# Monohull Research Vessel Motion and Comfort

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The comfort of vessels is a complex subject because subjective human experience and reporting will determine a vessel's reputation more than technical analysis. A vessel that operates from an island location where there is an almost immediate transition to open ocean conditions will be considered less comfortable than the same vessel which makes a gradual transition through river, harbor, and coastal waters. A new vessel with capabilities that bring an institution more into the mainstream of research will become less comfortable as she attracts investigators who compare her with larger ones. The perception of motion can be effected by factors such as the arrangement of windows and the location of mess areas. People will focus most on motion while eating and their experience in this one part of the ship will heavily influence their overall impression.

Larger vessels are more comfortable than smaller ones of similar configuration for the simple reason that the waves become relatively smaller. There has been a lot of interest over the last decade in catamarans, SWATH, and other "magic bullet" solutions to the comfort and motion issue. Motion of these vessels can unquestionably be better than that of similarly sized monohulls. They are expensive craft to build however. The question which seldom gets asked is how their motions would compare with a low tech monohull of the same cost. The monohull could be significantly larger which wwould increase its comfort as well as its capacity.

The initial stability of a vessel is a measure of how far it will heel either under the influence of a gust of wind or moving a heavy weight around on deck. Basic to any discussion of seakeeping is the fact that, all else being equal, a vessel's roll period will correspond to its initial stability. The greater the stability, the faster the vessel will roll. A vessel with dangerously low stability will feel very comfortable, a counterintuitive fact which causes the deaths of several fishermen each year. Monohull design has traditionally focused on determining the minimal acceptable initial stability in order to achieve the slowest possible roll period. Deep hulls of modest beam are thus usually associated with comfort and the ability to work in heavier sea conditions.

Waterplane, the part of the hull intersected by the water's surface, is a primary determinant of motion. As the waves pass the hull, the buoyancy of the hull below the water remains the same. The change in volume at the waterline, as the ocean surface moves up and down, creates forces that move the hull. The more waterplane, the more motion excitation. Minimizing this area is the rational for the SWATH ship. Traditional ships have low waterplane areas relative to their mass and depth for the same reason.

Once an excitation has occurred and passed, the waterplane takes on a different role. The vessel will continue to move due to it's inertia and the waterplane now contributes to damping out that motion. If a single wave passes a low waterplane vessel, the hull will tend to make a small motion and then continue rolling and moving for some time after. The large waterplane vessel will tend to have a single, larger, response which stops quickly. Single waves are rare however and the response to the repeated periodic input of waves is the second primary factor in ship motion.

Safety and other design constraints make roll periods longer than 8 - 10 seconds impractical for mid size monohulls. If they are ballasted to a degree of stability that produces roll periods under six, the fast roll, combined with low damping from the waterplane, produces fast, deep, uncomfortable rolling. There is a fixed relationship between the length and period of waves and longer waves tend to be larger. Longer and larger waves are created by higher winds. The traditional hull will have a natural rolling period that tends to be the same as the period of waves developed by winds in the 20 to 30 knot range. The motion of the hull can carry over from each wave excitation so rhythmic rolling can develop and this will tend to happen in the conditions that will define the upper weather envelope for most oceanographic operations. Motions can become very large in these conditions and all sorts of devices such as bilge keels, and anti roll tanks have been employed to reduce the amplitude of rolling.

The development of the offshore supply vessel began to open designers' eyes in the 1970's to the possibilities of generous waterplane area monohulls (GWASH) with degrees of initial stability that would be unthinkable in traditional vessels. The rolling period of this type of vessel will be in the 4 to 6 second range which corresponds to the smaller waves generated in fair weather. The large waterplane damps motion quickly so it is harder for rhythmic rolling to develop. As the wind rises into the 20 to 30 knot range, wave periods will be unlikely to match the ships natural roll period. Vessels of this type tend to exhibit their rhythmic rolling behavior in small waves that do not produce large motions.

Anything which impedes the transverse flow of water around a hull will tend to reduce the amplitude, or angle, of rolling while leaving the period unaffected. Accelerations at any point removed from the rolling center are a function of both period and amplitude. This is the rational for installing bilge keels. The GWASH hull typically has hard chines which are similarly resistant to transverse flow and bilge keels are often installed as well. The large amount of damping due to hull shape, combined with that provided by the generous waterplane, keeps the amplitude of the rolling low enough to compensate for the shorter period. Deck edge accelerations remain tolerable.

The drawback to the GWASH hull form is that its large waterplane makes it more reactive to waves. This is most objectionable in confused and irregular sea states when many individual waves will be felt as a short and unpredictable motions. This type of hull will be at its best in regular and consistent seas where the high damping will minimize the addition of any rhythmic motion to that of the waves. The traditional hull will do better in the confused and irregular sea as it's immediate response will be less and the lack of consistency in wave period will minimize resonant responses. Waves often run as sets and, in the irregular sea, the traditional hull may encounter patches of waves that correspond to its roll period. These will set off episodes of deep rolling. The GWASH hull will also encounter waves that correspond to its roll period but they will tend to be smaller and the hull damping will restrict the reaction. In the confused and random sea, the motion of the traditional hull could be characterized as generally easy but occasionally extreme. The GWASH hull can be described as generally jerky but seldom, if ever, extreme.

The high stability and damping of the GWASH hull work to greatest advantage when the waves become large enough for the vessel to sit entirely on the face of a single wave. The physics of wave surface acceleration are such that "down" will always be perpendicular to the water's surface. Thus, a vessel which follows the motion of the wave, wave profiling, will seem to the observer to be rolling very little. The angle of the deck to the horizon will change greatly but an object hanging from an A-frame will tend to remain pointing at the same spot on the deck. The more traditional hull, by reacting slower to the changing slope of the wave, and then having a motion which may carry on beyond the wave slope, will have its "down" shift around more dramatically. This can make it harder to work with heavy suspended objects in large seas.

In theory, it is possible for a person in the interior of a vessel that is perfectly wave profiling to be unaware of any rolling motion at all if deprived of an outside reference. If this observer were to look out a window, the horizon would seem to tilt as the vessel remained level. Conversely, a vessel with so little stability that it did not respond to the wave might move up and down with out any roll motion at all. The observer of the horizon would see it remain parallel with the deck as the wave passed. "Down" however would move from side to side and an object hanging from an A-frame would swing. Seasickness is a response to lack of agreement between visual and inner ear cues. The comfort of these two ideal vessels would be perceived very differently depending upon whether the horizon was visible. No vessel will wave profile perfectly but the GWASH will come closer to this type of motion than the traditional vessel when the waves are of sufficient size.

Objects in space rotate around their centers of gravity and vessels attempt to do this as well. The motion is modified by the hydrodynamic forces on the hull so that the rolling center will appear to be between the center of gravity and the waterline. The traditional hull will typically have a center of gravity close to the waterline and thus, a fairly low rolling center. This type of hull will generally need higher freeboard to produce the reserve stability necessary to comply with stability requirements. The result is larger side to side motion at the level of the main deck as the vessel rolls. The center of gravity of the GWASH will be well above the waterline and can even be above the main deck. The rolling center will be higher reducing side to side movement at deck level. Standing and moving around are easier and objects placed on deck tend not to slide around. I should note that the exact location of roll center for purposes of rigorous analysis does not correspond to this simple explanation but the two vessel types will generally appear to behave as described.

Since accelerations due to vessel motion are a function of both distance and time, comfort will decrease as you move out from the vessel's center of gravity. Upper decks will be less comfortable than the main deck. The main deck of the GWASH vessel be more comfortable, at least from the oceanographic and equipment handling perspective, than the main deck on a traditional vessel. On the 01 deck levels, the motion advantage of the wider hull is reduced or eliminated. The importance of the equipment handling aspect of motion qualities is also insignificant on upper levels in most vessel arrangements. Above the 01 level, the motion of the GWASH will generally be more objectionable than in the traditional hull.

The high center of gravity of the GWASH has a further advantage. Deck loads are closer to the overall center of gravity so they raise it less. These vessels have initial stability that is considerably in excess of any regulatory or safety requirement and deck loads will degrade it only slightly. The result is a vessel that is a tremendous load carrier. They can be designed to carry deckloads well in excess of anything that would be necessary in ORV service.

Your opinion of which vessel type may depend on your tasks. If your primary job is to wrestle with awkward objects hanging from the A-frame, you will probably favor the motion of the wider and more heavily damped GWASH hull form. Although the motion may be more jerky and less predictable, it doesn't translate into large impulses and heel angles that send equipment sliding across the deck. If you spend most of your time inside; especially seated, you will probably prefer the smoother and more predictable motion of the traditional hull. Your preference may also be influenced by your past. In many years of listening to people comment about different boats, I've developed an impression that people new to the seagoing experience react more favorably to the highly damped hulls, at least when they are out of the galley/mess areas, than experienced sailors who have learned how to walk and work with the long rolls of traditional hulls.

A critical aspect of research vessel motion is the effect of rolling on side deployed gear such as CTD's. Loss of gear on long wires is usually the result of the vessel rolling down faster than the gear can sink causing slack in the wire. The dynamics of the slack being snapped out on the return roll will often break the wire. The highly damped GWASH hull form will be less likely than the traditional hull to experience the occasional large roll excursions that can exceed the natural wire stretch and terminal sink velocity of the instrument package.

GWASH hulls tend to have pitching periods that are very close to their roll period and this can have an adverse effect on comfort. If the periods are very close, it is possible for pitch and roll to become coupled. Pitch energy is then converted into roll. A corkscrew motion can also be produced that will challenge the most hardened stomachs. The effect of this will be most noticeable in the bow. The need to put labs and other mission critical functions in the middle of the vessel tends to push galley and mess areas forward. This is the least comfortable place in any vessel, especially one with close pitch and roll periods. Even in the absence of pitch/roll coupling, the observer deprived of horizon reference may interpret the pitch motion to be part of the roll if occurs at the same time. Since vertical pitch motions near the ends of the vessel can be very large, this may give the appearance of an extreme roll.

The GWASH vessel tends to have a great deal of waterplane aft. This moves the center of pitch aft as well so pitch motions are reduced at the stern which is an advantage for handling gear. They are correspondingly increased at the bow which, in combination with the typical galley/mess location, makes for poor interior habitability. Crew comfort has not been a significant design requirement in the supply vessel class that make up the bulk of GWASH craft so little attention has been paid to pitch reduction or pitch/roll coupling. Conversions of these vessels are well represented in the ORV fleet but their perceived level of motion comfort does not necessarily reflect what could be achieved in new designs based on this concept.

It is tempting to contemplate a compromise vessel but this approach will be more likely to lead to a craft with the worst features of each type. The resonant nature of reaction to waves require a design commitment to one side or the other of a middle ground. The choice is similar to that of car suspensions. You can have the firm, responsive suspension of the sports car which is less comfortable but better adapted to the job at hand or, you can have the soft, mushy motion of the American highway yacht with some sacrifice of the primary mission requirement.

Consider though a hypothetical middle ground vessel with a given mass of structure. The choice is to increase hull depth to produce a traditional hull type or to increase beam to produce a GWASH. A 15% increase in beam will translate directly into a 15% increase in deck space and interior accommodation. A 15% increase in hull depth however, will not be large enough to add an additional deck. It will only contribute to increased headroom or tankage, desirable characteristics but not ones that have a significant impact on mission capability. For a given amount of basic structure, which closely corresponds to cost, the GWASH will have more deck and accommodation space. It can also have shallower draft which is an advantage for vessels working in coastal waters.

The supply vessel conversions currently in the fleet appear to be doing a good job in their primary role of providing good working platforms for deployment of gear and avoiding loss of long wire instrument packages. The anecdotal reports on their motion comfort generally derive from interior habitability issues secondary to the research mission. If the primary function of the research vessel was the transport of passengers in interior spaces, the traditional hull might be a better choice. However, the current supply vessel conversions have not been able to utilize the proportions and features such as bow bulbs that can mitigate pitch. Their galley/mess locations are typically inherited from the original supply vessel with its short superstructure. It should be possible to develop new designs based on this model that are more comfortable in the interior spaces without sacrifice of other desirable motion characteristics. Even if no significant improvement could be gained, the qualities of the GWASH hull type as a working platform and the economics of space utilization make them a compelling starting point for new research vessel design.