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PERFORMANCE EVALUATION OF HIGH SPEED SURVEY BOAT "RODOLF"

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ABSTRACT

The surveyboat *Rodolf* is the result of the Portland District's efforts to improve the efficiency of hydrographic surveys and use the full capabilities of electronic equipment. The *Rodolf* is an example of surface-effect-ship (SES) technology, the concept of an air-cushion supported vessel with rigid side hulls combined with the latest survey technology. With air-cushion assist, up to 80 percent of the vessel weight is supported by air pressure.

Approximately one year of operating experience has been accumulated with the *Rodolf* in the Portland District. The air-cushion assist principle has proven itself to be a valid concept for use as a high speed surveyboat. Supporting most of the vessel weight with an air-cushion is a fuel efficient method of attaining high performance with reduced propulsion power requirements.

Survey speeds of 22 knots are attainable with the *Rodolf*. Handling and maneuvering characteristics are similar to regular planing hulls in many ways.

BACKGROUND

The application of electronics to hydrographic survey work has had a major impact on surveying methods and personnel requirements. In recent years this evolution has continued with further advances and refinements in solid state technology and the application of mini computers to the hydrographic survey

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process. In order to better utilize integrated electronic survey system data-gathering capability, a high speed surveyboat was determined to be necessary in the United States. This office was given the assignment to evaluate various types of high speed vessels for use as a survey platform.

In 1974, preliminary investigation of design requirements for a high speed surveyboat was initiated. Desired performance criteria and general operating characteristics were established as a means of evaluating the relative advantages and drawbacks of high speed vessels best meeting the desired performance requirements.

During the preliminary investigation, different types of vessels were considered for potential surveyboat use. Besides traditional planing monohulls, unconventional hull forms such as catamarans, hydrofoils, air-cushion vehicles (ACV's) which are also termed hovercraft, surface effect ships (SES), and a rigid side wall ACV, were considered. Each type of craft was evaluated for its operating characteristics and capability of meeting established criteria. The proposed new surveyboat eventually selected by this process was a type of surface effect ship which offered considerable potential over the other vessels considered.

A suitably powered planing mono-hull would, at first glance, appear to be the most likely choice considering their wide range of uses. However, conventional planing hulls still have some characteristics undesirable in hydrographic surveying work. Ride quality deteriorates as speeds increase and the size of wake generated can restrict operations in developed areas. Rapidly increasing horsepower requirements are necessary for higher speed operation with concurrent increase in fuel consumption. Planing catamarans offer some improvements in ride quality and wake characteristics but these also require higher horsepower requirements for increased operating speeds.

Hydrofoils were considered but rejected because of very serious drawbacks for use as a surveyboat. Although capable of high speeds combined with smooth ride, they require sophisticated and expensive propulsion and foil control systems. Foils are also vulnerable to flotsam and debris prevalent in our navigable waterways. Perhaps an even more significant operational limitation would be the lack of a suitable middle speed operating range at which surveys could be accomplished. The hydrofoil would be limited to slow speed operation when hull-borne and to high speed operation when on the foils. The speed range between hull-borne and foil-borne is an undesirable transient operating condition unsuitable for survey work.

Air-cushion vehicles or hovercraft were also considered. An ACV is characterized by a full perimeter flexible curtain which captures the supporting air-cushion. There are several characteristics of an ACV which would limit its use as a surveyboat. Propulsion is normally achieved by airplane type propellers which generate considerable noise at higher power outputs, while at the same time not being very efficient. Maneuverability is limited because the vessel operates entirely on an air-cushion making no solid contact with water. When turning, considerable side slip is encountered, requiring relatively large open areas to maneuver. In many survey locations sufficient turning space would not be available due to the presence of other marine traffic or simply because of the size of the waterway itself. The air-cushion is also required to effectively operate the vessel, since off-cushion speed and maneuvering capabilities are very poor.

Another type of vessel considered was the surface effect ship, a rigid sidewalled air-cushion vehicle. This type of vessel is best described as a combination air-cushion vehicle and catamaran, wherein the longitudinal portions of the ACV's flexible curtain have been replaced with rigid sidehulls which contact the water at all times. The supporting air-cushion is maintained between these sidehulls by flexible seals across the bow and stern of the vessel, such that the majority of the vessel's weight is still supported by the air-cushion. This configuration showed considerable promise for application as a hydrographic surveyboat because of several desirable characteristics :

a) Desirable operating characteristics over a wide range of speeds;
b) Good maneuverability because the rigid sidehulls maintain contact with the water surface providing directional stability;
c) Noise comparable to conventional planing hulls because standard underwater propulsion and steering systems are used;
d) Lower power-to-weight requirements compared to planing hulls.

Having selected the SES concept as offering the best potential for our new high speed surveyboat, the advantages and disadvantages between a narrow and wide side hull SES were investigated. When off-cushion, the wider side hulls displaced all of the vessel's weight, maintaining clearance between the cross structure wet deck and the water surface; however, the narrow side hull SES displaced a majority of its weight with the cross structure in the water. Because of these differences, the wide side hull SES provided better operational performance while off-cushion. Based on this comparison of operating characteristics, the wide side hulled SES was considered best able to meet our operating requirements.

Now confident that a wide hulled SES could be an effective hydrographic surveyboat, Portland District developed the procurement package for obtaining this unusual type of vessel. A contract was awarded to Bell-Halter (a joint venture of Bell Aerospace and Halter Marine, Inc.) on 22 November 1978.

Bell Aerospace has been deeply involved in air cushion vehicle and surface effect ship research and development for many years, mainly through contracts with the United States Navy. Through this work, they have developed and operated many large surface effect ships. Bell Aerospace is one of the few United States Companies with experience in the development and use of bow and stern seals.

Completion of the vessel was required within one year. Acceptance trials were conducted in November 1979 and delivery was made to the Corps of Engineers in New Orleans in December 1979.

After delivery, a demonstration tour was conducted between New Orleans and Washington, D.C., with intermediate stops at eight other Corps of Engineers' installations. Upon completion of this tour, the *Rodolf* was transported to the Columbia River, Oregon, as deck cargo on a ship.

FIG. 1. – Full speed operations.

Details of boat

Length	14.6 metres
Beam	7.3 metres
Depth, molded	2.2 metres
Max draft (off-cushion)	1.8 metres
Max draft (on-cushion)	1.2 metres
Displacement (full load)	25,000 kilograms
Fuel capacity	5,300 litres
Range	1,600 kilometres
Maximum design speed	30 knots

Propulsion .... two 8V-92N Detroit diesel marine engines, 350 SHP each; two 61 cm-diameter, fourbladed stainless steel propellers.

Lift .... one 4-53N Detroit diesel marine engine, 105 SHP; one Bell 76 cm-diameter centrifugal fan.

Generators .... one, 7.5 kW, and one, 15 kW.

EVALUATION OF OPERATION

The *Rodolf* has been in service in the Portland District for approximately one year. Activities have included surveying and mobilizing operations under various conditions. The vessel has also experienced its share of shakedown problems, equipment repairs and modifications in getting through this testing period. The *Rodolf* is currently being utilized on a regular basis performing survey work on the Columbia River between Portland and Astoria. This first year of operation provides the experience and information necessary to describe the vessel's characteristics and capabilities.

Off-cushion operation

Off-cushion operation of the *Rodolf* is similar to that of a displacement or semi-planing catamaran. At slow speeds the hull operates in the displacement mode like a planing vessel would. Sufficient propeller thrust is available to push the vessel well beyond the displacement hull speed into a semi-planing mode of operation at 13 knots; however, continuous off-cushion operation, except at low speed, is not desirable as damage can occur to the stern seal. Low speed maneuvering and directional control while off-cushion is primarily a function of propulsion engine power settings. At low speeds the rudders have minimal effect on directional control. This is due partially to the fact that rudders are offset so far from propeller centerlines that very little rudder interaction with the propeller wash occurs. Response is similar to that of other twin-propeller craft except that the wide spacing of the propellers in the side hulls accentuates the rate of response. As hull speed increases, the rudders begin to contribute more to steering control. In the speed range of 9 to 13 knots, directional control can be accomplished with rudders only, provided both propulsion engines are evenly set.

On-cushion operation

On-cushion, low speed maneuvering and directional control remains primarily a function of propulsion engine power settings just as in the off-cushion mode. Reduced hull immersion and drag when on-cushion actually increases the effect of differential propeller thrust on maneuvering actions.

As hull speed increases, directional control becomes more a function of rudder position, although differential propulsion power can also be used to advantage at all speeds. Directional control above 13 knots can be accomplished with rudders only. Above 17 knots, rudder response characteristics are well suited to maintain survey lines. Moderate helm input provides the course corrections necessary to maintain predetermined courses.

The *Rodolf* can readily attain speeds of 30 knots. Maximum speed attained has been 33 knots, which was achieved in calm water conditions and with minimum payload aboard. Propulsion and lift engine power output to achieve these speeds are within the engine manufacturer's continuous power ratings. The two General Motors 8V-92N propulsion engines are rated at 350 horsepower each at 2100 rpm. The General Motors 4-53N lift engine is rated at 100 horsepower at 2400 rpm. Operating all engines at 1800-1900 rpm permits the *Rodolf* to cruise comfortably at approximately 26 knots.

Wake characteristics

During slow speed off-cushion operation, wake generated by the *Rodolf* is comparable to a planing hull operating in the displacement mode. As speeds increase, displacement operation is less efficient and wake increases.

During the semi-planing transition condition between displacement and planing modes of operation a large bow wave is formed. The condition is worst between 9 and 18 knots depending on the amount of cushion pressure applied. Higher speeds again produce minimal wake.

Single engine operation

If only one propulsion engine is available, the unbalanced thrust causes the vessel to turn continually in one direction despite full rudder in the opposite direction. The lack of directional control, if one propulsion engine is not available, has an obvious impact on operational considerations and the vessel capability. Vessel and crew safety could be compromised under adverse sea conditions because of the inability to maneuver to safety. Improvements in low speed handling should be possible by relocating the rudders to be more in line with the propellers. Structurally the consequences of rudder relocation involve considerable work, and for this reason the modification has not been undertaken. Another possible configuration for improved steering capability include installing a portable rudder directly behind the available propulsion unit during single engine operation. The wide separation of the two propulsion units in the sidehulls will always prevent attaining a high degree of rudder control with single engine operation, but steerage adequate for crew safety is expected to be accomplished. The location of thrust relative to the center of drag of the hulls does not permit the same characteristics that a longer length to beam ratio SES would provide.

Ocean operation

Operation of the *Rodolf* in the Pacific Ocean has been undertaken several times with results that have been less than satisfactory. Ride quality into a head sea with wave heights greater than 1.5 meters (sea state 3) rapidly deteriorates with increasing sea state, and handling and maneuverability becomes very cumbersome even at reduced speeds. The *Rodolf* has exhibited poor seakeeping characteristics compared to standard monohulls operating in the immediate vicinity of the *Rodolf*. As wave

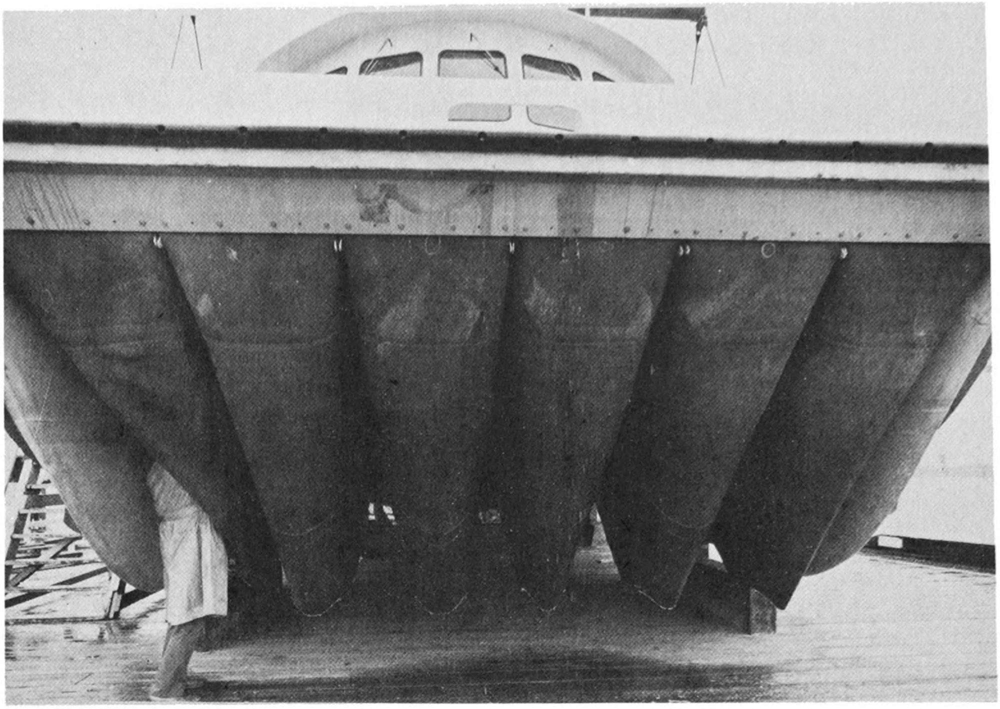

FIG. 2. – View showing bow seal.

conditions increase, vertical accelerations of the vessel increase rapidly to the point of discomfort for personnel aboard. A trip across the Gulf of Mexico to Florida during the East Coast demonstration tour was satisfactorily accomplished at a lower sea state. Response when operating in a following sea is quite different than operating into a head sea. The combination of relative speed between the vessel and wave, and the slope of wave fronts improves the vessel ride. This is very true with the *Rodolf*s response characteristics. Under following sea conditions the ride quality improves much more dramatically than would be expected, when compared to its inability to operate in head seas.

Air-cushion seals

The air-cushion support system consists of a diesel engine, a centrifugal fan, air distribution ducts that are integral with the structure, and the bow and stern flexible seal assemblies. The seal assemblies are fabricated from neoprene-coated, woven nylon fabric that was specifically engineered for SES applications.

Establishing the rate of wear and ultimate life of the air-cushion seals is an important element of the economic feasibility of this type of vessel. To that end, the bow and stern seals have been frequently inspected since the *Rodolf* arrived in Portland, to monitor their condition and rate of wear. Results show that both the bow and stern seals incur a certain amount of wear from normal operations.

Bow seal segment wear occurs on the lower edge of the segments which are in contact with the water (figure 2). These lower edges tend to vibrate rapidly, eventually cracking and separating the neoprene coating from the nylon fabric. As

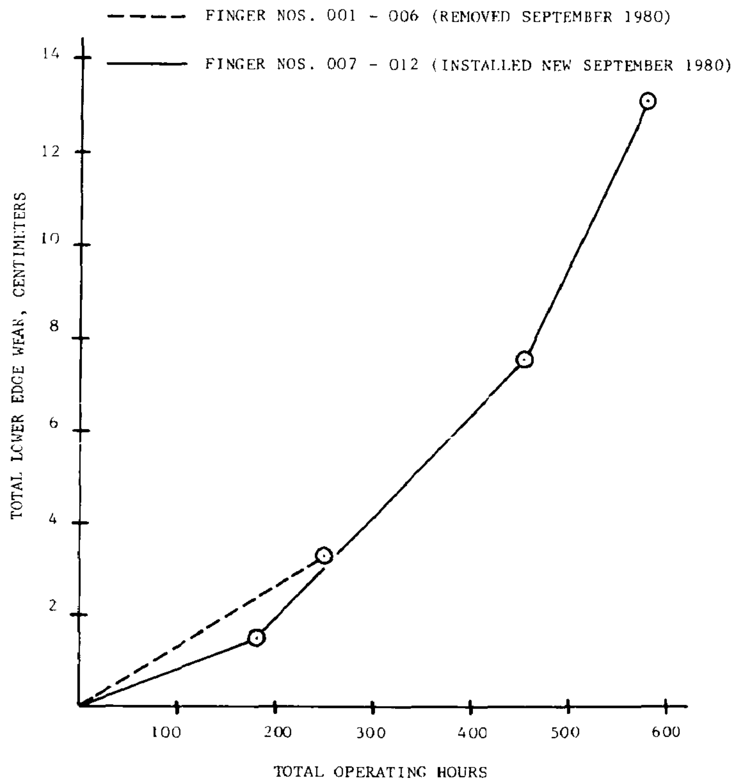

FIG. 3. – Bow finger wear.

the process of separation and fabric deterioration continues, the edge progressively wears away, exposing new material to continue the wear cycle. Eventually, seal material is worn away to the extent that the segment has to be removed and the lower portion replaced. Segment repair is still in the experimental phase and will be accomplished by vulcanizing, mechanical fasteners or both.

Results of the inspections on the bow seal segments are presented in figure 3. Comparing the progressive amounts of wear with the total operating hours indicates that the rate of wear accelerates with time. The service life of the bow seal now appears to be considerably less than that indicated by initial wear rates. The worn bow seal segments will be repaired and additional wear rates monitored to determine the effectiveness of the repairs. The rate of wear is being discussed with Bell-Halter and another material may be selected. Operating experience obtained on the Bell-Halter 110 SES has shown that bow seal wear rates much lower than those on the *Rodolf* should be obtainable.

Stern seal wear has not presented any problems. The design of the stern seal consists of an inflatable bag assembly attached to the cross structure of the hull. End panels of the inflated bag press against the sidehulls and the bottom surface inflates against the water surface to contain the air. This design does not expose any edges which can vibrate and wear. The only significant wear observed has been on the end panels of the bag, which rub against the sidehulls. The neoprene coating has worn off these portions of the seal, exposing the nylon fabric.

SURVEY OPERATIONS

Following the *Rodolf*'s delivery to Portland District, the integrated survey system was installed and surveying operations initiated. Operations confirmed the capability of sounding at speeds up to 22 knots. Fathometer analog recording of depth data show no appreciable deterioration at this speed. Automatic digitizing and computer processing of depth data by the survey system also does not present any problems.

The ability to sound at lower speeds is also an important requirement for a surveyboat. Transducer operation at slow and intermediate speeds is generally not a problem in either off- or on-cushion mode. The only limitation for transducer operation is restricting the amount of cushion pressure to prevent escapement of air from beneath the sidehulls. At speeds of 9 to 17 knots, transducer operation is satisfactory using most combinations of hull speed and air-cushion assist. Transducer operation does become intermittent under certain combinations of hull speed and lift pressure due to occasional venting of air under the hulls.

The Columbia River between Astoria, Oregon, and Portland, Oregon (150 kilometers) has been the *Rodolf*'s primary operating area since its delivery to Portland District. Operating characteristics of the *Rodolf* are well suited to the survey requirements and conditions encountered on the river. The long distances involved and the straight channel alignment utilizes the mobilizing and sounding capability to good advantage. Water conditions in the river are favorable for the *Rodolf*'s seakeeping capability limitations.

Rapid mobilization capability in the river has enhanced the flexibility of survey operations. The ability to do 26 knots has reduced the time spent in commuting to and from the survey site, thus making available more time for surveying. The high speed also permits going further out on short notice and still achieving a good day's surveys of critical shoals or dredging areas.

Columbia River navigation channel surveys are routinely being done at 17 to 22 knot sounding speeds. The 183 meter wide channel usually consists of straight reaches 3 to 5 kilometers long between bends. Typical surveys are made by running five survey lines parallel to the channel centerline of each reach. The time spent surveying a 5 kilometer long reach may only amount to one hour of actual sounding.

Maneuvering at higher speeds during surveying in the river does not present any unusual problems. The sidehulls maintain contact with the water to provide good directional stability to maintain course headings. Maneuvering around other traffic is readily accomplished with rudder corrections. The sidehulls prevent side slipping when turning, providing predictable response characteristics.

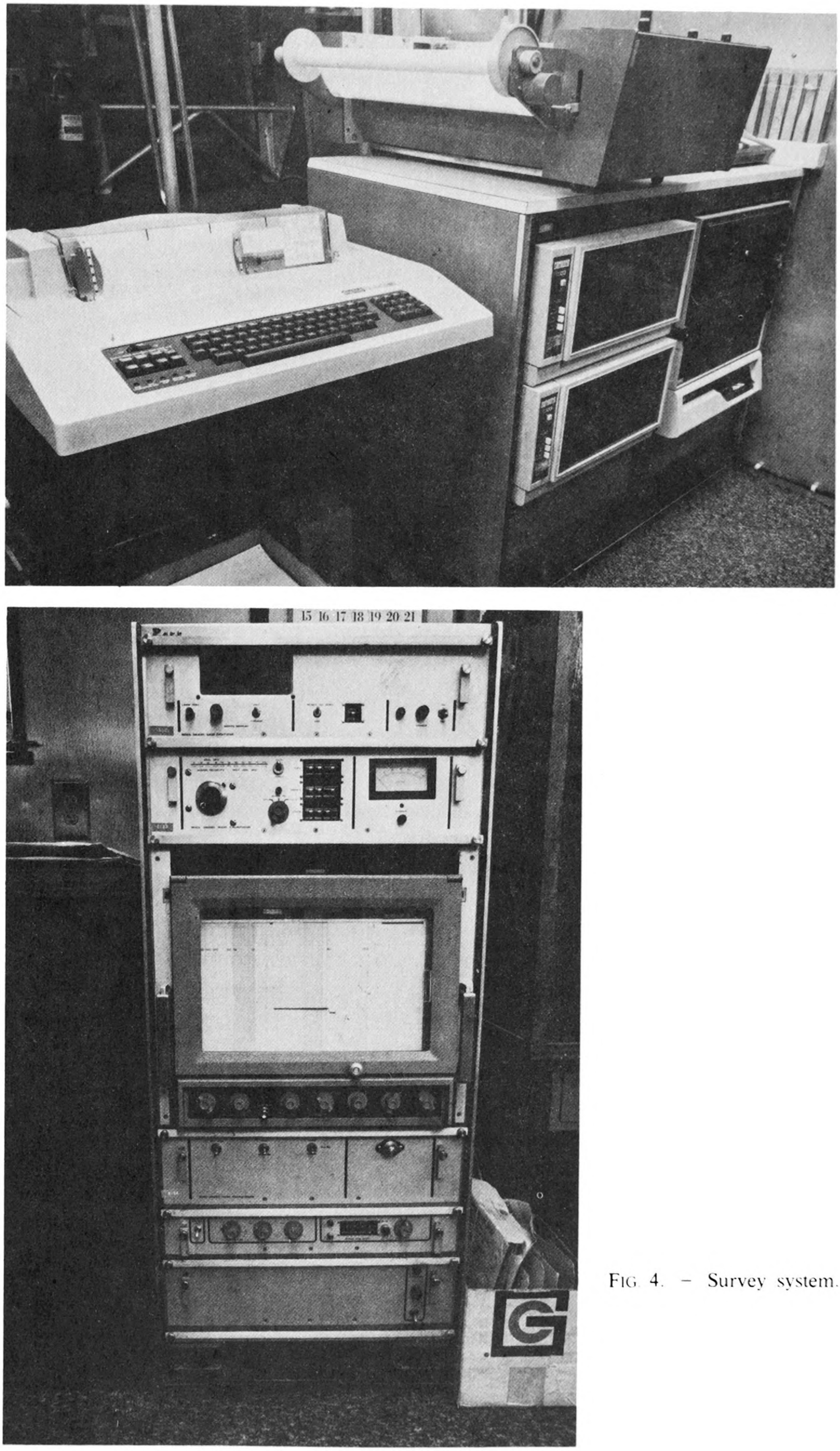

FIG. 4. – Survey system.

AUTOMATED SURVEY SYSTEM

The integrated Hydrographic Surveying System (figure 4) used on our survey-boat *Rodolf* is a Decca-designed Custom Auto-Carta system and is operated by a survey crew of three persons. Inputs from the Del-Norte Electronic Positioning System and Ross Fine Line Depth Sonar are stored in the computer memory and are transcribed onto a magnetic tape. The system includes a Houston Instrument Model DP-3 Plotter, with all equipment interfaced to the computer.

The system utilizes a "2-Pass" technique. Data accumulation and track plotting is accomplished in an on-line surveying mode; data outputs, chart plotting, quantity computations, etc., are provided in an off-line (editing) mode. During the surveying process (on-line mode), data from the electronic positioning system and depth sonar are accumulated and stored on a magnetic tape. In addition, a track plot is made of the vessel's location during the entire survey. During the off-line mode, soundings are edited, processed and plotted with the on-board plotter, and simultaneously, edited data is transcribed to a second magnetic tape for transfer into the District Office, where final plotting of the chart is completed on a computer actuated flatbed plotter.

A program has been put into the computer to help eliminate the error caused by waves and swells when surveying in ocean and estuary areas. Blocks of depth soundings which may be varied from one to twenty seconds by the operator, depending on the size of the waves and swells, are averaged to try to eliminate as much of the wave action as possible. Although this minimizes error due to heave of the vessel from waves, we cannot compensate for the error caused by pitch and roll. During normal river surveys the wave action is minimal causing only a slight error.

Depth correction for tide or river level is made during the editing phase by inserting the proper correction into the computer. When editing the raw depth data, the correction is applied to the raw depth, and the corrected depth is recorded on the edited tape.

Correction for height of the vessel when on-cushion is put into the depth sonar and corrected depths are recorded during the survey run. All surveys are completed using the same lift fan speed thus giving the same cushion pressure and height above the water surface. This height correction is checked before each survey by putting the surveyboat on-cushion and performing a bar check and allowing for the correction factor when setting the transmission line of the depth sonar.

The components of our automated survey system are as follows :

a) Ross Fine Line Model 200 Depth Sonar;
b) Del-Norte Trisponder Model 202A Positioning System;
c) Houston Instrument Model DP-3 RC Plotter;
d) Texas Instrument Silent 700 Terminal with 733KSR keyboard/thermal printer;
e) Digital Equipment Corporation Reader/Punch, Model PC11;
f) Digital Equipment Corporation Model PDP11/34 Mini Computer.

CONCLUSION

After one year of operating experience, the surveyboat *Rodolf* has proven itself to be an effective energy efficient high speed surveyboat. The first year's cost of operation has been higher than expected due to required modifications, repairs and a higher than expected wear factor on the bow seal. These costs should decrease in future to make this vessel more cost effective and competitive with other existing surveyboats.

The 1974 Safety of Life at Sea (SOLAS) Convention came into force in May 1980. Under Regulation 20 of this Convention, all sizeable vessels are required to carry an adequate set of up-to-date charts and publications. Yet, in October 1980, it was reported that a 13,000 ton EEC-flag tanker which arrived in Milford Haven from the North Sea only carried the same outfit of charts as had been supplied to her on being built in 1957. These were in a pristine state and had lain on board, uncorrected and without replacement by updated versions, for 23 years; for Milford Haven alone, the changes during this time have been sufficiently important for us to have issued six New Editions and countless Notices to Mariners. Yet her officers were unaware of all the new facilities at this busy, « new » (to them) port as well as of IALA Region A buoyage, Traffic Separation Schemes, changes in depths, wrecks, etc.

One must hope that international and national legislation is strengthened in order to reduce the dangers caused by such mavericks.

Extract from : *Report by the Hydrographer of the Navy for the year 1980*, Taunton, U.K.