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CONTENTS

1 INTRODUCTION

The motion of a ship deck influences both the difficulty of landing a helicopter on a vessel and the safety of the helicopter while it remains on the deck after landing. Often the helicopter operations are limited by the actual roll and pitch motions. The difficulty of the landing task and the risk of a helicopter sliding on a deck after landing depend on the frequency of oscillation of the deck as well as the angular inclination. The sliding threshold is primarily dependant upon the acceleration of the deck or the lateral force estimator (LFE) [Wilson, Tang & Crossland 1993]. The LFE increases with the height of the deck on the ship and with the frequency of the motion.

Helicopter landing and its subsequent handling on warships has developed into a necessity for the operational effectiveness of modern day Naval Frigates. The newest problem involves landing the EH-101(Merlin) on the flight deck of a Type 23 Frigate. From previous use of Lynx on these ships, a system has been adapted that suits the operations and properties of this helicopter. The differences between the Lynx and Merlin are extreme, making much of the existing practise ineffective, and probably operationally impossible with the present system. Hence the need for new and radical designs of capture and retention of the helicopter.

So a new system is needed to suit the operations of Merlin as well as complementing current operational helicopters and for those to come in the future.

This report consists of three sections:-

- Prediction of Quiescent Periods
- Landing and Entrapment Systems
- Deck Handling Systems

Combined, these elements provide a complete system to assist the landing of a helicopter from just before touch-down to stowage within the hangar. For each of these components a number of ideas will be described and discussed in the report, with conclusions detailing the practicality of each system.

From the data on the following page, it can be seen that Merlin is an extremely large helicopter, to land on the relatively small flight deck of the Type 23 Frigate.

The twin front wheel assembly is able to rotate, with the two rear wheel assemblies lacking the use of a castoring system. This means that 'on the spot' rotation as used so effectively on the flight deck by the Lynx is not possible, so a similar approach to that of a 'three point turn' is desired. So the manoeuvrability of this helicopter is quite limited.

EH-101 'Merlin' Dimensions

Length	
Overall, both Rotors Turning	22.81m
Main Rotor and Tail Pylon Folded	16.00m
Main Rotor Diameter	18.59m
Width	
Excluding Main Rotor	4.52m
Main Rotor and Tail Pylon Folded	5.49m
Height	
Overall, Both Rotors Turning	6.65m
Main Rotor and Tail Pylon Folded	5.21m
Maximum Take-Off Weight	14,600kg

Type 23 Frigate

Flight Deck Length (approx.)	25m
Flight Deck Width (approx.)	15m

2 SYSTEMS

2.1 PREDICTION OF QUIESCENT PERIODS

Quiescent periods are durations of time when the ship motions are within a range of low values predetermined for the operational limitations of the helicopter. Determination of these periods will provide the pilot with an indication when it will be safe to land on the ship, from a ship motion point of view.

Currently, Royal Navy pilots judge *quiescent periods* from visual observations of the present state of the ship and the approaching seaway. This places high demands upon a pilot and crew, who are already coping with a mass of inputs during the approach and landing phases. It is the hope that a prediction system will help to reduce the workload of the pilots, making the landing procedure safer. This is especially important at night, when judging quiescent periods is extremely limited.

2.1.1 Full Prediction Process using Remote Sensors

This process is aimed at predicting the motions of the ship for the determination of quiescent periods, for a duration of up to approximately 30 seconds providing sufficient time for the pilot to safely land the helicopter on the ship deck.

The sea surface in the surrounding area of the vessel is scanned with a remote sensing apparatus, the details of which are described later in this section.

A coarse grid scan of the sea surface is made, yielding the contours of the sea with waves being identified. From this, data such as wave heights, slopes and positions can be determined. When this process is repeated some short time later (Δt), an estimation of the direction of the waves will be obtained. From these scans and future scans, it will be possible to estimate the predominant waves that will affect the ship motion in the period of landing of the helicopter. These predominant waves will be used to estimate the motions of the ship. The first scan of the waves will be used to predict the sea surface some small time ahead and the actual scan at that time will then be compared to the predicted values. This process will be repeated at each forthcoming time step to gain a better predictive tool.

The geometry of the wave groups will then be converted using Discrete Fourier Transforms (DFT), which separate the irregular wave form into a number of sinusoidal components. From which Fast Fourier Transforms (FFT) are determined for each wave group as these are less demanding on computer time than the original DFTs, therefore the following calculations can be done using a modern PC on board ship.

The frequencies and amplitudes derived from the FFTs of progression time T, are at time T compared to the actual scanned progressed waves. This data will indicate any differences between the predicted and actual sea surface. This data is then added to the analysis in the form of a recursive estimation process to account for variations in time with the wave group, therefore accommodating external factors affecting the wave groups. Recursive estimations are methods whereby an output is formed from previous values of the output, as well as from the current inputs and previous input values to the system suitably weighted, allowing for variations to be accounted for in the process under investigation

Response Amplitude Operators (RAO) [St. Denis & Pierson 1953] are a method of calculating the ship response in a given sea condition. In this case the RAOs are a measure of the response motion of the ship to regular sinusoidal waves. The RAO values are related to the encounter frequency, wavelength and wave heading angle to the ship of the waves. The resulting predicted wave group data is still in the form of a spectrum, which aids the determination of the ship motion data. Ship heading and speed are used to retrieve the suitable pre-determined RAOs, determined from computer simulation for that condition. For each degree of freedom (DOF), every sinusoidal component of the wave is combined with the corresponding RAO value, with the sum of these components resulting in that DOF motion.

The predicted values of ship motion are compared to those experienced by the craft at the predicted time interval, with a recursive estimation being used to adjust the RAO values for future craft motion predictions after that time.

Two sets of RAOs are desired, one for the fin-stabilised conditions, the others for the situation when the fin stabilisers are inoperative, to allow for other ship condition scenarios. Figure 1 gives a diagrammatic representation of this whole approach.

This system has the potential of providing vast quantities of useful information for many other systems upon the vessel:-

Apart from the prediction of the quiescent periods, the method can also provide data as to the actual motions, velocities and accelerations upon the deck. The safest time to land the helicopter on the ship, is after the deck has heaved to its highest point and is then heaving in a downward direction. This will reduce the effects of heavy landings, as the pilot will have an indication device to tell him when these periods are going to occur.

The direct predicted motions of the vessel can be used as an aid to stabilise the helicopter landing & entrapment system, as well as to adapt the control of many other components upon the vessel, such as fin stabilisers, missile launch systems, the operations of drogue sonars. Many of the assets of this system have industrial applications.

2.1.2 Short Time Scale Prediction System with Remote Sensors

This system is relevant for a short distance scanning system, which can consist of two different approaches:-

1. Similar approach to the method described above, but using a smaller scanning area, therefore yielding shorter time scale predictions. A description of this system maybe taken from the previous example. The pilot will be provided with sufficient information to abort a landing safely, if an excessive motion is going to occur.

2. Using the remote scanner to identify a packet of waves that will cause an excessive motion to the vessel. Data used for the analysis would be inputs such as:-
    - Vessel Speed
    - Heading to Wave
    - Wave Height
    - Wave Slope
    - Wave Distance
    - Present Ship Position

Neural networks are processes where the system learns from previous experience, so the method effectively trains itself.

These data can be used to form a neural network type analysis to achieve an indication of whether it is safe or unsafe to land in the next few seconds. The problem is that this system would be limited to relatively short prediction times. This is due to the scanned wave being close to the vessel, therefore prediction time is short. There is also a limit on the number of inputs to the system from a computational point of view. The more inputs create potentially a more accurate analysis, but with a vast increased demand computationally.

2.1.3 Prediction System without Remote Sensors

This system uses no form of remote sensing and is based on the Energy Index formulation [Ferrier 1991]. This approach takes the separate inputs of roll, pitch, heave and sway motion, their displacements, velocities and accelerations relating to a formulation of the energy within the system.

Each component within the formulation is multiplied by a corresponding coefficient, these will be determined and adapted continuously, to allow for variations in operational conditions and for external factors.

A suitable process to predict the quiescent period would be achieved using a mathematical approach for predictions associated with random systems, and with the use of a recursive system to account for the discrepancies involved in accommodating all possible operating conditions.

2.1.4 Remote Sensors

The scanner is used to detect the sea surface contours, relaying the information to the ship for analysis to determine wave forms and directions as described in section 2.1.1 above. The system will be connected to motion sensors, to correct for the motions of the carrier vehicle upon the data of the sea state obtained. A remote sensing device can easily be designed and operated from a ship with little change to the existing vessel.

The main device types that are under consideration for the remote sensing of the waves are:-

- **Laser**
- **Ultrasonics**
- **Radar**

Ultrasonics are eliminated from the investigation due to the high energy requirements demanded for the propagation of sound waves through air, to obtain any reasonably powered echo signal. Thus the report only considers the use of lasers and radars.

There are three positions for the scanning apparatus:-

1. Mounted on the ship's antenna, along with much of the vessel's other signal equipment.

2. On the underside of the helicopter.

3. Attached to a balloon or MUAV flown above the ship.

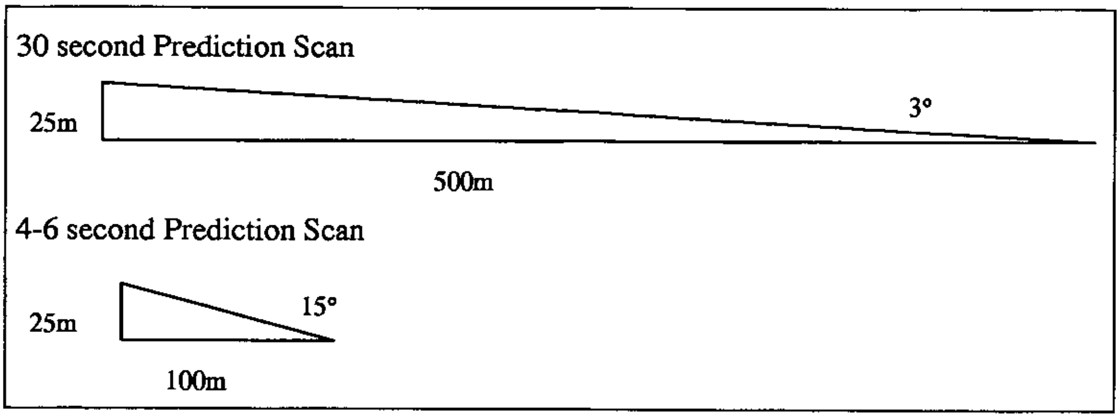
1) On the ship's antenna

The antenna is approximately 25 metres above the static waterline, therefore with a large area for scanning (i.e. up to 500m from the scanning point) will necessitate the system to use angles of incidence in the region of 3° to the mean sea surface. With current systems and developments this is clearly unachievable at the present time [Sviridov & Sudbin 1993]. So a large angle would be more suitable, decreasing the range of the system therefore lowering the prediction time length.

The maximum wave slope for non-breaking waves is approximately 7°. Hence systems should be capable of at least this as a minimum angular requirement.

If an angle of 15° is attainable [as investigated in Sviridov & Sudbin 1993], then the range of the system will be approximately 100 metres horizontally from the ship antenna position, giving a prediction time in the region of 4-6 seconds. This time prediction estimate is based on a ship speed of 15 knots, and wavelengths of between 0.5 - 2 times the ship's length. This particular range of wavelengths has been used, as it relates to the waves that will potentially cause the largest ship motions.

This diagram indicates the differences between the long and short time scale prediction scans.



For this system a laser would have to be used, because at such low grazing angles radar systems receive very poor return signals, from which information is difficult to extract. The system demands a high power input, in order to receive recognisable returns. Problems do exist in that the laser frequencies best suited to the lower angle energy returns are in the blue-green region, which yields issues about human safety and visibility to outside observers.

2) On the underside of the helicopter

When the helicopter is on the approach path to the ship it has a major advantage, height; therefore providing a relatively large angle to scan the sea surface. Thus it would be possible to carry a laser device coping with grazing angles in the region of 15° as described in the previous example.

As the helicopter approaches nearer to the ship, the sea surface scanning angles reduce. With these lower angles, the problems of the laser frequencies in the visible range become apparent, as described in the previous example. The position of the ship antenna would in fact be higher than that of the helicopter immediately prior to landing, with a conventional system.

The blockage of the ship on the signal will have significant effects immediately prior to landing, as it is in effect blinded by the ship. So the use of the helicopter mounted system needs an additional scanning device positioned elsewhere to detect the sea surface for periods when the helicopter is too low for effective scanning.

3) Attached a balloon or MUAV flown above the ship

The above two methods indicate height is a necessity, hence a balloon or MUAV released by the ship will have many advantages. This approach eliminates the low grazing angles to the water surface, which enables alternative laser frequencies to be adopted and is safer for the crew of the ship.

These unmanned vehicles will be launched before helicopter landing. The MUAVs have other activities, so scanning the sea surface would be just one of their many roles.

Because of the height of either of these devices, it is possible to use a different frequency range, radar. The sensing technology currently employed in satellite and airborne sea surface applications is *Synthetic Aperture Radar* (SAR). This technology is robust and well developed and is the prime candidate for balloons.

The MUAVs need take-off and landing systems, therefore similar approaches to those used for the case of the helicopter could be used. With the balloon, a relatively stable tethered hover would be maintained with control from a deck mounted winch. Weather balloons already exist that could achieve this goal. The heights of operation of the balloon/MUAV need not exceed the operational heights of the helicopter, so ship detection by a third party would be as limited as for helicopters.

2.2 LANDING AND ENTRAPMENT SYSTEMS

From an analysis of the problem and a study of existing systems there are three types of landing and entrapment arrangement.

1. **High Attachment Systems:** Helicopter is in a high stable hover, an attachment is made between the ship and the helicopter, then the helicopter is power directed to the deck and restrained.

2. **Low Attachment Systems:** The helicopter attaches to a system fractionally before / during touch-down, therefore is restrained immediately at touch-down.

3. **Zero Level Attachment Systems:** The helicopter lands, then a system is engaged / attached, or the system assists with the landing and handling stages, making the entire operation of landing the helicopter safer.

2.2.1. High Attachment Systems

a) Fully Active Arm

This system is a crane type arrangement illustrated in figure 2, consisting of a small platform (possibly with a harpoon type grid) mounted on the end of an arm. This arm is able to manipulate the platform in all six degrees of freedom.

The helicopter approaches from aft of the vessel to a hover position a significant distance from the aft deck edge, in both height and horizontal distance. Once a stable hover has been achieved the helicopter moves to the system engagement area, which is still a reasonable distance from the aft deck edge, therefore safe from deck contact.

It is considered that there are two different methods to make the connection between the helicopter and the active arm. The helicopter moves to engage the entrapment device mounted at the end of the arm. This system demands that the platform at the end of the arm will maintain a static position relative to the horizon reference frame, therefore the arm must counteract the ship motions. The second method entails the platform to track the helicopter as it approaches the ship and to make the attachment. This means the arm has not only to counteract the motions of the ship, but to also follow the motions of the helicopter prior to landing. In each case, once the attachment between the helicopter and the active arm has been made, then the helicopter is immediately power directed on to the deck.

The system is not designed to support the mass of the helicopter at the end of the arm, but to aid the helicopter in its path from its hovering position. This system uses a similar approach as that of the *Beartrap* in that the helicopter is still in flight. So the structure of the arm would not need to be extremely heavy. Hydraulics would seem to be the obvious powering medium.

The primary advantage of this configuration is that the helicopter is hovering near the ship in what is probably relatively undisturbed air flow. Therefore control should be much easier for the pilot than if it were to hover closer to the deck on the portside, as in the current practice, when air turbulence caused by the ships structures and the deck create position keeping problems.

With this conceptual system the pilot is following a point that is essentially static in space when neglecting forward ship speed. So the pilot is not hampered with perceived distortions in his own notions of motions caused by visually fixing on to the ship reference frame. The pilot's job is made easier by the fact that the reference is made to a point that is within the horizon axis system, rather than that of a continually changing axis system.

The apparatus has to be active, as at such heights above the deck, the motions of the ship are amplified due to the height above the centre of gravity (CG). Angular motions such as roll, yaw and pitch are at such heights, converted to heave, sway and surge motions. These angular motions are relatively easy to counteract due to the size and weight of the small platform, so existing ships could be retrofitted without difficulties, and would be able to supply the hydraulic rams' power requirements. The local heave motion could also be compensated for by the active system. The determination of these angular motions may be detected from rate gyros, such as roll rate gyros that are already in use on naval ships for the control of the fin stabilisers.

Landing of the helicopter will only be carried out during quiescent periods. The motions to be counteracted by the system are only those within the quiescent region. So excess motions do not have to be completely counteracted by the arm as landing would not occur at these times. With the roll period of a frigate approximately equal to 10 seconds, motions to be compensated for, are relatively slow therefore, speed of system response is not perceived to be a problem. Such apparatus exists on modern tanks in the position keeping of the gun barrels, where very high frequency response is demanded.

Weight addition to the helicopter is considered to be minimal.

A variety of landing angles/styles can be adopted. With no bias existing because of the central position of the proposed system, approaches from any aft angle will be possible, allowing problems caused by landing from pilots from other navies to be accommodated.

This system will also aid in the deck handling of the helicopter, from the landing deck to within the hangar as the system could be mounted on rails that are fitted to the ship' deck.

The addition to the basic system is to make the active arm, track the helicopter as it approaches the ship. The system could calculate approach velocity, position of the helicopter via closely coupled ship and helicopter GPS. With the system only attempting entrapment, if the helicopter enters within the safe retention area. If it appears that the approach velocity of the incoming helicopter is to fast, an indication is made to the pilot, if the discrepancy is not corrected then the platform is lowered clear of the helicopter to prevent damage. The active tracking option of the helicopter would be relatively complex, but technology already exists to accomplish this, quick movement of the platform will be made easier due to the low weight and compactness of the system to enable it to track the helicopter.

Additional visual cues may have to be added on high parts of the ship, because guides such as the bum line are now ineffective. This system, since it is remote from the ship, would not require the same visual cues as in previous methods.

Retractable support legs will be used to restrain the moments and forces caused by the helicopter at the end the arm. These can be folded in after the landing manoeuvre has been completed, to allow ease of movement of the entire system.

b) Active Arm with Positioning Guide

The helicopter is fitted with a forward facing 'prong' or joust, in a similar manner to a refuelling nozzle of a fixed winged aircraft. The joust concept is used in conjunction with a harpoon type system as seen from figure 3. This joust is used as a visual aid to guide the aircraft to the entrapment system. It is also used as a harpoon to engage the vertical harpoon grid. Once this connection is made, automatically the horizontal harpoon panel moves upwards to engage the harpoon device mounted on the underside of the helicopter. Then the aircraft is power directed to the deck. The vertical and horizontal grids are both mounted at the end of the active arm.

This system is a variation upon the previous discussed type, so benefits from many of properties already described, but now provides visual aids and prevents any rotation of the helicopter after entrapment.

The target panel can be rotated according to the relevant landing angle, so approaches from any angle will still be possible.

The weight addition to the aircraft is only slightly more than in system (a), as two small harpoon type spikes are added instead of one.

After landing the helicopter is still retrained at two points making deck handling easy, therefore on its own can be used as a complete handling system.

2.2.2 Low Attachment Systems

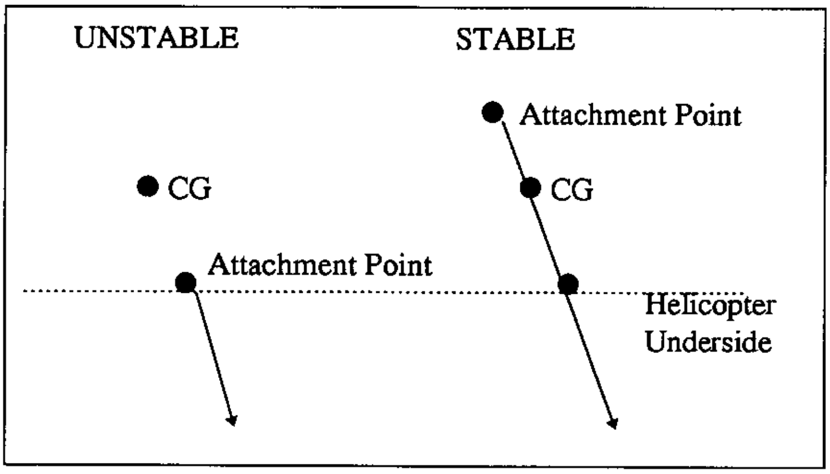
c) Wire Pull Down System

A wire is lowered from the helicopter prior to landing, at the end of the wire is a location device. This device is designed to be placed into the deck entrapment apparatus by positioning of the helicopter above it. Once positioned the location device is restrained, and the wire is tensioned by the below deck system, which pulls the helicopter to the deck. This system is illustrated in figure 4.

The wire line is set at such a length, as to engage the deck entrapment device just before/during touch-down. So the helicopter is restrained fractionally before and immediately after landing.

The helicopter attached system is small and relatively simple, needing minor modification to the aircraft itself. After the helicopter has landed it is already secured to the deck, so no craft movement is possible after landing.

In order to make the system stable a line will have to pass through the cabin space connecting to a point *above* the CG of the helicopter. As can be seen from the diagram below.



The system necessitates underdeck components, so slight modification within this vicinity is needed to accommodate this apparatus on existing ships.

d) Bar Pull Down System

This system consists of a harpoon grid, mounted on a hydraulic ram which is fitted below the flight deck. The helicopter locates the grid prior to landing, once locked on, the hydraulic ram hauls the helicopter to the deck. This procedure is represented in figure 5 and uses a similar approach to that of example (c), but the additions to the helicopter are reduced.

These types of systems are dependent upon the accuracy of the pilots, to locate a particular position upon the deck. With the pilot so far in front of the location point and without visual contact positioning over of landing point, this is perceived to be problem.

A positioning device may be placed on the deck and the helicopter to indicate when the helicopter is in position over the landing target. This indication device will be used in addition to visual aids to assist in the correct positioning of the helicopter prior to landing. Rate of deceleration on landing is controlled, so heavy landing damage will be limited.

Deck Handling is not aided with this type of system. So transferral from the entrapment system to the handling system will add complexity to the handling apparatus.

e) Raised Harpoon Pad with Hydraulic Damping

This system illustrated in figure 6, consists of a harpoon like panel mounted on a small hydraulic platform, this enables the platform to be used as either active (maintaining the same plane as the undisturbed sea level) or non-active having the same angle as the disturbed deck surface.

The helicopter makes contact with the platform fractionally before the wheels touch the deck, ensuring the helicopter is restrained. The hydraulics act as dampers, so heavy landings will cause less damage to the oleos and helicopter structure.

This system relies upon the pilot locating the device below the helicopter. Wheel interference with the system upon the approach to land is unlikely, due to the large distances between wheel locations and the CG (location point) position. So visual aids are essential in the positioning of the helicopter upon the deck. A video link showing the attachment in the instrument panel, would help the pilot fix the helicopter to the system.

Manoeuvring of the helicopter when it is on deck or in the hangar is simple as the system is simply mounted on rails, therefore the system is already partially integrated with the handling system.

The system is quite simple, no large highly loaded components or complex electronics. It requires very little modification to existing vessels.

It allows the helicopter to land at any angle to the ship's heading, the benefits of which have been described previously.

The only addition of weight to the helicopter is that of the harpoon like attachment.

f) Large Harpoon Type Grid

This approach is represented in figure 7 and consists of spikes that are attached to the oleos and engage the landing area just before the wheels touch-down, this allows landing and take-off from any angle with a turntable landing pad, and overcomes the lack of on the deck manoeuvrability of the EH-101.

The large landing area would be made rotational and moveable in the fore and aft directions to allow ease of deck handling. Once the helicopter has completed the landing manoeuvre it can simply be moved directly into the hangar, eliminating any handling problems.

Incorporated into the grid could be hydraulic rams to minimise the effects of heavy landings.

As the landing area is relatively large, positioning the helicopter in higher sea states and winds should not be difficult.

g) Aircraft Carrier Wires

This is similar to the system used for planes landing on aircraft carriers. A number of wires are laid transversely and longitudinally across the flight deck, this is illustrated in figure 8.

The hook mounted beneath the helicopter is slowly dragged across the deck, where it engages one of the many lines. Once contact with one of the wires is made, a ram mounted on the helicopter pulls the helicopter directly to the deck.

This apparatus adds a large weight to the aircraft, due to the addition of the hydraulic ram, which also needs power input from the helicopter system.

Heavy landing damage could become a problem, as the ram is pulling the helicopter to the deck with no restraint in the opposite direction.

Workability of the deck for the crew before and after landing will be difficult because of the large number of deck wires, therefore it will be difficult to handle the helicopter once on the flight deck.

It would be possible to land at any angle to the ship's heading, due to the wires being in both transverse and for-aft directions.

Problems may arise due to the helicopter needing a slow directional velocity to engage a wire, so when attached this movement would be converted into a moment, tipping the helicopter creating an unstable system.

h) Translating Harpoon Grid

This system represented in figure 9 demands that a pilot attempts to land within a set moderately sized area. The mini landing pad tracks (in the x and y axis) the spike mounted on the bottom the aircraft, on landing, the helicopter directly engages the system. A major advantage is that there is no exact landing spot, which relieves the pressure on the pilots. This is also perceived to be a disadvantage, since pilots are used to aiming at a particular point, that usually remains still, therefore the confidence of the pilot upon landing could be reduced.

This system would be quite complex, as instantaneous system response is demanded for safe landing. A tracking device between the underside of the aircraft and the entrapment device will be used.

The system allows for deck to hangar handling of the helicopter due to the built-in rails on deck, with the same rails used for the helicopter tracking.

Minimal weight is added to the aircraft, only a tracking device and harpoon.

Various landing angles maybe achieved, as the distances between the helicopter forward and aft wheels is large, so wheel interference is not going to pose a problem.

In the marine environment, over the life time of the system, some of the many intricate components of this system could deteriorate and corrode.

i) Locking Cup

This system, illustrated in figure 10, is active in the heave direction only. The helicopter hovers in the vicinity above the entrapment device. When the helicopter is directly over the device, which is indicated by sensors mounted on both the entrapment device and the helicopter, the deck mounted apparatus moves up to make contact and lock to the helicopter, then pulls it down to the deck.

This system can be used at high elevations (in undisturbed air flow) or closer to the deck. Problems exist at the higher heights due to the roll, yaw and pitch motions converting to sway and surge translations. It demands a tracking device between the underside of the aircraft and the entrapment device.

An under deck area is needed to house the upwardly translating pole, which will prove problematic with existing vessels.

j) Magnetic Attachment

Upon approach, the helicopter lowers a steel plate, as the aircraft lands the steel plate is attracted by the deck-mounted electro-magnet. A lock is made, then the helicopter winches in the slack to restrain the helicopter as it lands. This apparatus is represented in figure 11.

Magnetism will effect the navigational instruments of the vessel and helicopter, unless its effects can be shielded. The magnetism is only needed during the landing procedures, so the electro-magnet would effectively be switched on and off.

The magnetised deck area would be large, providing an adequate landing area for the pilot, allowing for any approach angle.

There would be the additional weight of the winch device and the steel attachment on the helicopter. The major advantage of this system is there are no significant moving parts.

k) Drag Hook

The helicopter has a capture device mounted to its underside. The helicopter is moved slowly across the deck to engage the deck mounted component. Once attached the deck mounted bar is pulled down into the deck. This eliminates the necessity for a helicopter mounted pull down system. The approach illustrated in figure 12 is similar to that in example (h), the difference is that in this case the deck mounted system pulls the helicopter to the deck, where as in example (h), a helicopter mounted system pulls the helicopter to the deck.

A weight addition is made to the helicopter of the attachment hook.

Approaches to the ship are only at one angle to engage this system, which limits the operational effectiveness of the helicopter.

The system necessitates below flight deck modifications.

2.2.3 Zero Level Attachment Systems

l) Wheel Clamping (Longitudinally)

This system consists of deck mounted hydraulic rams that control long panels, that can be rotated to be used to restrain the helicopter wheels. This system is represented in figure 13. These panels are transversely mounted across the flight deck. The clamps adjacent to the wheels are activated when all three sets of wheels engage the deck pressure pads, located between each set of clamping devices. The system relies on the fact that the tyres take the restraining load and not the helicopter structural components, this is of benefit as the tyres are able to deform to dissipate the loads from the system.

This type of arrangement is dependent on the accuracy of the pilot; but rows of clamps can be installed with the relevant devices being activated by the deck mounted sensors to reduce this problem.

A major problem is that the system restricts the movement in the fore and aft direction caused by pitch, but does not completely eliminate the possibility of sliding in the transverse direction.

This does not aid the deck handling system, in fact deck handling is extremely difficult as the clamps would obstruct the handler.

Only one approach angle can be used, so cross deck landings and take off will not be possible, limiting landing options.

m) Wheel Clamping (Transversely)

The system illustrated in figure 14, adopts similar principles to those used in example (l). The apparatus consists of hydraulic rams connect to longitudinally positioned panels, that can be moved in the transverse direction. These rams are set beneath the deck to prevent contact with the helicopter landing before and after landing. The wheel location areas are recessed into the deck to accommodate the ram positions.

This system is activated by the touch-down of all three sets of wheels, it restricts the wheels in the transverse direction. The rams are fitted with sensors to prevent crushing of the wheels.

This type of system prevents sliding, but not that of tipping over, or that of rolling on to the helicopter side.

Problems may arise if damage is made to a tyre. This damage will be limited with sensitive control of the hydraulic rams. There is the possibility of the rams inducing translation motions on the helicopter with insensitive hydraulics, therefore causing the helicopter to slide, with the risk of damage to the tyres and also that of it rolling over on to its side.

n) Fully Stabilised Landing Platform

A fully stabilised system of an aft area of the ship is considered to enhance the operational effectiveness of the ship in all rôles. The platform will be stabilised to minimise roll, yaw and pitch motions and to compensate for heave in the best manner possible. This is illustrated in figure 15. At first it may be conceived that the heave motion may prove to be impossible to control, but it must be recalled that the helicopter will only be landing in quiescent periods, hence the limits on heave are less onerous. The roll, yaw and pitch motions are controllable, given the existing capabilities of the rolling table at Boscombe Down.

This system is useful before and after the landing operation, it provides a stable platform for the pilot to approach and land on, but also provides a reasonably safe environment for the helicopter to rest on after this manoeuvre. Hence the chance of the helicopter sliding or toppling on the deck are reduced.

A centrally positioned harpoon type entrapment device would be used to restrain the helicopter safely after landing, to compliment the landing and entrapment system.

This system can be directly connected to the predictor of the quiescent periods/ ship motions data, to aid in the control of the platform. The approach would be to integrate the predicted motions data with the present displacement of the ship to assist in the control.

The ship will need substantial modification, size and demands of the system may prove too great, but would be suitable to design into a new vessel, allowing for the provision of adequate power and space requirements.

It will enable the pilots to approach and land without becoming involved in all the ship's motions, the benefits of which have been described previously.

2.3 DECK HANDLING SYSTEMS

The aim of a new handling system is to retrieve the helicopter after landing, from the flight deck to within the hangar. Precise positioning of the helicopter is essential due to the restricted dimensions on the flight deck and in the hangar. The system must operate without the necessity for crew members to be on the exposed flight deck.

The EH-101 is relatively difficult to manoeuvre on deck, due to its high mass and lack of castoring of the rear wheels, these facts have to be overcome with the new system. The handling system is closely associated with the landing/entrapment arrangement, combining the two systems would be advantageous in respect to weight addition to the vessel and helicopter, also allowing ease of transfer of the helicopter quickly and efficiently after landing.

2.3.1 System Configurations

Systems considered are listed below:-

1. 1-point configuration (CG position)
2. 2-point configuration (CG position and front wheel attachment)
3. 3-point configuration (front wheel attachment and rear wheel attachment)
4. Rotating and translating platform
5. Curved Arm (with two point attachment)

1) 1-point configuration (CG position)

One point of contact is made between the helicopter and the handling system. The handler which is mounted on rails can then move the helicopter into the hangar. A 1-point push/pull system could be easily incorporated with the landing/entrapment configuration.

Positioning of the helicopter would be aided by steering the front wheels of the helicopter, but this may prove ineffective due to the lack of a sufficient turning moment. To return the helicopter to the deck ready for take-off with a specific angle to the ship's heading would be quite difficult with a one point system [Reimering & Craig 1991]. This system is illustrated in figure 16.

2) 2-point configuration (CG position and front wheel attachment)

In this case two points of contact are made between the deck handling apparatus and the helicopter. So two deck handlers are needed, one to attach to each point. The handlers are mounted on rails. The first attaches to a point in the plane of the CG of the helicopter. The other consists of a rotating arm arrangement mounted upon the deck rails. This is attached to the front wheel hub, but still allows the wheels to pivot. This will provide an adequate turning moment to manipulate the helicopter on deck. The system is depicted in figure 17.

Turning the helicopter is achieved by varying the differential velocity between the two attachment point devices, rotating the contact arm and by turning the front wheels.

3) 3-point configuration (front wheel attachment and rear wheel attachment)

The handling apparatus consists of a rotating arm mounted on the rails to attach to the front wheel arrangement. A rotating arm mounted on rails that is able to attach to both the rear wheel arrangements. This can be seen in figure 18. This system is more complex in nature due to three different attachments needing to be made rather than two, using a similar principle to manoeuvre the helicopter as in the previous example. The angle at which the helicopter may be retrieved is limited as the inner rear wheel could block the attachment arm for the outer wheel. If the helicopter lands at a significant angle to the centreline, then recovery with this system would not be possible.

4) Rotating and translating platform

This is a platform mounted on the deck, that is able to move on the deck rails. It is capable of rotating about its centre, achieved by a central mounted pivot, rollers and a drive mechanism. This system is illustrated in figure 19. The three groups of wheels of the helicopter must land on the platform, which can then be rotated and transferred to the hangar. The system is relatively large, but simple to operate.

5) Curved Arm

This system consists of a rail mounted curved arm, that is able to rotate. At the end of the arm is a pivot with an additional arm attachment. This allows the system to be connected to two points upon the helicopter. This can be seen in figure 20.

The curved arm is used to prevent interference between the handling system and the front wheels of the helicopter. And when it is impractical to use continuous deck rails the entire length of the flight deck, as in the example of the fully stabilised platform (n). The curve reaches around the front wheels to make contact with two points on the underside of the helicopter, from these attachments manoeuvrability is achieved, allowing easy handling of the helicopter.

General Notes

The system chosen must be easily converted to manual operation in the event of an accident, such as hydraulic power loss. So helicopter operations can still be maintained.

Each system specified operates by the use of rails, which appears to be the safest option, as the 3-point, and 5-point wire systems that are presently used seem to be ineffective at higher sea states demanding a large amount of deck crew involvement, so an approach using wires has been considered unsuitable

2.3.2 Attachment Devices

It is essential that the device will provide adequate manoeuvrability, so the helicopter can be retrieved from different landing angles and be set-up for different angles of take-off. Different attachment points and devices are described below:-

1) A device on the helicopter underside below the CG

A device, such as a vertical bar placed on the underside of the helicopter can easily be grabbed by a handling system. It would be advantageous to use the entrapment system that is already connected to this point as part of the deck handling apparatus.

2) For attachment to the front wheel configuration there are three approaches:-

a) Hub Extensions
b) Oleo Connection
c) Towing Arrangement

a) Hub Extensions

A bar attached to either side of the wheel hub is grabbed by the handling mechanism, this allows steerage of the front wheels, with minor addition in weight to the helicopter. Positioning the device so it attaches to both bars would require a remote operator, who could be positioned safe within the hangar.

b) Oleo Connection

The oleo is grabbed above the wheel by the handling system. This requires that the oleo in the vicinity of attachment area to be strengthened, in order to prevent damage. Attachment is made easy because there are no other obstructions at the oleo attachment height, so a wide diameter grab device can be utilised, leading to a full automated system.

c) Towing Arrangement

A towing device is lowered after landing from between the wheels connected to the hub. This is then coupled to the handling device, which steers the front wheels. The system only provides the helicopter with a small addition of weight.

3) Attachment to the Rear Wheels

The rear wheels can be attached to the handling system in similar ways to those adopted by the front wheel configuration, described above. As the system has to attach to two points located off the helicopter centreline, problems may be caused be angled helicopter landing positions to the deck centreline.

Re-arming of the helicopter can easily be carried out by a system, using of the deck mounted rails utilised by the handling system.

3 CONCLUSIONS

This report has provided a large number of different ideas for aiding the landing and handling processes of helicopters on small warships.

The full prediction process utilising the remote scanner has the potential of providing the most accurate 30 second prediction data. To achieve this the most suitable approach would be to scan the sea surface from a large height above the sea (i.e. on an MUAV or balloon). This would allow the use of radar microwave scanning of the sea surface, which is a technology already well recognised, with remote sensing of the sea surface from aircraft and even satellites currently in practise. An alternative is to use lasers in a similar manner, with frequencies harmless to humans.

The use of a radar remote sensing device needs further investigation, with respect to the quality of output for various distances and angles to the sea surface. Also the prediction method applied in the analysis after this stage could be verified by experiment.

The fully active arm provides the pilot with a stable platform with which to lock on to, with the helicopter well clear of the deck. This reduces the risk of damage to the helicopter that could be caused by making contact with an upwardly heaving deck. The pilot is distanced from the ship reference frame, this reduces the effects of perceived helicopter motions caused by the pilot visual fixing upon the constantly moving deck.

There is the possibility of having the system moving to engage the helicopter, which vastly reduces the workload of the helicopter crew. Or alternatively, for the helicopter to move and engage the stabilised platform. It would be suited to installation on existing vessels, also aiding the deck handling of the helicopter.

The air wake in the entrapment region of the helicopter is unknown, one would assume the turbulence to be less than that close to the deck, but verification possibly by wind tunnel testing would prove this, as well as supplying information as to the flow regime up on the helicopter system. This data would be necessary for the calculations of the forces involved to direct the helicopter to the deck.

The fully stabilised platform uses a similar approach to that of the active arm, in that the pilot is distanced for the ship motions. This option clearly needs a high power requirement, combined with the size of the platform and necessity for large flight deck modification is only suitable for newly designed vessels. It has to be an integral part of the vessel, not just an add-on extra. The large area of the platform, relieves pressure for the pilot if landing is to be achieved within a particular area, instead of attempting to attach to a small area outside the pilot field of vision. The power requirements, weight and strength properties of this system need to be assessed, to determine the suitability of this approach.

The deck handling system is dependent upon the entrapment device used. A system using two points of helicopter attachment are needed to provide a turning moment, to assist in the manoeuvring of large, heavy and unagile helicopters. For a system of this type the forces to be encountered need to be assessed, allowing for effects of ship motion, wind and helicopter positioning to be accounted for.

Naval helicopter approach procedures will have to be adapted to accommodate the new systems. They will provide reduced work loads for the pilot, ensuring a safer landing as well as reducing the crew requirements in other associated areas of the entire landing procedure.

The majority of the systems described in this report are suitable, with minor modifications, for the landing, entrapment and deck handling of other types of helicopter with the EH-101 taken as an example in the text, and equally for combination helicopters and fixed wing naval aircraft on larger vessels. The systems are appropriate for many types of naval vessels, from frigates with limited flight deck areas to aircraft carriers, as well as being suitable for a range of civil applications.

4. FUTURE WORK PROPOSALS

a) Airflow Measurements at the Aft Area of the Ship

If the system proposed for the entrapment are to be developed further, then a major factor that affects the design and development will be the air forces developed by the helicopter. Thus a study needs to be initiated to investigate the airflow over the aft part of the ship and the effect of the helicopter in this region.

b) Control Arm Mechanism

A retrofitted system to existing ships to enable an active control arm needs detailed investigation. This will entail the research into the best strategies for the control system, should they be traditional PID (proportional integral differential), H_∞ adaptive controllers, fuzzy logic or neural networked. Each has its own uses but it is not clear at this early stage which will have the 'best' performance.

c) Quiescent Period Prediction

The method proposed in the main document will need proving. This will require the use of efficient algorithms to achieve quick response for the predictive tools available. Each ship will require its motions to be already calculated on board. It is therefore proposed that an enhancement to the ship will be an intelligent system to refine its predictive motions to be updated.

d) Balloon and MUAV

The use of SARs needs to be verified on these types of platforms.

e) New Landing Strategies of Naval Pilots

All of the systems proposed will entail a different landing strategy to be taken. Hence simulator trials followed by full scale ship trials will be needed.

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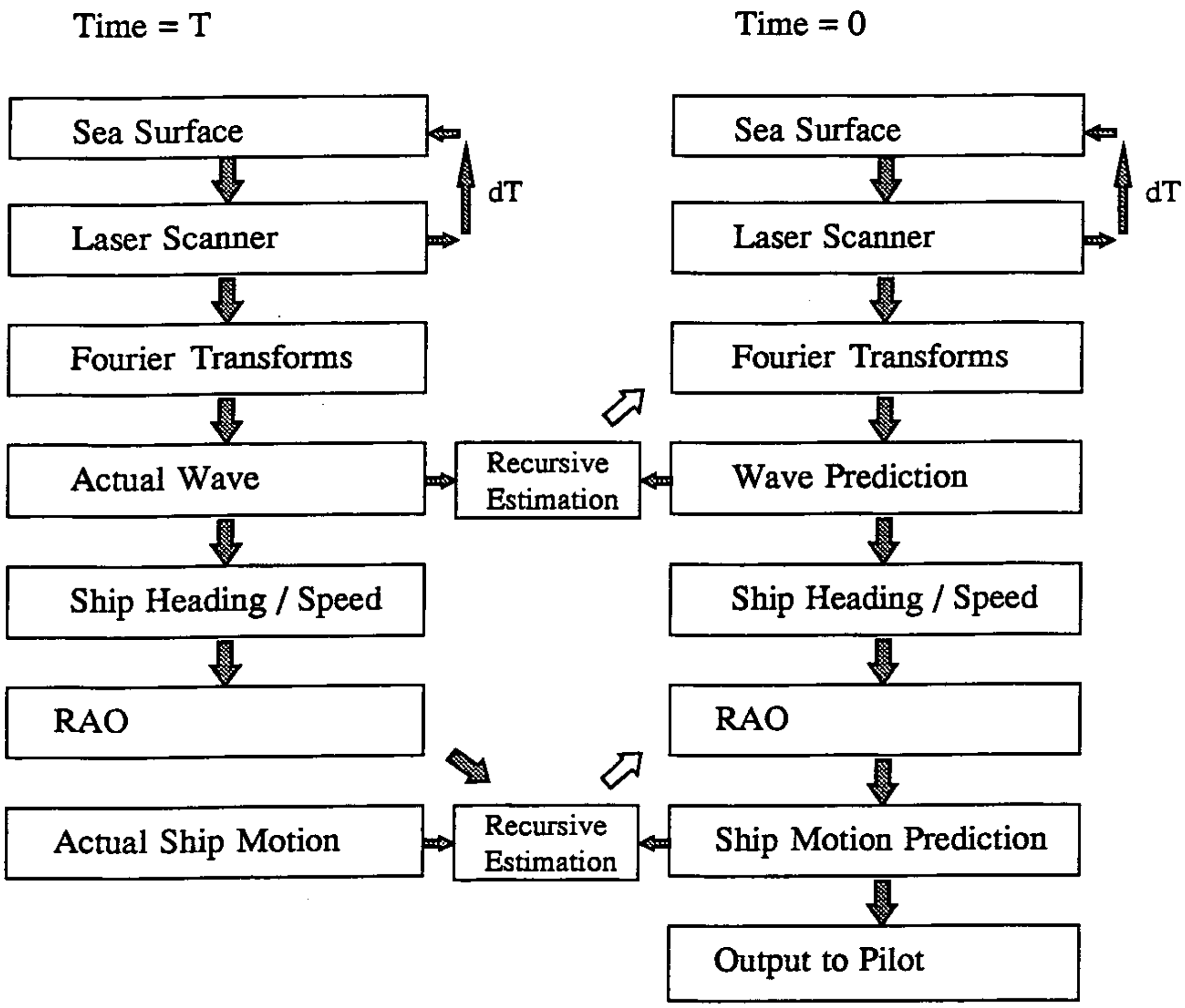
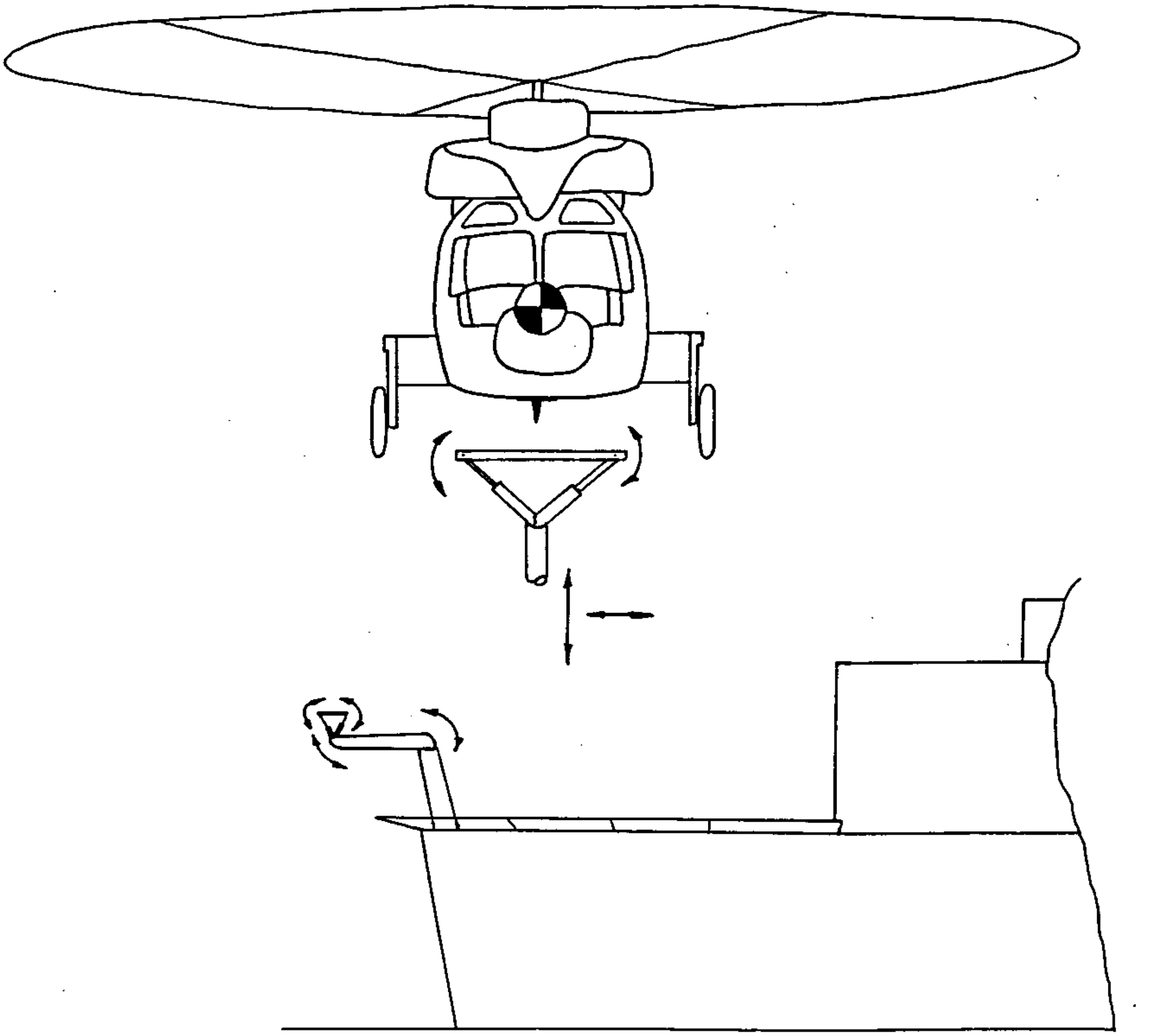
APPENDICES

Figure 1

Diagrammatic Representation of Prediction for Time T



Recursive Estimation — Adapts Fourier Transforms & RAOs for predictions after time T



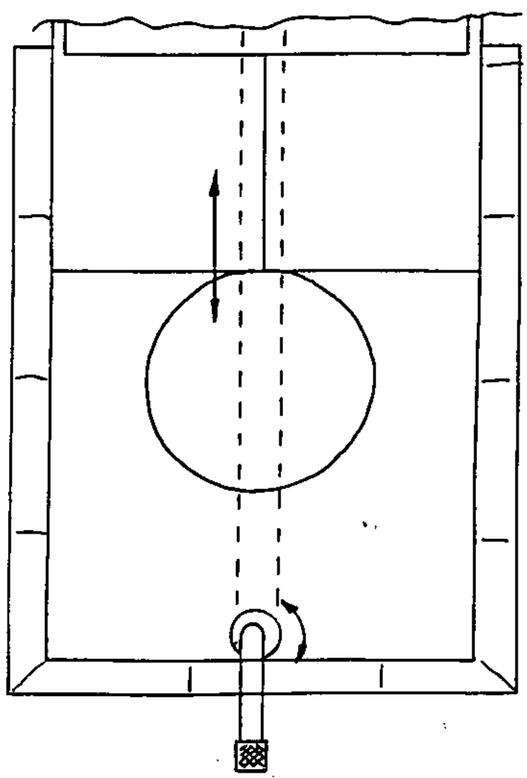


Figure 2 *Fully Active Arm*

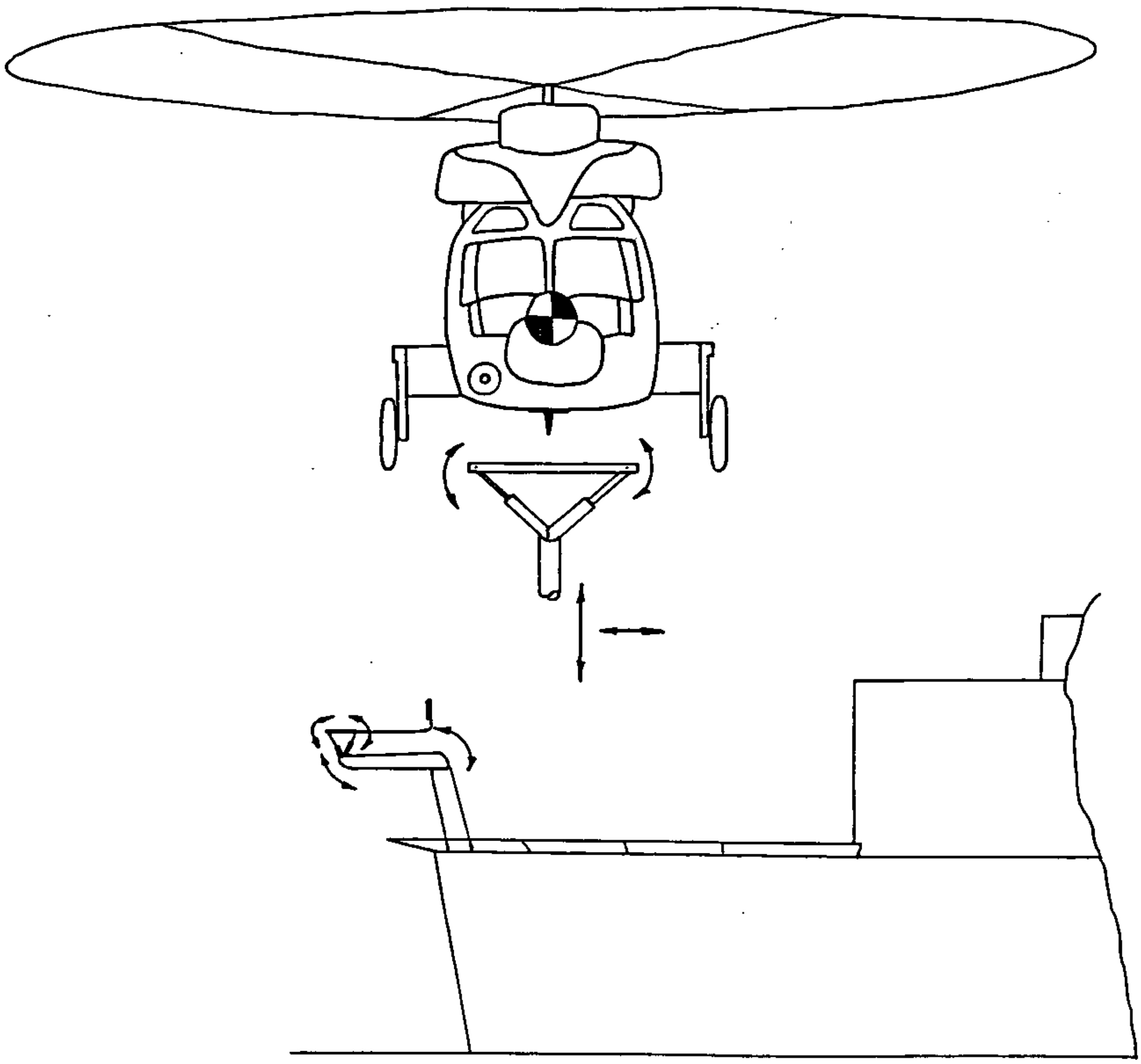
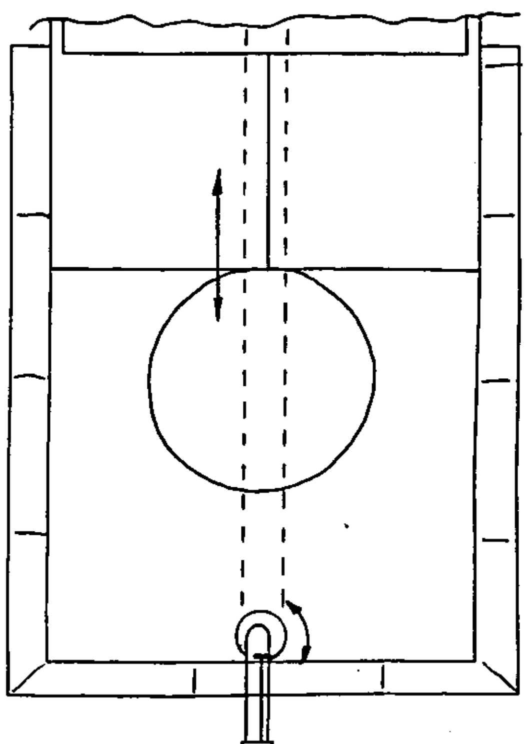


Figure 3 *Active Arm with Positioning Guide*



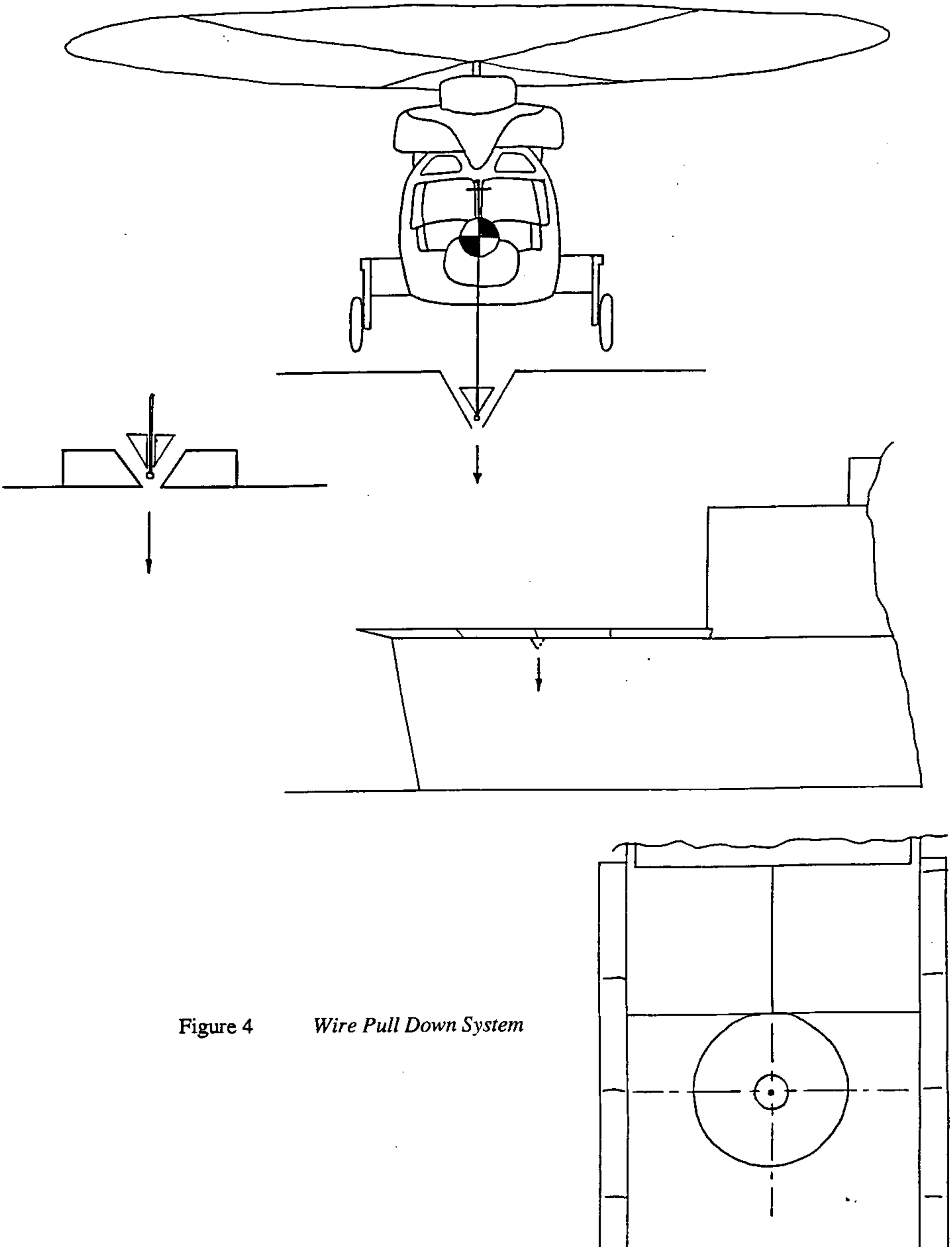
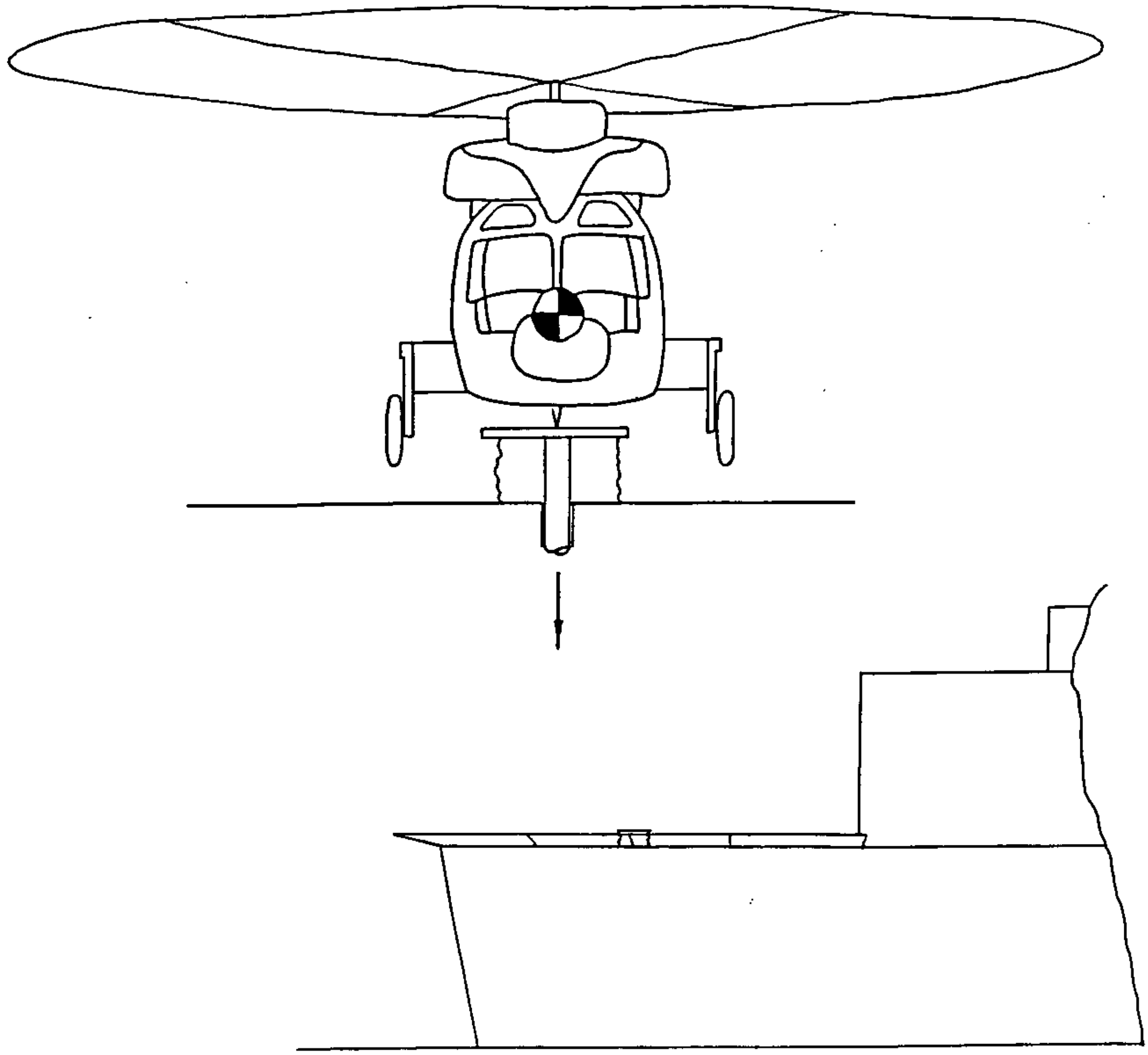


Figure 4 *Wire Pull Down System*



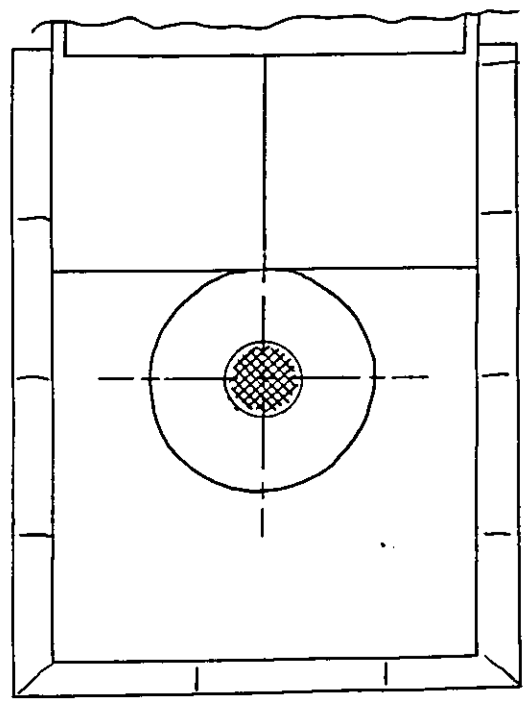
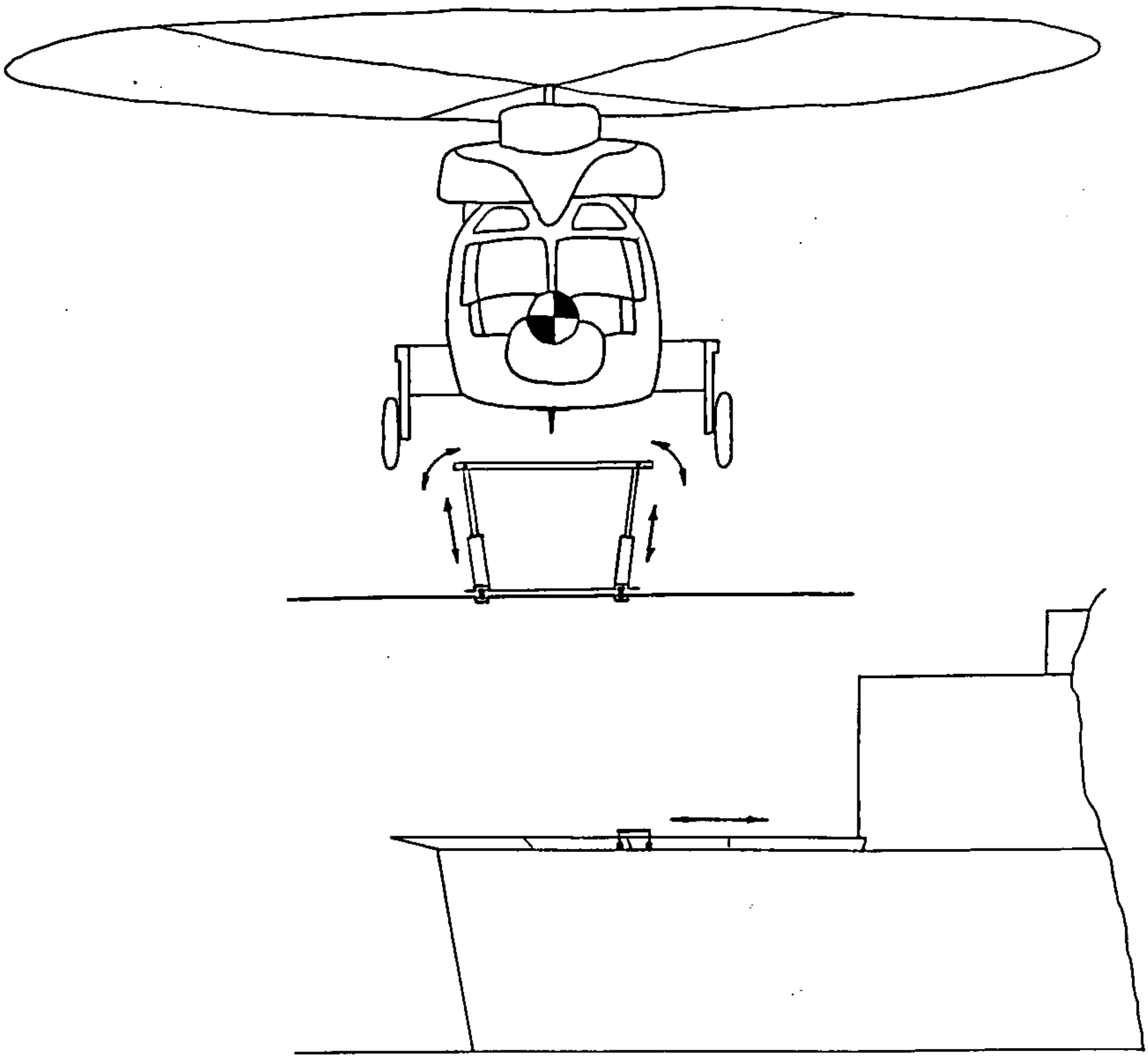


Figure 5 *Bar Pull Down System*



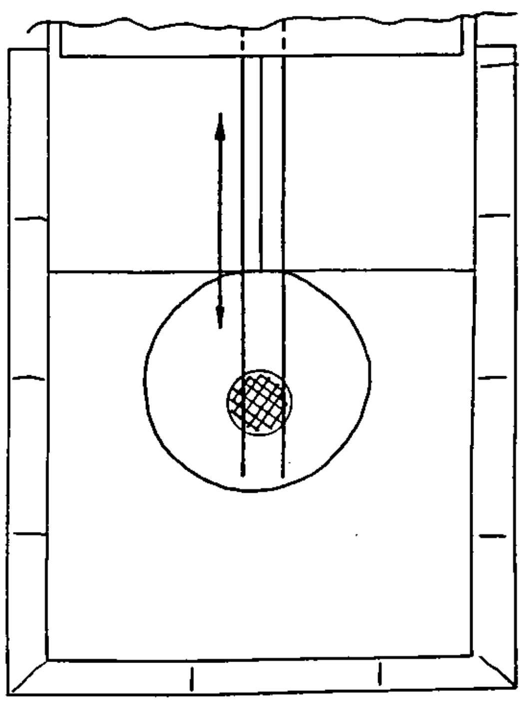
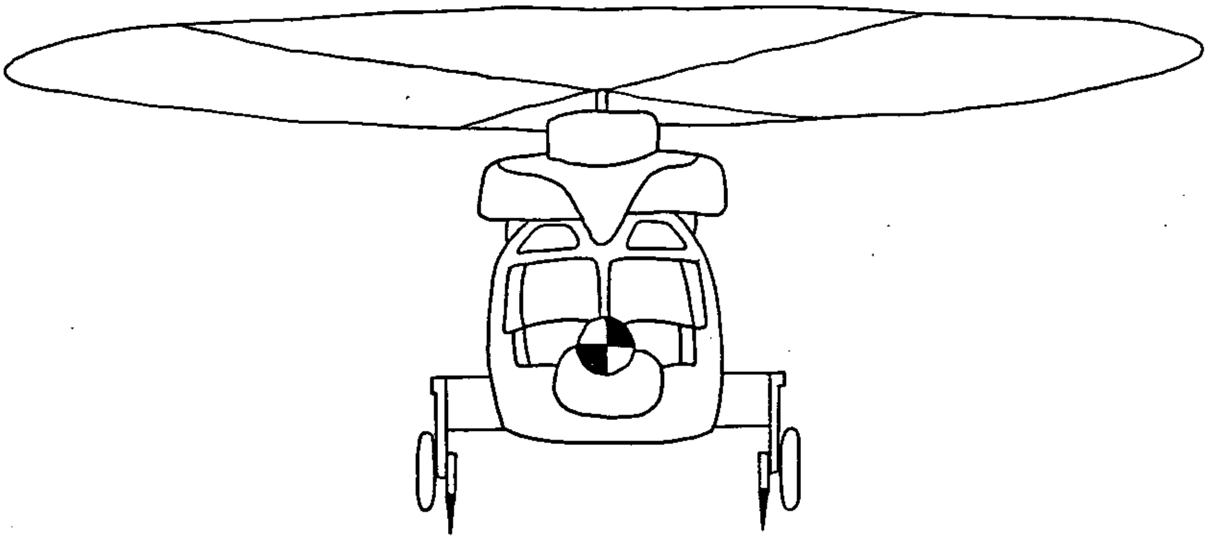
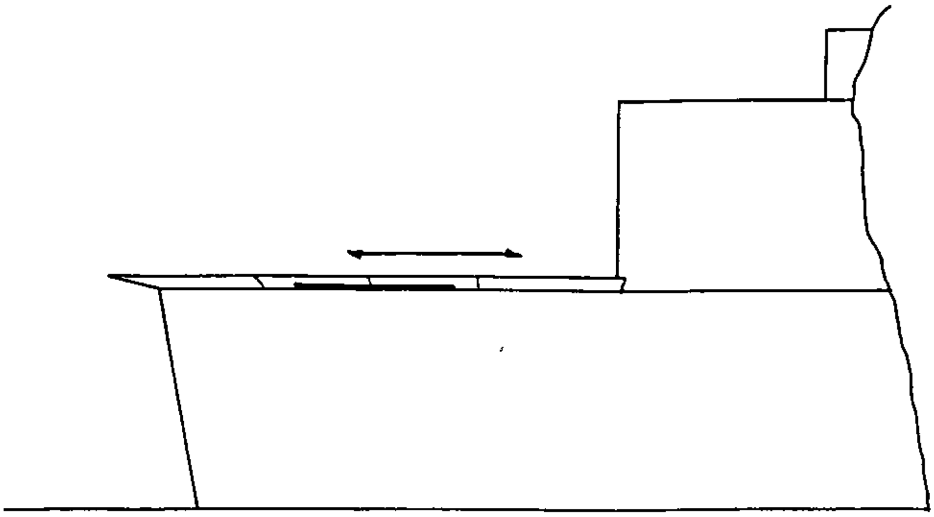


Figure 6 *Raised Harpoon Pad with Hydraulic Damping*





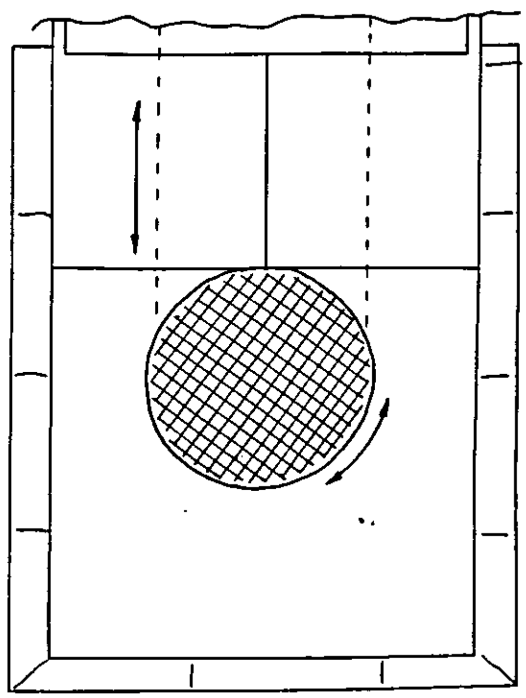
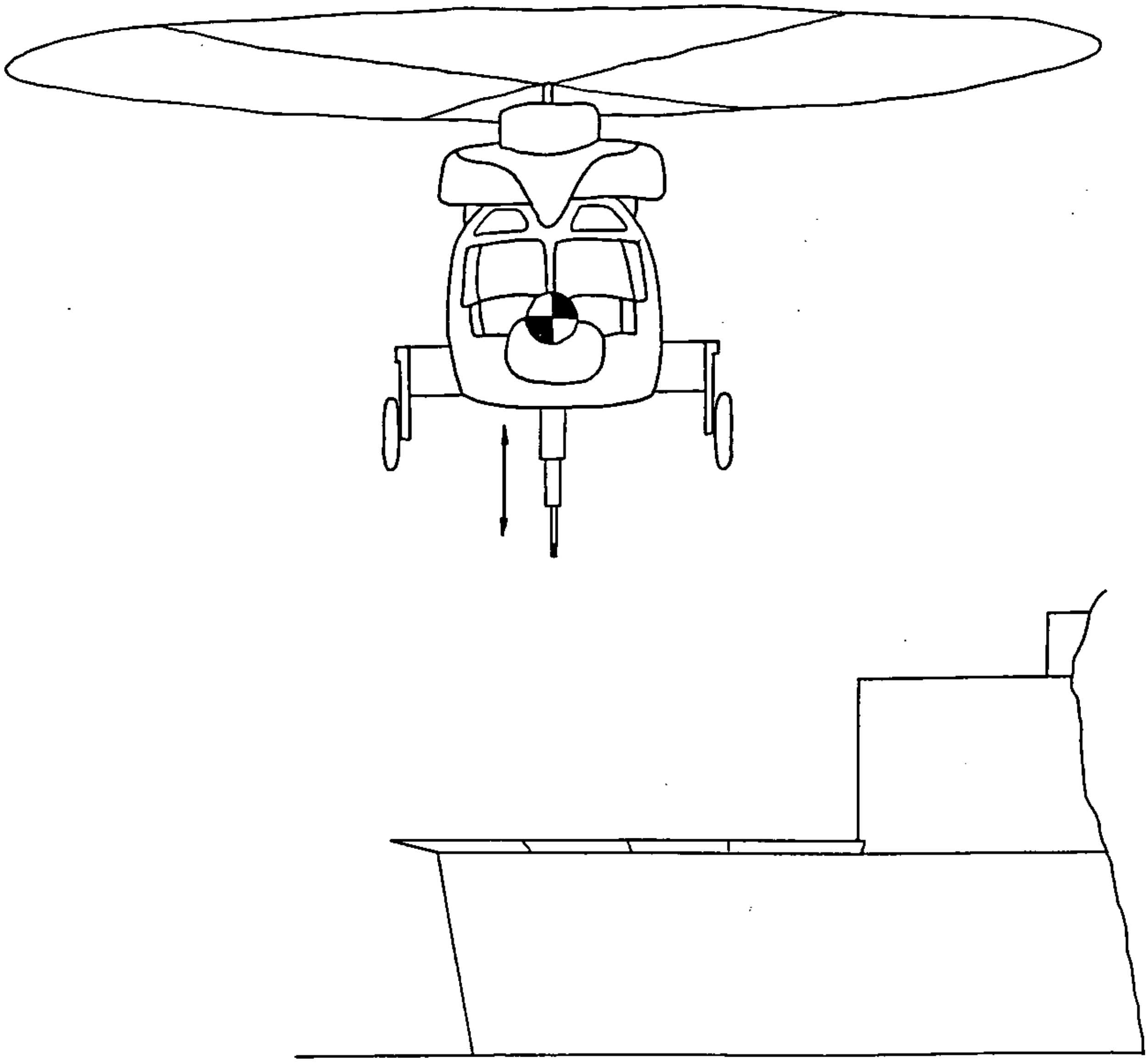


Figure 7 *Large Harpoon Type Grid*



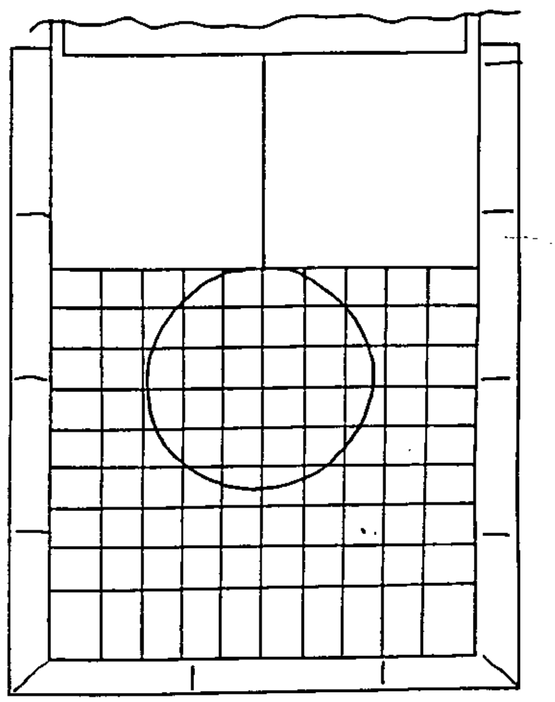
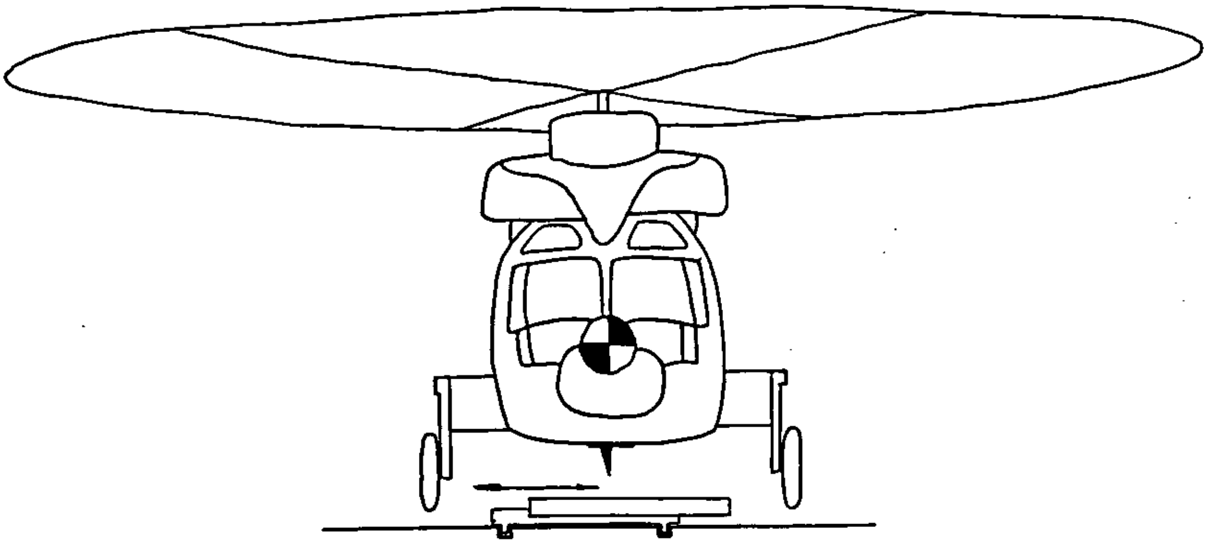
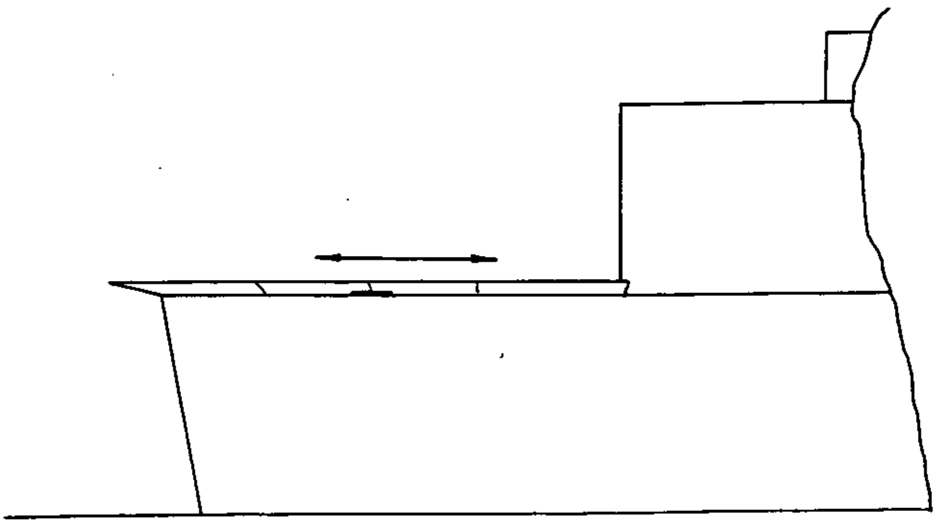


Figure 8 *Aircraft Carrier Wires*





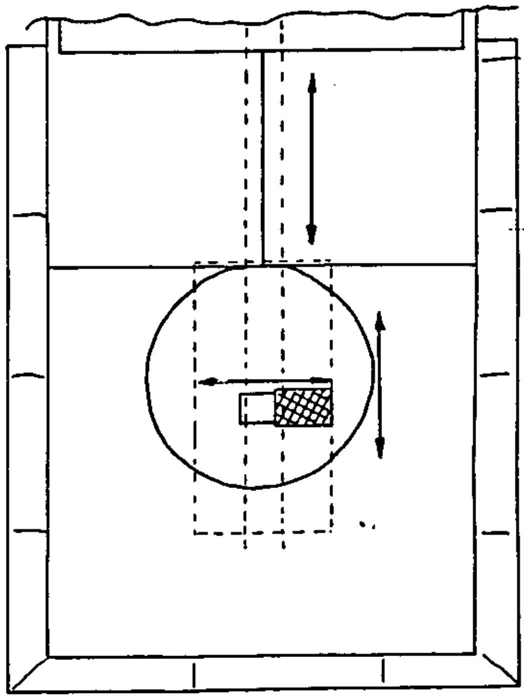


Figure 9 *Translating Harpoon Grid*

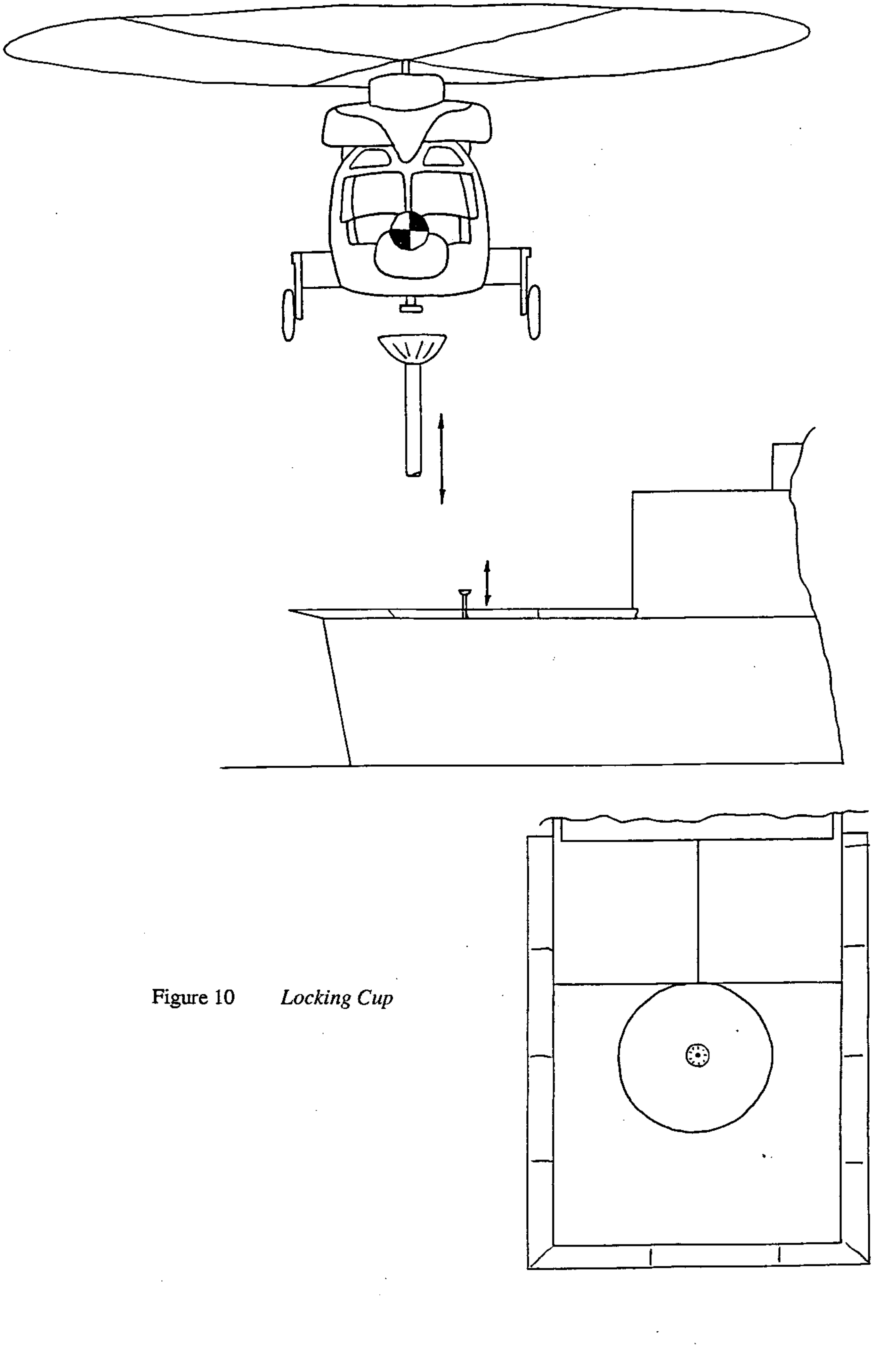
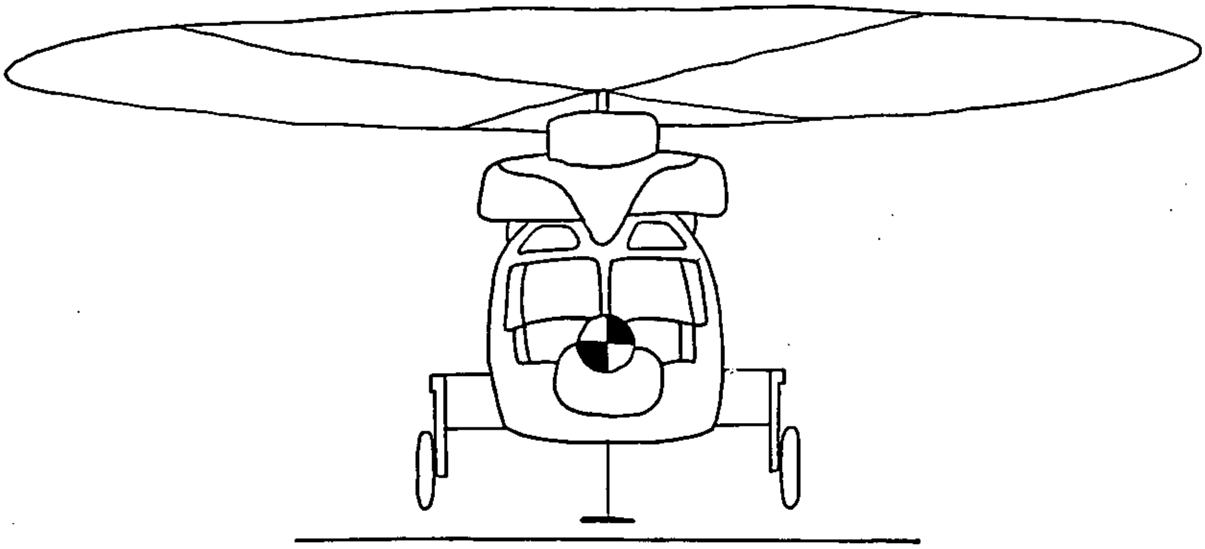
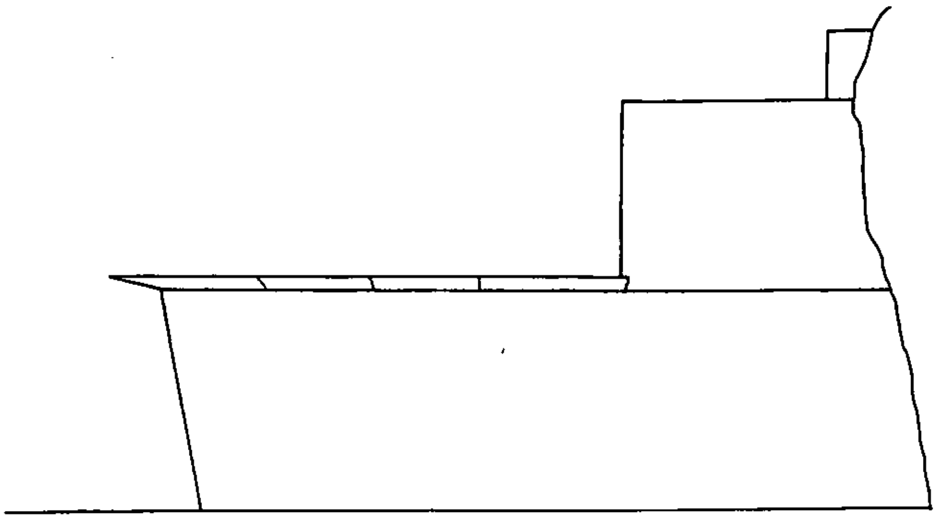


Figure 10 *Locking Cup*





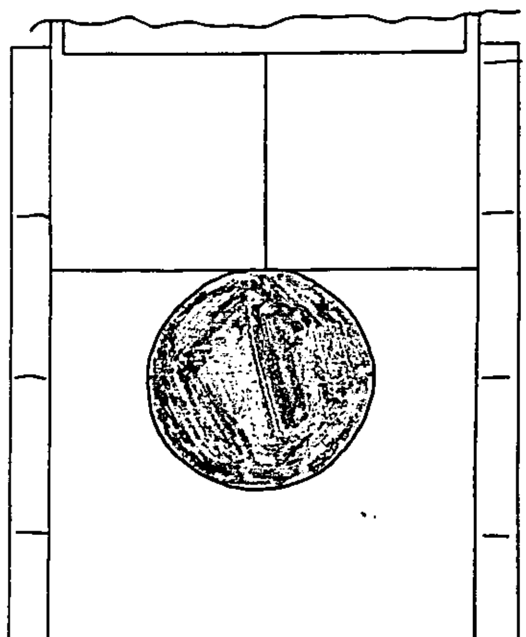
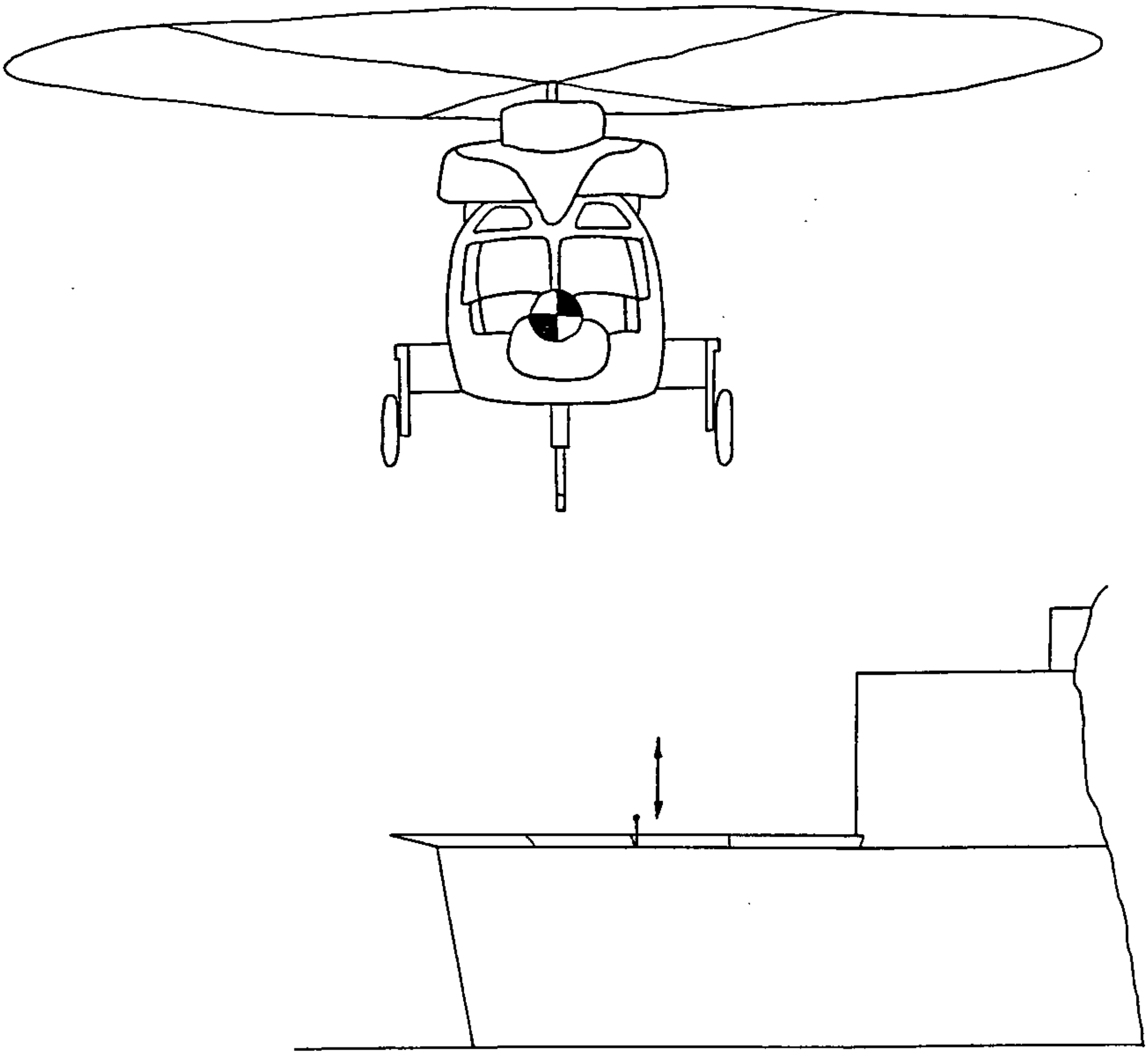


Figure 11 *Magnetic Attachment*



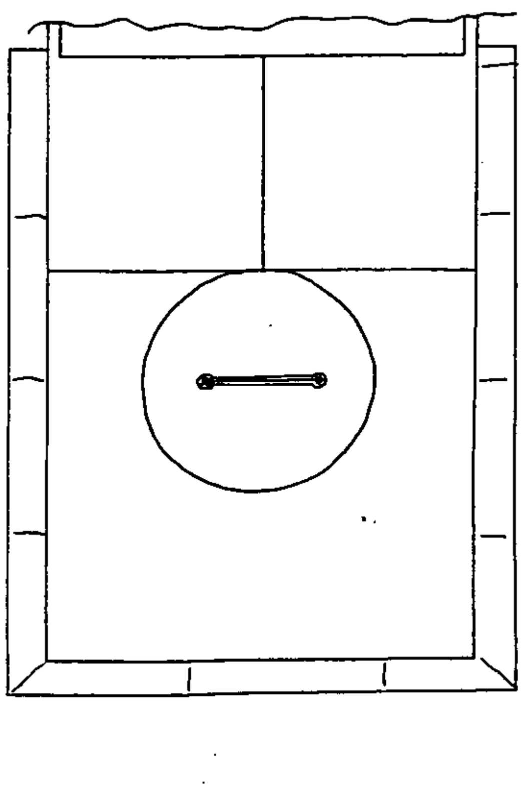
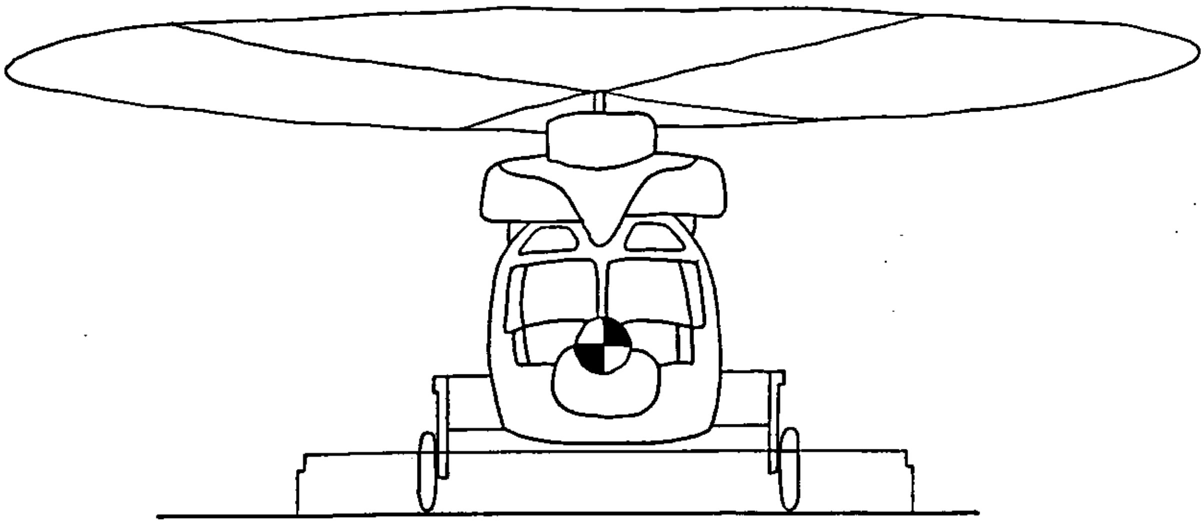
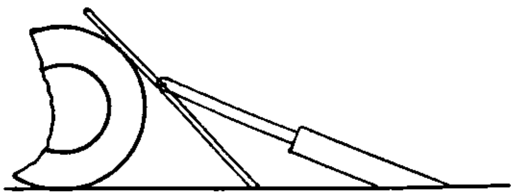
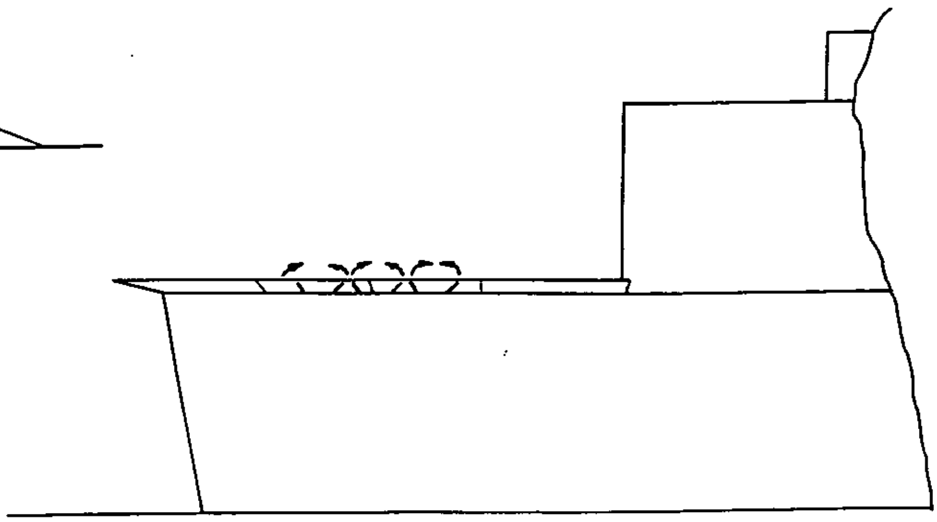


Figure 12 *Drag Hook*







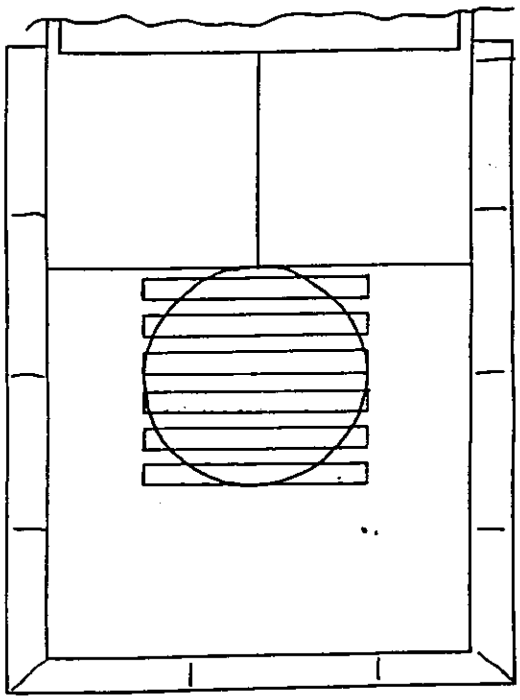
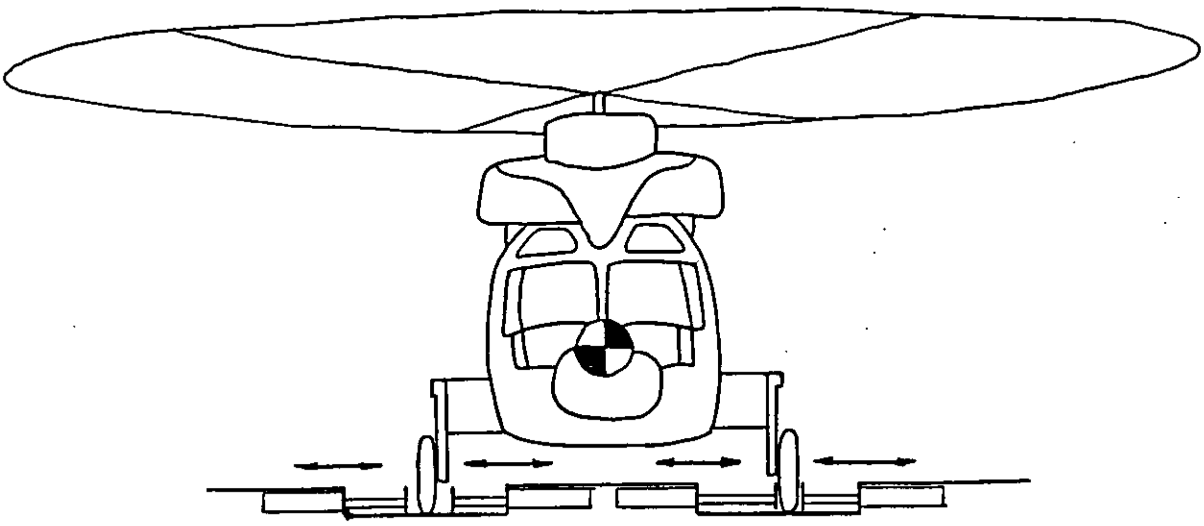
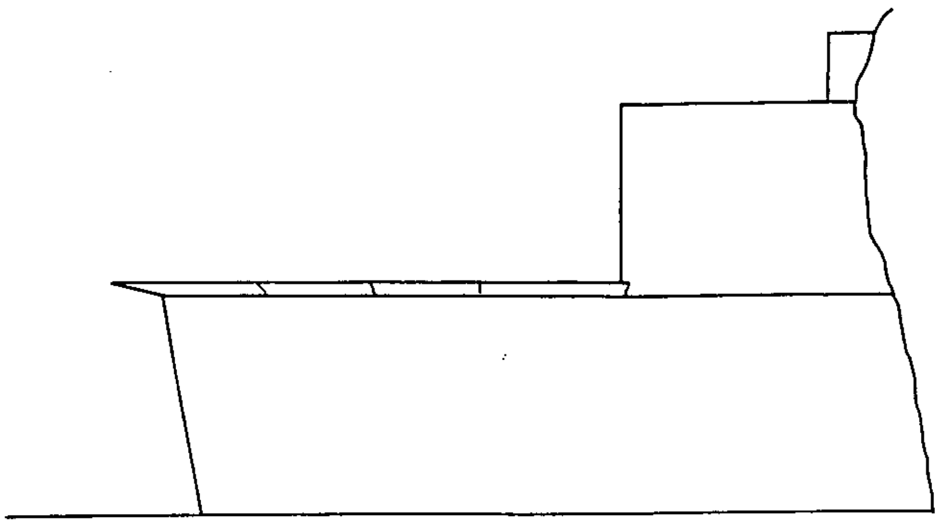


Figure 13 *Wheel Clamping (Longitudinally)*





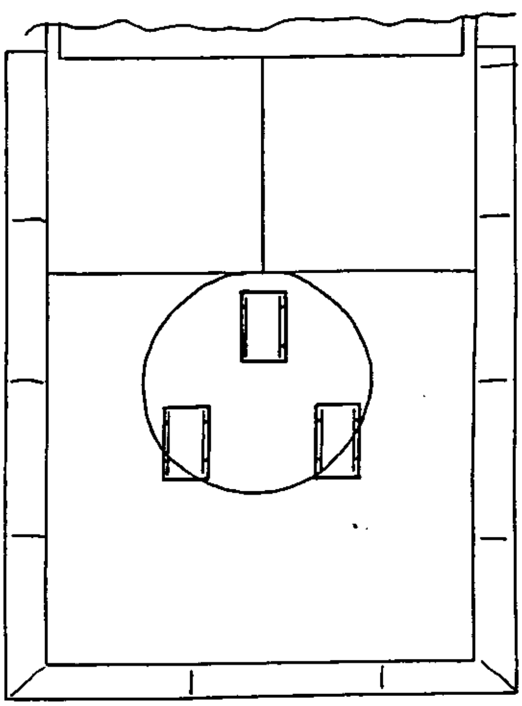
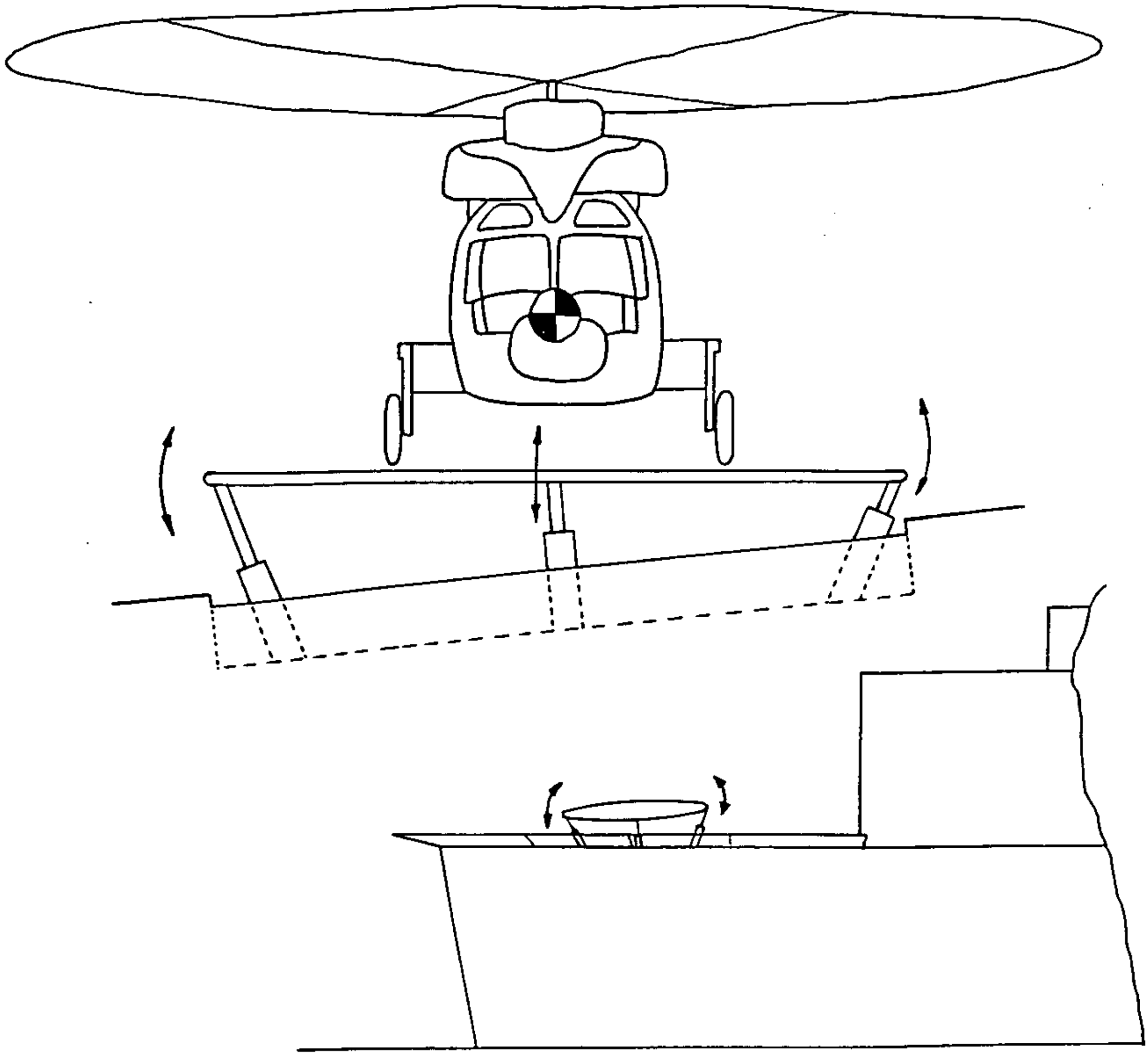


Figure 14 *Wheel Clamping (Transversely)*



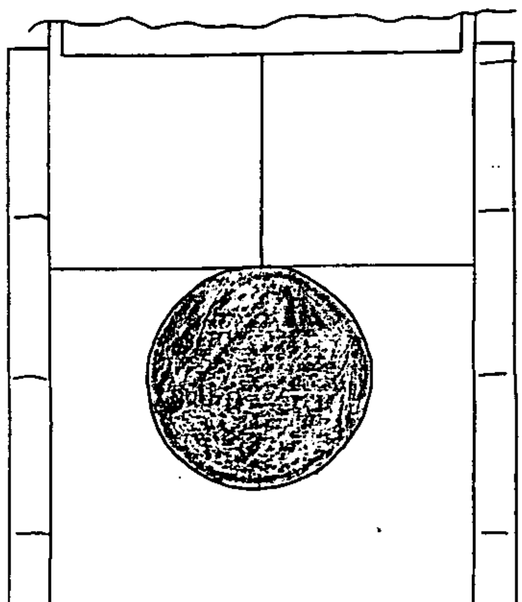


Figure 15 *Fully Stabilised Landing Platform*

Figure 16 *1-point configuration (CG position)*

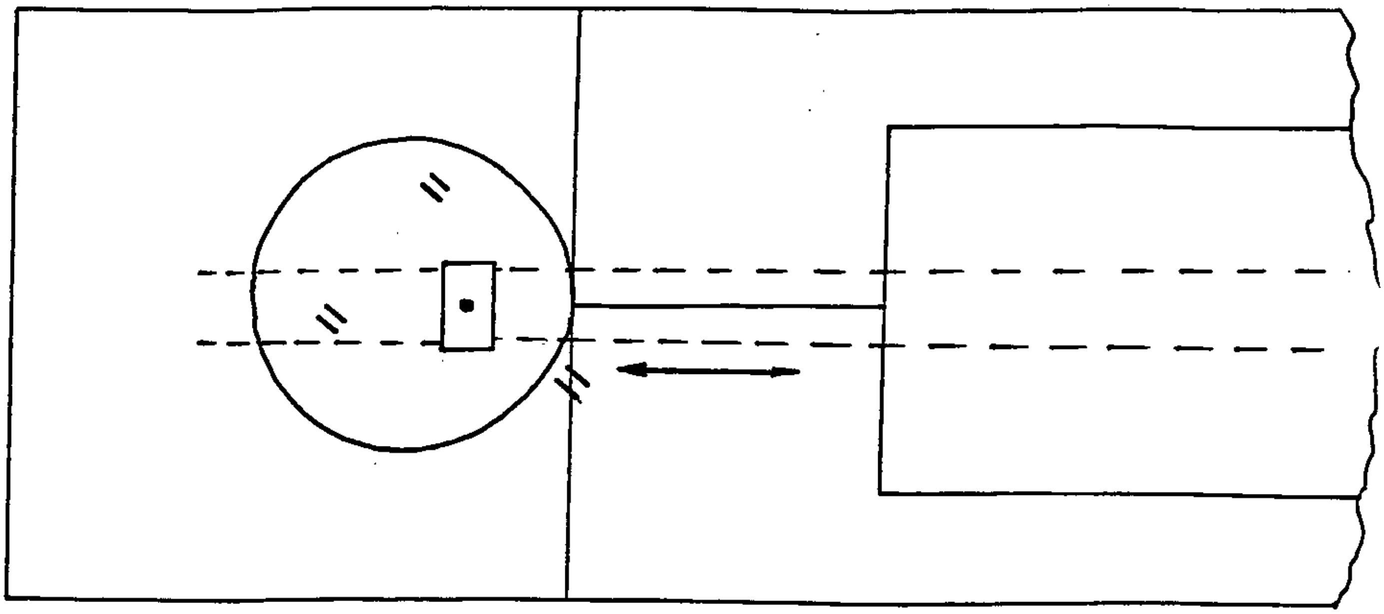


Figure 17 *2-point configuration (CG position and front wheel attachment)*

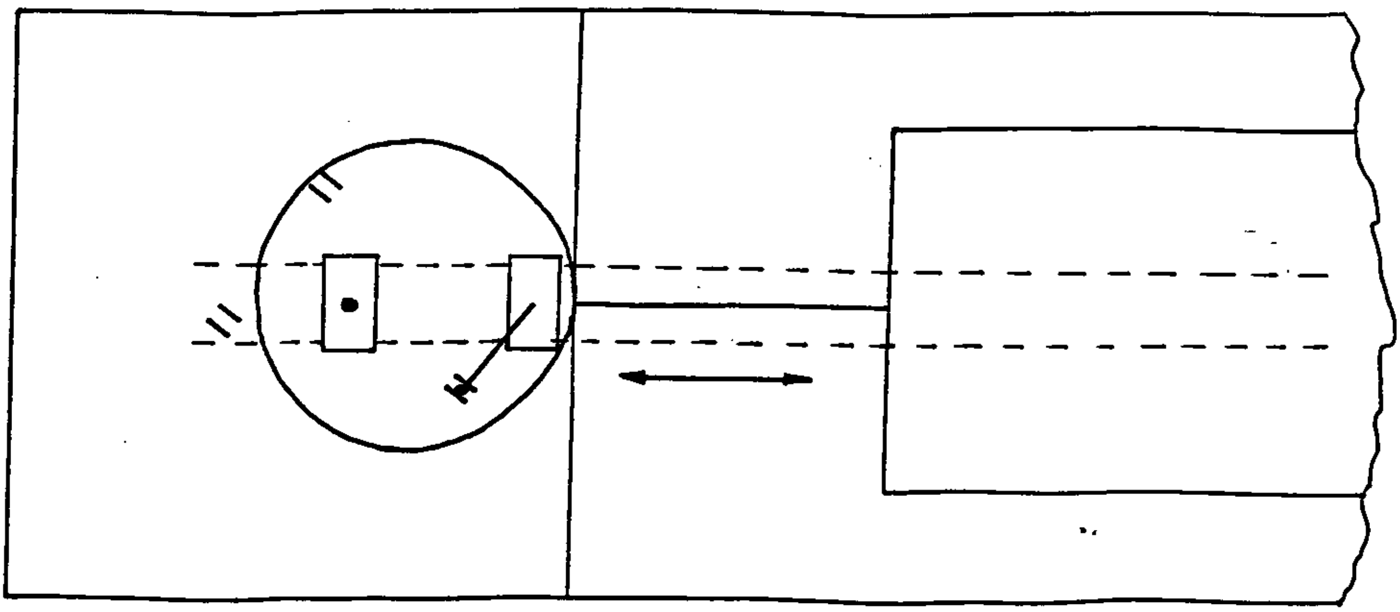


Figure 18 *3-point configuration (front wheel attachment and rear wheel attachment)*

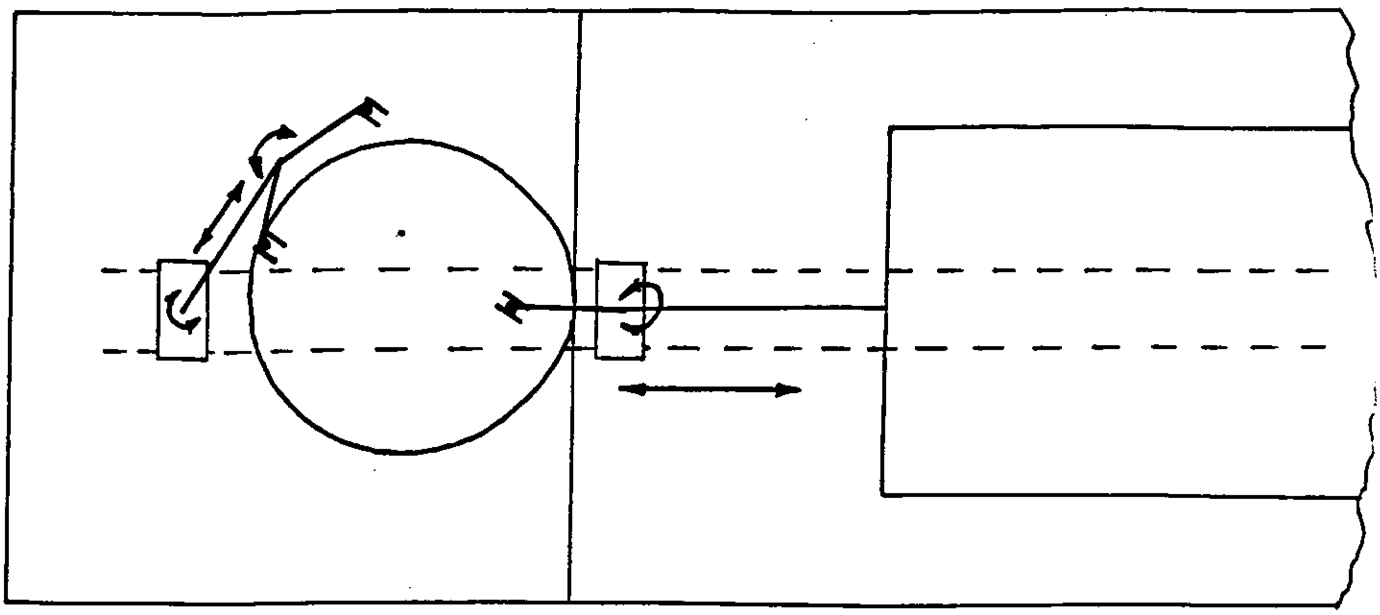


Figure 19 *Rotating and translating platform*

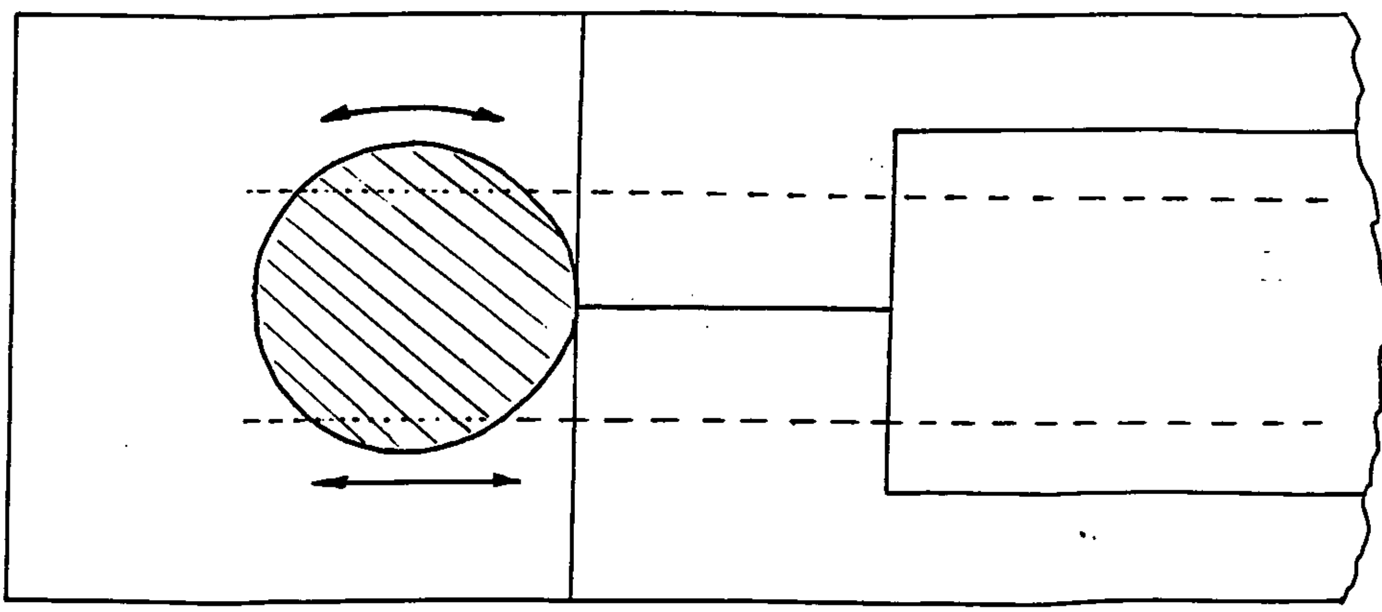


Figure 20 *Curved Arm*