founder, principle inventor and for starting and funding the whole show during its infancy.

12. AUTHORS BIOGRAPHY
Alex Robertson holds the current position of senior mechanical engineer at Nauti-Craft Pty Ltd. He is responsible for creating engineering concepts from design and patent ideas. His previous experience includes suspension engineer and senior engineer with Kinetic Pty Ltd.

Richard Monk qualified as an Automotive Design Engineer with a specialisation in suspension systems and was employed for many years by Kinetic Pty Ltd, gaining IP experience and holding positions including Chief Engineer and IP Manager. He is currently working as a Patent Engineer for companies including Nauti-Craft Pty Ltd.