SEA GRANT

RUFAS II
Phase One

by

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INSTITUTE OF ENGINEERING TECHNOLOGY

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REMOTE UNDERWATER FISHERIES ASSESSMENT SYSTEM
(RUFAS II)

A preliminary study of the design variables involved in a towed unmanned observation platform to operate to a depth of 2400 feet.

by

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ABSTRACT

This report is the result of a preliminary study of the design variables involved in a towed unmanned observation platform to operate to a depth of 2400 feet.

The system consists of three basic parts:

1. The underwater remote observation vehicle. The vehicle will weigh about 1000 pounds and will be approximately 11 feet long, 5.5 feet wide and 3.5 feet tall. This assembly includes control surfaces - with a control loop to maintain either a constant height above bottom or a constant depth. It also includes a television camera with a pan and tilt mechanism and lighting, a forward looking sonar for obstacle avoidance, and provisions for additional underwater instrumentation.
2. The control console on board a tow ship. The control console includes sled attitude controls, lighting controls, camera controls, television monitors, video tape recorders, depth and attitude monitors, control signal coders, and telemetry transducers.
3. The interconnecting cable. The underwater vehicle is connected to the control console by an armored four conductor cable with two power conductors and two coaxial conductors. One coax is used for the television and one

for the telemetry commands and data signals up and down the cable. A slip ring winch is employed.

The development of this system follows the successful design, development, and operation of a shallow water (50 fathoms) Remote Underwater Fisheries Assessment System (RUFAS) by the National Marine Fisheries Service.

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ILLUSTRATIONS

1. INTRODUCTION

The National Marine Fisheries Service, Pascagoula, Mississippi, has successfully field tested a remote controlled, underwater vehicle called RUFAS (Remote Underwater Fishery Assessment System). The towed sled is vane controlled and senses roll, pitch, and height above bottom, which allows an operator aboard the towing vessel to position the sled to the desired altitude above the sea bed.

Underwater lights, a motion picture camera, and a TV camera with video tape recorder allow rapid and accurate sea bottom resource assessment in waters of up to 50 fathoms depth. RUFAS was developed to accomplish the single objective of assessing calico scallops in their natural habitat. The successful accomplishment of this objective proved the value of an unmanned, controlled underwater vehicle for rapid bottom resource survey. A photograph of the RUFAS I vehicle is shown in Figure 1. Additional information and photographs of the RUFAS I system may be found in the Appendix.

It is apparent that by expanding the concept of an unmanned survey vehicle many applications can be found for it. Because of the uniqueness of its mission, RUFAS I was designed for shallow water, near bottom operation and its flexibility of operation is limited. Expanding the capabilities of a RUFAS-type vehicle to accomplish the bottom survey in both deep and shallow water would prove invaluable. The ability to conduct midwater resource surveys in the 0-600 feet range is also desirable.

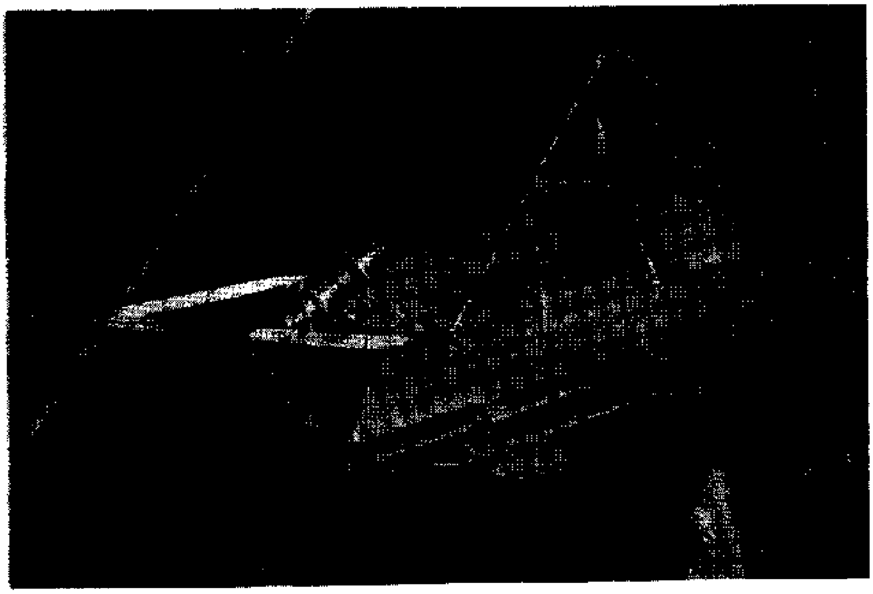

Figure 1a. RUFAS I vehicle view from above

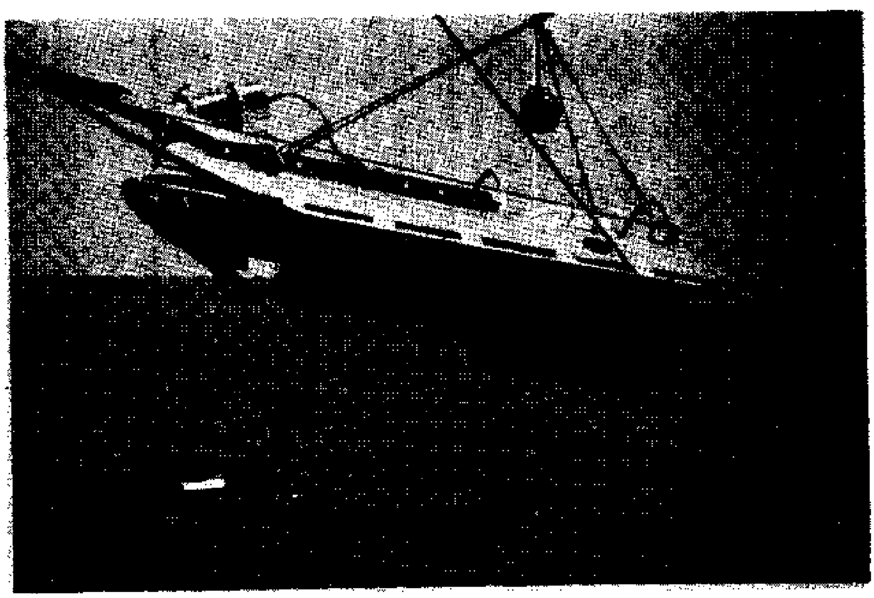

Figure 1b. RUFAS I vehicle view from below

These are two distinctively different applications and require a conceptual evaluation to determine whether it is necessary to design two vehicles - one for bottom and midwater shallow use and one for deep water bottom surveys - or whether it is feasible to design one vehicle to accomplish both objectives.

The National Marine Fisheries Service approached the Mississippi State University Engineering and Industrial Research Station through the University's Institute of Engineering Technology for a three phase, technical assistance program leading to the design, development, and testing of a functional RUFAS II system. Phase one of this technical assistance program is aimed at the development and evaluation of engineering design criteria that would result in the formulation of a detailed design of the RUFAS II system. Phase two of the program involves the acquisition of components, fabrication and assembly of system hardware, terminating with the production of a functional RUFAS II system. Phase three consists of a sea trial evaluation (using National Marine Fisheries vessels and crews) and hardware modification as required for completion of an operational RUFAS II system.

The National Marine Fisheries Service has supplied the Institute of Engineering Technology with their desired operational capabilities and performance criteria for the RUFAS II system. These operational capabilities which are outlined below establish preliminary design criteria. The handling, control, data acquisition, cable design, and other vehicle functions differ between a shallow water and deep water vehicle. These functions and systems could either be designed within the modular system concept for the two depth range applications or two separate vehicle designs. The initial concept breakdown is organized around the single vehicle, two depth range modular concept.

1.1 System Capabilities Desired for RUFAS II

I. Shallow water, 0-100 fathoms, functional requirements

A. Maneuverability to conduct any midwater resource survey or observation of fishing gear, trawls, oceanographic hardware, etc.

1) Vertical control and positioning required over a 50 fathom range

2) Lateral control restricted to function within given cable arc

3) Towing speed for bottom surveys no greater than 2½ knots; towing speed for midwater surveys up to 5 knots

B. Bottom and midwater viewing for explorations to 100 fathoms

1) TV cameras

a) Pan and tilt for bottom viewing and midwater scanning

b) Video tape recording

c) Wide-angle high resolution image

d) Low light sensitivity capabilities

2) Movie and still camera modules

a) 35 mm negative format

b) Steroscopic photography

3) Lighting systems as required for mission objectives

a) Flood lamps

b) Strobe lamps

4) Echo ranging equipment

a) A directional receiver on RUFAS II for locating fishing equipment, etc.

b) Forward looking sonar for obstacle warning and avoidance

II. Deep water, 100-400 fathoms, functional requirements

A. Maneuverability to conduct bottom surveys down to 400 fathoms

1) Vertical maneuverability from bottom to 25 fathoms above bottom for survey and obstacle avoidance

2) Forward looking sonar for obstacle warning

3) Towing speed from 1 to 2½ knots

4) Operation with cable lengths as required to achieve design depth

B. Bottom viewing and explorations in 100 to 400 fathoms range

1) TV cameras

    a) Pan and tilt for bottom viewing and scanning

    b) Video tape recording

    c) Low light sensitivity capabilities

2) Movie and still camera modules

    a) 35 mm negative format

    b) Steroscopic photography

3) Lighting systems as required for mission objectives

1.2 Systems Concept

RUFAS II is considered an extension of RUFAS I with increased depth capability: 400 fathoms, necessitating stronger pressure vessels and a much more complete towing system.

The value of an operational RUFAS II in gathering data required for better definition of resources of the continental shelf and slope out to 2400 feet is not difficult to visualize. The amount of information that could be gathered may well be useful to more segments of the marine community than those merely associated with biological resources. Geology and mineral resources could be revealed as well as various physical oceanography phenomena.

The chief difference between RUFAS I and RUFAS II is in the deeper operating capability and increased flexibility of the latter. The 400 fathom depth requirements demands stronger pressure vessels and a much longer cable presenting critical design requirements around which the whole vehicle-cable-winch system must be designed.

There is a great interdependence of variables associated with this system. For instance, cable size will first be determined by the electrical requirements for power, communication, and control. Next, structural requirements will depend upon vehicle drag, cable drag, cable immersed weight, and shock loads from ship motion, etc. Cable weight, lift, and drag, will in turn, influence the angle and curve of the cable, which is very important if the vehicle is to have the required maneuverability for bottom surveillance.

A considerable part of the design effort was required to achieve a workable preliminary balance of the vehicle-cable-winch system variables for operation at full depth. A more refined balance will require developmental work by full scale operation of the system. Preliminary estimates indicate the towed configuration is feasible and will operate at the proposed depth. Greater depth might bring the balance in favor of an independent self-propelled vehicle with acoustic telemetry.

This report presents results of the first four months of a design study conducted by the Institute of Engineering Technology. This study has been devoted to:

1) The gathering of technical data on available instrumentation suitable for the RUFAS II system.
2) Scale model testing to determine the suitability of proposed RUFAS II mechanical configurations.
3) An extensive study of the tow cable dynamics to determine type and length of cable required for the RUFAS II system

and the limitations to the system imposed by the cable.

4) System design of a telemetry system to carry data and commands between RUFAS II and the towing vessel.

5) System design of an altitude control loop to automatically maintain a preset height above the sea bed.

6) Study of operational procedures, deck handling equipment, requirements for the towing vessel, operator's controls and console, and related studies.

2. VEHICLE MODEL STUDIES

Two distinctly different models of RUFAS II, A and B, have been constructed and evaluated during the course of this project. The equipment listed below was selected in the early stages of the project and the original arrangement of this equipment on a sled was used to build Model II A-1.

RUFAS Equipment

1) Obstacle avoidance sonar with rotating head mounted on a cylindrical base
2) Submersible still camera with 400 picture capacity
3) Associated cylindrical strobe light
4) Pan and tilt mounting for TV camera and associated thallium-iodide light
5) A water tight cylinder for electrical, attitude and control equipment

This model was made of 3/8" dowling and shaped wooden blocks with balsa panelling and was ballasted to have negative buoyance. Details of the model construction may be seen in Figure 2.

A sketch of RUFAS II A is shown in Figure 3. As can be seen the towing bridle spanned the beam of the model and several locations for its attachment were provided. Two sets of control surfaces were evaluated.

The first set of control surfaces were semibalanced double plate with blunt after ends (Model II A-1). Later a second set of control surfaces with unbalanced single plates hinged at the forward edge (Model II A-2) were tested. The slow towing speeds reduced the need for streamlining and horizontal side planes, together with support legs, provided enough surface to give directional stability.

The test program, carried out in the university swimming pool was adequate to demonstrate that both models, II A-1 and II A-2, were stable in the direction being towed as well as in roll and pitch. There were no undesired excursions in any direction. The climbing and diving action of the two models was satisfactory for II A-1 and excellent for II A-2. The model was towed at the end of a rubber covered wire that scaled the anticipated prototype towing cable. Some photographs of the model testing are shown in Figures 4 and 5. Tow wire was attached to an aluminum pipe carried by members of the design team. Model speeds of three to five feet per second approximated actual towing speeds of the prototype.

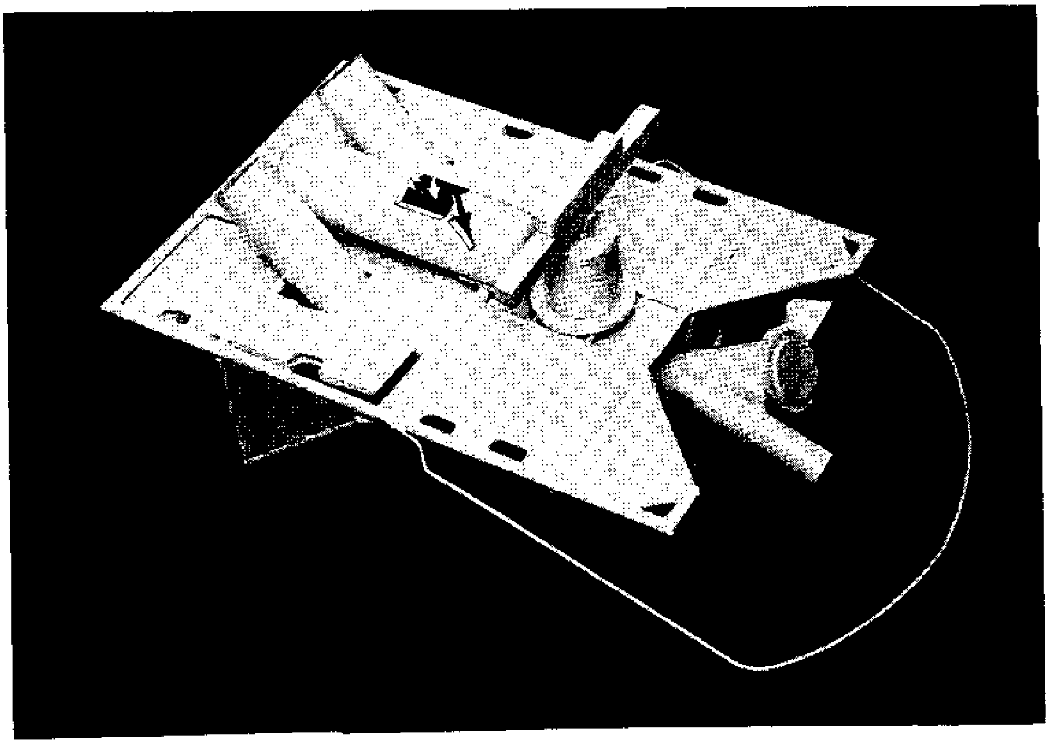

Figure 2a. Photograph of RUFAS II A-1 model top view

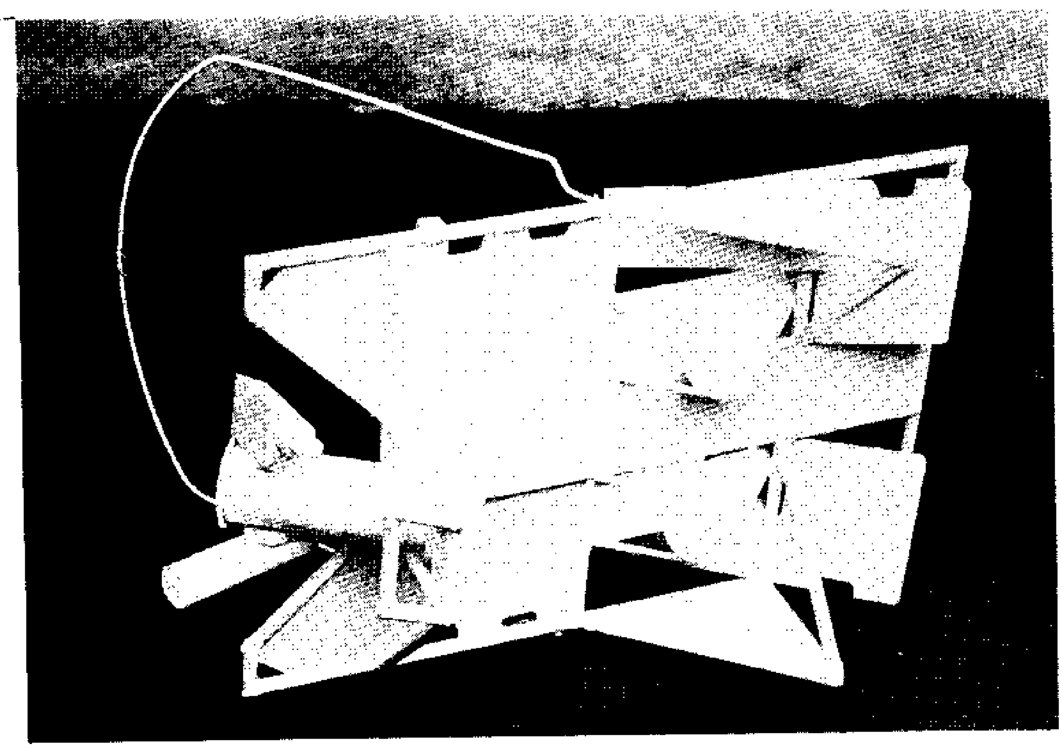

Figure 2b. Photograph of RUFAS II A-1 model bottom view

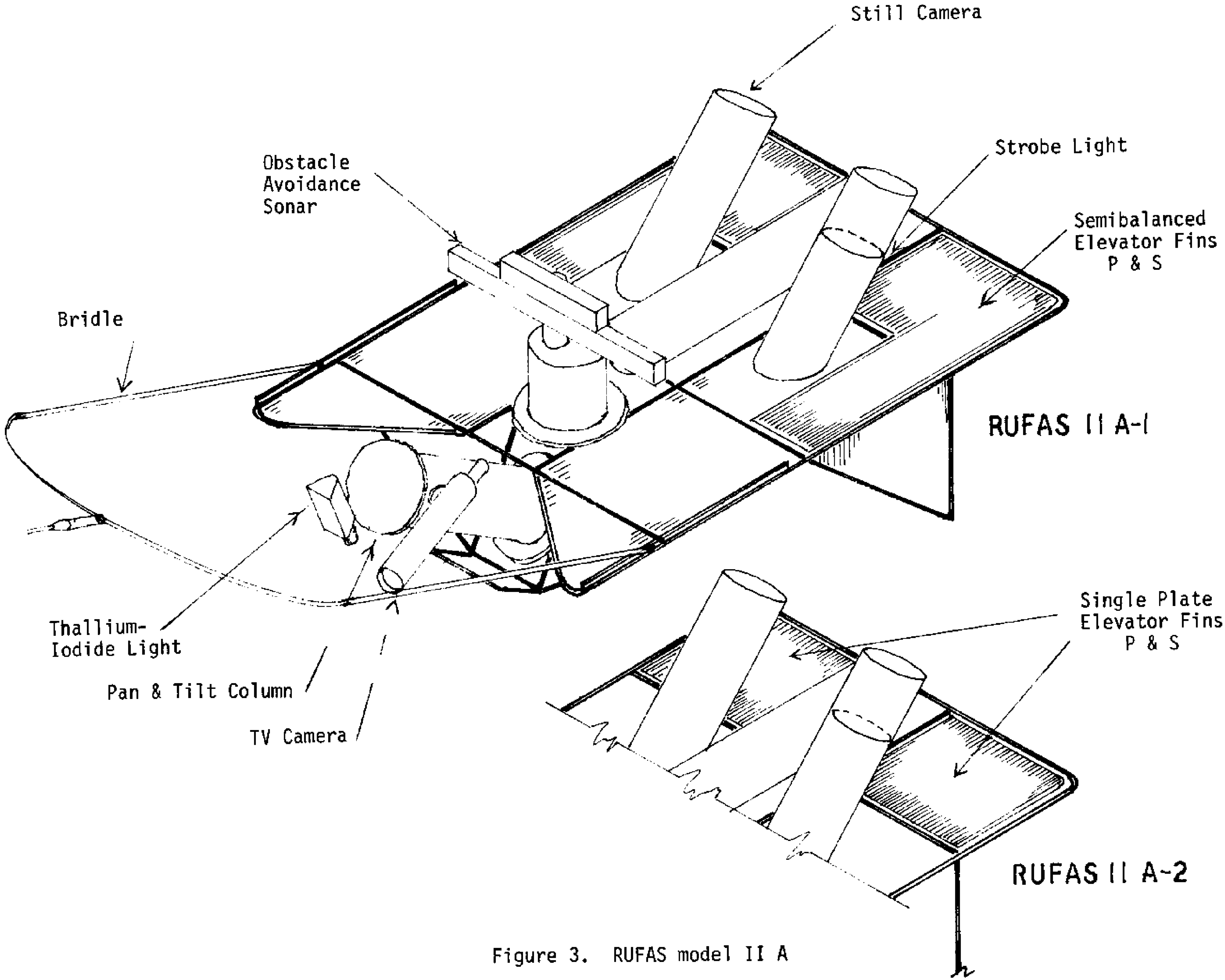

Figure 3. RUFAS model II A

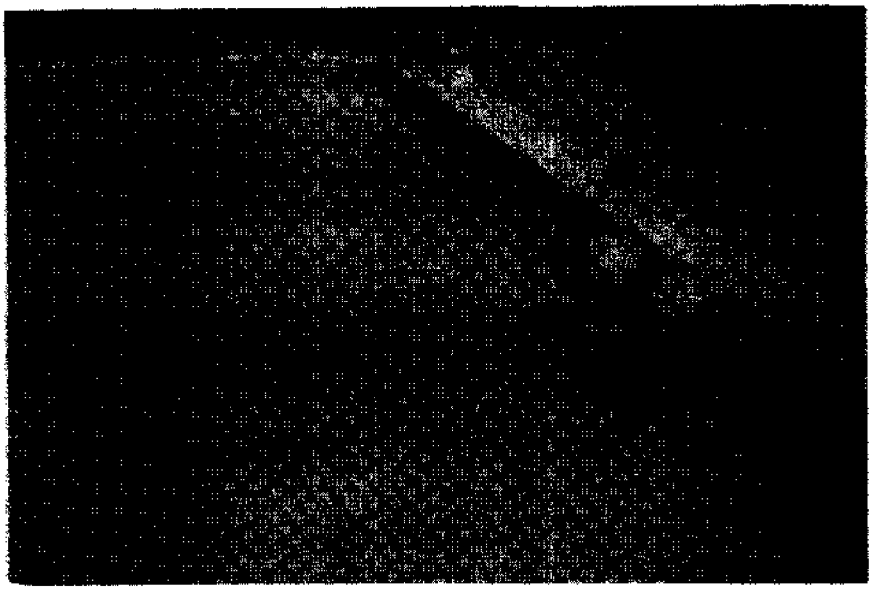

Figure 4a. RUFAS II A model at rest in preparation for a test tow

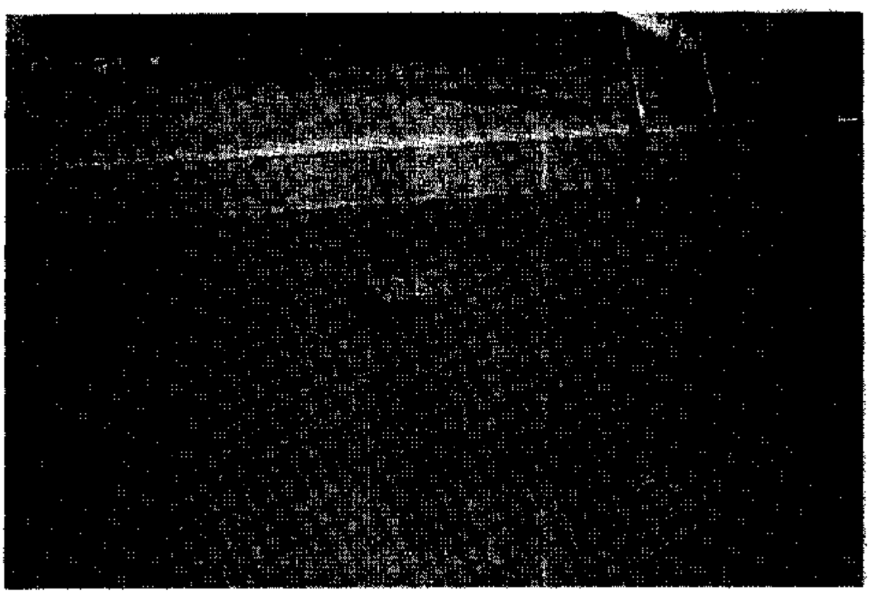

Figure 4b. RUFAS II A model undertow

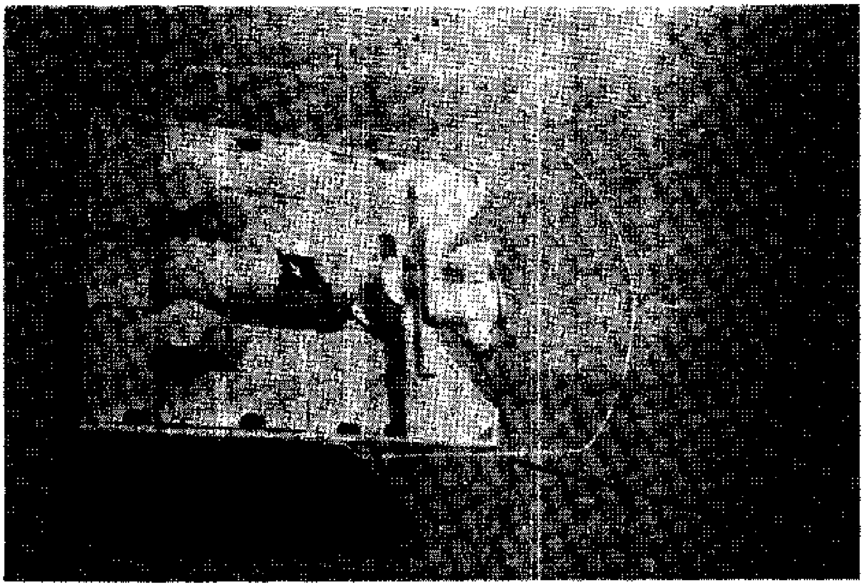

Figure 5a. Close-up view of RUFAS II A model undertow

Figure 5b. Adjustment of the model's elevator fins being made by design team member - tow yoke position was also adjustable

Model II A-2 having the elevator fins set one up and one down demonstrated the ability to change course. An attempt to purposely overturn the models underwater was unsuccessful thereby demonstrating the value of having distinct distance between the center of gravity and the center of buoyancy of the vehicle, the latter being the higher. When the obstacle avoidance sonar and pan and tilt were positioned off center there was a distinct tendency for the model to drift to either side. TV tape recordings were made of the model testing.

As a net result of testing RUFAS II A-1 and II A-2, the following conclusions were drawn:

1) The model was sufficiently stable.
2) The flat plate elevator fins gave superior dive and climb capability.
3) Unbalanced flow from off-center settings of pan and tilt and obstacle avoidance sonar cause the model to drift off course.
4) It is necessary to insure that the vehicle center of gravity is below the vehicle center of buoyancy.

2.1 Equipment Configuration

Reassessment of initial equipment assumptions following discussions related to RUFAS I operations indicated that the high capacity 35mm camera used in that sled was more preferable. This camera is not submersible and requires installation in a watertight sphere. Lighting requirements indicated the need for additional television lights and some changes in the cylindrical strobe light. Obstacle avoidance sonar was not included in the second model since its shape was not defined as a result of procurement problems. The electronic package, attitude control equipment and attitude sensors are housed in a second watertight sphere.

The arrangement for RUFAS II B (Figure 6) positions the two spheres forward and aft in the frame, with TV mounted on the pan and tilt amidships. Lighting for the still camera is located forward. Horizontal planes along each side with vertical panels in the support runners are located aft. The towing bridle spans the beam of the sled and has several positions for attachment to the frame. Model RUFAS II B was also made of wood and was ballasted to have a slight positive buoyancy.

Experience from RUFAS II A model tests reduced the work required to test RUFAS II B. Once the longitudinal, vertical, and roll stability was established, the effectiveness of the elevator fins to climb or dive the model were evaluated and performed as anticipated. As a result, the basic RUFAS II B configuration was considered to be acceptable for the prototype sled.

The RUFAS II B model configuration did have a considerable amount of drag. In the interest of easier handling, it has been decided to streamline the prototype sled. This will serve to reduce the drag. The RUFAS II B general configuration will be maintained in the prototype with the exception of this streamlining.

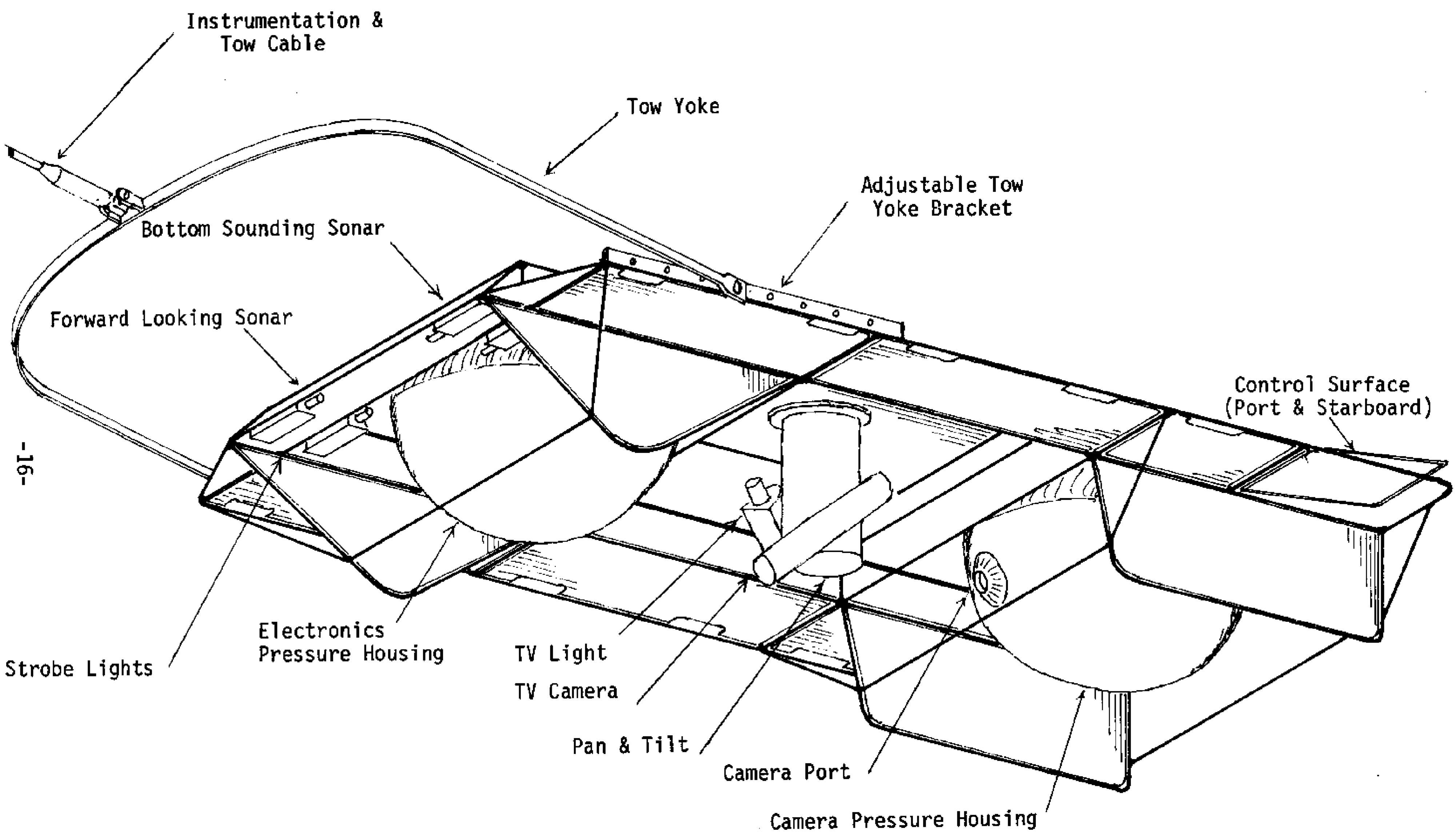

Figure 6. RUFAS II B - Bottom view

2.2 Vehicle-Tow Cable Interaction

The actual effect of the towing cable on the sled's operation was extremely difficult to evaluate using models. There are no test facilities available to Mississippi State University for this purpose and scale factors associated with a small diameter towing cable in the case of even quarter size model, lead to dubious results. For these reasons extensive testing is being considered for the prototype to actually evaluate tow cable hydrodynamic effects on the system.

3. VEHICLE CABLE MECHANICS

The mechanics of a towed underwater vehicle are complicated by a large number of variables. For steady-state conditions, equilibrium must be established in all six degrees of freedom. The forces arising from weight, buoyancy, drag, lift, side thrust and cable pull must all be in equilibrium with regard to forces and moments. In non-steady-state conditions, dynamic forces and moments must be added for all six degrees of freedom. In addition, the vehicle should follow a steady course and return to its previous heading and attitude if displaced from it. This requires a measure of static and dynamic stability. Further, intentional deviations from the previous path should be under command of the operator.

It is easy to perceive that all combinations of these variables present a vast number of cases. An equation representing all variables and cases would be extremely unwieldy. Also, for the case of

RUFAS II, accurate numerical values of most variables are lacking. Fortunately, it is not necessary to work with the general case. A less elegant and more practical method is available. First, the anticipated towing speed is sufficiently slow that dynamic forces are of second order and may be safely neglected in a first analysis. Second, by judicious location of the resultants of certain of the forces, an automatic cancelling effect can be achieved without ever knowing the magnitude of these forces. Third, the rate of change of the forces with attitude and speed is reasonably predictable. Fourth, the cable pull can be utilized as a simple stabilizing element.

A certain complexity results from the interaction of the cable force with other forces. For instance, when considering cable force versus drag, the cable thrust component is the dependent variable. When considering hydrodynamic lift versus cable force, the vertical component of cable force is the independent variable. Great simplification results, therefore, by equating lift to drag and cable angle of pull. This is shown as follows for the neutrally buoyant case:

$L = D \tan \alpha$

where L = hydrodynamic lift required,

D = total drag of vehicle,

α = cable angle measured from the horizontal.

This indicates the requirements of lift in terms of drag. For instance, to tow with a 45 degree cable angle requires a lift equal to the drag.

Another complexity is introduced by a difference in the rate of change of certain variables with speed. The weight and buoyancy may be considered as constant and therefore unchanging with speed. Also, if the centers of gravity and buoyancy are not at the same location, a moment results that is independent of speed. Since the variables related to hydrodynamic forces vary approximately as the square of the speed, special attention needs to be given to their changing interaction with speed change. The simplest case is to use a vehicle with approximately neutral buoyancy and static stability in a level attitude.

As discussed in the section on the towing problem, the cable is in equilibrium at a particular angle for each speed. At this condition the cable makes a straight line over its entire length, and there is a definite length of cable associated with each depth and speed. If more cable is payed out the cable will sag below the vehicle and may possibly drag bottom. Too little cable will require the vehicle to act as a depressor. This would require a higher negative lift to drag ratio and would tend to limit the vertical maneuverability of the vehicle. The operator then will have to pay out enough cable for the speed and depth to match the range capability of the vehicle-cable system. Within this range, sufficient control surface deflection should be supplied by the operator to put the vehicle into an attitude that provides sufficient vertical force to balance that part of the cable pull.

If the speed is kept constant, the vehicle should have enough inherent stability to tow at a uniform depth in spite of minor disturbances without further control input from the operator. To achieve this stability, the cable mechanics can be used to advantage. When the vehicle moves up, the angle of the cable pull gets smaller. If the cable is hinged to the vehicle ahead of the center of lift, a moment from the control surfaces must be supplied to balance the couple between the vehicle and cable. When the vehicle moves up, the cable moment decreases while the tail moment stays the same, thus an imbalance results which returns the vehicle to its original position. The reverse results if it goes too deep.

For directional stability, weathervane stability can be adequately supplied by vertical fin area near the stern. The couple between this fin area and the cable, assisted by the vehicle drag will bring the vehicle back in line with the stream following a disturbance. Lateral stability is best supplied by static stability introduced by placing the center of gravity well below the center of buoyancy.

Care must be exercised to locate the towing hinge at about the same height as the center of drag. If this is not done, it is difficult to provide uniform vehicle response throughout the design range of cable intersection angles. Variation of vehicle geometry may be introduced by movable equipment exposed to the water stream. Examples are cameras and lights on a pan and tilt support. These can have a noticeable affect on trim and possibly on stability. If such movements are infrequent, a small control input from the operator may be satisfactory. If the movements are often or continuous, these parts might have to be located very close to the towing hinge line. If this is not practical, an automatic compensating device is indicated.

The above considerations have been observed to apply in a qualitative way in tow tests of a one-fourth scale preliminary model of RUFAS II. These tests show that the above approach can be applied to model tests with satisfactory results. By the systematic variation of tow point locations and overall attention to these qualitative considerations, workable mechanics for the towed underwater vehicle can be developed.

3.1 Analysis of Cable Dynamics

RUFAS II is an unmanned towed underwater vehicle whose mission is bottom and midwater surveillance under remote control and monitoring from the towing vessel on the surface. The tow cable provides the sole means of communication while underway between the underwater sensor-carrying vehicle and the towing, monitoring, and controlling vessel on the surface. Electrical and mechanical requirements determine cable size and weight. The cable size and weight, in turn, influence the characteristics of the whole system.

It must be emphasized that the underwater vehicle, the cable, and the surface vessel constitute a single interdependent system. A change in any of the parts may affect, in varying degree, the other parts. The usual design approach to such an interdependent system is the method of iteration, or successive approximations. This discussion represents second order approximations in considering the mechanical characteristics of the system. At present, the electrical requirements of the cable are only roughly defined and are subject to change. It is felt, however, that they are known closely enough that a meaningful analysis can be made of the characteristics and capabilities of the system. Consequently, two sizes of representative (commercially available) cable are assumed for this analysis. These are approximately .50 inches and .68 inches diameter, weigh approximately .30 and .518 pounds per foot submerged, and have a breaking strength of 17,000 and 30,000 pounds, respectively.

The lift, L, per foot of cable is approximately

$$L = 1.1 \sin^2 \alpha \cos \alpha \, qA$$

and the dynamic pressure, q, is given by

$$q = \frac{\rho V^2}{2}$$

where α is the angle of the cable measured from the horizontal,

ρ is mass of seawater (2 slugs per cubic foot),

V is the velocity in feet per second,

and A is cable area per foot (width of cable, feet).

The drag per foot of cable is given by

$$D = (1.1 \sin^3 \alpha + 0.2)qA.$$

The forces contributed by one foot of cable can then be resolved vertically by $F_V = L + D \tan \alpha - w$

where w is the submerged weight of one foot of cable. This is shown in Figure 7 for speeds from 1.5 to 6.0 knots for angles from 14 to 54 degrees from the horizontal. It can be seen that there is an angle for each speed for which this summation is zero. This angle is plotted versus speed in Figure 8.

This equilibrium angle represents the condition for which the cable would be straight for its entire length. For convenience of calculation, this condition is used as the basis of this operational analysis of the system. This condition is fairly close to optimum for the design operating points of 2.5 knots at 400 fathoms and 5.0 knots at 200 fathoms. With the cable intersecting the towed vehicle at the equilibrium angle the vertical component on the vehicle is shown in Figure 9 for speeds from 1.5 knots to 6.0 knots. The cable force increases toward the winch. This amounts to the vehicle pull plus SD sec α where S is the cable length, and D is the drag per foot of cable. The cable force at the winch is shown in Figure 10 for 400 and 200 fathoms operation. The actual vehicle drag is not known yet but it will be made relatively small compared with the cable drag by streamlining. The assumed value of vehicle drag is based on an equivalent flat plate area for 4 square feet.

Generally, all forces appear to be moderate and the cable length is not excessive. The required cable length for equilibrium conditions is shown in Figure 11. The horsepower required for towing is shown in Figure 12. This study does show the need for relating cable length to

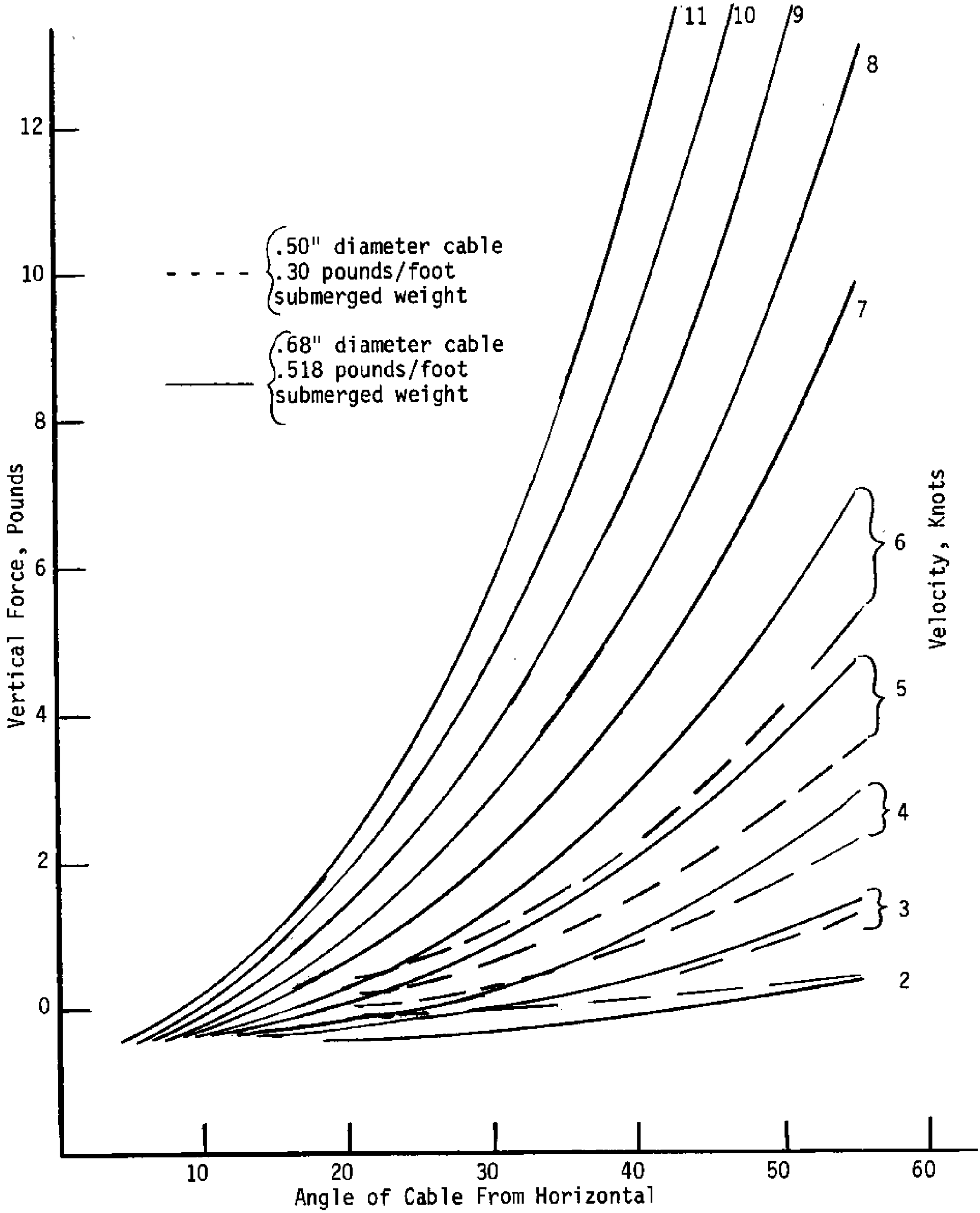

Figure 7. Vertical force on one foot of cable

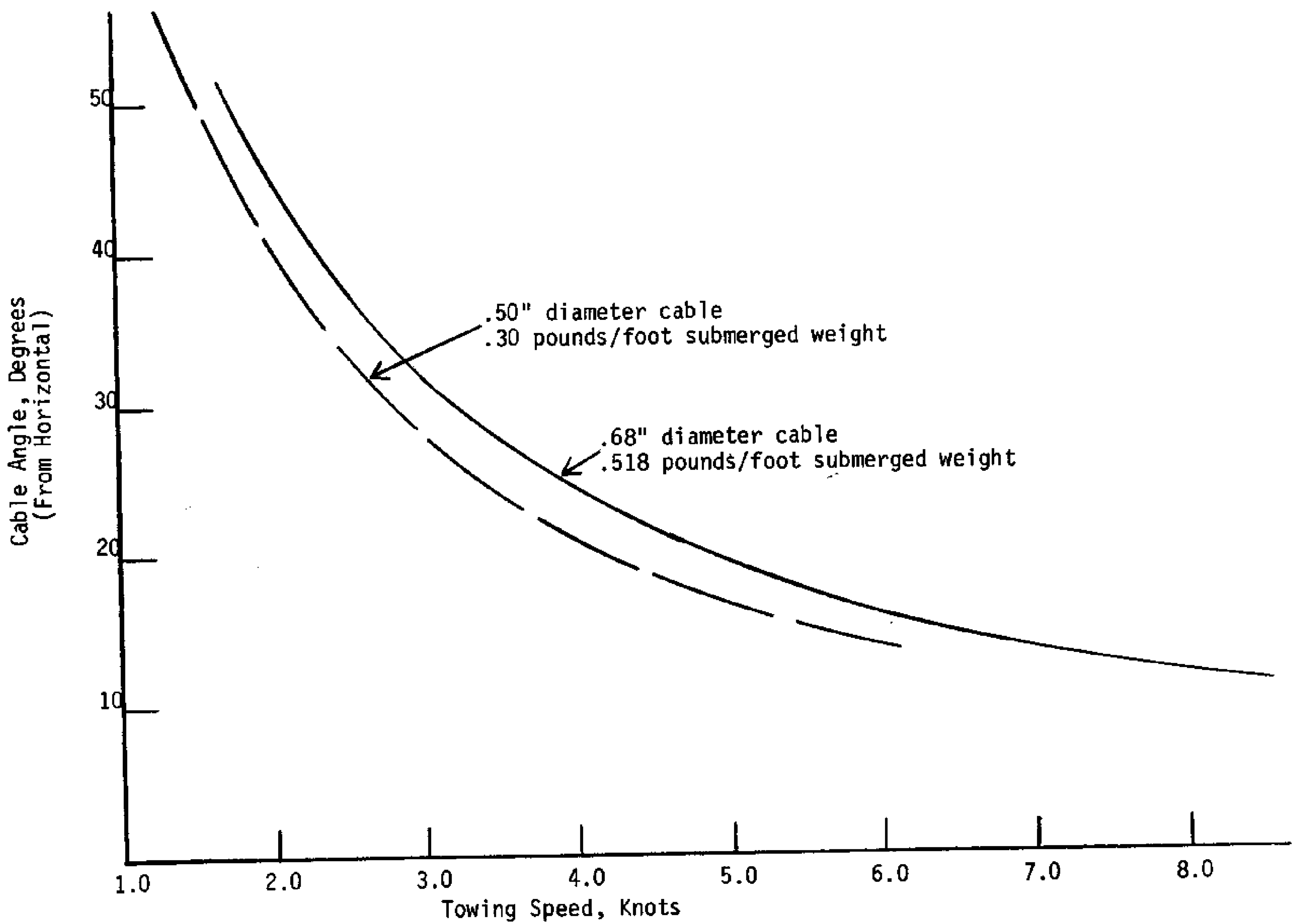

Figure 8. Equilibrium angle of cable vs. speed

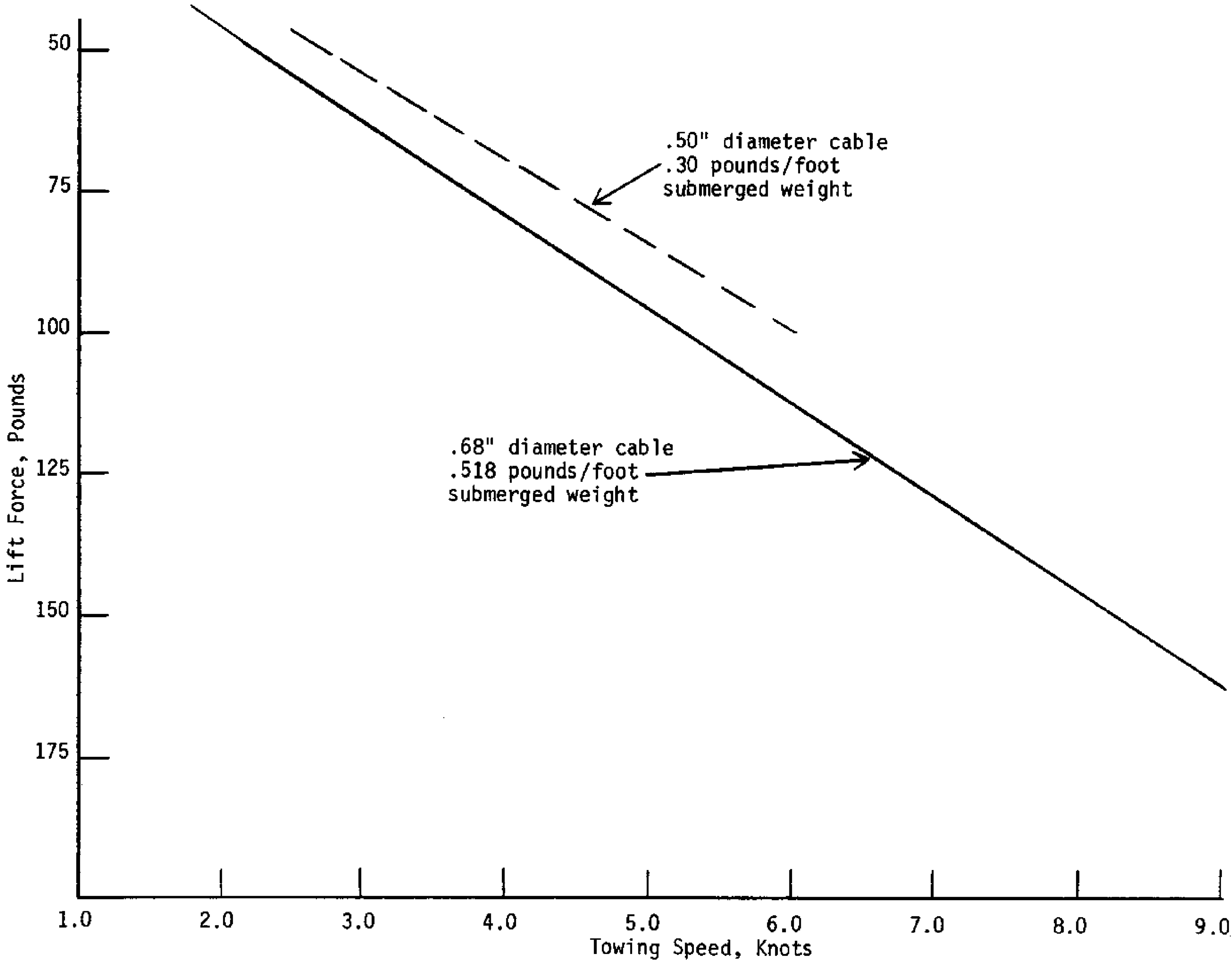

Figure 9. Lift required on towed vehicle for cable in equilibrium vs. speed

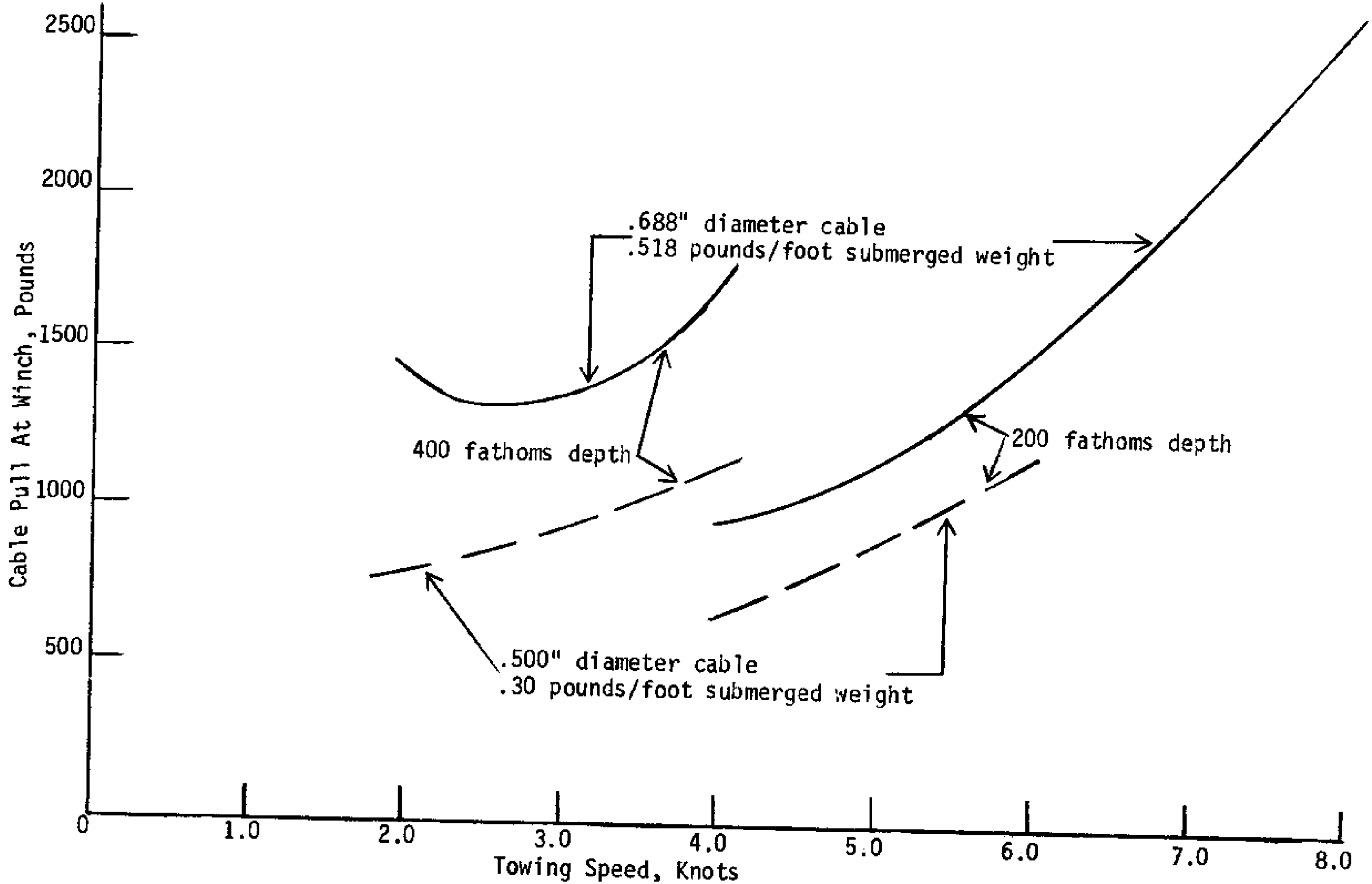

Figure 10. Cable pull at winch vs. speed

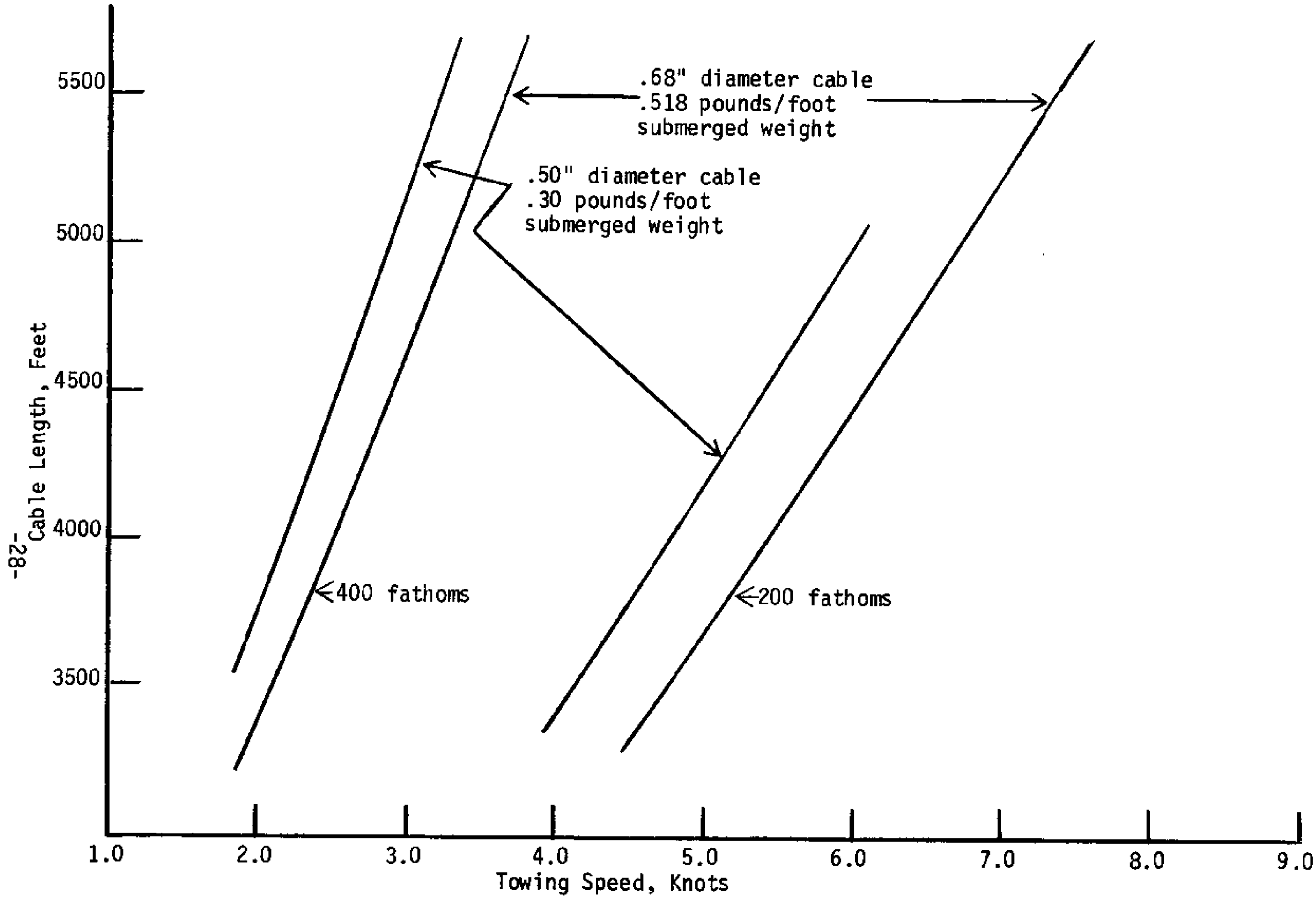

Figure 11. Cable length required at equilibrium angle vs. speed. 200 and 400 fathoms depth

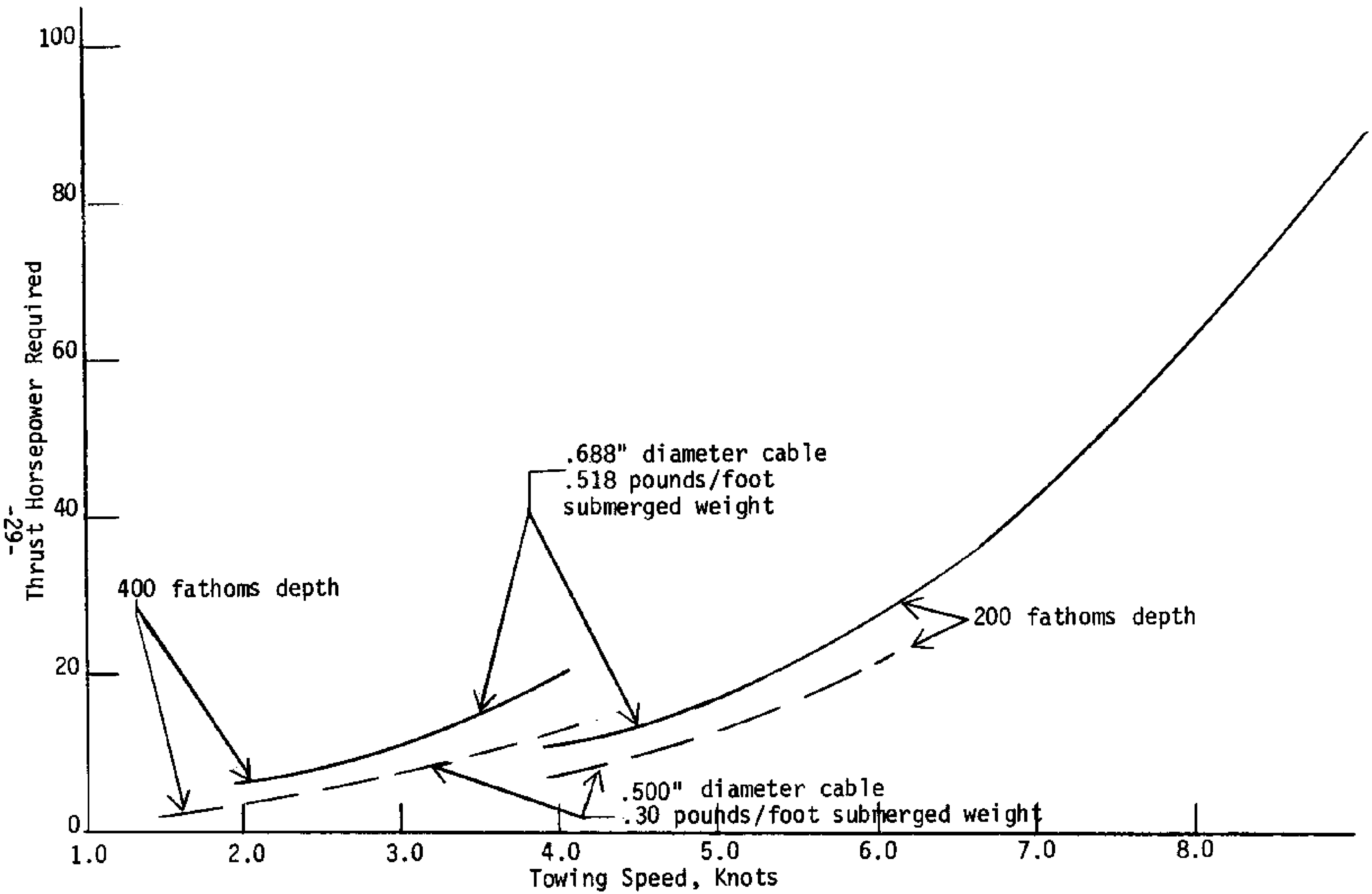

Figure 12. Thrust horsepower required for towing vs. speed

both depth and towing speed. It appears that enough leeway is available for control and obstacle avoidance, but the winch will have to be included as one of the control elements for large corrections. A degree of skill in coordinating all the variables is indicated for successful operation. Within these limits, however, the mechanics of the system appear quite practical.

4. SONARS

Sonar requirements for RUFAS II consist of a forward looking sonar and an altitude/depth sonar. System parameters for these two sonars are examined in the following subsections. The addition of a side scan sonar may be desirable at a later date. A side scan sonar will not be included on the prototype RUFAS II.

4.1 Terrain Avoidance Sonar Requirements

Forward avoidance sonar requirements are dictated primarily by the expected towing speed of approximately 2.5 knots and the vertical operating distance above bottom. At 2.5 knots, horizontal speed, V_h, is approximately 4.2 feet/second. The sonar range must provide adequate warning to maneuver over any obstacles to be encountered. For purposes of calculations, assume that a 100 feet cliff has been detected and the maximum vertical ascension angle is 30°. Vertical rise time is given by

$$t_v = \frac{100}{(4.2)(\sin 30)} = 47.6 \text{ seconds}$$

The horizontal distance covered in the meantime is 173 feet. As a precaution, additional lead time should be available for either operator or automatic control action. With a minimum sonar range of 300 feet, approximately one-half minute is available. With the inclusion of an operator alert tone, this should be adequate reaction time.

Since RUFAS is expected to be towed in a relatively straight line, resolution requirements are assumed to be vertical. Horizontal resolution will be fixed by the equipment characteristics. A fixed beam forward looking sonar is presumed since the vehicle has limited maneuvering capability. A study performed for lighting requirements indicates that the vehicle operating height above bottom may vary from 5 feet to 30 feet depending on local water conditions. The 5 feet operating height imposes the most severe constraints on the forward avoidance sonar due to bottom reverberations. Suppose, as is shown in Figure 10, that a 5 feet clearance is adequate for objects lying on bottom or protruding upward. The 3 db beam width for the vertical pattern is

$$\theta_V = \frac{2\ (5)}{300}\ (57.3) = 1.9 \text{ degrees}$$

Alternately, a wider beamwidth may possibly be employed by providing an upward tilt to the sonar pattern.

It can be seen from Figure 13 that returns from the sidelobes will complicate the problem of target detection. This problem can more realistically be examined using data from a commercially available

$$\Theta_v = \frac{2\ (5)}{300}\ (57.3) = 1.9 \text{ degrees}$$

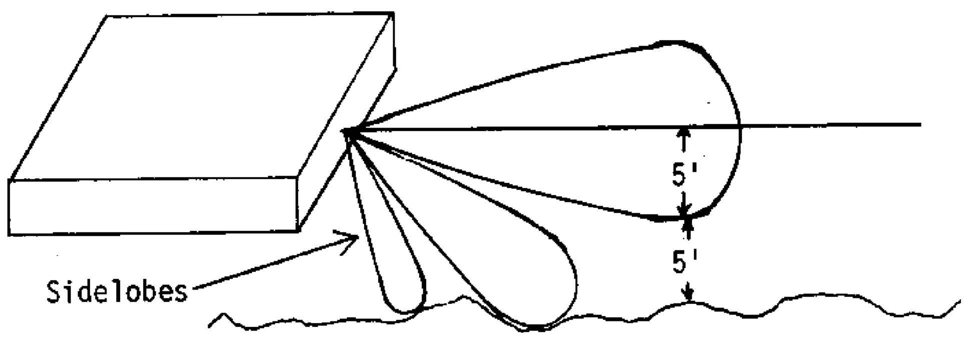

Figure 13. RUFAS II sonar pattern

sonar. A survey of sonar manufacturers has failed to produce a sonar with a narrow spherical beamwidth. Since resolution is required only in the vertical direction, one solution would be to use a narrow beam echo sounder and turn the transducer sideways. Figure 14 illustrates patterns obtainable with a forward looking sonar manufactured by BURNETT ELECTRONICS LAB, INC. Note that ground clutter from the side lobes would not be received for distances less than 300 feet except for side lobes greater than the second which would be down at least 28 db relative to the main lobe response. A solution to the problem

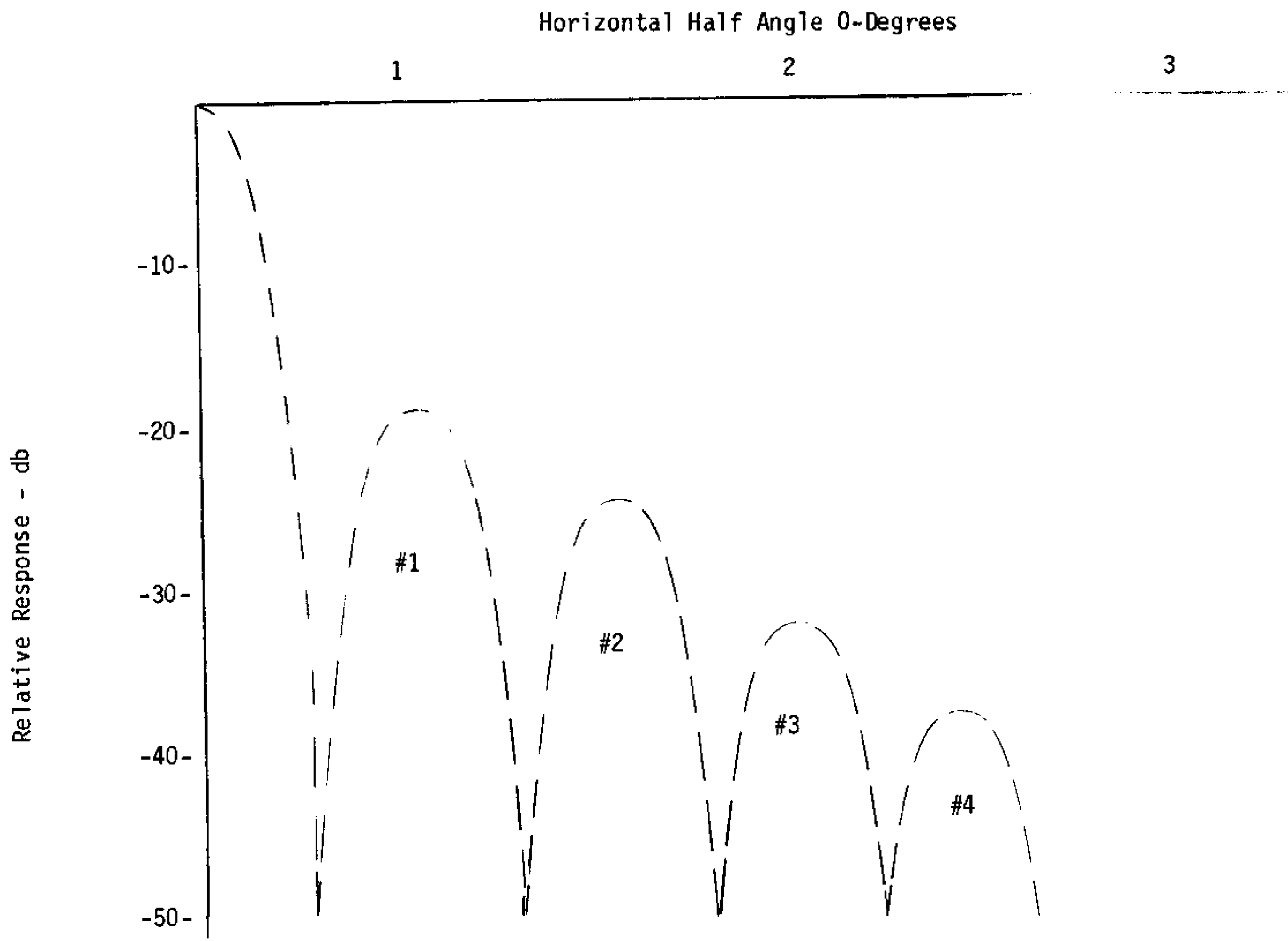

Figure 14. Horizontal receive beam pattern - 300 KHz

along these lines is preferable to range gating since the range gate would introduce a "blind" zone as the vehicle nears the target.

Additional systems parameters for the sonar may be investigated using the sonar range equation. The following calculations are made to investigate desirable sonar system parameters relative to transmitted power. The sonar range equation may be expressed as:

$$Pa = \frac{(S/N)\ (4\pi)^3\ R^4\ KTB\ (NF)}{(DF)^2\ \delta\lambda^2}$$

Where

S/N = Signal to noise ratio

R = Range in feet

K = Boltzman's constant, 1.38×10^{-16} watts/^{o}K · Hz

T = Temperature, ^{o}K

B = Bandwidth in Hz

DF = Directivity factor

NF = Receiver noise figure

δ = Target cross section, feet^2

λ = Wavelength, feet

Pa = Transmitted power, equivalent watts

The following system parameters are used for purposes of calculations and are chosen to lie within the performance capabilities of "off-the-shelf" equipment.

S/N = 10

R = 300 feet

$T = 14^{o}C$

$K = 1.38 \times 10^{-16}$ watts/$^{o}K \cdot Hz$

$B = 1000$ Hz

$NF = 6$ db

$\delta = 100$ feet^2

$\lambda = 0.089$ feet

$DF = 30$

The equivalent transmitted power in watts for a range of 300 feet is given by

$$Pa = \frac{(10)\ (12.56)^3\ (300)^4\ (3.94 \times 10^{-11})\ (4)}{(30)^2\ (100)\ (.089)} = 3.1 \text{ watts}$$

for ranges of 600 feet and 1200 feet this becomes 50 watts and 800 watts respectively.

The above calculations are for a calm sea, implying no sea noise is present. Values for sea noise may be obtained from Hundson curves and power calculations made for the same SNR. Somewhat higher transmitted powers would result. Also by choosing a reflection and transmitting coefficient the received power may be calculated. This power may be converted to an equivalent sound level and the necessary receiver sensitivity specified. These calculations are not continued here, however, since the power levels for RUFAS II are not expected to result in any threshold problems with receiver sensitivity. Electrical system specifications for the terrain avoidance sonar are shown below.

Terrain Avoidance Sonar Specifications

Transmit frequency	300 KHz
Receiver sensitivity	-0.05 microbars
Receiver bandwidth	-1 KHz
Pulse width	-1 millisecond
Range	-300 feet
Horizontal beamwidth	4 degrees
Vertical beamwidth	1 degree

4.2 Altitude Control Loop

The RUFAS II system is in large measure a photographic instrument platform and must be stable. In order for the photographic data to be properly interpreted, camera to subject distance must be known. This requires a system for maintaining constant height above the seabed. It is further desirable to incorporate a "minimum height above bottom" automatic system to reduce the possibility of catastrophic operator error. In addition, it is not difficult to envision that it may be desirable in certain midwater applications to fly RUFAS II at a constant depth.

The block diagram of a possible automatic altitude control system is shown in Figure 15. In this system the bottom sounding sonar produces an analog signal which is directly proportional to the RUFAS II vehicle height above seabed. The desired height above seabed voltage is supplied through the telemetry system be the operator on board the mother ship. The difference in the two signals is amplified and used to drive a motor which controls the RUFAS II control surfaces and therefore its height above bottom. The sonar signals close the loop. It is expected that winch action will supplement the altitude/depth sonar for obstacles which dictate a rate of change beyond the vane's capabilities.

Experience with the RUFAS I vehicle, which is not equipped with an automatic control loop, points to the desirability of a minimum of height above bottom capability. The tendency has been for the operator to fly the vehicle closer and closer to the bottom. This maneuver is both dangerous and unproductive as it increases the possibility of crashes and reduces the camera field of view. The minimum height above bottom feature may be accomplished by the inclusion of a fixed reference voltage corresponding to the minimum height desired.

The RUFAS I vertical sounding sonar appears to be adequate for this application if the transducer is capable of submerged operations at 400 fathoms. A brief set of typical specifications for this sonar is listed below.

Vertical Sounder Sonar	
Range	0 - 40 feet
Beam angle	22
Minimum depth	9 inches
Resolution	3 inches
Frequency	200 ± 5 KHz
Power consumption	24 watts

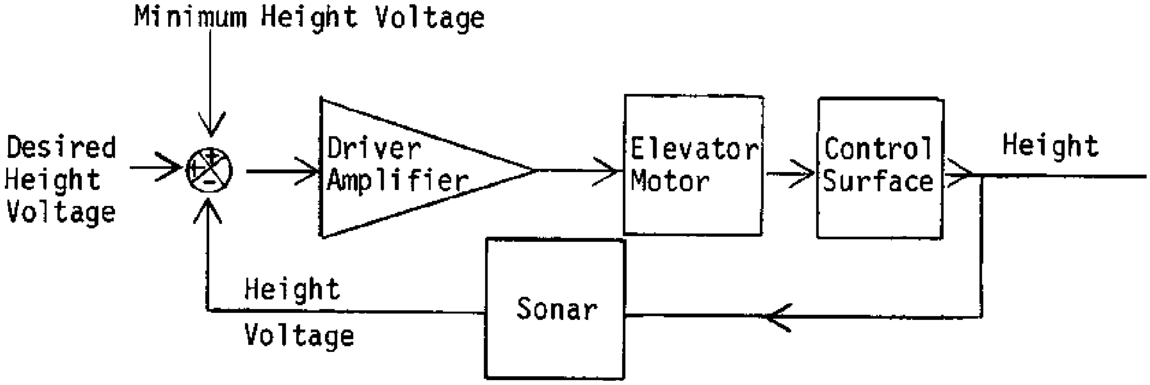

Figure 15. Automatic altitude control system

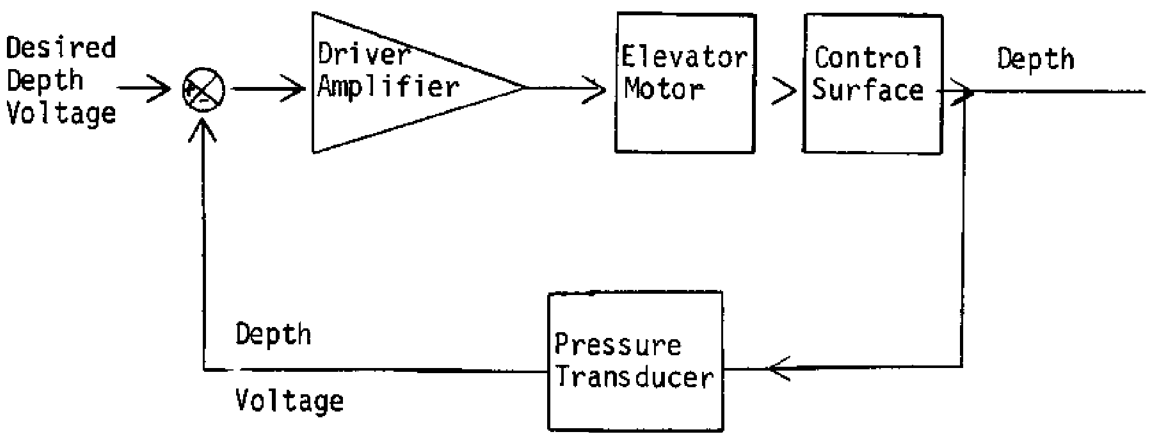

Figure 16. Automatic depth control system

The altitude control loop can be modified to become a depth control loop by replacing the sonar with a pressure transducer as shown in Figure 16. In this mode of operation the RUFAS II vehicle is flown at a constant distance from the surface. System operation is identical to the constant height above bottom system with the exception of the sonar.

5. ELECTRICAL SUBSYSTEMS

Electrical requirements for RUFAS II range from providing an efficient lighting system to telemetry control for the vehicle and associated equipment. A primary power supply must also be provided. The electrical cable from RUFAS II to the ship imposes limitations on design of all the electrical subsystems. In the following sections, system designs are considered subject to constraints imposed by the cable and the local operating environment.

5.1 Underwater Lighting Requirements

Underwater lighting requirements for RUFAS II must include the capability to provide for black and white television and both black and white and color photographs. Because of the spectral characteristics of seawater, lighting requirements for color are the most severe.

When light passes through seawater, it is strongly attenuated. As one proceeds downward from the surface of the sea the light available from the sun decreases in an exponential manner. The degree of attenuation reported by various authors differs, probably because of the different locations in which measurements were made.

Results of measurements for very clear water indicates that at 100 meters below the surface, the light level has decreased to 1% that of the surface and has a pale green diffuse character. At 200 meters it has dropped to .01% and the light appears dark green. Below 300 meters, the sea is virtually dark. Publications by other authors indicate that some light is available down to 500 to 600 meters. Regardless of the exact cut-off point RUFAS II will be operating in virtual darkness at 2400 feet requiring total artificial lighting. Commercially available lighting systems are designed to take advantage of those sea water transmission characteristics which match the spectral response of the human eye. In some scientific applications a photograph pleasing to the eye may or may not be necessary, thus changing the lighting requirements.

The transmission characteristics of light through 20 feet of clear sea water is shown in Figure 17 below. The most important feature illustrated in this plot is the attenuation characteristics versus wavelength since as mentioned previously, attentuation varies with the sample or turbidity of the sea water. As can be seen, maximum light transmission occurs at a wavelength of approximately 5000 angstroms with a transmission of 78%. This is fortunate for the application of black and white television.

A comparison of the spectral response of the human eye and a black and white television camera tube is shown in Figure 18.

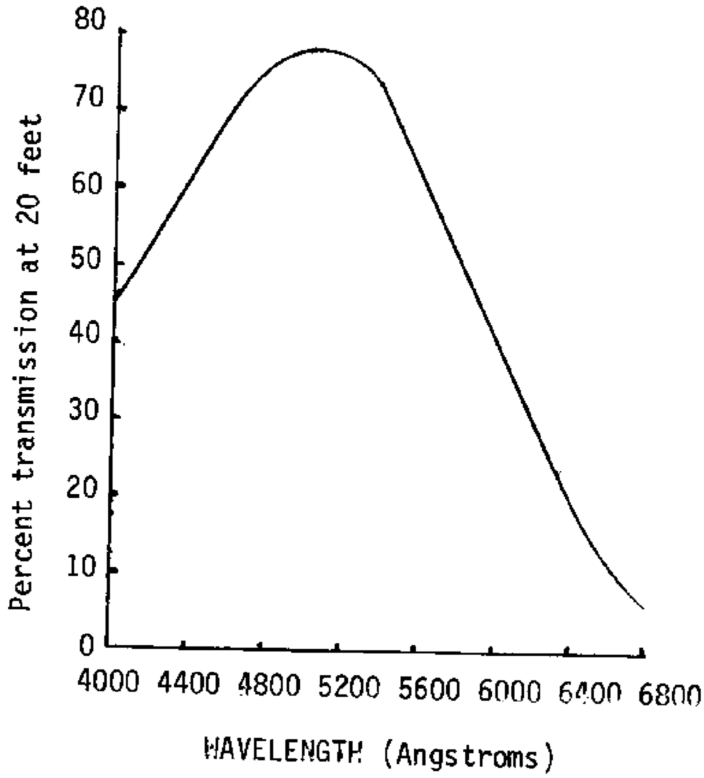

Figure 17. Light transmission as a function of wavelength through 20 feet of clear sea water

A number of factors account for the attenuation curve shown in Figure 17. Light attenuation is the result of a combination of absorption and scattering due to the spectral characteristics of the water itself, the materials in the water and small organisms, such as plankton, living in the water. The absorption effect is low in the blue-green region and high in the red region. For example, at 6400 angstroms, transmission is reduced to 16%.

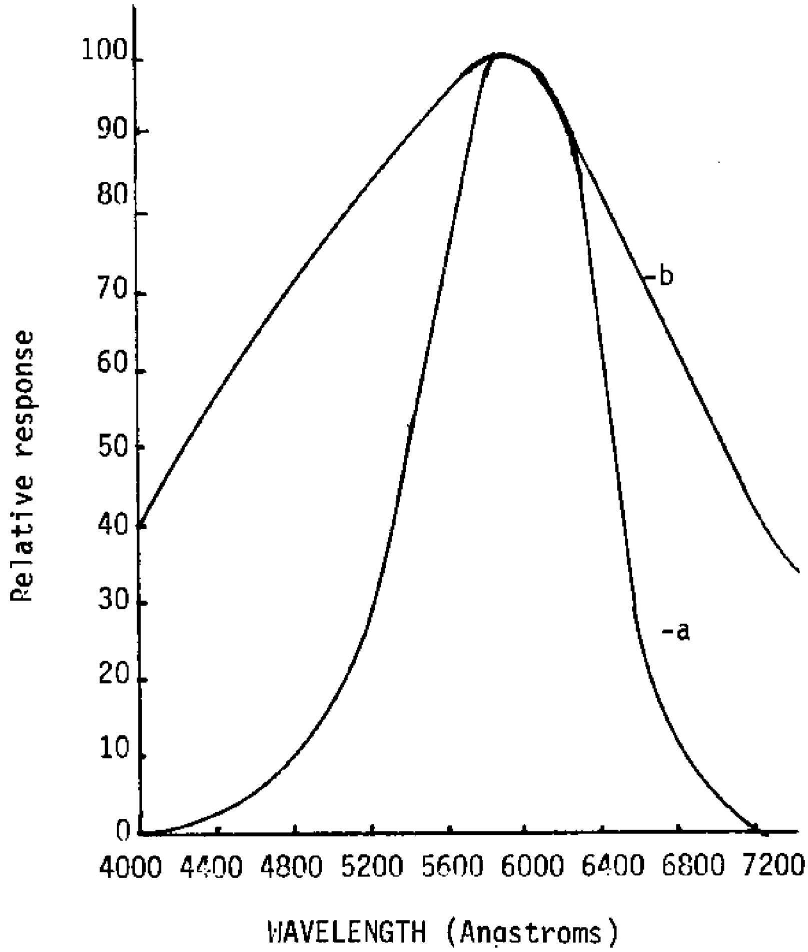

Figure 18. A comparison of the spectral sensitivity of the human eye (Curve a) and a typical black and white television camera tube (Curve b)

The scattering effects are practically independent of wavelength since the particle size is large compared to a wavelength. If the light is too close to the camera, particles of plankton immediately in front of the lens are subject to intense light. Exposure for the subject which may be 5 or 6 feet away, will result in these particles appearing like white out of focus blotches. Conversations with Joseph Pollio of the United States Naval Oceanographic Office have been helpful in determining the proper light-camera geometry for best picture quality with minimum back scatter. This back scatter effect is counteracted on RUFAS II by placing the light forward of the television camera. Particles immediately in front of the camera will not be illuminated and the problem of back scatter will be minimized.

By comparing Figures 17 and 18 it is apparent that the most efficient lighting system is one whose spectral characteristics match the curve for black and white television. For black and white television, the thallium iodide light has the desired characteristics. A typical spectrum is shown in Figure 19.

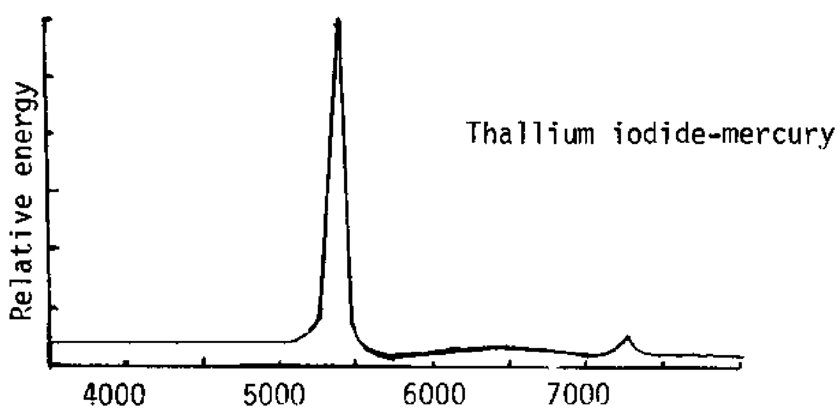

Figure 19. Spectral energy distribution of thallium iodides

Test results reported by Dillingham Corporation for the thallium iodide light indicate that the light is attenuated to 28 per cent after passage through 2 meters of clear sea water. This figure contrast with the transmission characteristics of Figure 17 and illustrates the effect of the sample of sea water used.

A different light source is necessary for color photography since color film utilizes three separate emulsions sensitive to blue, green, and red. Incandescent lights have been commonly used for this application and provide a light output of approximately 25 lumens per watt. An improved light source for color, the dysprosium-thallium iodide lamp, has been under development by the Lamp Division, Westinghouse Electric Corporation. Light output for the lamp is approximately 100 lumens per watt. Underwater color photographs taken at night by C. L. Strickland, Hydro Products Division, Dillingham Corporation, reportedly show that the range of a 500 watt quartz incandescent lamp was approximately 15 feet while the 400 watt dysprosium-thallium iodide lamp range was well over 25 feet.

Spectral distribution for the dyprosium-thallium lamp is shown in Figure 20. By plotting the sea water transmission curve of Figure 17 on this same graph and using approximate numerical integration, light intensity at the subject distance of 25 feet with a 90 degree field of view is approximately 4 lumens per square foot. Due to the variation of absorption with wavelength, color balance of a light source differs with distance from camera to object. For scientific applications, this should not prove objectionable and no special filtering need be used. Strickland indicates that it is difficult to obtain faithful color reproductions beyond 5 or 6 feet due to this selective light absorption. Pollio recommends the use of black and white film for all but those very specialized cases where color is required to perform the mission objective.

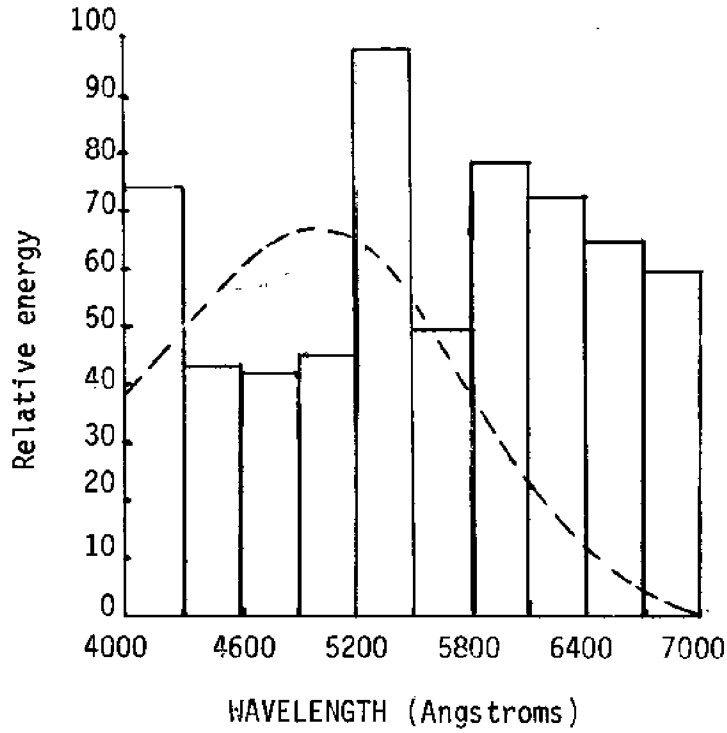

Figure 20. Spectral energy distribution of dysprosium-thallium iodide combination

Based on the preceeding quantitive investigation it is evident that considerable development work remains to be accomplished for underwater lighting, particularly for relatively large camera to subject distances.

The area of uncertainty for camera to subject distance may be as large as four to one for a given lighting system, depending on the particular sea water characteristics. Tentative recommendations for RUFAS II lights are listed below.

LIGHT SOURCES

DETECTOR	LIGHT	POWER
B & W TV	Thallium-iodide	400 watts
B & W film	Strobe or thallium-iodide	200 watt-sec (strobe)
Color film	Dysprosium-thallium iodide	400 watts

5.2 Telemetry System

The variety of information to be generated on RUFAS II for up transmission plus commands down to RUFAS II dictate that some form of telemetry system be employed. These requirements coupled with cable constraints resulted in the design approach to be discussed. In the following a telemetry system for RUFAS II is presented and some of the design problems are discussed.

Two design concepts have been investigated. These concepts are illustrated in terms of frequency spectrum in Figure 21 below. As can be seen, the only difference is in the use of one versus two coax cables. For both concepts, the low frequency uplink and downlink data will be transmitted on the same coaxial cable using standard IRIG channels. In Figure 21, the uplink television is shown being transmitted on the same coax at the channel 2 frequency of 64 MHz. The concept of using a single

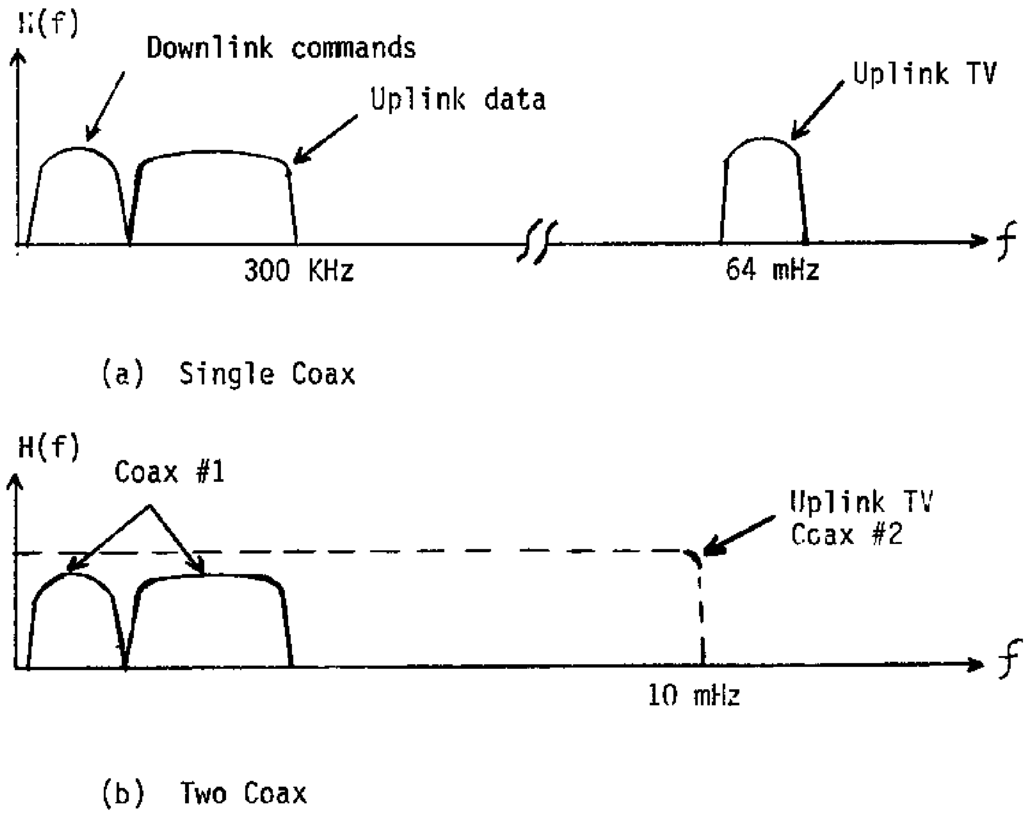

Figure 21. Telemetry frequency spectrum

coax was "breadboarded" in the laboratory to test its feasibility. A block diagram of the circuitry used is shown in Figure 22. Using this test setup, it was demonstrated that both uplink and downlink telemetry, along with television, could be transmitted and later separated with proper filtering.

When applied to RUFAS II, however, signal losses at the channel 2 frequency became rather severe. For RG-58, this loss is on the order of

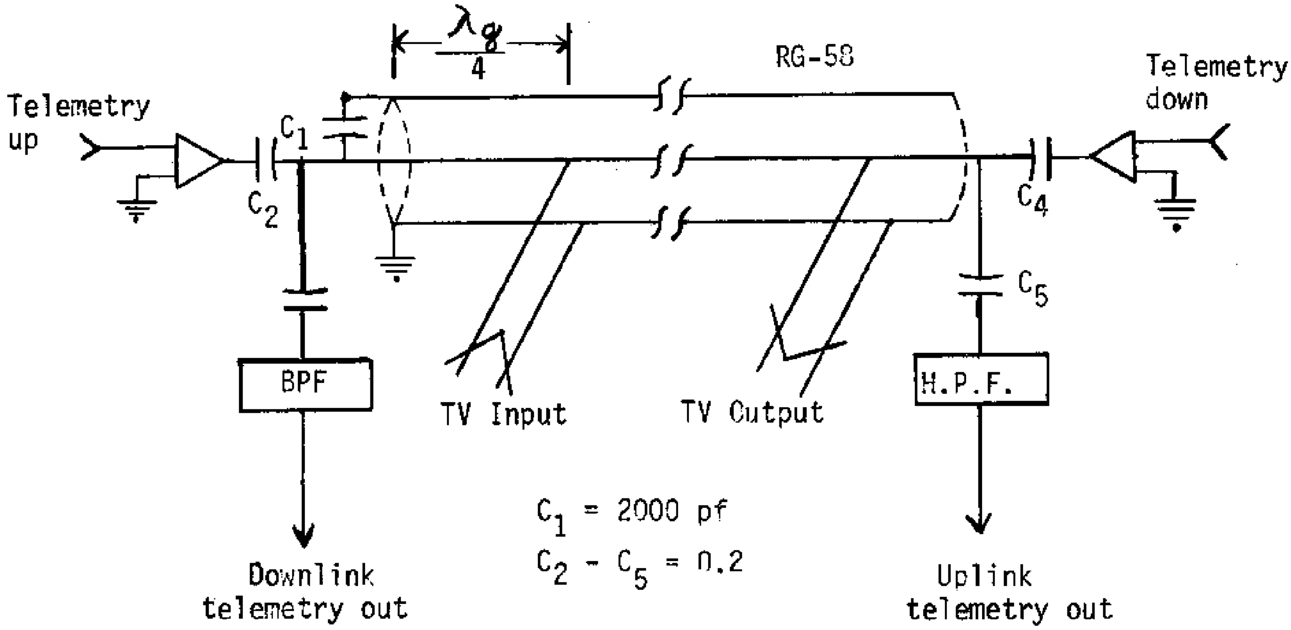

Figure 22. Test "setup" for single coax data transmission

3 to 4 db per 100 feet. Calculations made for cable mechanical requirements indicate that its length will be on the order of 6000 feet. For good television reception, a minimum received signal strength of 100 microvolts is necessary. If, for example, 10 volts rms is available at RUFAS II for transmission, the allowable cable loss may be calculated as shown below.

$$\text{db (loss)} = 20 \log \frac{10}{100 \times 10^{-6}} = 100 \text{ db}$$

Thus for 6000 feet, a cable loss of 1.66 db per hundred feet is acceptable. This corresponds to an RG-13 cable size.

With this same laboratory "setup" it was desired to investigate the possibility of also transmitting 60 cycle power on the same coax. Tests indicated that this was feasible if the price paid for overcoming the problem areas could be tolerated. These problem areas are listed below.

1. High insertion loss to strip off 60 cycle power
2. Higher voltage rating for all components which have 60 cycles impressed on them
3. In excess of 50 db of attenuation needed between the 60 cycle power and filter outputs for the telemetry

In view of these problems, it appears best to provide power conductors.

The spectrum shown in Figure 21 illustrates the concept of using two coaxial cables. Using this concept, the second cable is used to transmit television baseband. At 10 MHz cable losses for RG-58 is approximately 1.5 db per hundred feet. A similar or smaller cable can be used for the low frequency telemetry. The choice of one versus two cables will probably be determined by the constraint on cable size. Both concepts appear feasible.

The complete telemetry system is shown in Figures 23 and 24. As can be seen from the figures, IRIG channel 5 is provided for downlink commands. Seventeen commands have been identified at present and are listed below. These commands will be transmitted sequentially and consist of a six bit code to allow for expansion up to 64 commands. Uplink data is transmitted on several of the remaining IRIG channels beginning with channel 6. Both uplink and downlink data channels are transmitted baseband.

CONTROL SIGNALS

Function	
1. Pan left	
2. Pan right	
3. Tilt up	
4. Tilt down	Television
5. Zoom in	
6. Zoom out	
7. On-off	
8. Light on-off	
9. Focus	
10. Camera and strobe on-off	
11. Focus	
12. Aperture setting	35 & 70 mm camera
13. Shutter speed	
14. Manual/automatic picture sequence	
15. Reference depth	
16. Obstacle avoidance sonar on-off	Vehicle control
17. Control fin position	

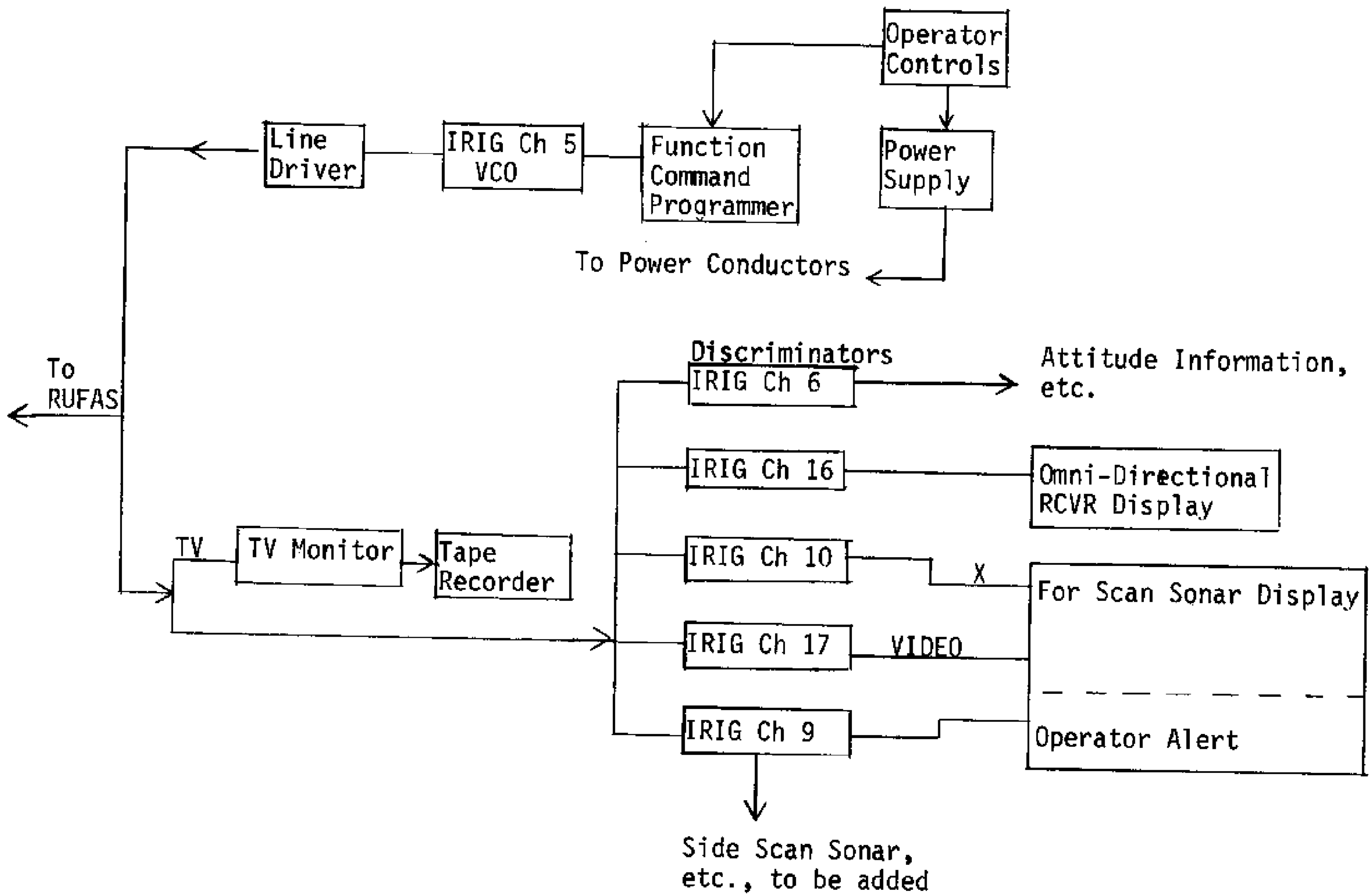

Figure 23. RUFAS II block diagram for shipboard equipment

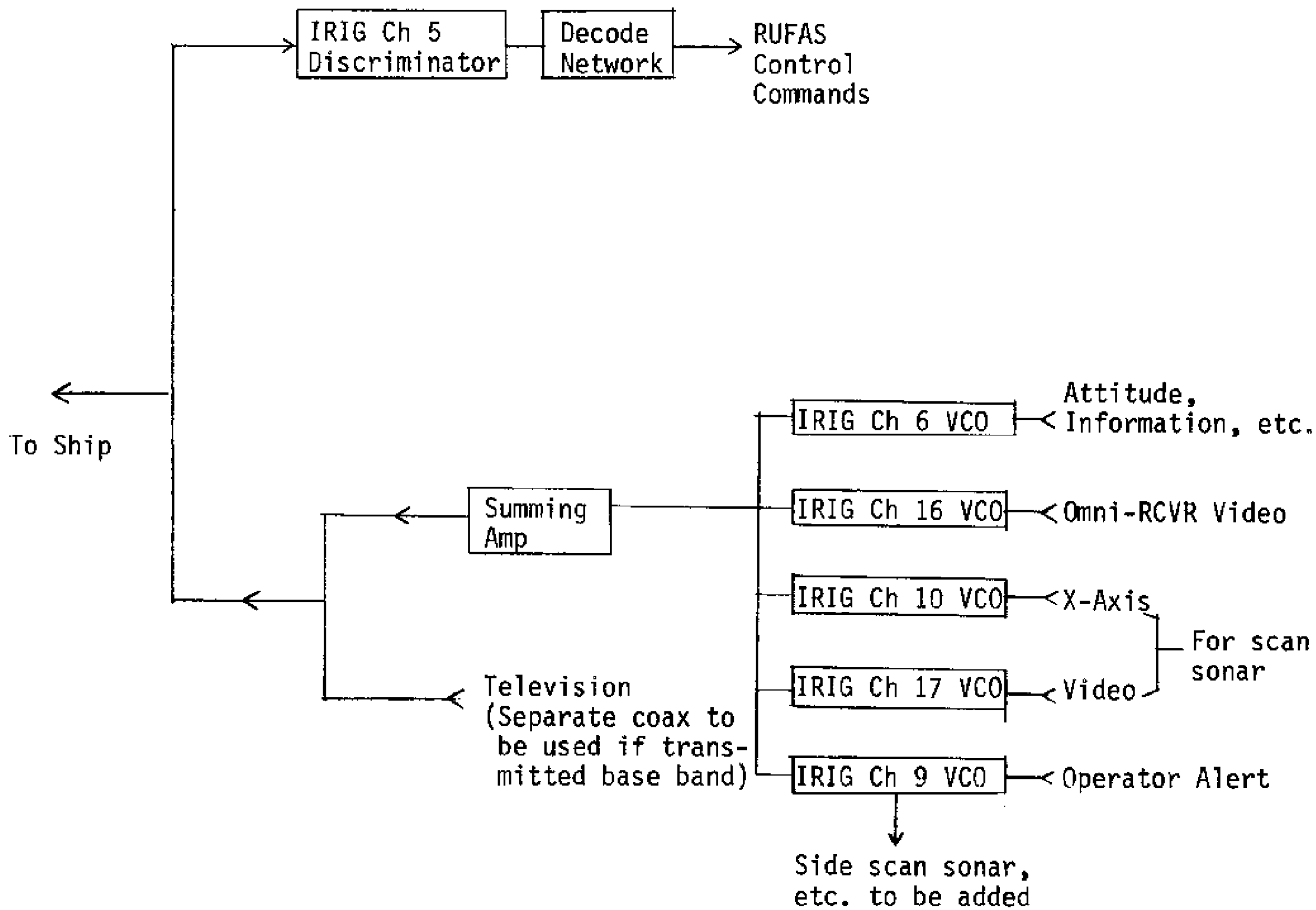

Figure 24. RUFAS II telemetry block diagram

5.3 Control Commands

In the previous subsection, the application and transmission of control commands was introduced but not expanded upon. A list of necessary control commands was listed and will not be repeated here. The following provides detail on implementation of the control commands.

A six bit binary code will be used for control commands. This allows a total of 64 commands to be utilized. Referring to Figure 23 in the telemetry subsection, it is seen that IRIG channel 5 is reserved for transmitting control commands. A data rate of 20 Hz is allowed for this channel. Since this is a 20 Hz sine wave, the binary code which consists of square waves should be reduced to a 5 Hz rate to minimize roll off due to bandpass filtering. An analog representation for a typical command with binary representation 100011 is shown below.

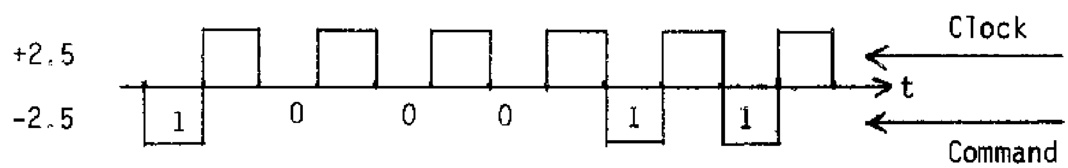

Figure 25. Analog representation of control command

This command is generated by the "function command programmer" in the console and applied to channel 5 VCO for transmission to RUFAS II. The detected output of the discriminator on board RUFAS II appears in the same form as Figure 25. Processing of the command is illustrated in Figure 26.

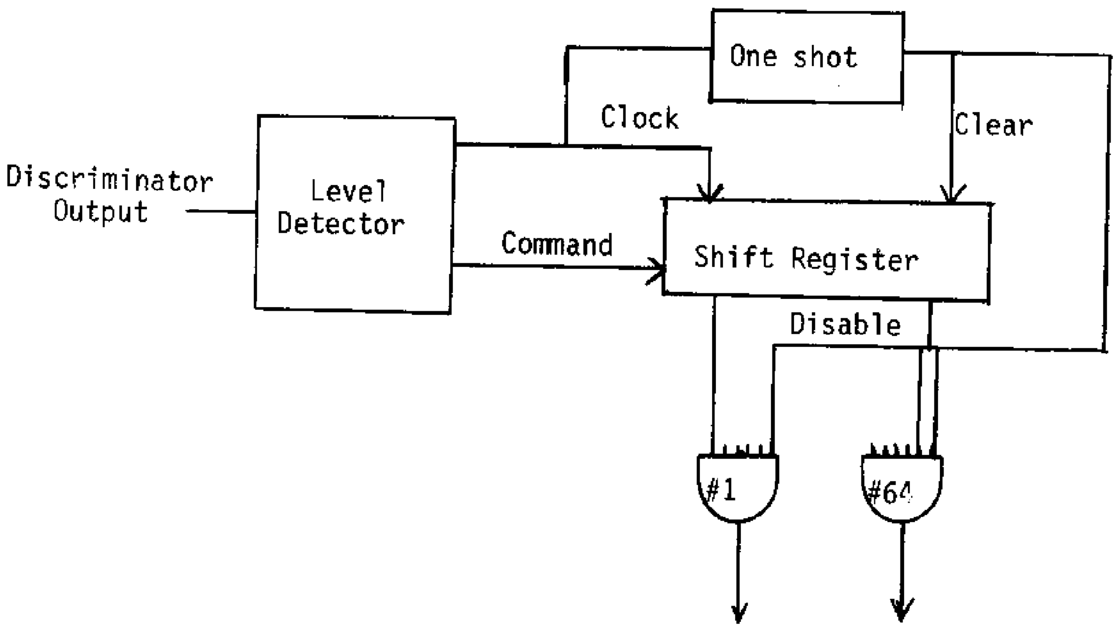

Figure 26. Command decoder

The discriminator output is applied to a level detector to separate the clock and command. This enables the command to be shifted into a six position shift register. In operation, the first clock pulse triggers a "one shot" with a 1.5 second time duration. The output of the one shot disables the command gates. During this disable period, the next six clock pulses transfers the command into the shift register. At the end of 1.5 seconds the "disable" is removed and the command is executed.

5.4 System Power Supply

Power supply requirements aboard RUFAS II include both AC and DC voltages. Present plans are to exclude the use of any batteries and related charging devices which would interfere with a 100 per cent duty cycle for RUFAS II use. Design concepts for an AC power supply are examined in the following.

Transmission of power from the control vessel to RUFAS II poses several design problems directly related to cable length. Foremost among these is voltage drop along the cable. It is expected that a ship's supply of 440 volts will be available. A block diagram of the power supply is shown in Figure 27.

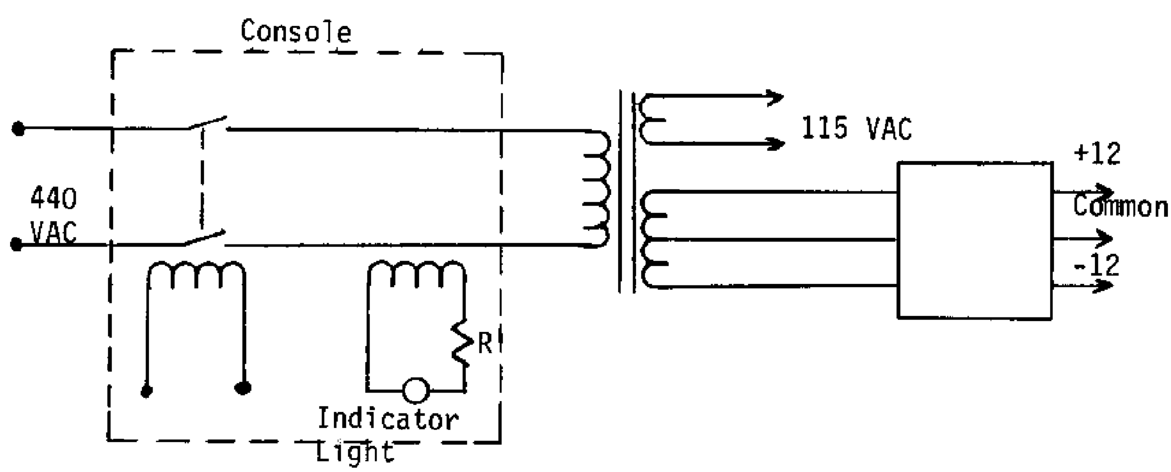

Figure 27. RUFAS II power supply

As can be seen from the figure, RUFAS II voltage requirements are 115 VAC and ± 12 VDC. An estimate of the total power requirements is given below.

RUFAS II POWER ESTIMATE

	ITEM	WATTS	VOLTAGE
1.	Television camera	150	115 VAC & ± 12 VDC
2.	TV camera light	400	115 VAC
3.	Lights (color)	400	
4.	Strobe light	350	
5.	Camera (35 & 70 mm)	1	
6.	Altitude/depth sonar	50	115 VAC
7.	Forward looking sonar	100	115 VAC
8.	Pinger	2	
9.	Telemetry, line drivers, etc.	600	± 12 VDC
10.	Directional receiver	75	
11.	Vane motors	300	115 VAC
12.	General electronics	50	± 12 VDC
13.	Transformer, power supply, losses, etc.	200	
		2678	

The estimate for total power is 2,678 watts. For a conservative design it was decided to select power conductors which will deliver additional power. Since the above figure is a minimal estimate, 4,000 watts is assumed as the maximum required as actual equipment is procured.

A #10 conductor has a resistance of approximately one ohm per thousand feet. The two-way resistance for 6000 feet is approximately 12 ohms. For a matched load, the maximum power which can be transferred is

$$P = \frac{V_L^2}{R_L} = \frac{220^2}{12} = 4{,}300 \text{ watts}$$

Power conductors smaller than #10 would not be capable of delivering 4,000 watts. Preliminary designs for a cable have been received from United States Steel and Rochester Corporation using #8 and #12 power conductors respectively. The #12 conductor would need to be increased to #10 size since the maximum deliverable power with the smaller conductors is 2,545 watts.

The power estimate will be firmed up as specific pieces of equipment are selected. Assuming for the moment that the estimate of 2,678 watts is adequate, design parameters for the transformer may be calculated. The current, I, which must be supplied may be calculated as follows:

$$440I - 12I^2 = 2{,}678$$

$$I = 7.75 \text{ amps}$$

Primary voltage at the transformer will then be

$$V_p = 440 - 12\ (7.75) = 347 \text{ volts}$$

The turns ratio to obtain 115 volts is

$$\frac{N_1}{N_2}\ \frac{347}{115} = 3.02 : 1$$

An input of 35 volts to the rectifier is adequate to obtain the regulated ± 12 VDC. The necessary turns ratio is

$$\frac{N_1}{N_2} = \frac{347}{35} = 9.9 : 1$$

It is presently planned to use modular power supplies to obtain the d. c. voltage.

Due to possible load fluctuations, it is of interest to examine the voltage regulation of the entire system. Considering the equipment listed in the table, the maximum load fluctuation would probably be the lights. The most extreme load fluctuation would not be over a third of the total or 900 watts. Current, for this case, may be calculated from the power balance equation.

$$I = \frac{440 - 440^2 - 48\ (1728)}{24} = 4.47 \text{ amps}$$

The primary voltage, V_p, would rise to

$$V_p = 440 - 12\ (4.47) = 386.5$$

This is a percentage change in load voltage of

$$\text{percent change} = \frac{286.5 - 347.0}{347.0} \times 100 = 11.4 \text{ percent}$$

The secondary voltage would rise to 131 volts for a fluctuation of 16 volts in the secondary AC supply. Thus self regulation of the system is good enough to dispense with any additional AC voltage regulation. During design, it is recommended that the secondary voltage be set at 110 volts for full load. A rise to 126 volts will not affect equipment performance.

An additional factor which must be considered in distributing power to the various system components is the introduction of unwanted "ground loops". For example, referring to Figure 27, a common ground does not exist between the DC and AC power supplies. It is recommended that chassis grounds be "floated" independently of the RUFAS II structure, if necessary, to prevent this. Additionally, a difference of several hundred volts will exist between ship's supply and RUFAS II equipment supply. The isolation introduced by the transformer must be maintained.

6. EQUIPMENT WATER-TIGHT INTEGRITY CONSIDERATIONS

Water-tight integrity for RUFAS II will be maintained by enclosing most electrical equipment and the film camera inside two 28 inch diameter spheres. Orientation of the spheres is shown in the section on vehicle studies. Both spheres will be identical and will have windows for cameras in addition to electrical and mechanical penetrations. Standard deep submergence aluminum spheres are commercially available for this application. The Aluminum Company of America offers a 28 inch diameter sphere capable of operation to a depth of 5300 feet.

However, in order to save cost and lead time on the prototype, a similar size surplus sphere is being utilized. The spheres will be split for easy access and water-tight integrity must be obtained at a working depth of 400 fathoms. The feasibility of adapting surplus helium storage spheres as pressure resistant vessels for RUFAS II is investigated in the following.

The surplus helium storage spheres are Airite Products Division of Electrada Corporation, part number 6444-1. Both spheres are made of two titanium hemispheres welded together. Two cover plates are located at the polar positions. Wall thicknesses are .362 ± .005 inches and are increased to .455 ± .008 inches at the weld. The material is 6 Al 4V titanium alloy heat treated to a minimum yeild of 146,000 psi. Sphere radius at mid-thickness is 13.769 inches.

The following formula may be used to calculate a conservative value for collapse depth of the spheres.

$$H = 2 \quad \sigma y \frac{h}{R} \times 2.25 \times K$$

Where: H = depth of collapse, feet

σy = yield strength of the material, psi

h = wall thickness, inches

R = radius to mid-thickness, inches

K = manufacturing factor : $.6 \leq K \leq 1.0$

Parameters used are:

y = 146,000 psi

h = .362 inches

R = 13.769 inches

K = .6 (for a conservative value)

$$H = 2 \times 146{,}000 \times \frac{.362}{13.769} \times 2.25 \times .6$$

H = 10,363.88 feet : collapse depth

With an operating depth of 400 fathoms (2400 feet), the safety factor is:

$$\frac{H\ \text{collapse}}{H\ \text{operating}} = \frac{10{,}364}{2{,}400} = 4.31$$

This safety factor represents an adequate margin to allow for uncertainties introduced by the split line, electrical and mechanical penetrations, and windows.

A preliminary investigation does not indicate any great problems in splitting the spheres, installing O-rings, attachments, windows, and making penetrations. The material is well suited for marine use and should not present any corrosion problems except for less noble metals in contact with the spheres. These attachments will require organic protective coatings and crack seals.

7. OPERATIONAL REQUIREMENTS

Sufficient controls must be available to allow the operator to position the sled at the desired operating depth. It is anticipated that a two man crew will be available for operation. A two man crew is desired partially to help offset the effects of operator fatigue.

During operation at the 2400 feet level, the required dive time will be on the order of 30 to 40 minutes. Because of interference with schools of fish, it may be necessary to leave the sonars inoperative until the vehicle nears bottom. In this case, the television monitor will provide a visual sighting of the sea floor so that the vehicle may be leveled off. Alternatively, it may prove practical to turn the sonar equipment on after a given elasped time. The sonar would aid in positioning the vehicle. The console to accomplish this is considered in the following.

7.1 Operator's Console

Information displays and control switches fall into four distinct groups. Displays for data and vehicle positioning is outlined below.

Data Displays

1) TV monitor
2) Pan and tilt position indicator
3) Elapsed time indicator

Maneuvering Displays

1) Obstacle avoidance sonar indicator
2) Height above bottom indicator
3) Roll and pitch indicator
4) Elevator fins position indicator

Control Switches for Data

1) TV camera control

2) Data camera control - manual, automatic

3) TV camera focus control and zoom

4) Pan and tilt control

5) Light control for TV camera

6) Light control for data camera

7) Focus

8) Aperture

9) Shutter speed

Control Switches for Maneuvering

1) Elevator fin control

2) Winch control link

3) Pilot house communication link

4) Power on-off

5) Reference depth on-off

6) Obstacle avoidance on-off

Anticipated operational demands for RUFAS II in deeper waters indicate that techniques for flying the sled along a rough bottom will require equipment arranged in a pleasing and comfortable fashion. The roll and pitch indicator may be a diminutive model of RUFAS II mounted on a slender pillar which is controlled by data from the sled such that the model assumes an attitude identical to that of the sled. In addition, this model could display elevator fin positions. From this display the operator would then be able to make necessary adjustments to control the

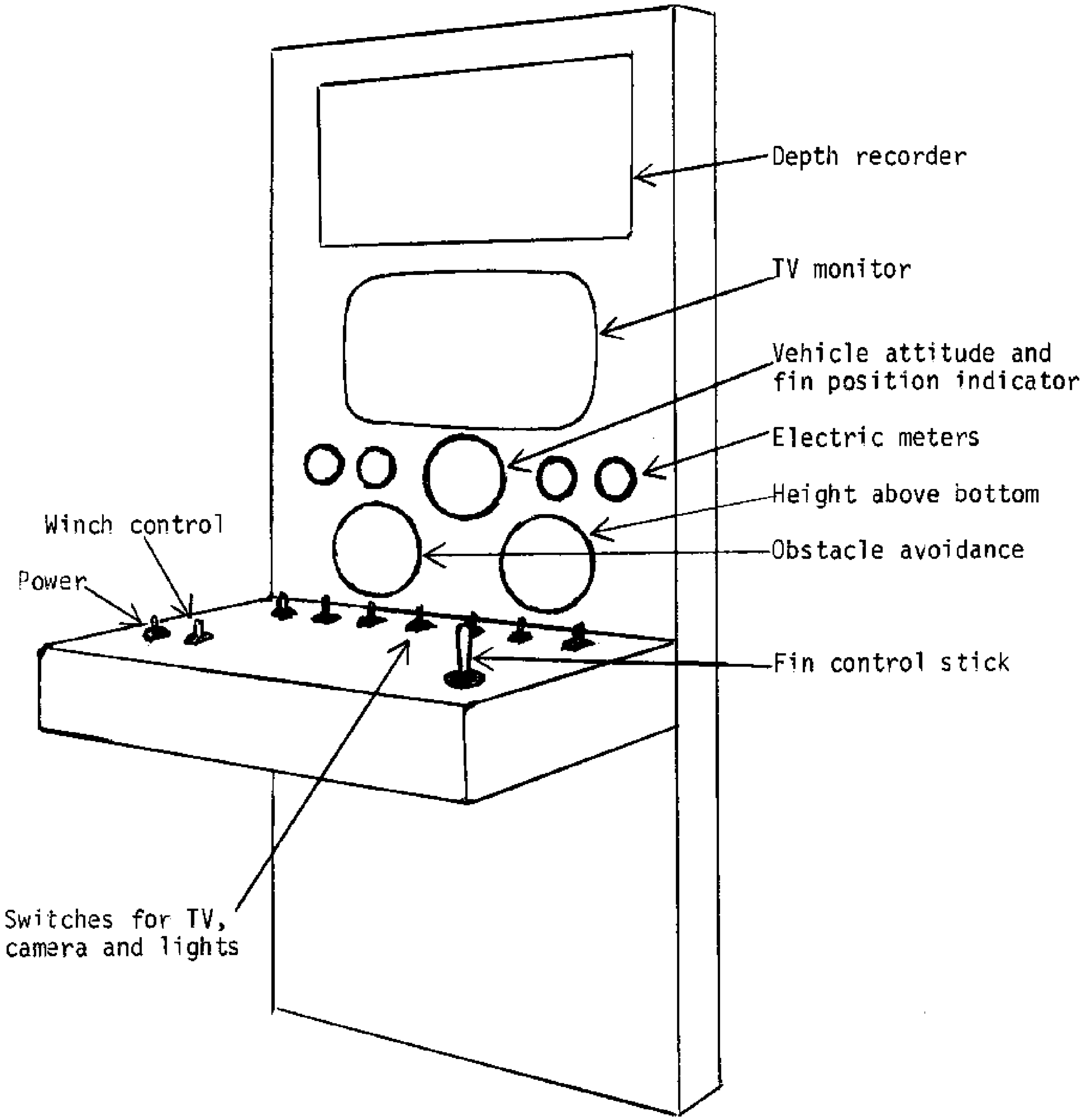

Figure 28. Tentative control console layout

sled's attitude. Layout of the control console is shown in Figure 28. It should be pointed out that the operator's console design is tentative.

7.2 Deck Handling

Arrangements for handling RUFAS II aboard any vessel are controlled to a large degree by the winch requirements necessary to handle 6000 feet of .68 inch diameter cable. Cable dry weight of 4,080 pounds plus weight of the winch requires approximately 20 HP to reel in 6000 feet of cable at 120 feet per minute. This winch would also be equipped with a spooling gear to lay the cable evenly on a 30 inches diameter drum , 36 inches long with 50 inches diameter flanges. This particular winch would be a major installation on a small craft. To handle the cable properly, 30 inches sheaves through which the cable would be reeved would be necessary. The distance from the heel block to the winch should be about 18 feet for proper cable handling procedures. Additional deck gear needed to handle RUFAS II will depend on the vessel that is selected to operate with RUFAS II. An ideal situation would be the choice of a vessel with a stern ramp and an articulated stern gantry such as the small British Stern Trawler "Universal Star" built around 1960. Calculations for the winch are shown below.

Winch for a 68 inches cable

Drum size: Rule of thumb, 50 x cable diameter (50 x .68 = 34 inches)

U. S. Steel advice for .665 - 28 inches diameter

Use 30 inches diameter

Drum width: 36 inches $\frac{36}{.68}$ = 52.94 or 52 rows

Circumference at mid depth of first layer = 2 x 3.1416 x 15.34 = 96.384 inches

Capacity of first layer = $\frac{52 \times 96.384}{12}$ = 417.665

$2 \times 3.146 \times \frac{52}{12} = 27.227$

Capacity of drum (by layers)

27.227 x 15.34 = 417.66		
27.227 x 16.02 = 436.17	-	853.83
27.227 x 16.70 = 454.69	-	1308.52
27.227 x 17.38 = 473.21	-	1781.73
27.227 x 18.06 = 491.72	-	2273.45
27.227 x 18.74 = 510.23	-	2783.68
27.227 x 19.42 = 528.75	-	3312.43
27.227 x 20.10 = 547.26	-	3859.69
27.227 x 20.78 = 565.78	-	4425.47
27.227 x 21.46 = 584.29	-	5009.76
27.227 x 22.14 = 602.81	-	5612.57
27.227 x 22.82 = 621.32	-	6233.89
27.227 x 23.50 = 639.83	-	6873.72
27.227 x 24.18 = 658.35	-	7532.07 feet

Outside diameter of wire on drum : 45.64 inches

OD of flange on drum: 50 inches

Fleeting distance: 6 x 3 = 18 feet

Dry weight of .68 inch cable: 680#/1000 feet

Assuming 5000 pounds maximum pull 3 Fps HP = $\frac{5000 \times 3}{550 \times .85}$ = 32.08 HP

2 Fps HP = $\frac{5000 \times 2}{550 \times .85}$ = 21.39 HP

at 3 Fps $\frac{6000}{3 \times 60}$ = 33 1/3 minutes to haul

at 2 Fps $\frac{6000}{2 \times 60}$ = 50 minutes to haul

8. CONCLUSIONS

The need for a RUFAS type vehicle to economically survey the ocean bottom to a depth of 400 fathoms is evident. This study indicates that the RUFAS II system concept is technically feasible.

There appears to be some complication in finding a commercially available forward looking sonar suitable for use as part of the avoidance system. However, a well known sonar manufacturer - Ross Laboratory - has a system under development for use with the RUFAS I system. It is anticipated that this or a similar system will be available for use on RUFAS II when required.

The design and fabrication of the RUFAS II prototype system is underway. It is anticipated that the system will be ready for sea trials in the late summer of 1972 if the project is funded adequately.

The mechanical configuration will be a streamlined version of the model shown in Figure 6 (page 16). Provision will be provided in the prototype for a number of different attachment points for the towing yoke. Model studies indicate dynamic response of the vehicle is greatly influenced by the choice of the point of application of the towing forces. The prototype will be approximately 11 feet long, 5.5 feet wide, and 3.5 feet tall. It will weigh about 1000 pounds when fully instrumented.

The data camera used in the RUFAS I system will also be used on RUFAS II but the larger pressure sphere of the latter will allow a film magazine with 2.5 times the capacity of the RUFAS I system. Provision is also being made for the installation of a second camera in the forward sphere if required on future missions.

A major departure from the RUFAS I system is the use of a time shared telemetry system to send commands to and receive data from the towed platform. This makes the use of a single armored cable feasible and eliminate the two cable system used on RUFAS I.

APPENDIX

In order for the Institute of Engineering Technology design team to get a first hand knowledge of the operation of RUFAS I, Professor Glenn Bryant sailed on an operational mission of the vehicle. His trip report and photographs of the operation are presented in this appendix to provide information on the operation of the RUFAS I system.

SUMMARY OF CRUISE ON NOAA R/V BOWERS AUGUST 3 THROUGH 6, 1971

G. D. Bryant, Observer
to witness operation of RUFAS I

I. I reported to National Marine Fisheries Service Dock, Pascagoula, Mississippi, 7:30 a.m. on Tuesday, August 3, 1971. I was informed that repairs to the winch were incomplete and the Bowers would sail 8:00 a.m. Wednesday. Mr. Bennie Rohr, the new RUFAS party chief showed me the NMFS facility. Discussions of the RUFAS problem with NMFS personnel indicated a high priority should be given to obstacle avoidance. There is great interest in exploring the bottom from 100 to 400 fathoms. Reef material and rough bottom are encountered on the U. S. Gulf Coast in these depths. The maximum depth capability is intended for exploring De Soto Canyon, south of Panama City. Mr. Richard B. Roe elaborated on the bottom structure to say that corral is found in the northern Gulf of Mexico from 50 to 175 fathoms. In the eastern Gulf off

Florida the bottom is smooth from 175 to 300 fathoms and is rough again below 300 fathoms. Off the Texas Gulf Coast, the bottom is rough from 50 to 100 fathoms. These rough bottoms harbor marine organisms and attract fish of commercial interest. There is therefore great interest in a survey vehicle that can bring back data from this environment. It was agreed that great operational difficulties would be represented, and a major effort should go into obstacle avoidance and maneuverability of the vehicle.

II. The Bowers left Pascagoula about 8:30 a.m. Wednesday, August 4, 1971. RUFAS I was put over the side outside the harbor for a check-out. All systems were O. K. and RUFAS was brought back aboard. The trip to the Panama City area took all day and all night. Under way at about 8 or 9 knots, the boat showed an irregular pattern of rolling and pitching in a light wind with about a two foot swell running. The roll and pitch periods both varied from about 3 to 7 seconds. The average appeared to be about 4 seconds for roll and 4 to 5 seconds for pitch. The amplitudes were moderate and not uncomfortable, although scientific work would be better performed from a more stable platform. The decks were dry, but a noticeable salt film developed on the skin when out in the wind.

III. A transect was started about 8:00 a.m. Thursday, August 5, 1971, from about ten miles west of Cape San Blas and running south.

About the same two-foot swell was running as the previous day, but the wind diminished to very light during most of the day. A glassy appearance and clear water made downward visibility into the water very good. Very little life was evident in the surface water at this time. A few jellyfish and sea hares were seen. A moderate amount of plankton was evident that seemed to be concentrated in the upper foot of water and was uniformally distributed over the surface during the whole eight hour transect.

RUFAS I was deployed over the side in its normal manner. The routine went smoothly, but the double cable and clip system would be totally unsatisfactory for a deep running vehicle. The single cable proposed for RUFAS II will eliminate much time, require two or three fewer people, and greatly reduce the required skill and hazzard to the crew. Some problem had been experienced from capsizing of RUFAS I during launch in rough water. Capt. Randall of the boat crew suggested the need for more static stability in roll for this condition. Towing was done at a nominal three knots but the distance covered indicated two knots over the bottom. The film load in the underwater camera was sufficient for the entire eight hour transect at one frame every five seconds.

Some control difficulties have been troubling RUFAS I more or less continuously. Slippage develops in the drive for one vane and there appears to be more binding, and/or less power in the drive to one side. This gives a much different response rate for the two vanes resulting in a roll input. The result is that control of RUFAS I is largely a juggling operation. Fortunately, RUFAS I usually tows very steadily except when disturbed by curious porpoises swimming around it. Also the low speed allows slower reaction time. If it were not for these factors, it would be unmanageable. It seems more desirable to have a mechanical system with one motor to raise and lower the vanes together and another to move them differentially. I believe the rough bottom operation of RUFAS II will require quick, positive response such as this should provide. Quick response may also demand an improved display that is better suited to rapid visual scanning. The present indicators are scattered over a great distance, and too much time is needed to monitor the vane position, vehicle altitude, distance above bottom, and bottom terrain trends. Two people are required to monitor the TV and operate the vehicle. This further increases the reaction time in emergency. Frequently, it appears that the vehicle is not closely monitored for considerable periods of time. This is acceptable for smooth bottom and slow speeds but would have to be changed for the anticipated RUFAS II conditions.

The transect started in relatively shallow water of about 20 fathoms or less and something on the order of 10 miles from shore. Visibility of the bottom on the TV screen was poor at first. This gradually improved with depth and distance from shore. The shallow bottom was largely covered with a short grassy weed with bare sandy patches showing. Sea hares were abundant and an occasional crab and evidence of burrowing worms were the chief indications of animal life. The resolution of the TV system was not up to the state-of-the-art and recognition was generally poor. The definition of the photos should be much better, but I did not see any examples of them. A higher resolution TV would greatly improve the efficiency of the system. Sand ridges were indicated on the recording depth sounder, but they were limited to 2 to 4 fathoms in height or depth. RUFAS I was maneuvered up in these areas to be well clear and they were not visible on the TV. The clarity of the water was excellent as the distance from shore increased. A porpoise could be clearly seen at an estimated 50 feet.

IV. Following the transect, the Bowers returned to a point a little north of the starting point and anchored for the night. The intention was to start another transect in the morning. However, the sea rose during the night to the degree that the transect was canceled. It was felt that marginal conditions existed for retrieving RUFAS I and considerable risk would be involved in getting it back on deck. Also, the rolling and pitching of the Bowers introduced varying disturbances through the tow cable that made accurate positioning of RUFAS I over the bottom difficult. It was expected to be in a favorable position to photograph the bottom for only a portion of the time.

When anchored or moving slowly, the Bowers has rather small damping in roll. Toward morning the sea rose with waves about four feet high and a wave length of forty to fifty feet. Not much long swell was evident. This caused the Bowers to roll so violently that all activity was very difficult. Once under way, however, at eight or nine knots the frequency of hitting the waves was enough faster than the natural roll frequency of the Bowers that almost no rolling was evident. Spray came over the bows and sides, however, and a continuous flow of water came in the hawse pipes.

V. I was impressed with the fact that the components of the RUFAS cable-winch-boat system have to have a high degree of compatibility in order to constitute an effective survey instruments. This effectiveness is measured by the quality and quantity of data gathered in the shortest time at the lowest cost. I do not believe the present system rates high in this regard except under limited conditions close to the base of operations. The RUFAS I crew was satisfied with the reliability of RUFAS I for the present mission. Taking the whole system together, however, the actual time spent surveying the bottom was only a small part of the total time that crews and equipment were tied up. Major amounts of time are lost for boat and equipment repairs, time to get to station, crew changes, refueling and reprovisioning, bad weather, waiting for daylight, etc.

Of the two fisheries vessels available on the Gulf, neither appears very efficient for this operation. The Bowers has the advantage of small size and low operating cost. Otherwise, it is poor in every respect. It loses too much time because of its low speed. Its lack of roll damping limits its operation to very moderate seas. Its cruising range is insufficient. Crew accomodations are insufficient for a boat crew and scientific party. Not enough room is available for instrumentation, monitoring, computation, or scientific work. Of the available volume, its utilization is marginal. On the other hand, the Oregan II is just the opposite. It is adequate in all the above respects except that it is much larger and more expensive to operate than necessary.

If bottom survey using the RUFAS I technique is to be widely adopted, efficiency would be much improved by acquiring a more suitable boat. All the above requirements could be well met by a fine-lined, high powered boat of about 120 feet length having good roll damping and sea keeping.

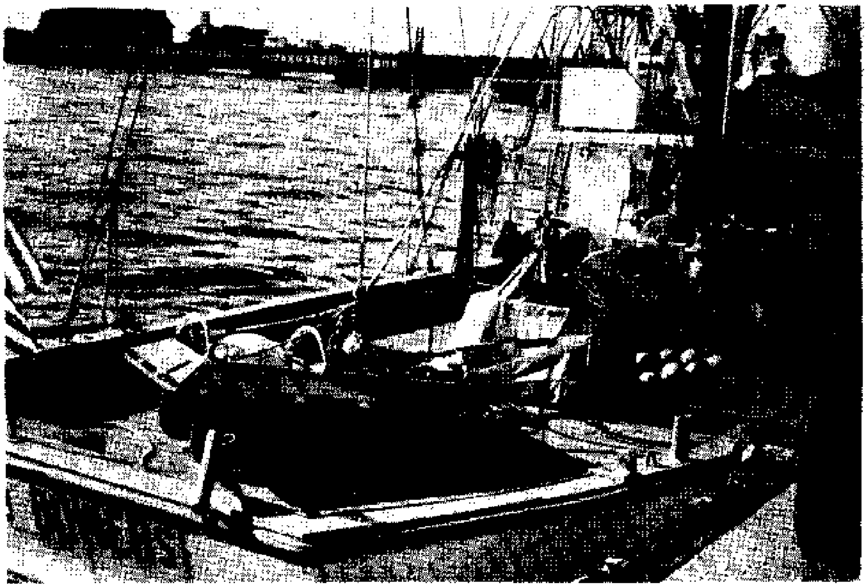

Figure 29. Photograph of RUFAS I on deck of NOAA R/V George M. Bowers. Control vanes are not yet attached. The towing winch and the pile of electrical communications and power cable may also be seen on deck.

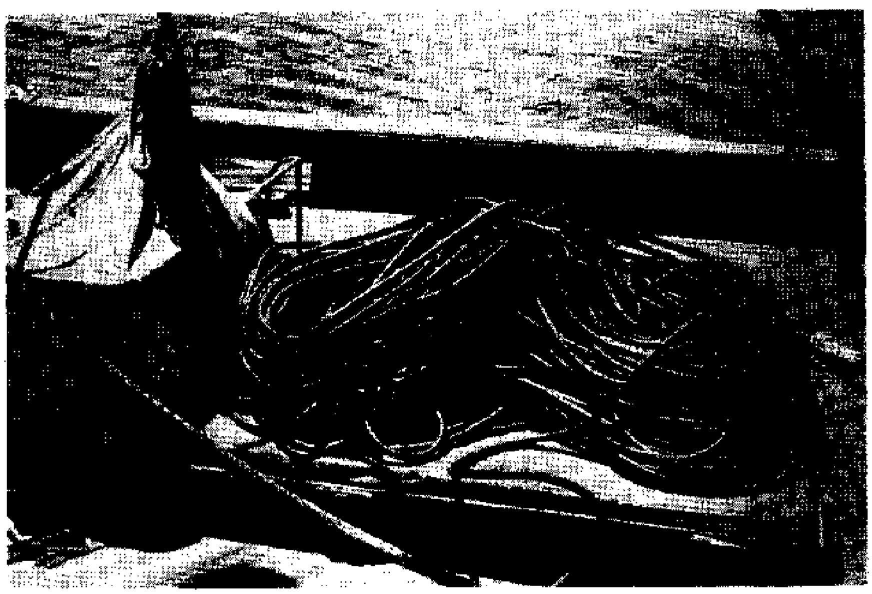

Figure 30. Close-up view of the electrical cable used on the RUFAS I system

Figure 31. RUFAS I just after being lowered over the side

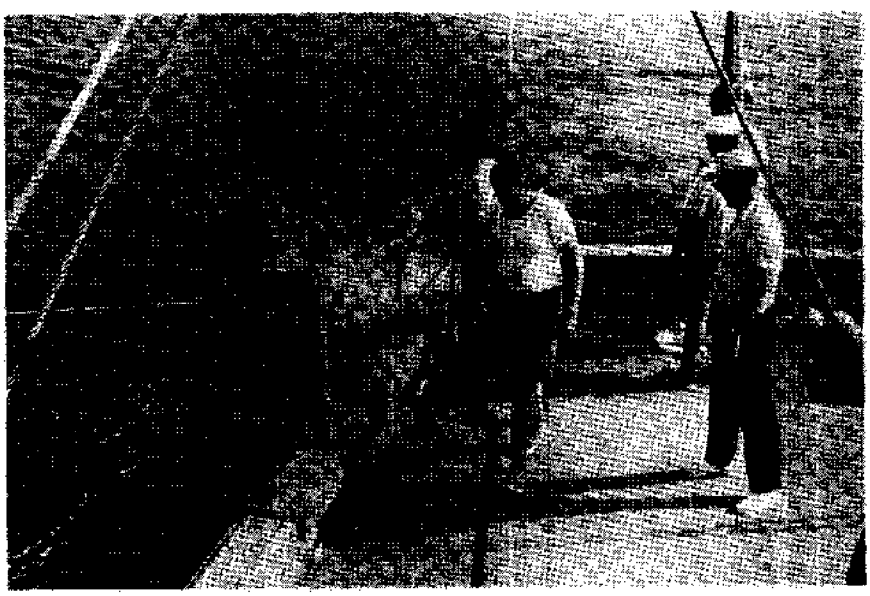

Figure 32. The black electrical cable is clamped to the steel tow cable after it passes through the sheave

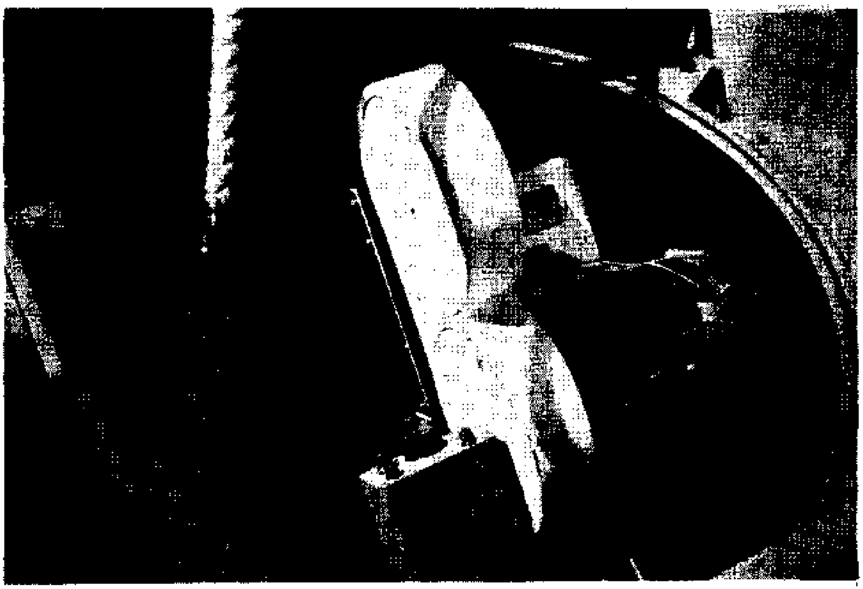

Figure 33. View of the RUFAS I camera sphere with the top hemisphere removed