AERIAL STEREO-PHOTOGRAPHY AND OCEAN WAVES*

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Abstract

A need for experimental verification of new ocean wave theories is discussed. The use of aerial stereo-photography as a means to this end is outlined. A brief summary of the operational plan is given and special attention is focused on those aspects of the operation which make photography of a moving target, which changes shape with time, unique. The reduction of the stereo-pairs to data form and the application of this information to ocean wave research is discussed. Results of the operation are given.

Introduction

RECENT investigations have produced theories which explain the generation, propagation and decay of ocean waves (Pierson, 1952, Neumann, 1953); in general the behavior of the waves can be predicted, if certain parameters are known. To describe any motion it is necessary to know the initial state of the system and the laws which govern the motion. These laws are known for waves, to a fair degree of approximation; it is the initial state which must be determined. The complexity of the sea surface rules out a precise mathematical description, of every configuration, in time and space, but a way to describe the features of ocean surface has been found in a statistical approach to the problem.

The energy in the waves can be described by a spectrum which is a function of wave frequency and direction of travel of the spectral components. The energy spectrum can be found if the sea surface is "captured" in either time or space. Many methods have been tried, with only partial success. A wave pole, for example, may record a time history of the waves as they pass a fixed point. The energy spectrum as a function of wave frequency is determined (Pierson and Marks, 1952) but nothing is known about the distribution of energy with respect to direction of travel. This argument holds for all such single point observers. Perhaps a battery of wave poles is the answer, but the theory governing the analysis of such data has not yet been derived An attempt has been made to record the sea surface with a sensitive radio altimeter mounted in an airplane which makes a run over the sea surface. (Deacon, Darbyshire and Smith, 1949). In this case, wave frequencies (periods) are distorted because the plane cannot fly perpendicularly to all the wave crests all the time, and directional information is at best inferred. Some other attempts at wave measurement have been: pressure elements placed on the ocean bottom to record the pressure of the water column above; submarines moving and stationary, equipped with pressure elements and accelerometers (to compensate for the submarines' vertical motions), (Ewing and Press, 1949); ships equipped with pressure elements and accelerometers; and several other methods which are variations of the above.

A good deal of thought was given to the Sonne strip camera as a means of "laying a carpet down on the sea surface," that is, a narrow strip of the sea surface is recorded by a fast, low flying airplane (Sawyer, 1949). Here again, the field of view is too narrow to determine the direction spectrum. The next logical step is consideration of high altitude stereophotography. This satisfies all of the conditions imposed above with respect to determination of the energy distribution as a function of frequency and direction of travel of the wave components. From the stereo-pairs, elevations are read at discrete points, where the spacing of the points depends on the properties of the sea surface and the resolution (of the spectrum) desired. The information is fed into an electronic computer and the end result is the two-dimensional energy spectrum of the waves (Marks, 1954).

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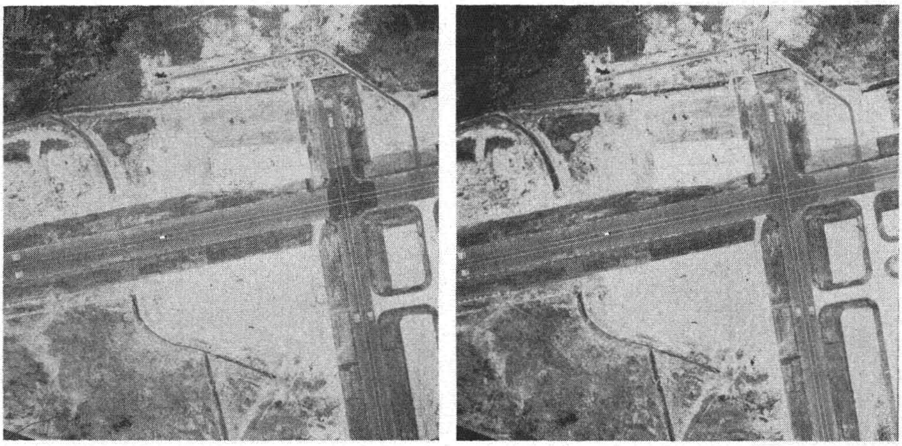

FIG. 1.—Stereo-pair showing the truck on the runway.

TEST FLIGHT

In order to capture enough of the sea surface for analysis purposes, it was necessary to use two planes. The cameras were triggered at the same instant by an FM signal sent out by the master plane.

It was desired to prove that the electronic link would actually fire the two cameras simultaneously. Oscillograph measurements made on the ground with the engines of the two airplanes turned up, indicated that the cameras could be fired within one millisecond of each other, or better. To substantiate further the ability of the F. M. link to trigger the cameras simultaneously, a test flight was made over the airfield, along the runway. A truck traveled in the opposite direction at 40 mph (the fastest wave speed anticipated); the plane moved at 160 mph. The photographs were made with various delays installed in the cameras. That is, one camera was purposely fired 5 milliseconds after the other one. Then the delay was reversed. The result was that in no pair of photographs could it be visually ascertained that there was any change in position of the truck. Furthermore, the photos were enlarged 25 times and no difference could be measured that was greater than the measuring error itself. Figure 1 shows a stereo-pair of the truck on the runway.

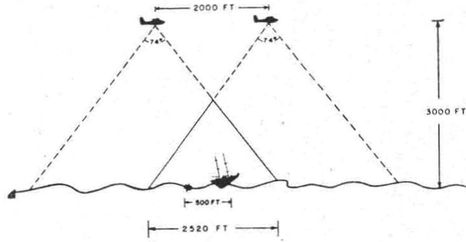

FIG. 2.—Schematic representation of operational procedure.

OPERATIONAL PROCEDURE

Stereo-photography of the sea surface involves certain problems not encountered over land. The sea presents a relief pattern which is always moving and changing its shape, and it offers no fixed marks which can be used for ground control.

However, in the case of a rough sea (waves 15 to 20 feet high) such as are required for this experiment, there is a great deal of contrast between the foam (due to breaking wave crests) and the water, and this can be utilized for the separation of tonal values in the photographs. The serious problem of reflection glare can be overcome if the pictures are taken at a time of day when the sun is at a relatively low altitude (40°) or, ideally, when there is a high overcast.

Attempts have been made to obtain oblique stereo-pairs from a ship (Schumacher, 1932) but this method is not altogether satisfactory. The camera base line is too short to be useful except over a small area, the backs of the waves are not recorded, and the nearer waves obstruct those more distant.

To satisfy the needs of the oceanographer for a statistical analysis of the sea surface, it is essential to have vertical photographs covering a large area.

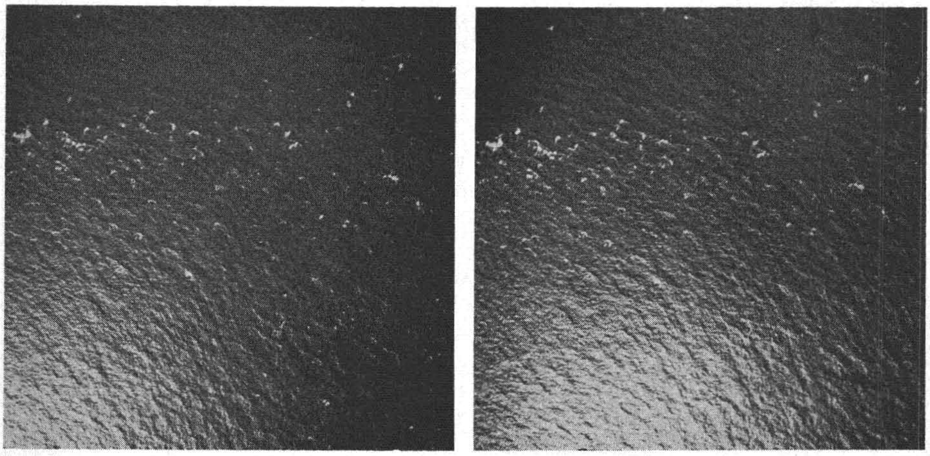

FIG. 3.—A stereo-pair showing ocean waves.

The operational procedure involved the use of two airplanes flying in tandem 2,000 feet apart and at an elevation of 3,000 feet. Each plane was equipped with a standard mapping camera (CA-8) and the cameras were triggered simultaneously from the forward (master) plane, by an FM radio link. The planes flew directly into the wind. This eliminated crabbing, reduced the air speed and allowed the major wave fronts to pass at right angles to the line of flight.

To help establish some sort of ground control, the WHOI research vessel *Atlantis* was stationed in the area of operation. The vessel towed a target raft 500 feet behind it. The distance between the raft and the ship was monitored during the entire exercise by a sonar buoy located on the raft which received a radio impulse through air from the vessel and retransmitted the signal to the vessel, through water. The travel time was recorded every 2 seconds by a Speed-O-Max installed in the research vessel. (See Figure 2.)

The planes adjusted their altimeters to the barometer on the ship at the time the pictures were taken. The distance between the two planes was maintained nearly constant at about 2,000 feet by means of a range finder located in the slave plane, and utilizing the wing span of the master plane as base line.

The research vessel was instructed by radio at the moment each run started and made a side-mark on the record paper of the Speed-O-Max. Since only 10 pairs of photographs are made during the run (a time interval of about 36 seconds), it was felt that if the ship and raft appeared in one of the pairs, this control may be inferred for each of the other pairs in the run. A stereo-pair of ocean waves appears in Figure 3.

Analysis of Stereo-pairs

It is necessary for the purposes of prediction that a select number of photo pairs be contoured. The exact number depends on the highest frequency waves present and on the short-crestedness of the sea surface. In order to determine the energy spectrum of the sea surface a grid of spot heights must be made; the spacing of the grid depends on the parameters mentioned above. The points on the grid might be read from the contours directly, but the interpolation between contours is difficult even when the shape of the sea surface between contours can be seen from the pictures. After the elevations are read from the photographs the values are tabulated for analysis by an electronic computer. The end results is the two-dimensional energy spectrum of the sea surface.

Conclusion

High altitude stereo-photography of the sea surface from two airplanes flying in tandem has produced a sequence of 100 stereo-pairs which show waves ranging in height from one to ten feet. The heights at discrete points on these photographs will yield the two dimensional energy spectrum of the sea surface. It is hoped that this information will establish confidence in new theories which describe the behavior of ocean waves.

ACKNOWLEDGMENT

Professor W. J. Pierson, Jr., N.Y.U., initiated the project and served as advisor to the group. The Naval Air Development Unit, South Weymouth, Mass. contributed the planes and flight personnel. The Aerial Photographic Experimental Laboratory, Naval Air Development Center, Johnsville, Pa. tested the cameras for mechanical efficiency, and installed them in the planes. The Hydrographic Office, Photogrammetry Division is analyzing the photographs. The Hydrographic Office, Forecasting Section prepared all meteorological intelligence and signaled the start of the exercise. The Woods Hole Oceanographic Institution provided a research vessel, ground baseline and the electronic link for synchronous photography.

Lastly, the Office of Naval Research has sponsored the project under contract Nonr 769(00), assembled all of the interested parties, procured equipment and personnel, arranged meetings, organized schedules, and in general administered and coordinated the entire project.

All of the groups above offered suggestions and criticisms which were extremely useful.

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EXCEPTIONAL MEANDER SCARS AND THEIR SIGNIFICANCE IN DETERMINING THE DIRECTION OF STREAM FLOW

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THE direction in which a stream may be flowing is not always apparent from air photographs, and determinations should rest upon several lines of evidence. Criteria used for streams in youthful stages are commonly of no value for streams which are in an advanced stage of maturity.

Trails of white water below rapids or waterfalls are self-evident for youthful streams or for the youthful stretches of otherwise mature streams. The cut banks formed where strong currents strike and undercut steep valley slopes, are not as self-evident criteria as are the angles made by tributaries where they join major streams. Other criteria include attenuated sand bars. The sharp points are customarily, but not always, on the downsteam side.

Meandering streams, with their loop-like curves, make direction of flow difficult of interpretation if meander markings are not observable. Smith* has called atten-

* Smith, H. T. U., *Aerial Photographs and Their Applications*, D. Appleton Century Company, New York, 1943, pp. 124–125.