NEAR-INFRARED LASER INSTRUMENT FOR MEASURING DYNAMIC MOTION OF AIR SEALS ON HIGH-SPEED SURFACE EFFECT SHIPS

INTRODUCTION

An air cushion vehicle (ACV) uses a pressurized bubble of air, confined within a flexible skirt, for lift. Because ACV's have little contact friction, they can move at speeds greater than 50 knots over calm water when propelled by air screws. A variant of this technology is the surface effect ship (SES), which captures an air bubble between two rigid sidewalls and two flexible skirts or seals, located at the bow and stern. The SES is constrained to operate only on water. However, its ability to use efficient propulsion systems such as water propellors and waterjets, together with the improved sidewall sealing, enables the SES to achieve very high speeds (over 90 knots by a 100-ton test ship).

The flexible bow and stern seals present severe problems of materials and maintenance when the vehicles are operated at high speeds. The seals also have typically slow dynamic response to impact by waves, which reduces their efficiency in high sea states. A new design, termed a "planing" seal, has been developed and installed on a 100-ton SES test ship (SES-100A) for evaluation. The planing seal potentially can extend the life of the seal while providing a lightweight system with individual elements that allow rapid differential response to fluctuating wave forces. The seals are constructed from a number of rigid planer elements, 2 feet in width, that are held together by heavy rubberized joints (Fig. 1). The position and attitude of the seal are controlled by an inflatable bag and seal retract straps (Fig. 2). The seal deflects up and back as it encounters a wave while maintaining an effective seal against the air. The rubberized joints allow the seal to conform to three-dimensional waves by allowing a small degree of lateral motion.

For the purposes of SES performance analysis, the dynamics of the seal must be known as a function of ship speed, sea state, and wave spectrum. In addition, a real-time measurement of the vertical position of the seal with respect to the ship (i.e., seal height) is helpful to the ship's commander in achieving optimum ship performance.
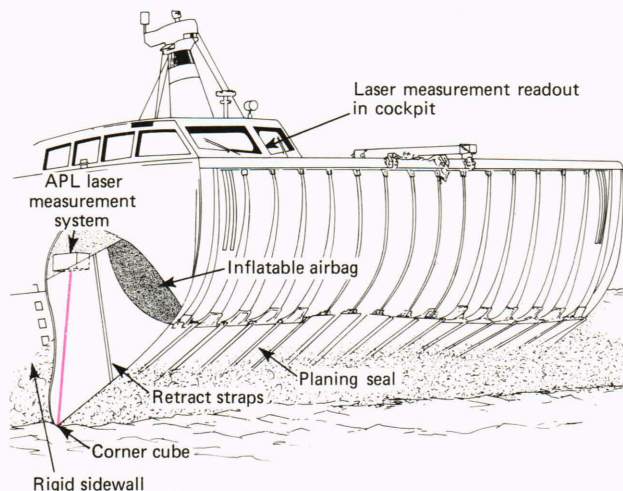
INSTRUMENT DESIGN

A rugged noninvasive system has been developed at APL to measure continuously the position of the
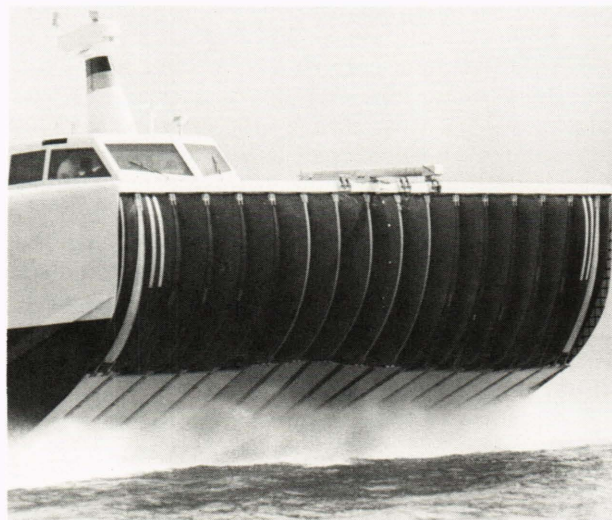
Fig. 1—The SES 100-A, an experimental 100-ton surface effect test ship, undergoing high-speed trials of planing seals. Note the wavy movement of the seal assembly caused by differential water forces acting on the individual planers.

Fig. 2—Locations of the bow planing seal and the instrumentation system on the test ship. A corner cube reflector is mounted rigidly on one of the planing seal elements. The laser instrument mounted inside the ship's hull views the corner cube through a water-tight window.

seal in three dimensions with a resolution of 0.1 inch and a bandwidth of about 100 Hz. (It originated in an ongoing program that was attempting to demonstrate the feasibility of a laser instrument used to obtain accurate wave profiles in front of a high-speed ship.) The system consists of a laser ranging device that measures the distance to a corner cube reflector mounted on one of the planers and a two-axis tracking device that provides azi-

muth and elevation angles to the same point (Fig. 3).

Range is related to time by imposing a CW modulation on the optical carrier and measuring the phase shift brought about by the time delay in the round trip of the light beam. A modulation frequency of 30 MHz was chosen to accommodate the maximum expected excursion range (8 feet) of the corner cube with respect to the instrument. Such a change in range implies a 16 foot change in the total path length travelled by the laser beam. This corresponds to half a wavelength of the 30 MHz modulation, thus providing an unambiguous range measurement from the phase information.

Range resolution of 0.1 inch requires that the phase difference between the received and reference signals be resolved to better than 0.2°. The phase detection is made manageable by mixing the 30 MHz reference and the quadrant receiver signals with a precise 30.01 MHz signal to obtain 10 kHz signals. Relative phase information is preserved, and the phase difference can now be measured at the intermediate frequency with conventional instrumentation.

The laser ranging system operates with a low-power CW laser at 0.9 μm (near infrared). The transmitted beam is collimated and has a diameter of 0.6 inch. A precision corner-cube reflector 1 inch in diameter serves to define a point on the planer element whose dynamics are to be measured. Its purpose is to provide a reliable and efficient return of the transmitted laser beam. The planer motion will produce changes in range along the line

of sight to the point on the planer as well as actual motions normal to the line of sight. For small lateral motions, the corner cube reflector sends the collimated beam back toward the receiver parallel to the incident beam but translated. The translation is sensed by the quadrant detector and the processing electronics and produces a tracking error signal. The two tracking error signals are derived from the four quadrant signals by conventional sum and difference electronics. A wide-bandwidth track loop is closed about these two axes by the two steering mirrors.

The angular position of the steering mirrors is an indication of the angular position of the corner cube. Both steering mirrors have capacitive pick-offs whose outputs define the elevation and azimuthal angles of the laser beam line of sight.

A real-time measurement of the vertical position of the planers (seal height) with respect to a ship reference location is needed by the pilot to obtain optimum ship performance. The seal height is calculated by multiplying the line-of-sight range by the sine of the elevation angle. The instrument performs the seal height calculation by using a Taylor's expansion approximation of the sine function and an analog multiplier. The resulting output drives an analog meter (in the cockpit) that provides a visual display of the seal height.

The system also contains an adaptive scanning and acquisition device that permits the system automatically, upon loss of track, to begin a low amplitude, high frequency scan pattern about the last valid track point. If the corner cube is not reacquired immediately, the scan pattern slowly opens into a sawtooth pattern that covers the spatial area of all possible locations of the corner cube (−15 to −60° elevation and ±5° azimuth).

On start-up, the system is designed to self-test the optical system and its electronics automatically by closing the optical path on a corner cube built in at a precisely known range. The self-test range is compared with a very narrow range window, thus providing an operational check and a range calibration verification. (The seal height instrumentation system is environmentally qualified, installed, and calibrated on the SES-100A at the Surface Effect Ship Test Facility, Patuxent River, Maryland.)
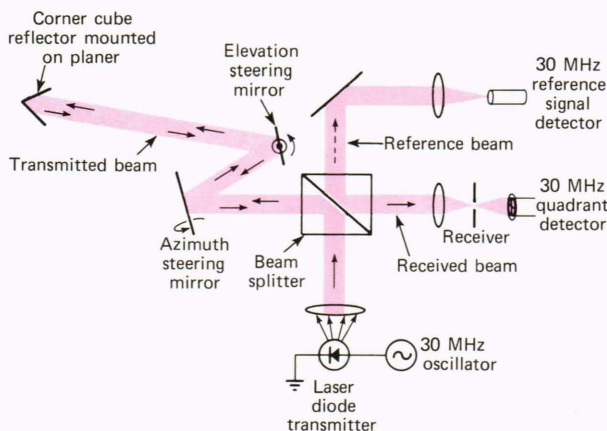
Fig. 3—Diagram of the optical system. Two steering mirrors hold the laser beam in the center of a corner cube reflector so that the reflected beam is always centered in the quadrant detector. Distance is obtained by measuring the phase difference between the received and the reference beams. The position of the steering mirrors indicates the azimuth and elevation angles of the line of sight to the reflector.

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