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ABSTRACT

Handling heavy objects through the ocean-air interface requires improved technology for successful operations in high sea states. Investigation has shown that one solution to the problem is to install adequate energy absorbers to the device being handled and pull inboard as well as upward to reduce pendulum type swinging. A shipboard lift system utilizing this technique when hoisting has the added advantage of minimizing adverse heeling moments since the overturning lever is the shortest distance from lift point to axis of roll of the handling ship.

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Finally, the author would like to thank his wife, Florence, for her patience and understanding during this study.

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I INTRODUCTION

Historically man's progress can be closely tied to his ability to utilize the sea. According to John P. Craven[(1)*] the development of Western Civilization can be outlined as proceeding along specifically defined steps culminating each cycle with a step change in "sea technology." Presently, if the resources of the sea and the sea bed are to be exploited, then extensive commercial/military activity must take place in all sectors of the ocean engineering problem. The time honored tradition of sailors seeking protected harbors or anchorages in order to launch or recover heavy objects from over the side does not blend itself with the aim of exploitation of the sea and the sea bed. History has shown that man has attempted to avoid confrontation with nature due to the lack of technological advances in handling equipment and energy absorption devices when handling heavy objects through the ocean-air interface.

During the decade of the 70's man will turn more of his attention toward development of the last great frontier on earth--the sea. Recent developments in deep diving submarines and the emphasis on undersea operations have extended man's interest from surface oriented operations down to the deep depth of the ocean. This shift in emphasis has generated a new requirement for underwater research and engineering in

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*Numbers in parentheses indicate references at the end of the text.

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areas that did not exist a few years ago. Associated with this development is the requirement of ships to handle increasing large and heavy objects over the side. The need for a flexible response in adverse sea conditions have emphasized the necessity for improvements in existing handling systems. Many existing systems are marginal, but because of their innate simplicity and the cost of providing an increment of improvement have remained essentially unchanged for decades. Appreciable improvements in handling heavy objects at sea are possible within the limitations of present technology.

At sea a buoyant payload, like the support ship responds to the sea state, but at different frequencies and magnitudes. In addition to the static weight of the payload, the geometrical configuration is affected by the environmental dynamics of the surrounding water which produce drag forces and added mass effects. A lift system must therefore overcome the incompatibilities of the support ship and its payload. The hydrodynamic forces and dynamic motion of the support ship and payload as they heave in the water at different frequencies make the handling system requirements for open sea operations significantly more difficult and severe than dock side handling.

There are many existing shipboard systems that attempt to accomplish the mission of handling large payloads. The majority attempt, in one way or another, to modify the

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motion dynamics and coupling effect between the support ship and the payload with the handling mechanism. Additional minimization of motion is possible by reducing the motion of the ship itself.

Reducing the motion effect of the ship may be realized by prudent selection of the ship's size and configuration or locating the hoist point at the point of least ship motion. Also, anti-motion mechanisms may be installed in the ship. A typical subsystem for reducing the motion effect between the ship and the payload is a tension control device that will pay out and haul in to control the load on the system, such as a hydro-pneumatic ram tensioner.(2) This is referred to as a passive compensating system. An example of a dynamic compensating system is the transloader system.(2) This device measures the change in distance between the ship and the deck of another floating structure by use of a taut wire and subtracts the motion from the load being handled.

Articulated hydraulic cranes have gained increasing favor on oceanographic research ships. The booms of these cranes consist of hydraulically actuated, pivoted sections, which make it possible to handle scientific gear with a minimum of pendulum motion because the booms are capable of reaching the ocean-air interface. Also a minimum length of hoist line is used to facilitate handling by minimizing pendulum motion.

Many systems are designed for handling a single type of payload. An example of this is the Single Arm Gravity Davit System which Ram Hoist[3] used for recovery of life boats in heavy weather. This system was developed specifically for rapid launching and recovery of 26-foot motor whaleboats from destroyer type ships. The basic premise of this system was to pass through the ocean-air interface as quickly as possible.

Summarizing, it is justifiable to say that trends in lift system design and operation have been towards fighting the ocean-air interface and reducing pendulum type swinging. A new design concept that incorporates the below listed essential features can improve the ability to handle heavy objects in a sea way by one, two or perhaps three sea states:

a) Smoothing the side of the ship as a roadway so the payload will not catch when lowering or recovering.

b) Permanently attaching adequate energy absorbers to the device being handled.

c) Hoisting with a resiliant line to reduce jerking forces.

d) Locating the hoist point inboard and pulling inward as well as upward to reduce pendulum type swinging.

A lift system that incorporates the above features (Figure 1) can be designed so that most elements of the system are modular and easily taken off or put on a variety of ships. Also it is simple to visualize the advantages to the system if the heavy payload is designed to be handled

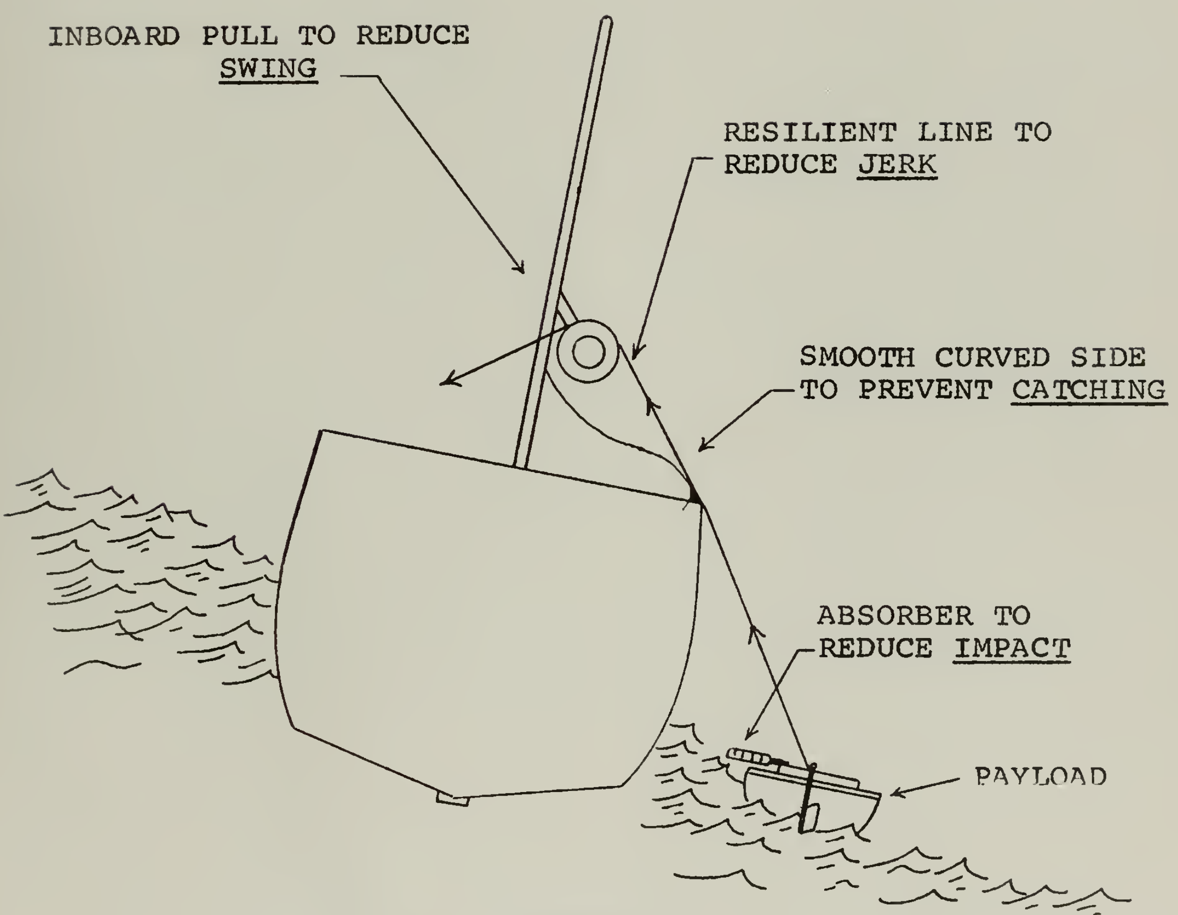

FIGURE 1

Schematic of Proposed Lift System

instead of just trying to handle something designed for other purposes. The primary concern of the investigation is to develop a handling system that will enable research, salvage and rescue, and surface ships in general to routinely handle large deck carried payloads in a wide range of sea states.

II THEORY

Energy Absorption

The design concept proposed in section I has one major area that warrants more detailed investigation. The area centers on energy absorption since it is easily conceded that modern technology has the capability to smooth the side of a ship, locate a hoist point inboard or provide resiliant line for hoisting. If adequate energy absorption is not feasible to protect the payload from severe impact loads when alongside the ship during handling then the system has little merit. By the same token if energy absorption is feasible but the resulting devices for energy dissipation are very cumbersome then the system may be of very little practical value. The remainder of this section will be devoted to: (1) formulation of useful equations, (2) determining stop distances with associated deceleration forces, and (3) modeling a lift system that can be solved analytically.

Note: The Reference Payload was a 24-Foot Work Boat Weighing 2 1/2 Tons. (Appendix A has complete details of reference payload since it was used in all experiments)

Method of Calculating the Kinetic Energy

The kinetic energy possessed by a body in motion is easily found from the formula:

$$E = \frac{1}{2} \frac{W_1 V^2}{g}$$

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where: W_1 = weight of the payload in pounds

V = velocity in feet/second

g = gravitational acceleration 32.2 feet/second^2

However, the actual energy involved at the ship-payload interface is a rather complicated system to analyze since a number of factors are involved. These include:

1. The magnitude and direction of the velocity at the instant of impact
2. The magnitude and direction of angular velocity in yaw of both the ship and payload at the instant of impact
3. The angular orientation of the payload with respect to the center line of the ship
4. The distance from the point of impact to the payload's center of gravity
5. The radius of gyration about the yaw axis
6. The effect of the hydrodynamic mass

In most cases, the required information to perform a detailed analysis is not available and furthermore, in high sea states the attitude and velocities are variables over which little control can be exercised. Therefore, a simplifying practice would be to consider the relative component of the velocity perpendicular to the center line of the ship.

It is insufficient to consider only the mass of the payload. One should also consider the mass of water moving with the payload in proximity to the hull. The approximation

for ship hull forms (like reference payload) is expressed in terms of the weight of the sea water in a cylindrical vessel where the diameter and height correspond to the draft and length of the craft respectively.

Accordingly, the additional weight W_2 will be:

$$W_2 = \frac{\pi}{4} \rho D^2 L$$

where: ρ = specific gravity of sea water

D = draft in feet

L = length of craft in feet

The assumed weight (W_p) of the payload is expressed by the sum of displacement weight (W_1) of the payload and the additional weight (W_2). That is,

$$W_p = W_1 + W_2$$

Realizing that both the payload and ship are in motion in the open ocean the total kinetic energy to be absorbed can be calculated from the following formula:

$$E_T = \frac{1}{2} \frac{WV^2}{g}$$

where: E_T = total kinetic energy (ft-ton)

g = gravitational acceleration 32.2 ft/second^2

V = relative approaching velocity of ship and payload (feet/second)

$W = \frac{W_p \cdot W_s}{W_p + W_s}$ (ton) when the assumed weight of both payload and ship are assumed to be W_p and W_s, respectively.

However, the above formula only holds when both ship and payload come to an equilibrium stop position after impact. Since the handling ship is normally orders of magnitude larger than the payload, a good approximation for the energy that the equipment will be required to absorb can be obtained by:

1. Assuming that handling ship is stationary
2. Using the above formula with relative approach velocity but substituting $W = W_p$.

Simple laws of mechanics indicate that this is a valid approach to obtain approximate kinetic energy values when a payload comes in contact with the side of a ship in the open ocean.

Deceleration/Stop Distances

If it is assumed that the energy absorbers will dissipate energy through linear motion (compression) under constant deceleration then the following formulas from mechanics are applicable.

$$s = \frac{1}{2} at^2 \quad \text{or} \quad t = \sqrt{2s/a}$$

taking derivative

$$\frac{ds}{dt} = V = at$$

substituting $V = a\sqrt{2s/a} = \sqrt{2as}$

where: s = distance moved in feet

V = velocity in feet per second

a = deceleration (feet per second per second)

t = time of deceleration in seconds

By modeling the system around the idea that the payload acts like a pendulum when it is alongside the handling ship as indicated in Figure 2

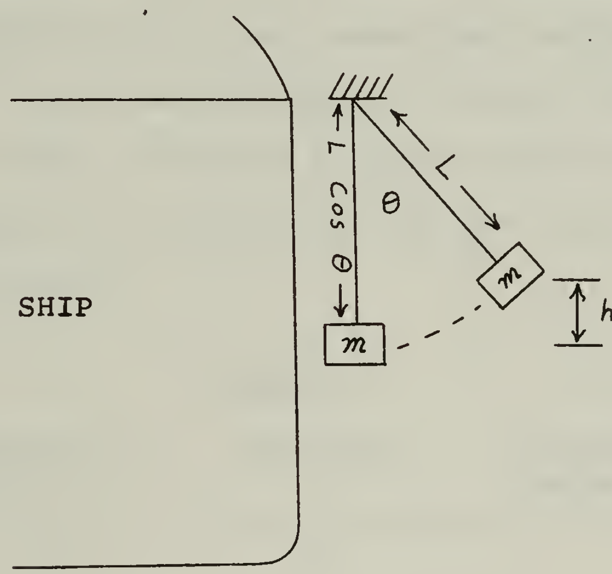

Figure 2

Pendulum Model

The following additional equations can be derived if it is assumed that the mass of the line is small compared to the mass at the end.

$$h = L - L \cos \theta$$

Potential Energy = $mgL(1 - \cos\theta) = mgh$

Kinetic Energy = $1/2\ mV^2$

equating: $mgh = 1/2\ mV^2$

reduces to: $h = \frac{1}{2}\frac{V^2}{g}$ or $V = \sqrt{2gh}$

By substituting the gravitational acceleration in the above equation, it reduces to $V = 8.02\sqrt{h}$. Table 1 reflects the range of velocities with the associated equivalent drop heights that may be encountered in the open ocean. This table assumes that a buoyant payload would not exceed the associated particle velocity of the wave train that is exciting the motion.

Table 1

Particle Velocity (V) (ft/sec)	Sea State	Equivalent Drop Height (h) (feet)
1	2	0.0156
2	3	0.0622
3	4	0.140
4	5	0.249
5	5-6	0.389
6	6-7	0.560
7	7	0.763
8	7-8	0.995
9	8-9	1.220
10	9	1.550

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Since commercial energy absorbers cover a wide range of deceleration rates and stop distance, a graph was constructed, Figure 3, so that state-of-the-art energy absorption components and systems could be compared to the anticipated requirements of the reference payload. The stop distance values considered feasible for the reference payload varied from 6 to 12 inches. Since both automobile and aircraft shock absorbers fell in this range and both were off-the-shelf items, it was decided to do the initial tests with these components.

In summary, the theoretical energy absorption requirements for the lift system outlined in section I are not considered excessive. In fact, through use of Newtonian physics modified by hydrodynamic considerations, the energy requirements can be approximated. However, there is little to chose from, other than pneumatic or elastomer fenders and bumpers, for mechanical energy dissipation in the marine environment. In the past mechanical parts have been purposely kept separated from the corrosive environment of the ocean but I do not see why this trend need continue in the future. If large aircraft can routinely land on the stern of an aircraft carrier that is exibiting all six degrees of freedom in the open ocean, there is no reason why it is not technically feasible to have a buoyant payload, properly designed, come in contact with the side of a ship and remain there through a wide variety of sea states.

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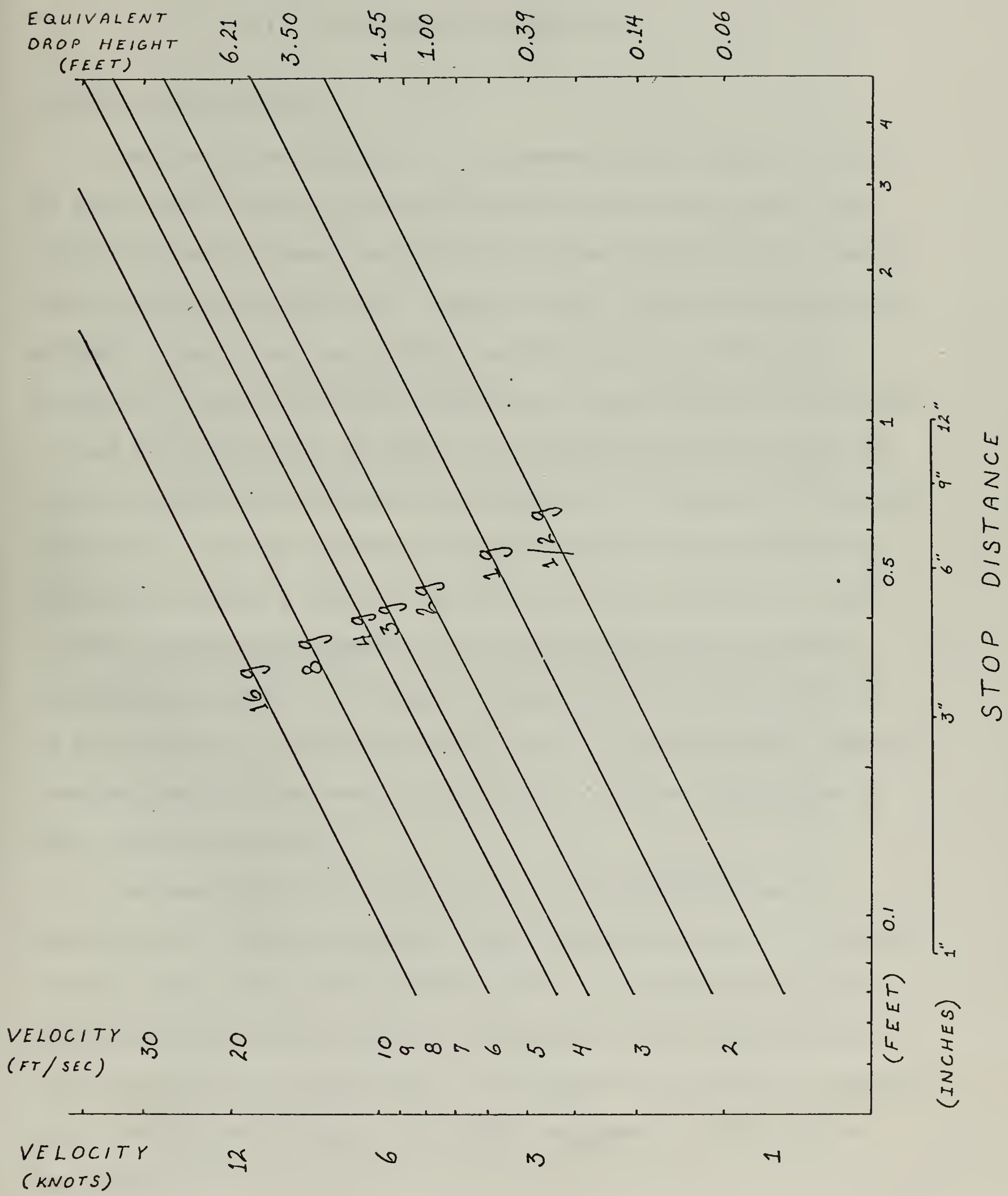
EQUIVALENT DROP HEIGHT (FEET)
6.21
3.50
1.55
1.00
0.39
0.14
0.06
16 g
8 g
4 g
3 g
2 g
1 g
1/2 g
VELOCITY (FT/SEC)
30
20
10
9
8
7
6
5
4
3
2
VELOCITY (KNOTS)
12
6
3
1
(FEET)
0.1
0.5
1
2
3
4
(INCHES)
1"
3"
6"
9"
12"
STOP DISTANCE

Figure 3

III FABRICATION/PROCEDURE

Initial Installation

Cost and availability of components had a great deal to do with the initial configuration of the 24-foot Work Boat. Aircraft landing gear was obtained from the Naval Air Rework Facility at Quonset Point, Rhode Island. The equipment consisted of two wheel and strut assemblies from A-1 type aircraft. Since the wheel radius was approximately 30 inches it was not practical to mount the assemblies vertically due to the excessive overhang and reduction in compressive stroke. Therefore, the two assemblies were mounted horizontally as shown in Figures 4 and 5. Since the 24-foot Work Boat had a steel reinforced gunnel it was determined for strength considerations that the impact loads should be distributed to both sides. This was accomplished by mounting the support foundations for the energy absorption devices transversely from gunnel to gunnel.

The configuration of the small craft necessitated mounting the forward absorber with approximately a 15 degree forward angle from the perpendicular on the starboard side. Likewise, the after absorber was mounted with an angle of approximately 15 degrees aft. This gave an effective approach angle on the starboard side of 025 degrees to 155 degrees for impact.

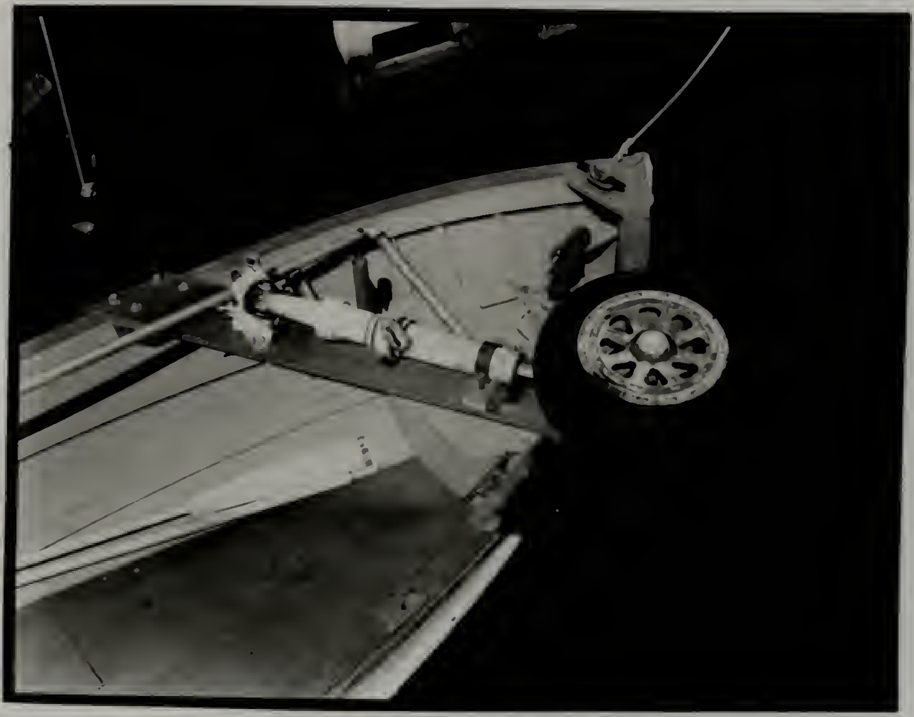

FIGURE 4

Forward A-1 Energy Absorber

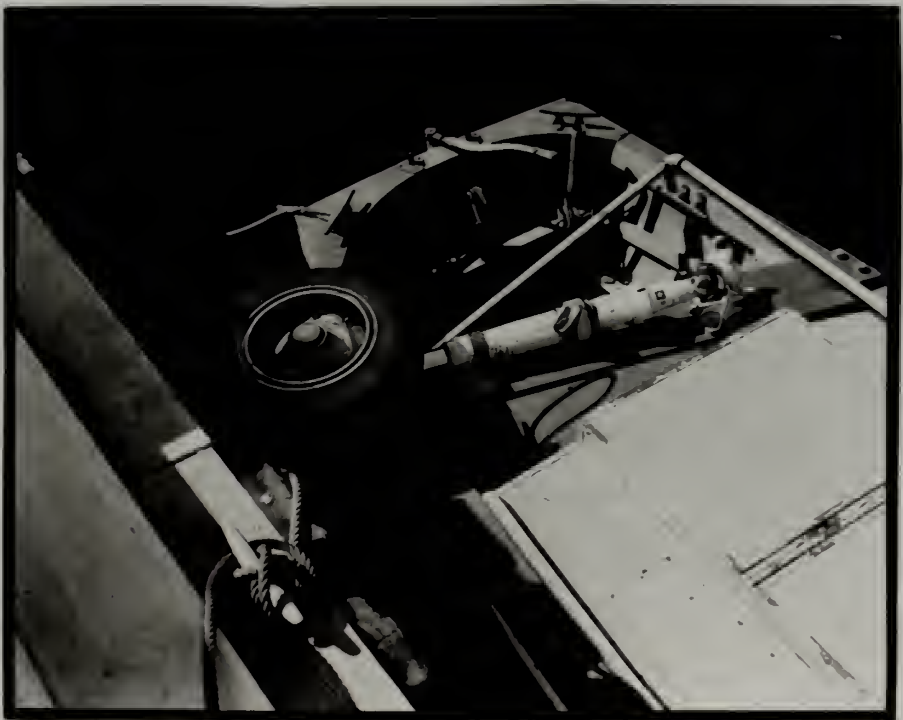

FIGURE 5

After A-1 Energy Absorber

Due to the horizontal mounting of the energy absorbers the craft was restricted in its freedom of vertical motion when in contact with a rough vertical surface. The high coefficient of friction for sliding rubber tires did not blend itself favorably with the proposed lift system since it was known that the predominant motions of a buoyant craft in the water being hoisted would be vertical. However, the horizontal motions along any impact surface could easily be handled through the rolling motion of the tires.

Another major constraint was that the impact point for both absorbers was above the center of gravity of the boat. This meant that there would be an overturning moment at impact that would tend to roll the reference craft to port. This was not considered significant because it was doubtful that enough moment could be generated to have the unprotected bottom of the craft strike the vertical impact surface.

By using aircraft landing gear as the initial energy absorption device a wide variation of tests could be accomplished. The aircraft landing gear basically dissipates energy through two modes of operation. First, the tire is an energy absorption device that compresses under load and stores energy. Second, the pneumatic strut section also compresses and stores energy. Since both the tire and strut had charging connections, the pressure in both could easily be changed in order to adjust the deflection stroke. In addition, a pressure gage was installed on both struts so

the maximum pressure at impact could be recorded. The linear deflection of the aircraft strut could also be measured after impact. However, the deflection of the tires was difficult to ascertain and readings were accomplished mainly through visual estimates.

The instrumentation package consisted of three accelerometers mounted to record deceleration rates along the reference crafts local x, y, and z axis. Attempts were made to obtain a velocity meter in addition to the accelerometers, but this did not prove successful. A good estimate of transverse speed at impact was possible because the forward speed and initial angle of impact were known.

Procedure

The primary objective of the experimentation was to obtain conclusive data either supporting or rejecting the concept of energy absorption between a large payload and a handling ship. To do this, the modified 24-foot Work Boat was to act as the platform from which the following data was to be obtained in at sea tests:

1) Deflection of Energy Absorbers under varying impact velocities.
2) Maximum pressure build-up in the strut energy absorbers and the tires.
3) Maximum deceleration rates for the various degrees of stiffness of the energy absorbers.

4) Structural integrity of the reference craft and energy absorber installation after continued usage.

5) Human reactions and responses to the deceleration rates and the motions involved.

All tests were to be conducted in the Woods Hole area using the wood faced pier at WHOI, the WHOI vessels Crawford and Knorr, plus the 180-foot Coast Guard Buoy Tender Hornbeam as impact points. As many tests as possible were to be run. The tests were basically of two types. The first type was to propel the 24-foot Work Boat at the reference Targets at various velocities up to 5 knots and record the measurements. The second type test was to moor the boat along the same vertical surfaces under rough sea conditions and allow the water surface to cause the excitation. Again the required data was recorded.

The criterion used to evaluate the results was very simple. First, if the energy of impact exceeded the calculated values then the installed absorbers would be insufficient to handle the load and larger ones would be required in order to dissipate the energy. Second, if deceleration rates became excessive, then the possibility of damage to equipment became probable and this was considered very detrimental to the overall lift system. Also considered very important was the reaction of people in the reference craft to deceleration rates and motions. People riding in the reference craft had to feel that it was safe and reliable

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at the time of impact. A qualitative type assessment of the energy absorber system was desired because the final proof of the lift system would be an actual open ocean test.

FIGURE 6

24 Foot Work Boat With Energy Absorbers

IV RESULTS

The results of the at sea testing proved very enlightening with over 500 controlled impacts being accomplished under a wide range of conditions. For impact velocities up to 5 knots (max possible with reference craft) the energy absorbers easily dissipated the impact energy. The initial runs were made with full tire and strut pressure and these runs resulted in maximum deceleration rates being experienced. However, even with the stiff energy absorbers (deflection about 3 inches) the deceleration rate never exceeded 0.4g which was lower then anticipated. Associated with minimum deflection of the absorbers was maximum roll angles of 10-12 degrees. Actually some energy absorption was accomplished by the viscous drag of the hull as it rolled after impact.

It was found that by reducing the pressure in both the tires and strut to a minimum, a stop distance of 8 to 10 inches could be achieved for impact velocities of 5 knots. This stop distance proved to be the most acceptable since it decreased the deceleration rate to 0.2g and the associated roll was almost completely eliminated. The softer energy absorbers were also favored by the riders in the boat. However, no one thought that the 0.4g was excessive and the biggest complaint was about the 10 to 12 degrees of rolls associated with the fully charged absorbers.

When alongside the wooden pier the vertical motions of the vessel were hampered somewhat by the resistance of the tires to slide on the wooden surface. However, when the tires were against a wet steel ship surface they seemed to slide more easily, even when under impact pressure. On the other hand, horizontal motion was always easily compensated for by the rolling motion of the wheels. It was quite evident that the horizontal resistance to rolling friction was orders of magnitude less than that of the vertical sliding friction. In fact, an actual demonstration prompted a senior Coast Guard officer to say, "This craft is the best I've seen for training inexperienced coxswains. It is impossible for them to make a bad landing since the energy absorbers can compensate for all their mistakes."

It was found that the effective approach angles had to be kept between 30 degrees and 150 degrees on the starboard side. If the approach angles exceeded these values, the energy absorbers experienced excessive shearing forces for which they were not designed. Also the mounting structure itself was not designed to withstand shearing forces and on one approach that was too sharp some minor damage did occur. However, continuous inspections of the mounting structure and the absorbers themselves showed no adverse effects from continual usage or from the environment. The reference craft itself also showed no ill effects from the continual impacts.

Numerous people were taken for demonstration rides to prove the feasibility of the installed energy absorption system. Most had reservations about the system prior to embarking and it would not be overstating the truth to say all had reservations about the system just prior to their first impact. The idea of a 3-ton craft heading at a solid pier or ship at 10 knots with a 30 degree approach angle stimulated the riders imagination. However, after impact and the proper functioning of the absorption devices people were enthusiastic about the overall system and its potential. It took only a single demonstration to change a persons prejustices about man's ability to conquer the impact problem and to show that it is technically possible to dissipate the required energy within reasonable stroke lengths.

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V DISCUSSION OF RESULTS

The investigation has shown that it is both possible and practical to use advanced equipment to dissipate energy associated with at sea impact forces. Not only can it be accomplished in a reasonable distance (8-10 inches for a 3-ton buoyant craft) but the deceleration rates involved are within acceptable tolerances. Therefore, the proposed lift system for heavy objects is indeed feasible. In addition, the absoption concept has opened many new applications for energy absorption components on such things as pleasure craft, small submarines, buoys, and ships in general. The whole field of marine applications for mechanical energy absorption systems is still virtually untouched.

The at sea testing of the absorption components verified the need to observe Newton's law of action and reaction. Since both the forward and after absorbers were mounted above the center of gravity of the work boat, a roll moment was generated at each impact. It was quite obvious that the proper location for the absorbers was in the same vertical plane as the payloads center of gravity. With proper absorber placement almost all impact induced moments could have been eliminated. This points even more strongly to the fact that large, heavy payloads that are to be handled at sea must be designed with impact in mind.

Even though the duration of the tests was limited in time (only about 500 tests were conducted) there was no

reason to believe that the reference installation could not withstand continuous operation. A primary goal of the research was to design a continuously operational system. In fact, the durability of the aircraft absorption system points out the enormous amount of research that has already been carried out in the aircraft industry in energy absorption. The same energy absorption expertise also exists in the automobile industry and other associated industries. There are many energy absorption components available now that are off-the-shelf items which can be used in marine applications with little or no modifications. This is very significant because research and development costs normally are extremely high. Also since the components are presently available there would be little delay placing a system into operation.

From the description of the installation it should be obvious that the reference craft was intended to absorb all of the impact force with its installed absorption system. However, it could be possible that an optimal system may have the energy absorption components mounted either completely or partially on the vertical impact surface. In no way was the limited research conducted to date intended to point out the best possible method of energy absorption for marine applications. Rather it was to demonstrate that the proposed concept was sound and practical and should be expanded.

When lifting the reference payload and also when observing other heavy objects being handled at sea it was very apparent that they were not designed to be handled. It seems that most heavy objects which are eventually hoisted at sea are designed around their primary mission. Little or no consideration is given to the fact that it has to be handled under a wide range of sea conditions. Designers for some reason assume that the handling problem is trivial and as a result many operations that involve handling heavy objects through the ocean-air interface become very sea state dependent. The neglect in designing heavy objects to be handled or to absorb energy has resulted in compensation being applied to the lift cranes or to the support ship design itself. For example, the Navy has gone to a catamaran ASR for handling the DSRV because of payload weight, motion, and ship stability problems. A single displacement hull form vessel with the proposed lift system may be a comparable solution. Investigation to date indicate that the proposed lift system warrants more extensive study.

Not all aspects of the installed energy absorption system could be considered favorably. First and foremost was that transverse reinforcement of the payload was a necessity due to impact forces. Also required for extra large payloads would be strengthening of the impact surface on the handling ship itself. The installation of the absorbers and the associated transverse strengthening resulted in a heavier

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payload. However, considering the overall lift system, the total weight would diminish because the need for a heavy crane would be eliminated and replaced by a lighter winch mechanism. Since the absorbers required a deflection stroke to dissipate energy it meant that the absorbers had to protrude from the side of the payload. This resulted in the effective payload width being increased.

The ease by which the surging motions of the reference craft, alongside a pier or vessel, was handled by the rolling motion of the absorber wheels seemed to indicate a satisfactory way to overcome the friction problem. Since the wheels were large and fixed to roll only in the horizontal direction, the vertical motions were often hindered by the inability of the wheels to slide easily in the vertical direction. This problem was not thought to be too significant because the following alternative solutions were deemed practical:

1) Install small swivel wheels or casters so that both horizontal and vertical motion would involve rolling friction.
2) Mount smaller wheels vertically only because this would be the primary direction of motion of concern.
3) Install teflon hemispherical heads vice wheels so that sliding friction in all directions would be reduced.
4) Allow wheels to remain mounted horizontally but have the impact surface made of vertical rollers.

However, the best solution for overcoming the friction problem when the payload was in contact with a vertical surface was not determined. Nevertheless, it was felt that it is within the scope of present technology to achieve an optimal solution to the friction problem.

An often overlooked interface that was considered important for present handling evolutions was the one between the deck and the payload. On numerous occasions, especially in high sea states, heavy objects have been successfully snatched from the sea only to be ruined by severe impact on the deck while being lowered. As shown in Figure 1, the faired surface that runs from the ships deck edge inboard to the center line is the surface on which the heavy payload always rests. The location of the absorbers on the payload and the lift arrangement itself ensure that the payload would always be protected from impact either when contacting the vertical side of a ship or when in its storage location. Due to the configuration of the smooth lift surface and the fact that the payload always remains in contact with the smooth surface when clear of the water eliminates the need to worry about the deck-air interface problems when handling heavy objects with the proposed system.

The orientation of the installed energy absorbers was of utmost importance. Since the reference craft was self propelled, it was an easy operation to make certain that the absorbers were always properly oriented for impact. On the

other hand, for payloads that may not be maneuverable, it would be important to install absorbers so the payload is afforded maximum protection regardless of impact orientation. This can become a difficult task because of the numerous payload shapes that may be encountered. For the reference work boat the energy absorbers were installed so that maximum protection of components took place during test runs. It was felt that other payload shapes could likewise be protected.

By locating the proposed lift point amidships on a single displacement hull form ship many advantages are possible. First, most larger vessels tend to be wall-sided in the amidship area so a minimum amount of effort would be required in order to smooth the lift surface. Also the amidship area is the place of minimum motion and this is important in higher sea states when ship motions become a problem. By handling heavy payloads amidships, the servicing ship would be subjected to more of a uniform sinkage attitude rather than a pitching attitude as encountered when handling a payload at the bow or stern. Since ship control stations are generally forward on most ships, the proposed amidships lift operation could be directly observed from most ship control stations. Whereas the proposed lift system for heavy objects never went to sea as an integrated system enough component research and testing was carried out to show that the lift system has much merit and potential for use with heavy payloads at sea.

To better understand the open water response of the buoyant payload the computer program (4) by T. A. Loukakis was used to evaluate motions. The results were as expected and appendix C has the plotted results of reference work boat motion verse sea state. The program also provides velocities and accelerations which were used to help determine the anticipated impact velocities and accelerations.

The wide range of tests and research that were conducted indicated that a great many variations were possible within the proposed system. As previously mentioned, an absorber system mounted either fully or partially on the servicing ship could be a way to reduce the size or the weight of the energy absorbers that would be required on the payload. Also the various solutions to the friction/sliding problem indicated an area where more trade offs could be accomplished. Since the experimentation and proposals included are considered the first generation approach to the problem, a large amount of work still has to be done to get an optimized system for at sea applications.

What was particularly attractive about the results was the total cost it took to obtain them. Components were kept simple and rugged, plus they had to be available. By use of surplus Navy equipment it was demonstrated that energy absorption could be accomplished without the need for sophisticated components. Furthermore, simple winchs are orders of magnitude cheaper than heavy lift cranes so an

[illegible]

overall lift system cost, including smoothing a ships side and adding payload energy absorbers, favors the proposed lift system.

The energy absorber phase of testing also demonstrated that components could be of a modular nature and still accomplish their mission. Once installed on the work boat the entire absorber outfit could be lifted off in just a few minutes time with a minimum of effort. The ease at which the absorber package could be installed or removed from the reference craft gave creditability to the concept of being able to adapt portable energy outfits to many large buoyant payloads that have to be handled at sea.

The significance of the results point to the feasibility of the proposed lift system utilizing energy absorption principles. The inherent advantages of the system, its simplicity coupled to its inexpensive cost in terms of both development time and money, make possible more extensive exploitation of the sea and the sea bed. The proposed system, consisting of modular components, provide a method by which a large majority of existing ships can easily be adapted for handling heavy objects at sea.

VI CONCLUSIONS

Marine applications for mechanical energy absorption devices provides a very promising field. Initial test results showed that energy absorption for at sea impact not only was possible but practical as well. Even though the state-of-the-art for marine mechanical energy absorbers was woefully inadequate, energy absorbers from other applications were available to fill the marine void. These were successfully used to demonstrate that absorption could be accomplished without excessive deceleration rates. Since reasonable deflection distances were encountered during impact testing it is considered possible to mount energy absorbers on any shape payload that may be handled at sea with the proposed system without excessively increasing its dimensions or weight. However, if some size and weight reduction is desirable for the payload absorption installation then it is considered entirely possible to incorporate absorption devices on the impact surface in order to aid in dampening the impact. Even though no testing was accomplished with absorption devices mounted on impact surfaces it is felt that an optimal impact system would incorporate components both on the payload and on the impact surface.

Fear and resistance to change appear to be two of the biggest obstacles that have to be overcome in order for the proposed system to become a reality. Observers in the test craft were normally apprehensive prior to their first impact.

[illegible]

[illegible]

[illegible]

Most people seem to have the idea that impact and momentum forces in a marine environment are unconquerable or greater then they actually are. Upon completion of a demonstration ride, with the associated impacts, most observer outlooks changed radically. They realized that the fear of impact was unfounded when properly compensated for. Nevertheless, a major stumbling block will continue to be the education of people so that they will want to go to sea with the system. Since there has been no historical precedence for this type of lift system there are many who feel that it won't work or that its usefulness is limited. Demonstrations have shown that the proposed system can work and a quick study of operational heavy lift systems indicate that presently there is a need for all weather seagoing heavy lift systems.

Like many research projects this particular one started out to prove one thing but in the process opened other areas for investigation. Initially, the thrust was to develop the heavy lift system as indicated in section I. Since the major unknown was energy absorption most research centered on this aspect. By concentrating on the development of energy absorption, it was possible to see the advantages of marine energy absorbers on tug boats, life boats, pleasure crafts, buoys, piers, and small submarines, to name a few. Since all the above are subject to impact in their marine applications, it is considered possible and cost effective to develop efficient energy absorption devices in order to increase in service life.

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Continuous operation of absorption devices in a marine environment was shown to be possible over the two-month test period. Therefore, it is considered technically feasible to develop devices that can go to sea and operate for extended periods with little or no maintenance. What is particularly advantageous is that the development time and cost would be minimum because of the existing expertise in the automobile and aerospace industries.

The proposed heavy lift system has a big selling point in that it is very inexpensive when compared to similar systems. It also has a wider range of sea states over which it can operate without damaging the payload. This makes the system attractive for numerous ocean engineering evolutions where handling is a critical part of the overall operation. Since it is envisioned that the lift system will consist of modular components, a variety of ships could easily be pressed into service handling heavy payloads within a minimum outfitting time. If the oceans are to be fully exploited, then a large number of vessels have to be continuously available for service.

An optimum lift system has not yet been devised. The tests that have been run indicate only the feasibility of combining energy absorption with a drag type lift system. Further investigation is required to determine what components or group of components best satisfies the total system. Factors such as, stiffness, damping, friction, deflection,

deceleration, size, and weight are some of the variables that must be evaluated in greater detail in order to develop a good working system.

One must not get the impression that only good things occur with the proposed system. As previously mentioned, both the size and weight of the payload has to be increased due to the added absorber installation. Also the ultimate configuration of the payload may have to be changed in order to afford the payload maximum protection regardless of its orientation. However, when considering the total lift system effectiveness and cost, then the proposed lift system becomes very attractive. It is felt that this type lift system will enable man to more swiftly exploit the world oceans.

VII RECOMMENDATIONS

An operational heavy lift system using the principle discussed in section I should be fabricated and put to work in the open ocean so "in situ" usage data can be obtained. Also additional research should continue because of the need for an all weather heavy lift system in many military/commercial applications. Since the proposed lift system is inherently an inexpensive system to adapt to a large number of existing vessels, it should be developed to provide the link for widespread exploitation of the sea and sea bed.

Further optimization studies should be carried out in order to determine the following: the location, size, and type of energy absorbers; the most practical way to overcome the relative motion problem when the payload is in contact with the lift surface; the best configuration and impact strength requirement for the lift surface; and the special requirements for the hoisting winch and hoisting line. Presently, there are many alternate configurations that are possible for energy absorption type heavy lift systems that still need investigation. It is recommended that these investigations be carried out in order to determine the most practical configuration.

The initial investigation should be expanded in the area of marine energy absorption. There are many applications for marine energy absorbers other than in the proposed lift system. The energy absorption principle could be applied

to tug boats, pleasure craft, buoys, and other buoyant objects with great success. Since the field is still relatively unexplored many inroads could be made through further research and exploration.

Last but not least, people have to be shown that the proposed lift system is feasible and that it can work. Therefore, it is imperative that a maximum number of demonstrations be conducted for the education of people who are doubtful of the merits of the proposed system. When people realize the potential of the Heavy Lift System for Handling Heavy Objects at Sea, then significant advances will probably take place in ocean engineering and in the exploitation of the sea and the sea bed.

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IX APPENDIX

A. Characteristics of 24-Foot Motor Cargo Boat

B. Description of Absorber Installation

C. Computer Prediction of Cargo Boat Motion

A. 24-Foot Motor Cargo Boat Characteristics

Purpose	A rugged work boat used by larger Coast Guard Tenders
Capacity	3,000 lbs. cargo or 10 men
Crew	2 Men
Length Overall	24 feet 5 inches
Beam	6 feet 11 1/2 inches
Draft (normal)	2 feet 3 inches
Full Load Displacement	8,100 lbs.
Normal Operational Displacement	5,100 lbs.
Construction	Round Bottom, Wood, Carvel
Speed (maximum)	11 knots
Fuel Capacity	33 gallons
Engine Details	1 Diesel, Cerlist Model 3M, 65 HP at 2600 RPM, Reduction Ratio 1.91:1, Fresh Water Cooled, 12 Volt Electrical System
Propeller Details	18 inch Diameter by 15 inch Pitch by 1 1/8 inch Bore, 3 Blade, R. H. Rotation, Type "B" Bronze

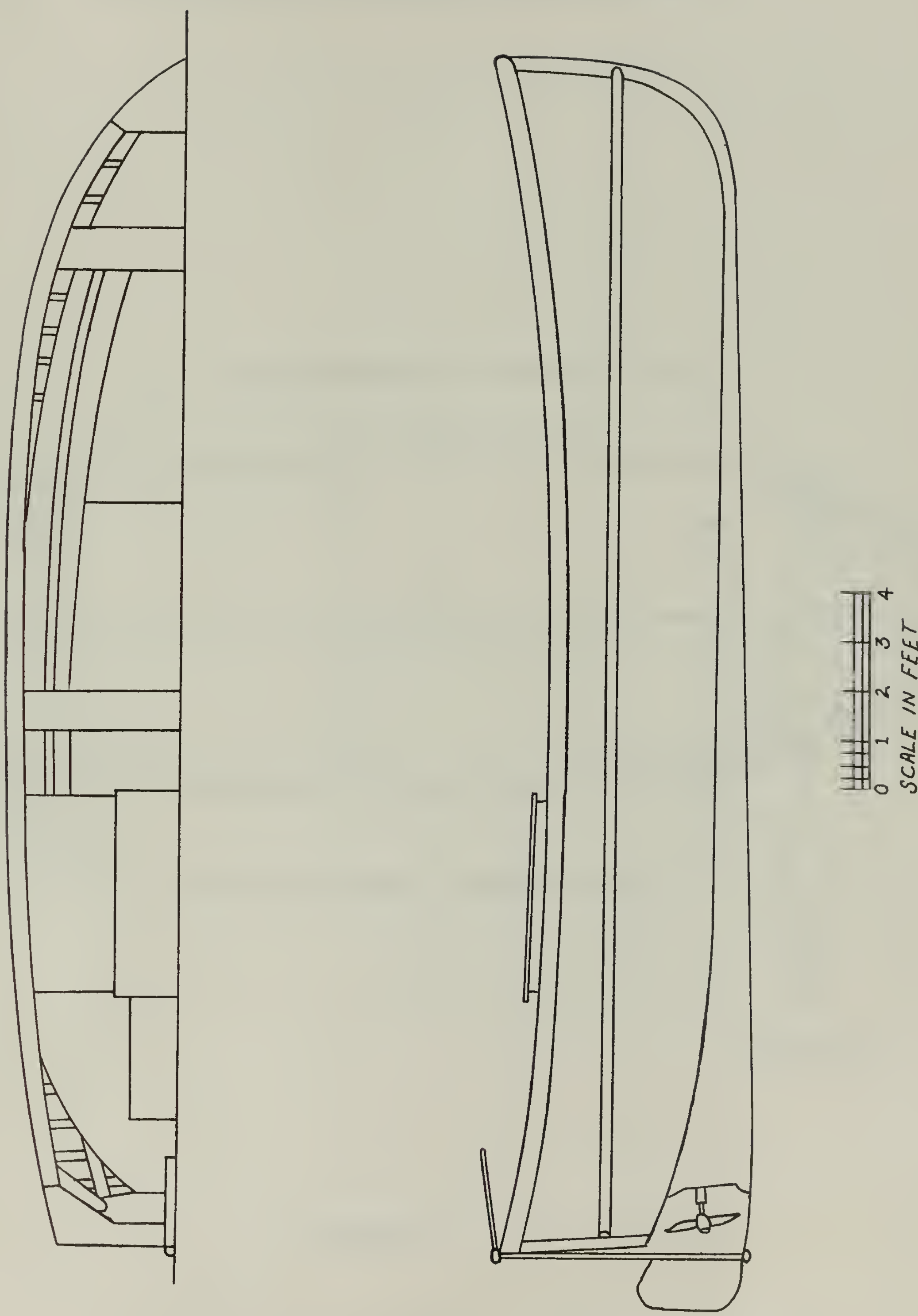


Figure 7

B. Description of Absorber Installation

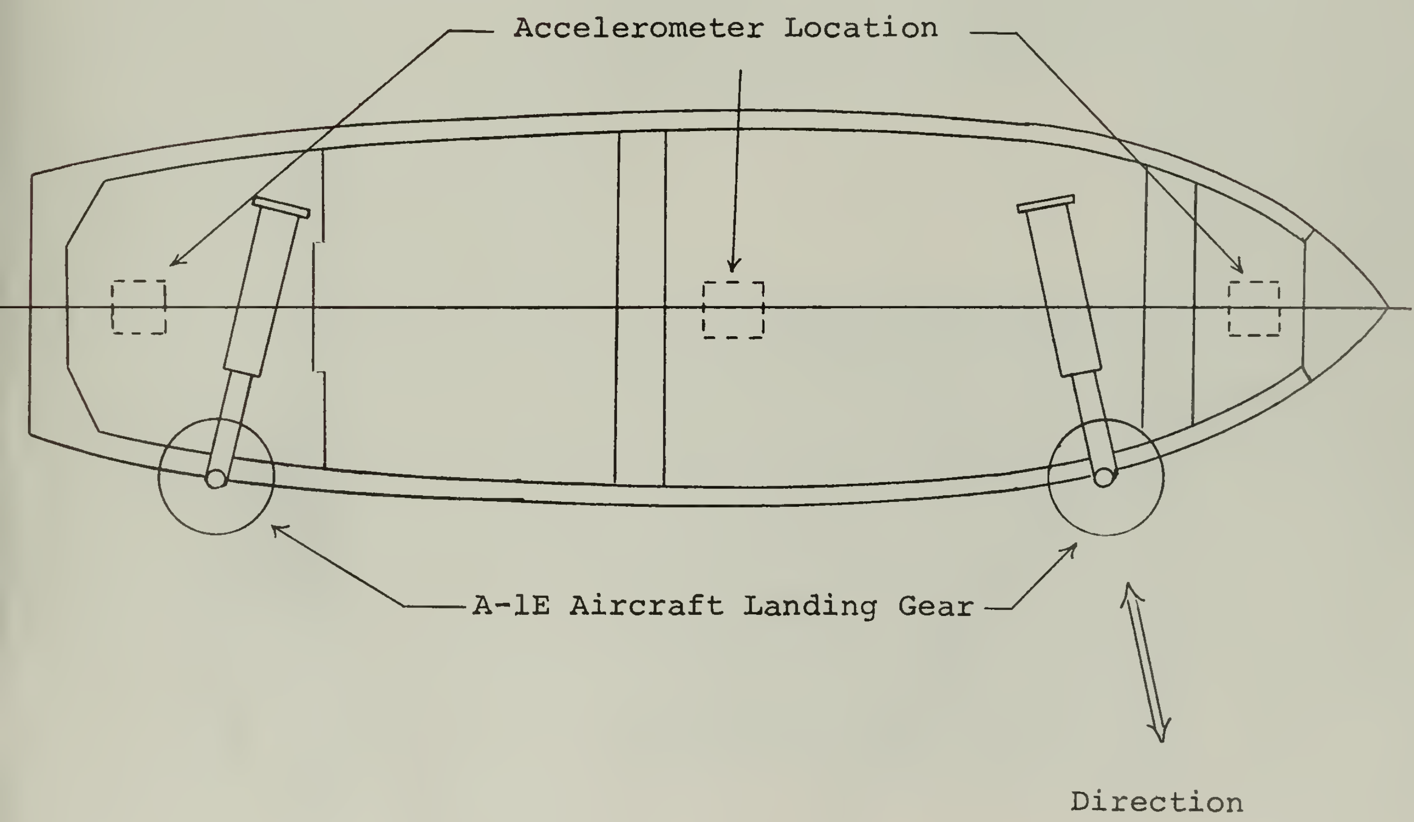
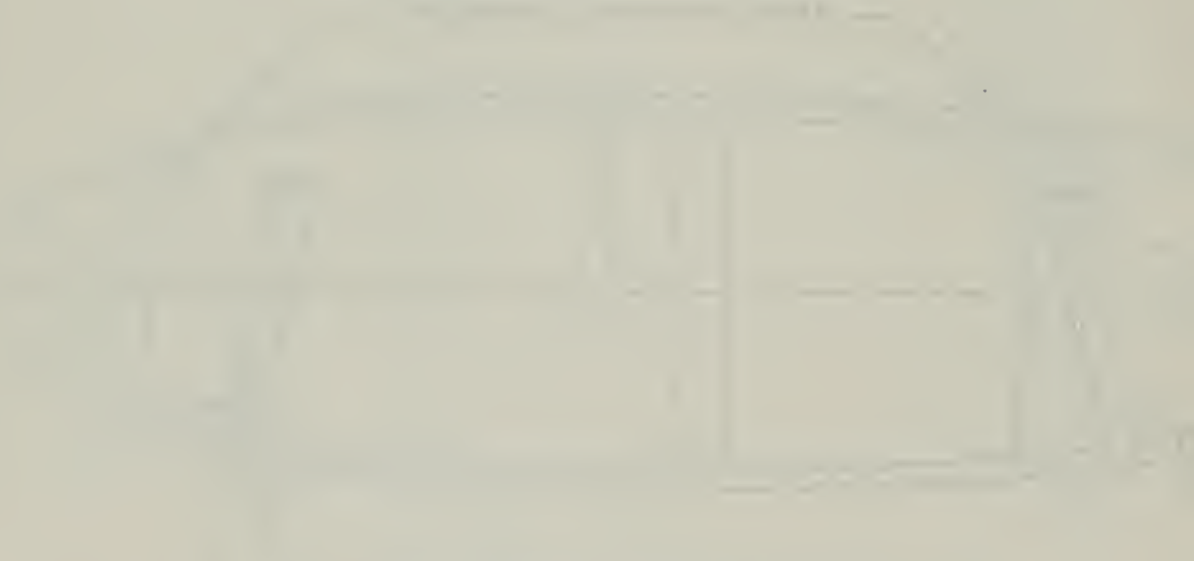


Figure 8



C. Computer Prediction of Cargo Boat Motion

The following is the open water heave response predicted by the computer program of reference (4) for an exciting wave 1 foot high:

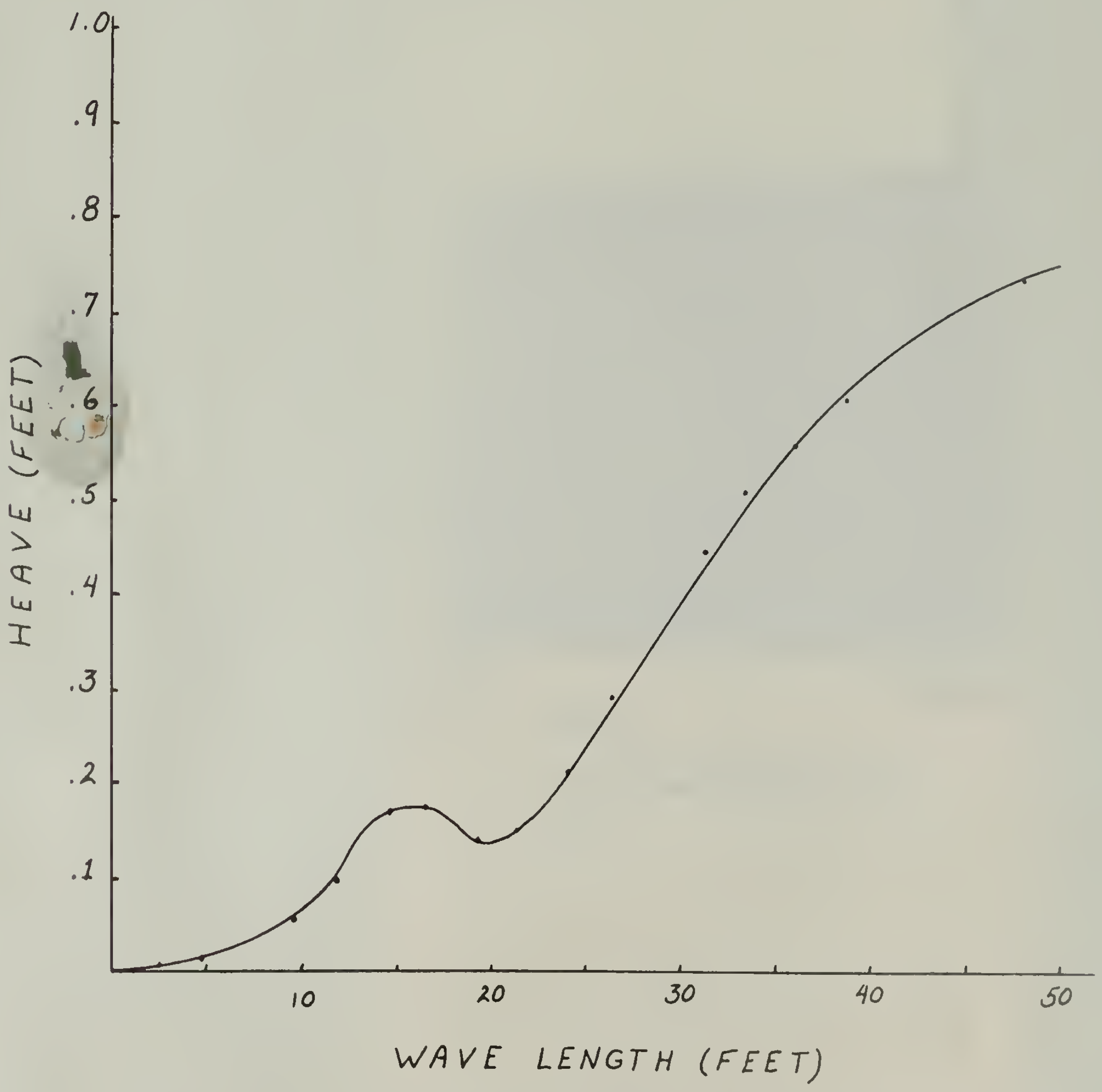


Figure 9

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Lift system for handling heavy objects at sea.