Wave Impact Reduction of Planing Boats

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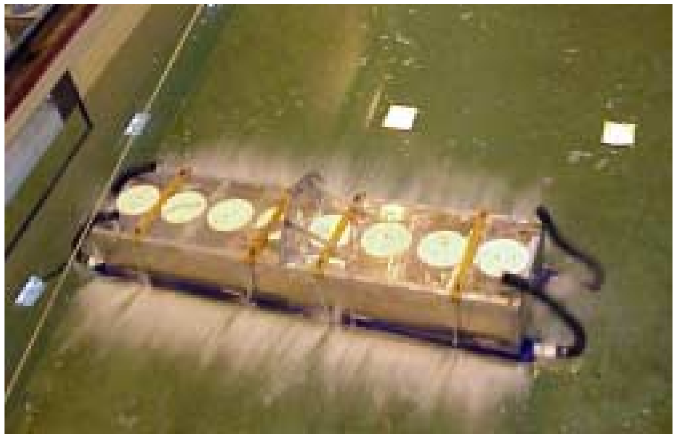

ABSTRACT

The 3-year research effort reported here was dedicated to conception and development of devices for reducing the wave impact shock inherent with high-speed planing craft operating in waves.

The first two years focused on assembly of rational methodology for predicting the hydrodynamics of generalized cylinders dropped onto a calm water surface. The generalizations were for a range of cross-section shapes typical of planning craft. Since hull surface shape dynamics was considered a prime candidate for the focus of the program, the theory implemented was extended to allow for special compliance incorporated into the hull bottom plating.

The third year of the research applied the theoretical/analytical/numerical achievements of the first two years, supported by drop-test experiments, in development of the planing boat impact reduction concept. The system that resulted is acronymed "LocalFlex," for which a UNO patent is pending. LocalFlex involves the passive flexure of air-bag-supported flexible plates contiguous with a section of the boat bottom structure. The system is designed dynamically to reduce the level of impact deceleration in simulated drop-tests of cylinders. It is shown by both computations and the experiments that impact acceleration reductions on the order of 50%, relative to the bare cylinder case, should be achievable with this approach.

The development of the LocalFlex concept has been covered in quarterly reports of GCRMTC issued over the last three years. This paper, prepared from the GCRMTC final report, summarizes the concept development and presents the comparison of calculated and experimental drop-test data that indicates the level of impact reduction possible with the system installed on an actual planing craft. Work is continuing beyond the project to implement the LocalFlex software into an existing planing craft seaway dynamics code for an advanced-level numerical evaluation beyond the drop-test simulations. Following resolution of a few remaining uncertainties, i.e., bag re-inflation after impact and avoidance of bag collapse in calm water, plans call for design and construction of a prototype system for implementation into an existing planing boat for underway evaluations at sea.[1] Presentation

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I. INTRODUCTION

A planing craft is a high-powered water-craft that develops the lift force that supports its weight primarily through hydrodynamic water pressure. This is versus displacement craft, which are supported by hydrostatic water pressure. In order to develop sufficient dynamic supporting lift, the speed of the planing craft must be high relative to its size and the surfaces of the hull must be properly configured. The proper hull surface configuration is generally a shallow V-section with some variation both longitudinally and transversely. The planing boat is typically run with a bow-up trim angle of a few degrees. This trim results in development of high pressure on the hull bottom, which pushes the boat upward toward the water surface, thereby reducing its immersed surface area, and, consequently, the boat resistance relative to the case of full displacement. This process of rising up to the water surface and traveling at high speed on the surface is called "planing." Many craft operate in the planing mode to the extent that a large portion of the supporting lift is hydrodynamic, versus hydrostatic. The relative components of the hydrodynamic and hydrostatic lift making up the total lift classify the craft as to planning, semi-planing, semi-displacement, or displacement.

The majority of recreational boats, from jet-skis to offshore fishing yachts, are at least semi-planing; recreational boating is a multi-billion dollar US industry. Planing boats have important commercial applications, such as in offshore supply operations for the oil industry; high-speed support is becoming increasingly important as oil production operations move into deeper water farther offshore. Militarily, the role of Special Forces is increasing and speed is necessary for effective littoral zone operations. The military high-speed Sealift effort has recently renewed its interest in the development of smaller, high-speed ships, of which planing or semi-planing hull-forms are a principal alternative.

In spite of the desirability and need for high speed in many important applications, there are constraints and limitations. One limit is the technological limit on installed power as boat size increases. But the condition that most directly limits the speed of planing craft is the environmental limit of water-surface roughness. Impact loads become intolerable to craft systems and structure, as well as to craft occupants, as boat speed is increased in waves. The design speeds of large off-shore sport fishing yachts are set lower than desired because of the rough-ride constraint in transit operations, and the propulsive efficiency is compromised in running these craft in a semi-planing mode near the resistance "hump" to limit occupant discomfort. In far-offshore supply operations, the high cost of large-scale helicopter operations has established a need for effective sea-surface support. But adequate boat speed is generally not now attainable due to the seemingly unavoidable severe level of pounding that planing boats experience in a seaway at high speed. In military Special Forces operations, high-speed craft must often be run at maximum attainable speeds, in spite of bad sea conditions, to meet mission requirements. Occupant injury, in terms of joint and organ damage attributable to severe impact acceleration in the seaway, is reflected in the high number of injury and disability claims recorded in the US Navy Special Forces.

Substantial incentive for design technology for reducing seaway impact of planing craft has existed for years, and hull forms have evolved which have improved rideability, but much more is needed. The hydrodynamics of planing is very complex and has not been well enough understood in the past to allow development of reliable, rational design methods with the needed sensitivity to detail. Some significant empirical work on planing boat seakeeping, in the form of systematic series of model experiments, exists in the literature. This includes the work of Fridsma (1969) and Savitsky and Brown (1976). But little of the empirical work of the past was considered directly useful for the objectives of this research, as the very nature of empiricism is in conflict with the development of new concepts. The rational method of Martin (1978) for predicting seakeeping of planing boats is a theoretical development involving low-aspect ratio wing theory (Jones, 1946). An approximate theoretical approach in the spirit of that of Martin has been employed in this research on planing boat wave impact. The methodology developed, both for understanding the physical processes in adequate depth and then for providing the design tool for implementing the concept derived, is built upon the basic work of Vorus (1996).

In terms of existing devices available for wave impact mitigation, some have evolved in an effort to meet the needs. For short term impact in high speed planing, where the needs are most critical and where the interest here lies, the limited shock reduction devices developed have been based mostly on vibration isolation concepts within the hull enclosure, e.g., damped and sprung seat bolsters. There is a Ride Control System offered on the market for relatively low-speed semi-displacement vessels which uses the concepts of dynamically controlled anti-pitching fins. In the fully planing mode this latter application would be difficult to implement because of the very short time duration of the high level impacts of most interest here. The direction of the subject research was to first investigate passive systems not involving any type of active control. Establishing the limits of passive systems is the logical prerequisite step for research on more complex wave-impact reduction concepts employing some mode of active control.

The incentives for increasing the speed of planing craft in waves are in-place, but new technological break-throughs are needed for capitalizing on the incentives. The need is for increasing boat speed in a given seaway, or for the ability to operate in a more severe seaway at a given boat speed. Either requires that the impact accelerations associated with seaway relative motions be reduced. A basic concept has been developed in this research toward accomplishing this objective; the concept is called "LocalFlex." Its establishment and verification are the subject of this paper.

II. DEVELOPMENTAL APPROACH

The following development sequence was employed in pursuing the above objective:

1) Conception of candidate ideas for theoretical investigation,
2) Development of the theory and its implementation for both understanding and quantifying the physical processes and selecting best configurations for further evaluation,
3) Construction of experimental hardware and performance of laboratory experiments,
4) Analysis of experiments relative to theoretical predictions, with the product being a verified concept, plus a base for new design technology for planing boat impact reduction.

III. METHODOLOGY

The seed idea for this research appeared from previous theoretical work on steady planing hydrodynamics by the authors. It was based on the strong hydrodynamic non-linearity associated with the high-speed "squeeze" flow transversely from under the bottom-sides of the relatively flat, and trimmed, planing hull bottom. Because of the non-linearity, large changes in hydrodynamic forces can result from small, localized changes in the shape of the hull bottom. Therefore, execution of small bottom shape variations temporally, and of the correct character, suggests a "smart surface" technology developable to counter impact forces, and thereby reduce impact accelerations of planing boats traversing sea waves.

It was first necessary to develop predictive theory for use in both understanding the detailed physics of the impact processes as well as providing the basis for designing the experimental gear. The necessary theory and algorithms for computing planing boat unsteady hydrodynamics in waves was not available during the course of this research. This, coupled with the fact that a cylinder drop-test program was underway at NSWC/Coastal Systems Station in Panama City, FL, suggested a development program based on drop testing, rather than actual at-sea simulations. The premise was that impact reductions achieved in cylinder drop-tests would map to reductions when running systems so-developed in a seaway. A two-dimensional hydrodynamic theory of generalized cylinders impacting on calm water was therefore needed for this simplified developmental approach.

A long record of cylinder water-impact research spanning many years exists in the literature, e.g., von Karman' (1929), Wagner (1932), and Mayo (1945) represent the earlier work, with, among others, Howison, Ockendon, and Wilson (1991), Zhao and Faltinsen (1993) and Vorus (1996) more recently. Almost all of this previous work applies only for rigid wedge-cylinders. A theory was needed with the flexibility for incorporating the temporal hull shape variations at the focus of the research. The base theory used was that of Vorus (1996). This theory was initially developed to apply to the impact of rigid cylinders of arbitrary cross-sectional shape as reported in Vorus (1996), but was readily extendable to the generalized predictive theory needed.

The base theory of Vorus (1996) is a non-linear numerical time integration solution for the hydrodynamic flow from the initial condition at cylinder impact. It employs the usual simplifications of high-speed water flows: zero viscosity, zero compressibility, and zero gravity in the flow dynamics. These are the conventional set employed in water-impact analysis. Vorus (1996) differs from the previous theories in that, while the boundary conditions are satisfied to second order on the horizontal axis in the limit of bottom flatness, it is recognized that in approaching this limit geometrically, the hydrodynamic nonlinearity becomes increasingly stronger. Therefore, the boundary conditions, while satisfied on the axis as in linearized formulations, retain their full hydrodynamic non-linearity to consistent order.

This theoretical model, while approximate, has proved to be very versatile in handling time-dependent geometry of the impacting cylinder. Extension to time dependent geometry was implemented in extending the theory to analysis of calm-water planing via slender body theory, Royce and Vorus(1998). In steady planing, the boat hull sections passing through a transverse plane fixed in space drop and generally change shape in time as they pass through. The transformation from space to time is x = Ut, where U is the boat speed. The changes in cylinder cross-section shape in time therefore correspond to the full range of boat cross-sectional changes in x, from stem to stern.

In the current impact work, the analysis is that of a cylinder dropping uniformly in x, but with sectional shape changes in time during the drop. This was to investigate the effects of small temporal bottom shape changes on impact pressure and forces. It was imagined that a compliant surface technology, either actively or passively actuated, might be employed to meet the objectives of the research.

On the basis of preliminary investigative analysis using the code, it was decided that focus would be on a first-level system with the following characteristics:

1) The system would be entirely passive and unobtrusive, without complication of active control of the hull surface shape and obvious to the operator and passengers only in its beneficial effects on the vessel ride. The "passiveness" implication is a system that reduces hydrodynamic impact loading in the process of deforming in response to the hydrodynamic impact loading.

   It is emphasized here that the concept does not involve the conventional theory of vibration isolation. The base computer code, Vorus (1996), has been applied in a vibration isolation study that was presented in Kim, Vorus, Troesch, and Gollwitzer (1996). But that is not the nature of the application here.

   In classic vibration isolation, vibration reduction is of sprung mass achieved through adjustment of system mass-elastic characteristics. Here, on the other hand, the exploitation is of the sensitivity of the level of hydrodynamic impact force to the characteristics of the system response that it produces; the excitation force is more a function of system dynamics, than vice-versa. It is also possible to view the model as that of a system with time variant mass, damping, and excitation. The time-variant mass is the large hydrodynamic added mass developing with the impact, and the damping is the velocity dependence in the total impact force.

2) The second system attribute set is that it would be retro-fitable to existing boats by replacing the proper section of the existing boat bottom with a matching section designed to achieve the desired shock reduction.

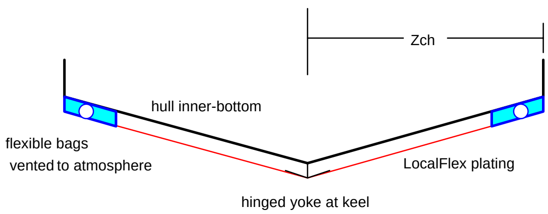
Once this passive, self-excited, concept was settled upon, extension of the existing analysis code was required. The 2-D cylinder bottom was modeled flexurally as strip beams coupled to the hull via the beam elasticity. Therefore, at any time in the impact event, the pressure distribution on the bottom produces normal deflection according to the theory of generalized beam dynamics. The resulting bottom deflection changes the cylinder shape, which changes the hydrodynamic pressure distribution for the next time, and so on through time progression of the slam computation. Results from this coupled analysis are shown subsequently.

IV. CONCEPT PROTOTYPE

The end-result of the development is the prototype concept called "LocalFlex." The LocalFlex system is depicted schematically on Figure 1, and in the photograph, Figure 2.

LocalFlex and dropping the bare cylinder with weights added to maintain the same total weight. This provided a basis for confirming the system effectiveness, as well as further verifying the validity of the analysis/design software.

LocalFlex, as designed for the drop test experiments, consists of thin (0.092 in. thick) aluminum plates hinged at the cylinder keel and supported by airbags at the chine. The data on the experimental program is summarized on Table 1. The NSWC/CSS aluminum drop-test cylinder has a 2-ft. beam and is 8 ft. long, with a 20-degree deadrise angle. The air bags are 4.5 in. wide, 2.5 in. thick, and also 8 ft. long, vented at the ends through 2 in. diameter flexible tubes. The tubes were originally attached to an air accumulator for control of the air pressure in the bags, but the accumulator was eliminated in the progress of the experimental program and the tubes were left open in the final configuration. The assembled system weighs 340 lbs. LocalFlex was drop-tested in the UNO, School of NAME towing tank, following initial preliminary work at NSWC/CSS. Drops from 2 and 4 ft were conducted with 2 and 12 ft tube lengths. These conditions are also summarized in Table 1. An accelerometer system was mounted inside the cylinder and recorded acceleration, in g's, versus time over the duration of each drop event. The experimental program was concluded by removing LocalFlex and dropping the bare cylinder with weights added to maintain the same total weight. This provided a basis for confirming the system effectiveness, as well as further verifying the validity of the analysis/design software.



Drop Tests Cylinder with LocalFlex
Figure 1

Figure 2: LocalFlex Photograph

The accelerometer package acquired for the experiments is worthy of further definition. The EDR3D mounted aboard the CSS test cylinder consists of a shock resistant case containing a triaxial ±50g accelerometer with integral 10-bit data acquisition and 4Mb of memory. It has a sample rate of 3.2kHz and includes a 340Hz low-pass (anti-aliasing) filter. This data recorder is well suited to this type of testing due to its small size, 4.2" x 4.4" x 2.5", and weight, 2.6 lbs. with four C-cell batteries. After the drop tests were performed the data was downloaded to a desk-top computer and time histories were analyzed using the DynaMax software provided by IST with the instrument. This procedure is essentially the same as that devised by NSWC/CSSC in their original drop-test program.

Table 1
LocalFlex Configuration and Experiments

<u>CSS Drop Test Cylinder</u>

Weight (with LocalFlex)	340 lbs
Length	8 feet
Beam	2 feet
Deadrise Angle	20 degrees
Material	.375 inch Al plate

<u>LocalFlex</u>

Plate	.092 inch Aluminum plate
Keel Hinges:	8 steel pinned door hinges equally spaced over length
Air Bags:	4.5 in. x 2.5 in. x 96 in. fabricated plastic
End Vents:	2 in. diameter corrugated flexible tubing, 2 and 12 ft. lengths
Clearance to Cylinder	2.5 in. uniform

<u>Experimental</u>

Drop Release	Peck & Hale, Release-A-Matic RAM-Hook, model number H44-3.
Accelerometer	IST-EDR3D Environmental Data Recorder

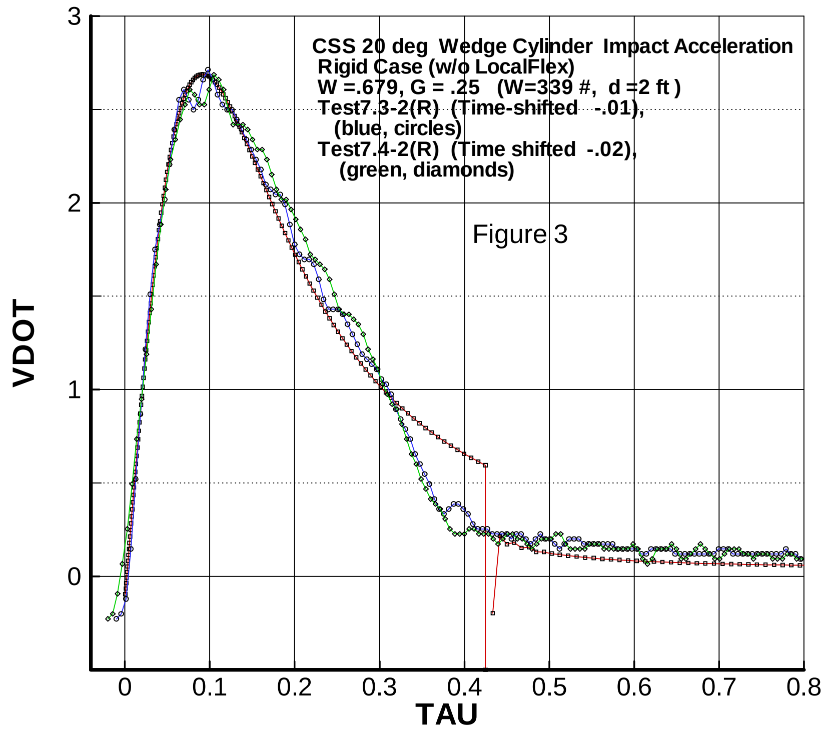
V. RESULTS

The results of the research are presented on Figures 3 through 10, with the rigid cylinder data, without LocalFlex, presented first as Figures 3 and 4.

V.1 Rigid-Cylinder Drop Tests

Figure 3 is a plot of impact acceleration versus time for the bare cylinder without the LocalFlex gear attached. Here, the acceleration is taken as positive up, starting at –1 g. The acceleration, and the time, are both dimensionless as:

$$Vdot \equiv \frac{AZ_{ch}}{V_0^2} \;, \quad \text{and} \quad \tau \equiv \frac{tV_0}{Z_{ch}} \qquad (1)$$


CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid Case (w/o LocalFlex)
W =.679, G = .25 (W=339 #, d =2 ft)
Test7.3-2(R) (Time-shifted -.01),
(blue, circles)
Test7.4-2(R) (Time shifted -.02),
(green, diamonds)
Figure 3
VDOT
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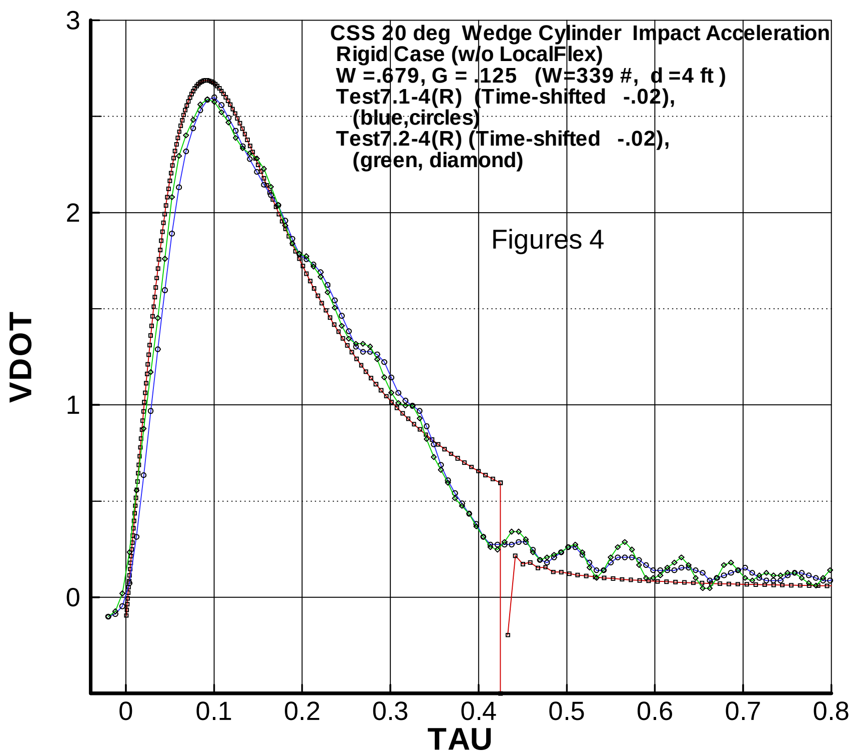
CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid Case (w/o LocalFlex)
W =.679, G = .125 (W=339 #, d =4 ft)
Test7.1-4(R) (Time-shifted -.02),
(blue,circles)
Test7.2-4(R) (Time-shifted -.02),
(green, diamond)
Figures 4
VDOT
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In (1), A and t are the respective dimensional acceleration and time. Z_{ch} is the cylinder half beam, Figure 1. V_0 is the impact velocity, $V_0 = \sqrt{2gd}$, where d is the drop height, which is d = 2 ft. for Figure 3. The convenience of this nondimensionalization is that the acceleration, Vdot, is independent of drop height for the rigid cylinder case. This fact is clearly evident on Figure 4, which is the same as Figure 3, except the drop height is increased from 2 to 4 ft. The dimensionless weight and gravity listed in the title blocks of these figures are:

$$W \equiv \frac{w}{\rho g Z_{ch}^2} \quad , \quad \text{and} \qquad G \equiv \frac{gZ_{ch}}{V_0^2} \qquad (2)$$

where w is the weight per unit length of the cylinder. It is clear from (1) and (2) that the acceleration in g's is Vdot/G.

Three sets of data are plotted on Figures 3 and 4. The red curve, denoted by squares, is the theoretical prediction, and the other two are the points from the drop-test measurements. The two drop-test measurements on each figure are simply repeated measurements for the same condition to indicate the level of experimental repeatability achieved. More detailed features observed from Figures 3 and 4 are discussed as follows:

1) The most distinctive difference between theory and experiment for the cylinder drops without LocalFlex is the discontinuity exhibited in the theoretical computation at approximately τ = .42. This occurs at the time when the jet-head reaches the chine (chine wetting), located at z = Z_{ch}. The singular discontinuity is due to the instantaneous halt in the migration of the zero pressure point on the contour outward when the chine is encountered. There is no anticipation of the chine in the theoretical model; refer to the development of Vorus (1996). The experiment shows a steep gradient in this region, but not a singularity, indicating that some upstream effects of the chine are felt in the actual physics.
2) It is expected that higher order compressibility effects are also present very early in the slam, as evidenced by the initial curvature in the experimental data. The theoretical model does not include compressibility, and the computed Vdot curve starts linearly. But because of the curvature, there is some uncertainly in the reference zero time of the experiments. The experimental data on Figures 3 and 4 has been shifted by the amounts indicated in the heading for alignment at the start.
3) The small oscillations appearing in the data are due to flexural beam-type oscillation of the test cylinder. These oscillations are reduced from earlier "rigid" cylinder drops at CSS, Panama City by relocating the accelerometer near the ¼-length point to minimize contamination by the 2-noded beam flexural mode, but some of this is still present.

V.2 Drop Tests With LOCALFLEX

Figures 5 through 8 show the corresponding plots of dimensionless acceleration versus dimensionless time with the LocalFlex gear installed on the test cylinder; the theoretical bare-cylinder curve is also included for reference.

Figures 5 and 6 are the 2 ft drop heights, for 12 and 2 ft hose lengths, respectively, and Figures 7 and 8 are the 4-ft drop cases. It is useful to discuss Figures 5 through 8 first with regard to the experimental predictions, and then the computed data.

V.2.i Experiments

The following can be observed from the figures:

1) LocalFlex is effective in reducing the level of impact acceleration. Significant reductions are observed for all cases, with the most significant being the 4-ft drop with 2 ft of hose, Figure 8, where the reduction is from the bare cylinder maximum of Vdot = 2.7 to the LocalFlex maximum of Vdot = 1.7, which is 37%.
2) The impact hydrodynamics represents a conservative process. The area under any of the acceleration curves up to some time is the reduction in the initial impact velocity at that time, $1\text{-}V(\tau)/V_0$. The lower impact acceleration means that the cylinder system maintains its downward velocity longer, and the slam process, while reduced in intensity, has longer duration. Ultimately, the velocity reduction achieved is, of course, the same.
3) The extended duration but lower intensity of the slam with LocalFlex has an added benefit, potentially. In moving from drop tests to boats in waves, the relative wave duration is of limited time. With extended impact duration in the drop tests via LocalFlex, clipping of the slam should theoretically occur

in relatively short waves, such that low intensity for short duration is achieved. This is provided that re-inflation of the LocalFlex airbags is achieved prior to the next slam event.

4) The impact time-history is highly complex, clearly involving significant dynamics of the LocalFlex plating and airbag assembly. However, a detailed understanding of the driving physics responsible for the reductions shown is not available from the experiments, but requires the analysis via first-principles mechanics, which is provided by the computations.

V.2.ii Computations

It can be said, generally, that the theoretical calculations and experimental data presented on Figures 5 through 8 are supportive. But there are differences in detail:

1) The theoretical and experimental impact acceleration reductions are of the same level.
2) Essentially the same number of humps and hollows occur in both time-histories.
3) There is a phase shift of the humps and hollows that occurs a little differently for the four cases.
4) The essential deceleration magnitude difference is in the initial hump just after the deviation from the bare-cylinder reference, where the calculation seems to consistently over-predict the experiment.

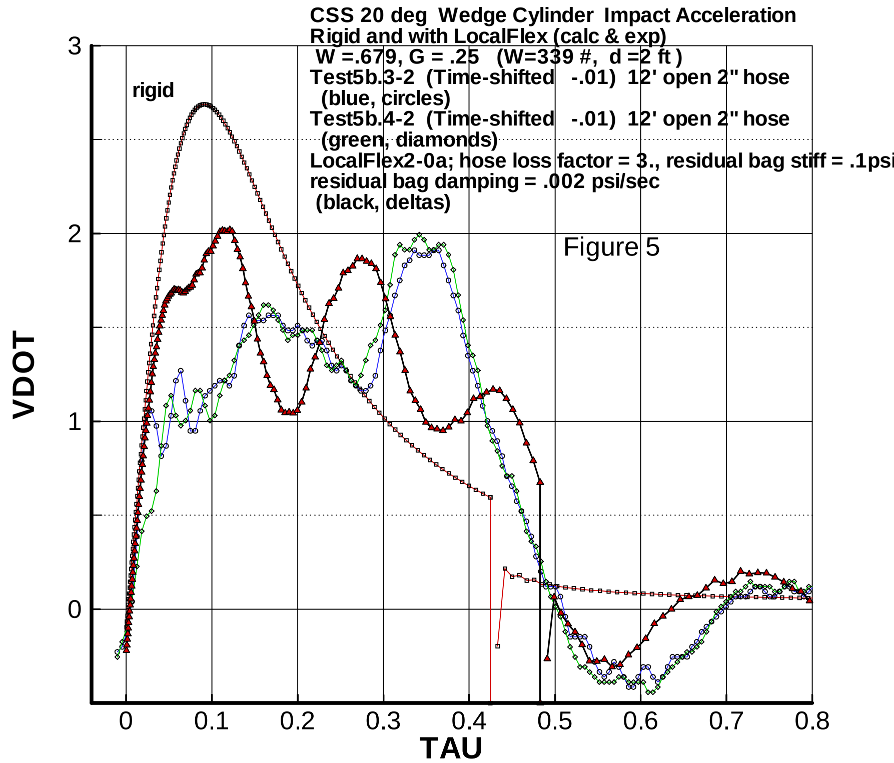
Some understanding of the rich dynamics exhibited by Figures 5 through 8 can be sorted-out with the aid of Figure 9, which is a plot of the LF plate deflections over the plate length for a sequence of times. The wetting of the LF plate is denoted in red on the respective curves so that the predicted outward advance of the jet-head in time is clearly evident. The peaks observed in the acceleration curves of Figures 5 through 8 can be explained in term of two potentially amplifying effects also evident on Figure 9.

1) One is "snubbing," which would occur when the LocalFlex plate deflects enough to collide with the bottom plating of the cylinder; refer to Figures 1 and 2.

   Figure 9 shows the calculated LF plate deflection for the 4ft drop height, 2 ft vent-hose case of Figure 8. Here, the computed plate deflection is plotted versus dimensionless offset, $\zeta = z/Z_{ch}$, from keel to chine. The curves on Figure 9, in covering the response beyond chine-wetting (Figure 8), include the maximum DEFL, which is <0.1. DEFL is normal deflection relative to the cylinder, dimensionless on Z_{ch}; the dimensionless clearance, Table 1, is 0.208. Therefore, snubbing is not occurring in the impact response exhibited on Figures 5 through 8.
2) The other physical effect discovered from the theoretical analysis that is of most relevance to the character of the acceleration curves of Figure 5 through 8 is termed in this research as "arching." Note from Figure 9 the "whipping" of the LF plate as it flexes toward the cylinder. This whipping corresponds to a variation in plate curvature, or "arch" fluctuation in time. The first peak in the Figure 8 acceleration characteristic occurs at $\tau \sim .06$ on Figure 8. This is at time step 60, which is the 6th deflection curve from the zero on Figure 9. Note the high arch (negative curvature) in this deflection curve, relative to those to either side. As the plate whip-flexes in the next cycle, another arch occurs, corresponding to a second peak in the acceleration characteristic, and so on. The impact is generally being reduced by the plate flexure upward relative to the cylinder, but the flexural arching is amplifying the pressure locally much as in a "flare-slam" associated with displacement vessels with concave side-shell camber in the bow region. Also note the troughs in the acceleration characteristic as the plate flattens with the upward whip of its tip.

   It is, in fact, the allowance of tip deflection that is responsible for the effectiveness of LocalFlex. The rising tip limits the degree of arching that can occur. Ando (1989) concluded that plating flexibility could not be used as a device for reducing impact in V-bottom boats because the adverse effects of the "arching" more than offset the beneficial effects of the plate flexibility. But that work not only ignored the plating dynamics that must be exploited, but assumed the plate to be pinned on both ends.

The LocalFlex physics can be viewed as "cracking a whip" to produce the high upward plate tip velocity relative to the cylinder needed to produce the suction pressure component needed for slam force reduction. In fact, the initial dip of the plate tip in "cracking the whip" (Figure 9) is essential in springing the plate upward with adequately large velocity, and adequately small net tip deflection. In this regard, from Figure 9 and as noted above, plate excursion relative to the cylinder bottom is less than 50% of the clearance.


CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid and with LocalFlex (calc & exp)
W =.679, G = .25 (W=339 #, d =2 ft)
Test5b.3-2 (Time-shifted -.01) 12' open 2" hose
(blue, circles)
Test5b.4-2 (Time-shifted -.01) 12' open 2" hose
(green, diamonds)
LocalFlex2-0a; hose loss factor = 3., residual bag stiff = .1psi
residual bag damping = .002 psi/sec
(black, deltas)
rigid
Figure 5
VDOT
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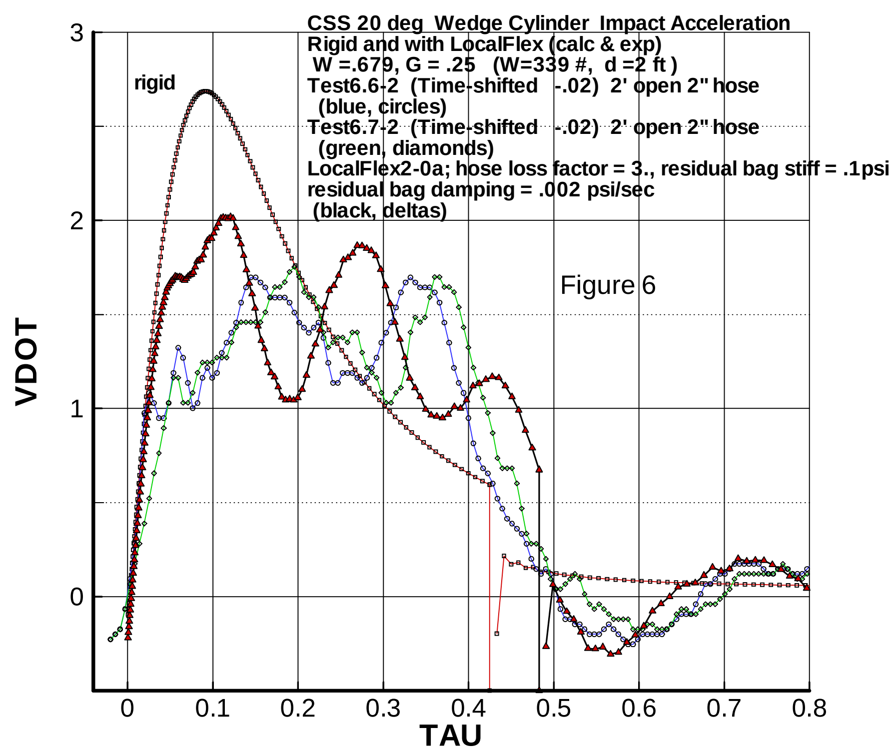
CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid and with LocalFlex (calc & exp)
W =.679, G = .25 (W=339 #, d =2 ft)
Test6.6-2 (Time-shifted -.02) 2' open 2" hose
(blue, circles)
Test6.7-2 (Time-shifted -.02) 2' open 2" hose
(green, diamonds)
LocalFlex2-0a; hose loss factor = 3., residual bag stiff = .1psi
residual bag damping = .002 psi/sec
(black, deltas)
rigid
Figure 6
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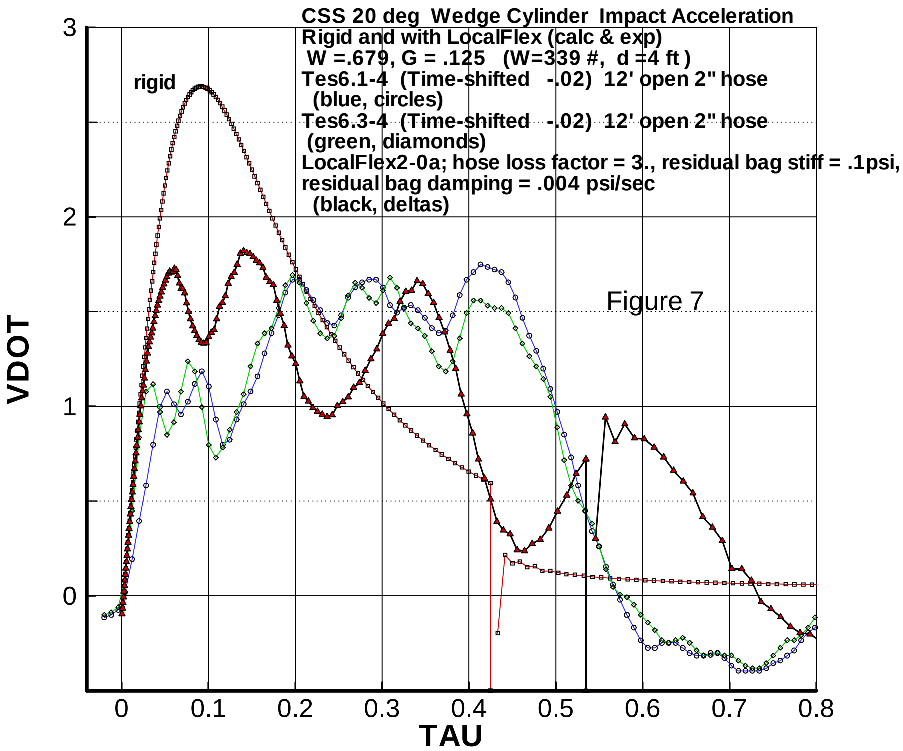
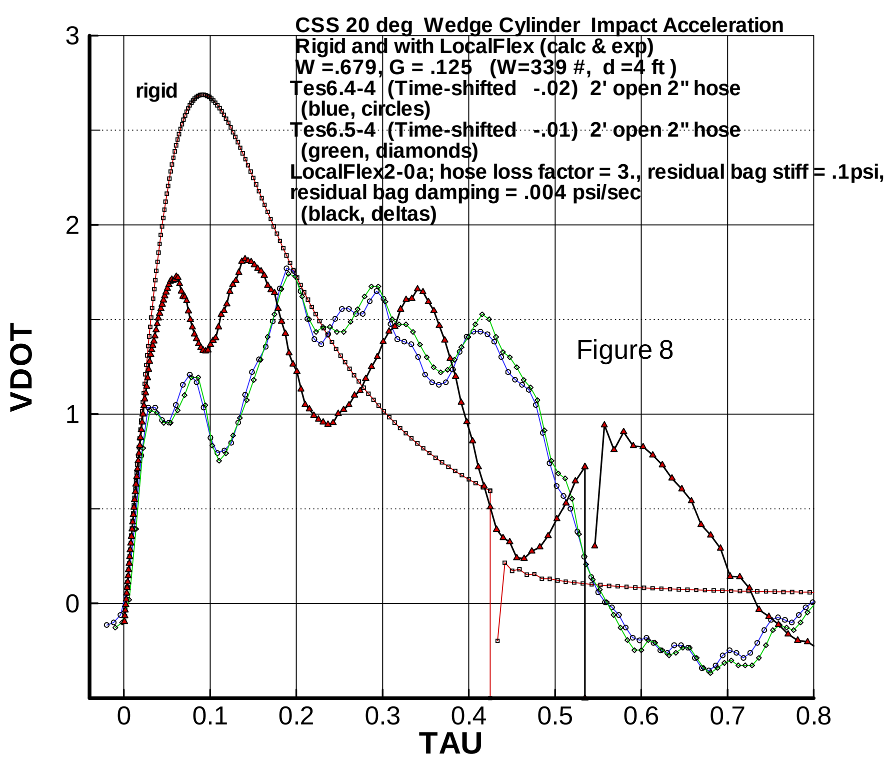

CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid and with LocalFlex (calc & exp)
W =.679, G = .125 (W=339 #, d =4 ft)
Tes6.1-4 (Time-shifted -.02) 12' open 2" hose
(blue, circles)
Tes6.3-4 (Time-shifted -.02) 12' open 2" hose
(green, diamonds)
LocalFlex2-0a; hose loss factor = 3., residual bag stiff = .1psi,
residual bag damping = .004 psi/sec
(black, deltas)
rigid
Figure 7
VDOT
TAU


CSS 20 deg Wedge Cylinder Impact Acceleration
Rigid and with LocalFlex (calc & exp)
W =.679, G = .125 (W=339 #, d =4 ft)
Tes6.4-4 (Time-shifted -.02) 2' open 2" hose
(blue, circles)
Tes6.5-4 (Time-shifted -.01) 2' open 2" hose
(green, diamonds)
LocalFlex2-0a; hose loss factor = 3., residual bag stiff = .1psi,
residual bag damping = .004 psi/sec
(black, deltas)
rigid
Figure 8
VDOT
TAU

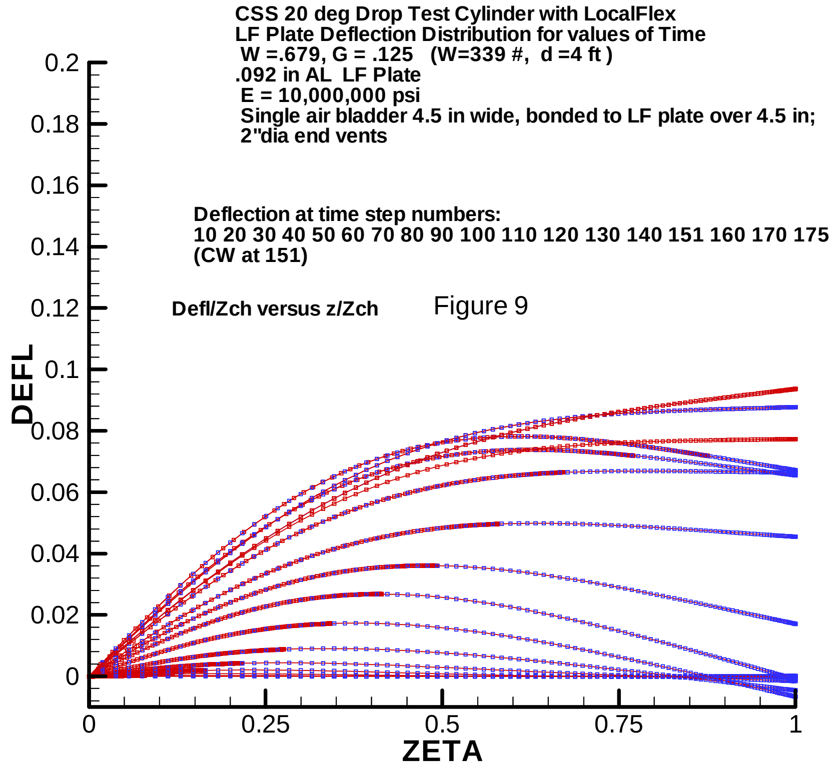


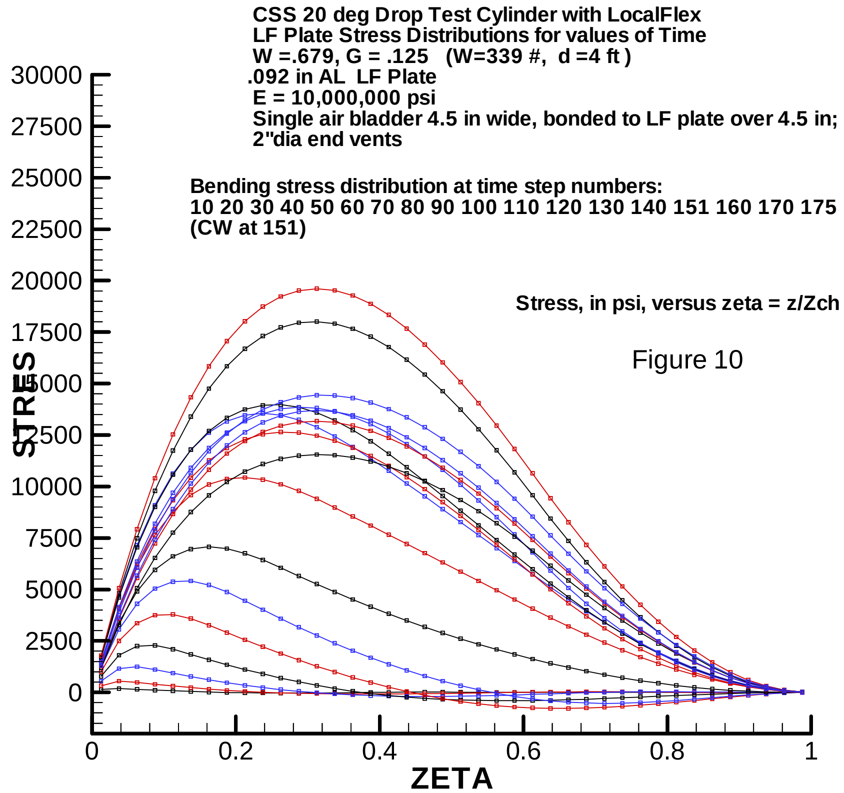
Figure 9

Greater impact reductions than achieved on Figures 5 through 8 could be realized by using more of the available clearance-space without "snubbing." This should be achievable by the use of smaller LocalFlex system airbags. This observation is supported by events that developed in the progress of the experiments. Initially, a pressure accumulator, to allow a positive gage pressure on the airbags, was installed in spite of the theoretical prediction that the inertial and friction forces with free air flow in the bags would provide appropriate resistance. After poor experimental results with inflation gage pressure of around 1/2 psig on the bags, the resistance was systematically removed until only the 2-foot hose connections, as needed to prevent post impact flooding, remained. This is the configuration represented by Figure 8, which is also the configuration for which the largest impact reductions were achieved. The implication is that the maximum effectiveness of the system has not yet been encountered experimentally.

LocalFlex exploits complex plate vibration characteristics in functioning. The highly nonlinear hydrodynamic impact pressure acts in the system as time dependent excitation, added mass, and damping. It has been found that LF design characteristics must be rather precisely set to achieve the acceleration reduction levels of Figures 5 through 8. This is a challenging engineering endeavor, particularly considering that the slam process last at most only a few hundredths of a second.

However, the LF software system is believed, on the basis of the preceding figures, to be capable of reliably and consistently producing the results shown for variation of other system parameters, such as weight, deadrise angle, drop height, etc. in the simulated drop-test evaluations. It then remains to translate the drop-test configurations into designs for actual craft operating in a seaway. The extrapolation of the drop-test technology to at-sea application is not exactly straightforward, as is subsequently discussed.

Figure 10 is included to confirm that LF plate stress levels are acceptable. Here, the theoretical plate bending stress distributions, in psi, are plotted in the same format as the deflections on Figure 9. The deflection "arches" identified on Figure 9 correspond in time to the bending stress maxima on Figure 10. The yield strength of T6061 Al is around 40,000 psi. A factor of safety of around 2. is predicted by Figure 10. Consistently, no yielding of the LF plating occurred in the experimental drop-test program for the weight and drop heights tested.



VI. SUMMARY

1. LocalFlex is a planing craft wave impact shock reduction concept that, as demonstrated herein, should have the potential of reducing short-term impact acceleration levels on the order 50%.
2. LocalFlex functions as an impact excited dynamic system mounted in the surface of the hull that exploits the fact that, in highly nonlinear planing hydrodynamics, small changes in geometry result in disproportionately large changes in hull surface hydrodynamic pressure.
3. LocalFlex is "smart surface" technology but, at least at this point, is entirely passive in that the slam produces the surface deformation temporally, which reduces the slam pressure on the surface. No actively actuated elements are currently involved.
4. The concept prototype system is composed simply of flexible side-hull plates hinged at the keel, and supported by vented air-bags at the chine.
5. Intelligent selection of design parameters is required to achieve effective reduction levels. Complex nonlinear physics must be understood, characterized as to detail, and exploited.
6. Analysis technology, in the form of the research codes developed as described, is in-hand for optimizing system parameters for maximum shock reduction in a cylinder drop-test environment.

VII. CONCLUSION

In further development of LocalFlex the following needs and potential difficulties have been identified:

1. The drop-test experimental program needs to be expanded. The test results shown here were for one specific configuration. The variables of primary interest are: drop height, weight, deadrise angle, LocalFlex plate material and thickness, and airbag and bag vent size. To date only drop height has been varied, with only two different drop heights evaluated. The tests were done with the NSWC/CSS 20 degree deadrise cylinder.

A new cylinder has been built by UNO with a 16 degree deadrise angle. Changes in the LocalFlex components is rather simple and inexpensive. A parametric variation with comparative experimental and analytical results would be an easy and valuable addition in further evaluating the concept.

2. The research should be extended from the constraints of drop-test evaluations to the capability to evaluate shock reduction for boats planing in a seaway. This requires a reliable planing boat seaway dynamics code on which to "piggy-back" the LocalFlex algorithms. At the time that this research was well in progress, such a code, with the needed sensitivity to boat detail, did not exist. It now does in the form of the code VsSea. VsSea is planned for use in further work in LocalFlex concept development.

One fundamental feature that requires primary attention in the extension to seaway simulations is airbag re-inflation. The airbags are now open-vented to the atmosphere through the short tube extensions, and collapse fully with each slam. In a seaway, in order to be prepared for the next slam, the bags must be re-opened and refilled with atmospheric air. This will tend to naturally occur due to the weight of the hinged plates, but not fast enough for typical seaway wave encounters. For a relatively small high speed craft, on encountering a wave event, the short term slam intensity would develop in approximately 1 hundredth of a second, and the slam is essentially over in 0.05 seconds. Wave encounters would be expected to be on the order on 1 second apart, typically.

Soft assistance springs, selected to avoid degradation of the impact reduction properties, might be added between the LF plate edge and the chine (Figure 1) or inside the airbags to re-inflate the bags in time for the next encounter. Compressed air flask, or an air compressor operated through a control system onboard, might also be employed for rapid system redeployment. However, avoidance of complexity is most desirable.

It should be finally mentioned in this regard that the LF plates should not fold-up on the keel hinge under normal calm water planing, however slowly. This further suggest some type of automatic control system to monitor system depression and re-inflation. This research is underway at the present time.

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Discussion