SEMI-SUBMERGED SHIP CORPORATION
THOMAS G. LANG
PRESIDENT
417 LOMA LARGA DRIVE, SOLANA BEACH, CA 92075
(714) 481-6417

SEMI-SUBMERGED SHIPS

PRINCIPLES AND APPLICATIONS

Lecture Notes by Thomas G. Lang

OUTLINE

I. Fundamentals of the Semi-Submerged Ship (SWATH) Concept
   - A. Concept
     1. Features
     2. Advantages and Disadvantages
     3. Variables
   - B. SWATH Developments
     1. History
     2. SSP KAIMALINO
     3. Japanese Developments
     4. SUAVE LINO
   - C. Design Considerations
     1. Drag and Propulsion
     2. Motion
     3. Structure
     4. 1 or 2 Struts Per Side
     5. Other Considerations
   - D. Future Applications
     1. Government
     2. Commercial
     3. Private
   - E. Design Tradeoffs
     1. Theory
     2. Applications
     3. Examples

II. Semi-Submerged Ship (SWATH) Experience
   - A. SSP KAIMALINO
   - B. SEAGULL (MESA 80)
   - C. Other Vessels
   - D. Conclusions

SWATH CHARACTERISTICS

Hull Form

A Small Waterplane Area Twin Hull (SWATH) ship consists of two parallel, torpedo-like hulls located under the water surface, attached to two or more streamlined struts which pierce the surface and support an above-water platform. A SWATH can be designed in any size range to meet nearly any operational requirement, including large deck loads.

Stabilizing fins are placed near the after ends of the hulls, and a pair of smaller fins is usually attached near the forward ends. These fins contribute to the exceptionally smooth, stable ride of SWATH. They may be automatically controlled, if desired, to further reduce motion in waves.

The only unusual aspect of a SWATH vessel is its shape; consequently, it can be built with presently-available components and technology. Figure 1 is an underside view of a typical SWATH. Although simple in concept, the design of a SWATH is both different than that of a monohull and somewhat more complex because of the many design variables to be considered. These variables include the size and shape of the lower hulls and the distance between them; the thickness, chord, taper, height, and spacing of the struts; the water clearance of the cross structure, and various details of the hydrodynamic and structural shapes and interactions. Shaping of the lower hulls can smooth out the usual humps and hollows in the curve of drag coefficient versus speed, and can help to minimize the drag at the design speed.

Large differences in motion and drag may exist between different designs of SWATH vessels. For example, the two-strut-per-side SWATHs tend to have less motion in waves than the one-strut-per-side versions. A well-designed SWATH should be able to operate in one to two sea states beyond that of an equivalent monohull before reaching the same magnitude of motion.

SWATH Advantages Over Monohull Vessels

The inherent characteristics unique to SWATH vessels give them the following technical advantages over conventional monohull designs:

A. Reduced motion characteristics in waves, both underway and when stationary. The motions of SWATH vessels in operational sea states are small because their small waterplane areas result in longer natural periods and reduced buoyancy force changes. The submerged hulls and fins provide good damping of any motion. The fins further assist in reducing the motion in waves when underway, and help ensure passenger comfort.

B. Better transit speeds. A SWATH vessel has very small wave-making drag; consequently, its propulsion power and fuel consumption at cruise speed is less than conventional vessels. Being little affected by waves, SWATH vessels are also able to sustain their speed in waves far more effectively than conventional vessels, and are consequently more dependable and economical to operate.

C. Greater deck areas. A SWATH provides greater deck space than a monohull vessel of comparable displacement, and is especially suitable for transporting passengers and cargoes requiring large deck areas and storage spaces.

D. Better payload-handling characteristics. SWATH vessels have large payload spaces above the waterline which permit ready access. This improves handling efficiency. Also, center wells in the deck can provide improved submersible equipment handling capabilities.

E. Versatility. With excellent motion characterisitcs, high-speed performance, and modular construction potential, SWATH designs are applicable to many types of outfitting needs.

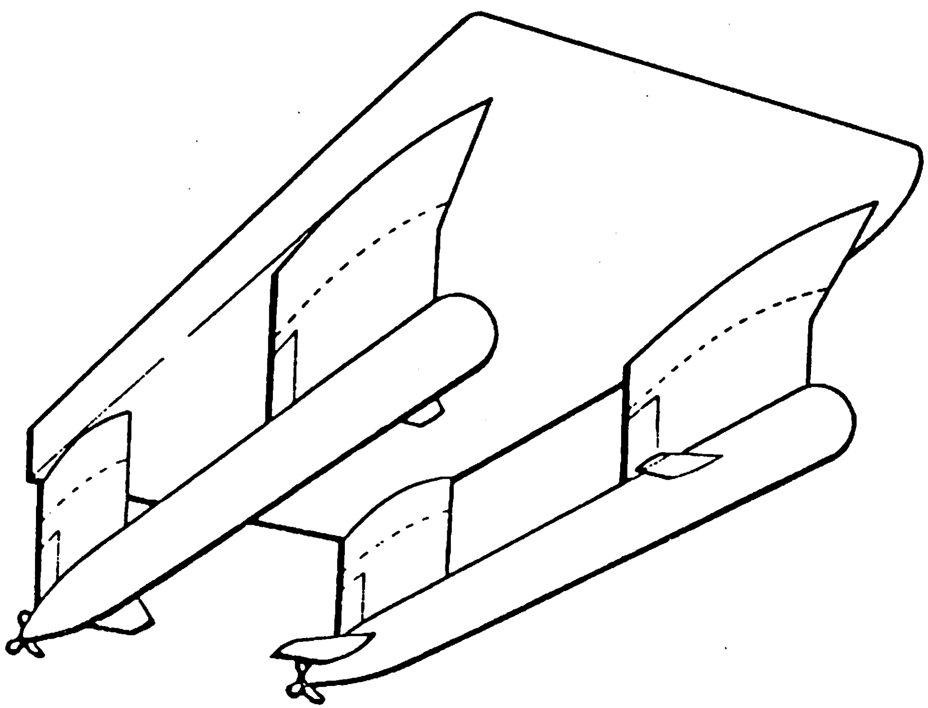
SWATH Developments

The SWATH is proven technology, as demonstrated over the past ten years of successful operation of the SSP KAIMALINO (see Figure). The SSP is a range-support vessel, designed and developed by the US Navy, which has been operating in the rough seas of the Hawaiian Islands since 1975 following two years of operation on the East Coast.

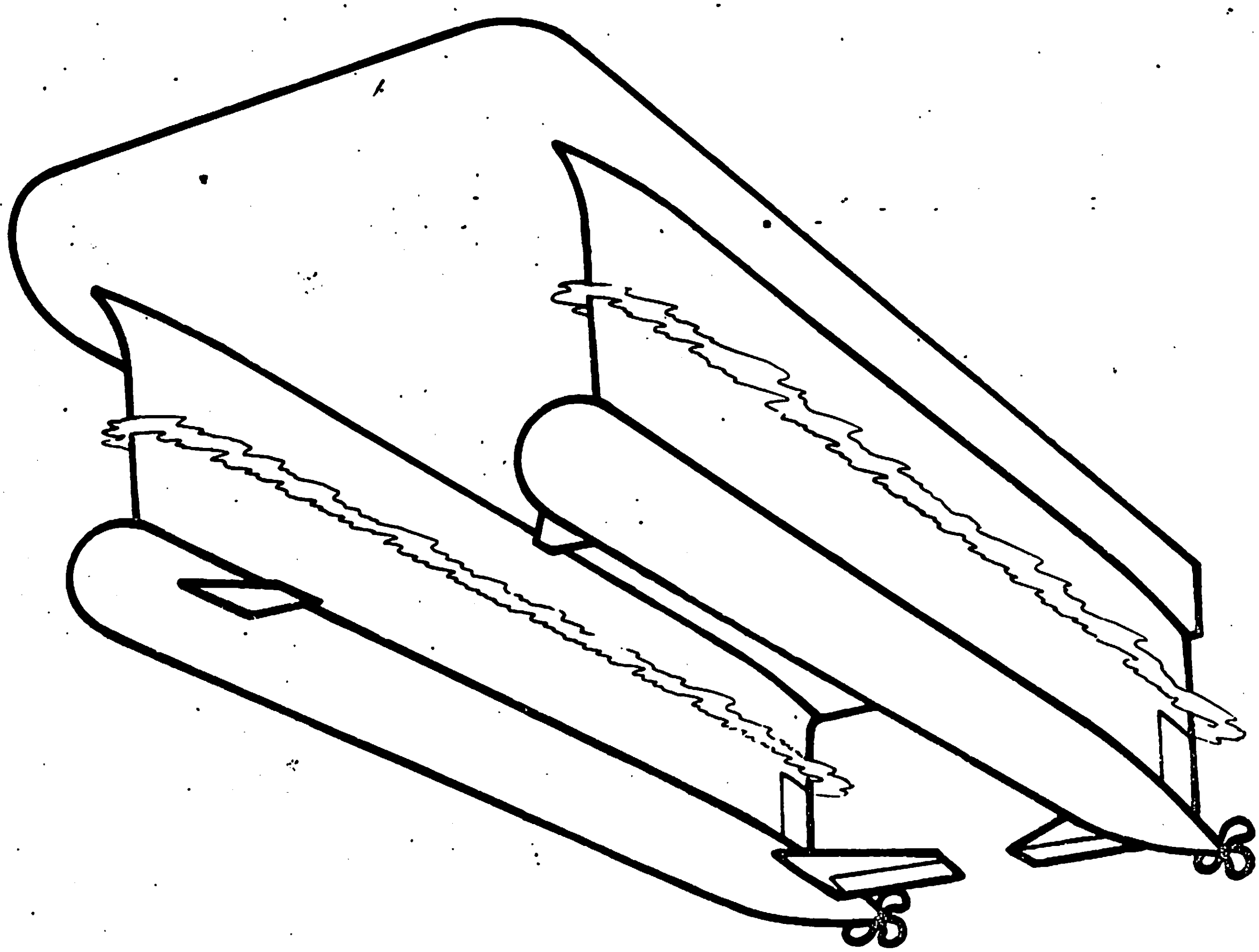
The KAIMALINO, a unique 217-ton vessel, is 89 ft (27 m) long, 46 ft (14 m) wide at mid-section, and 32 ft (9.7 m) high. Her range is 400 nautical miles, and she has operated at speeds up to 25 knots. She has operated under widely different loading conditions and sea states wherein waves have ranged up to 30 ft high.

More recently, Mitsui of Japan has built three SWATH vessels, and is currently building their fourth. SSSCO has conducted several design studies and model tests for British Shipbuilders on a variety of designs ranging from 210 to 5,800 tons displacement. Also, SSSCO has conducted numerous design studies for clients in the US and elsewhere which displace from 20 tons to 2,000 tons.

S^3 CONCEPT



- HIGHLY STABLE < AT REST / UNDERWAY
- HIGH SPEED CAPABILITY, QUIET
- CAN BE BUILT WITH PRESENTLY AVAILABLE COMPONENTS
- LOW COST THROUGH MODULAR DESIGN
- LARGE DECK AREA
- GREATLY IMPROVED HABITABILITY



ONE-STRUT-PER-SIDE VERSION

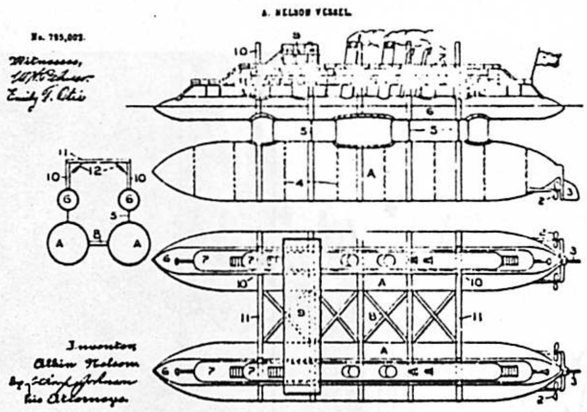


Figure 2. NELSON – 1905.

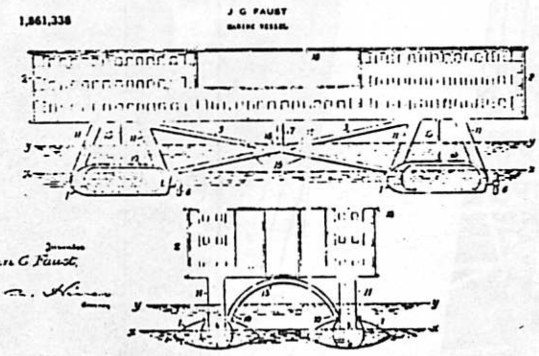


Figure 3. FAUST – 1932.

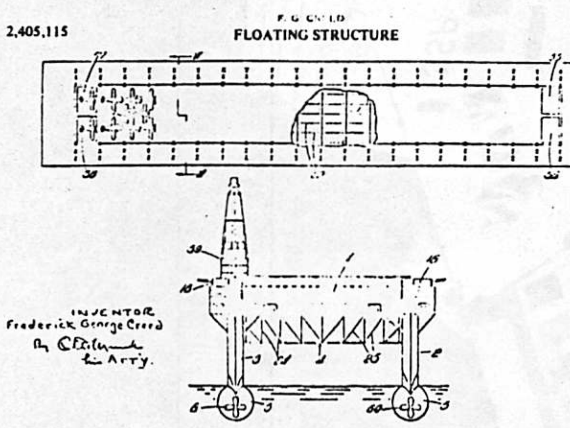


Figure 4. CREED – 1946.

PATENT HISTORY OUTLINE

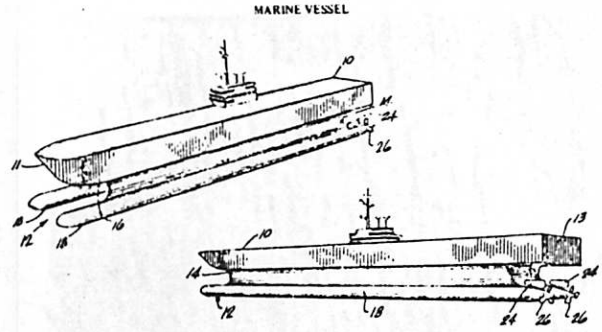


Figure 5. LEOPOLD – 1967.

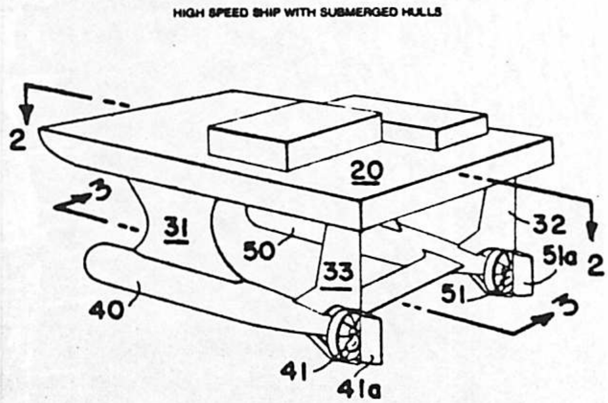


Figure 6. LANG – 1971.

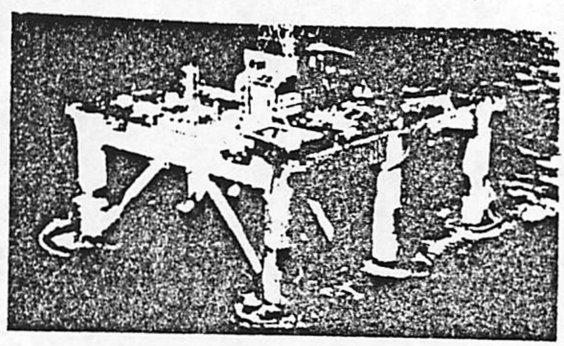


Figure 7. Offshore drilling rig.

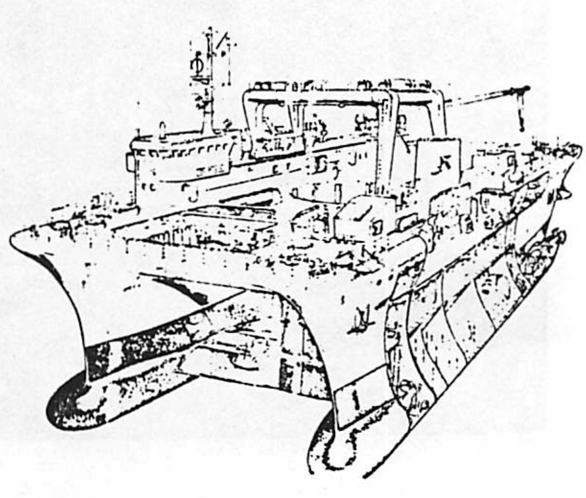
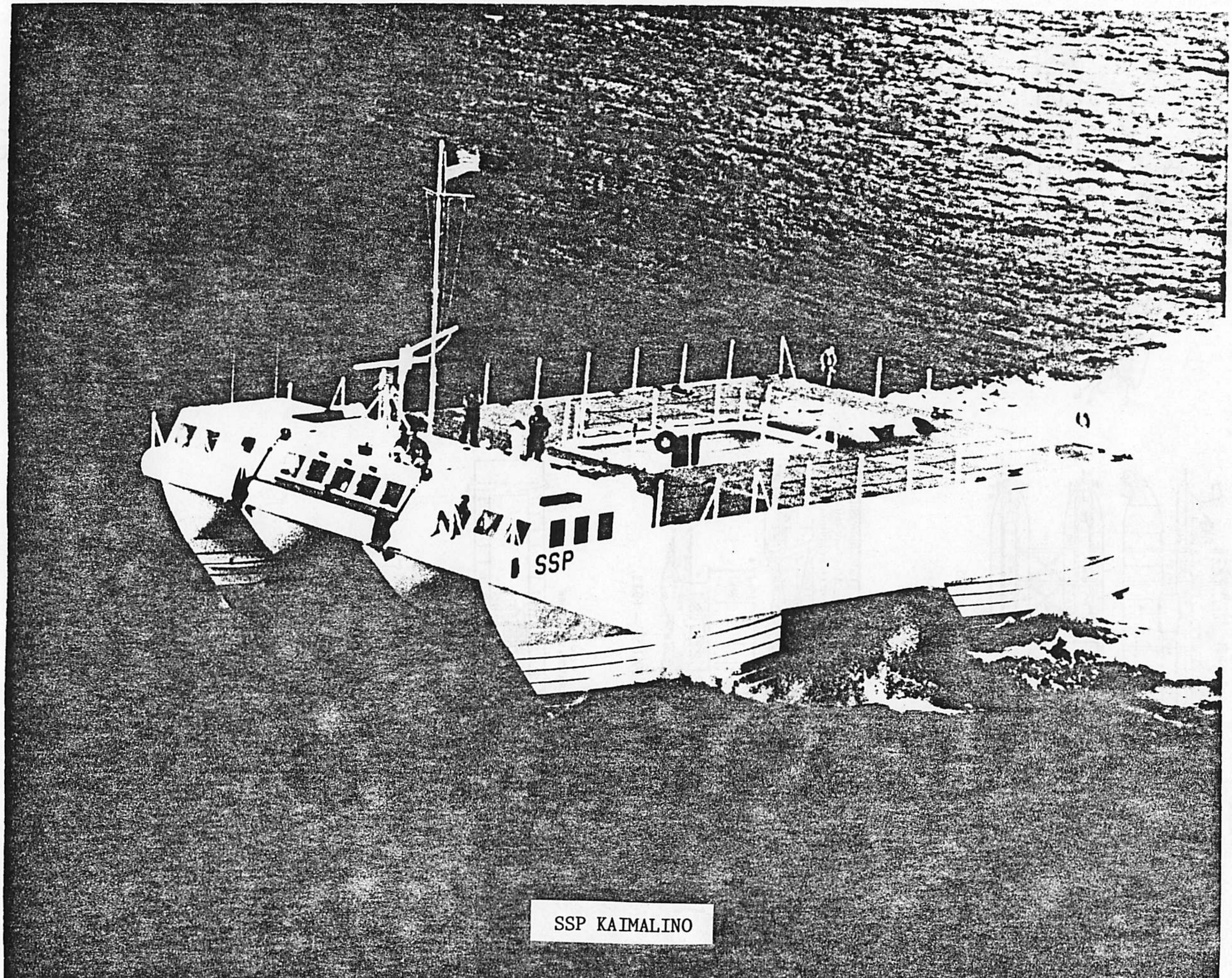
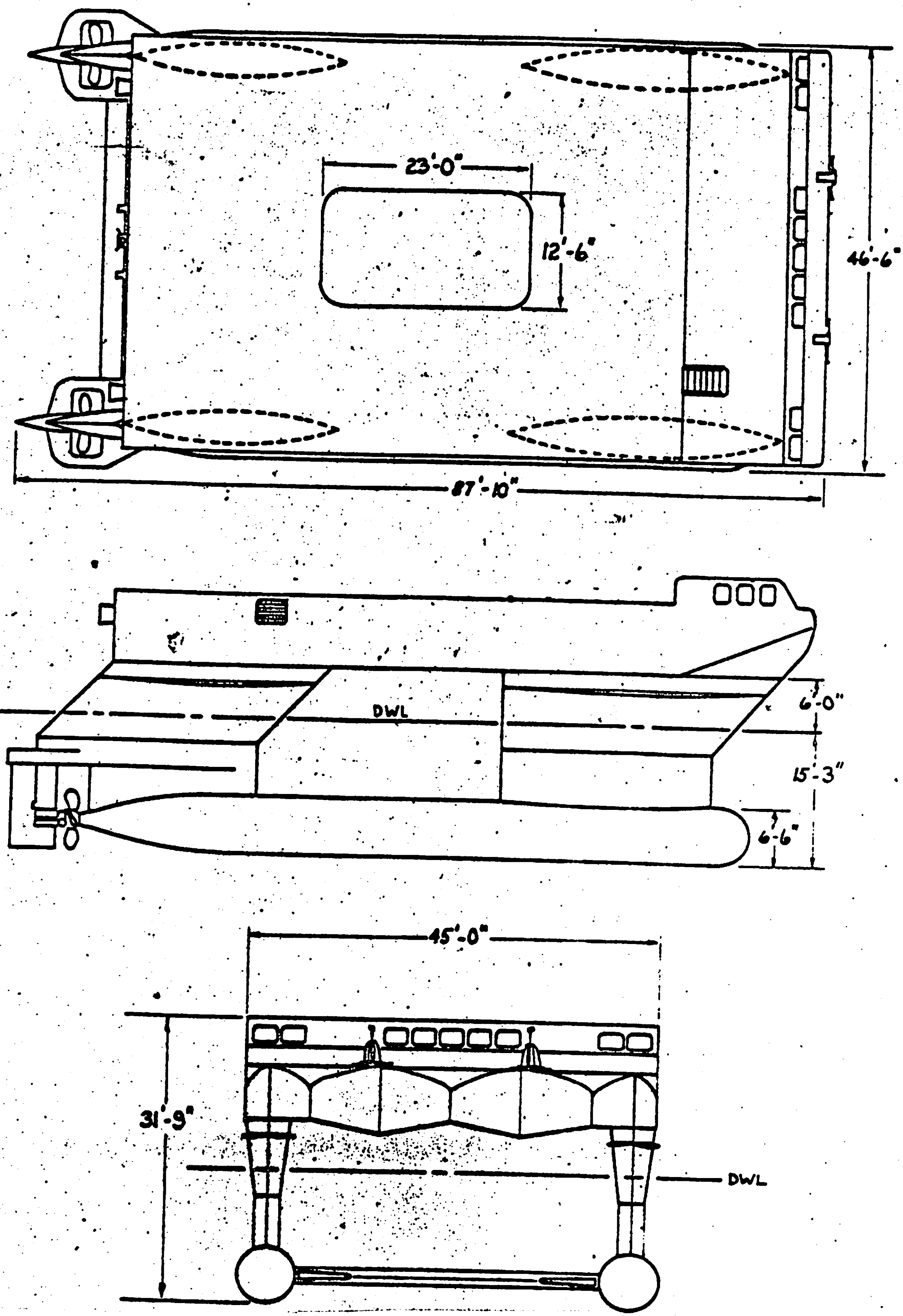


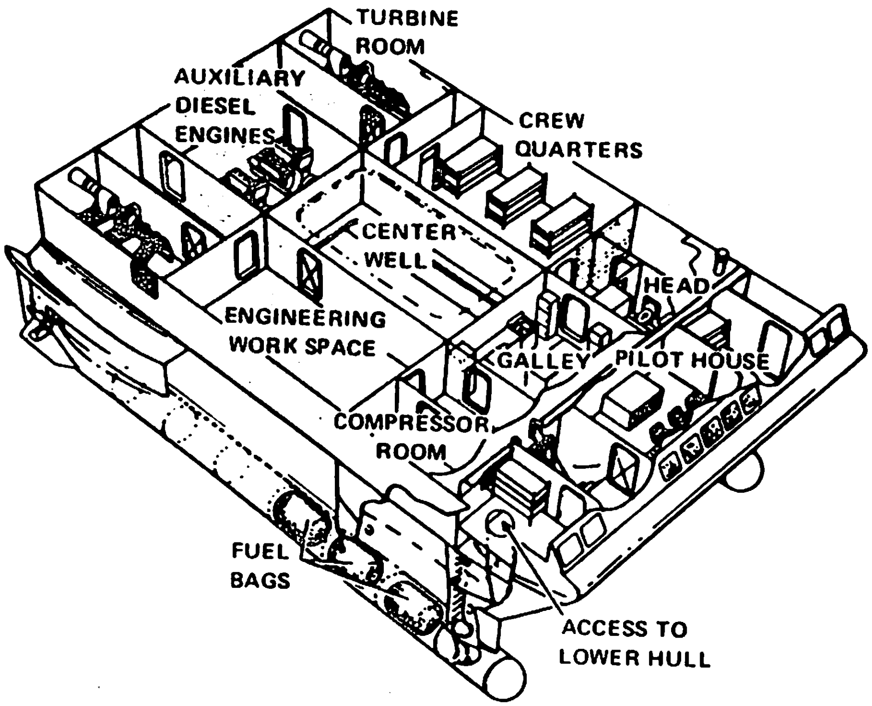
Figure 8. Netherlands DUPLUS



SSP KAIMALINO



Ref: Lang, Hightower, Strickland, "Design and Development of the 190-Ton Stable Semisubmerged Platform (SSP)", J. Engineering for Industry, Nov 1974.



Kaimalino CHARACTERISTICS

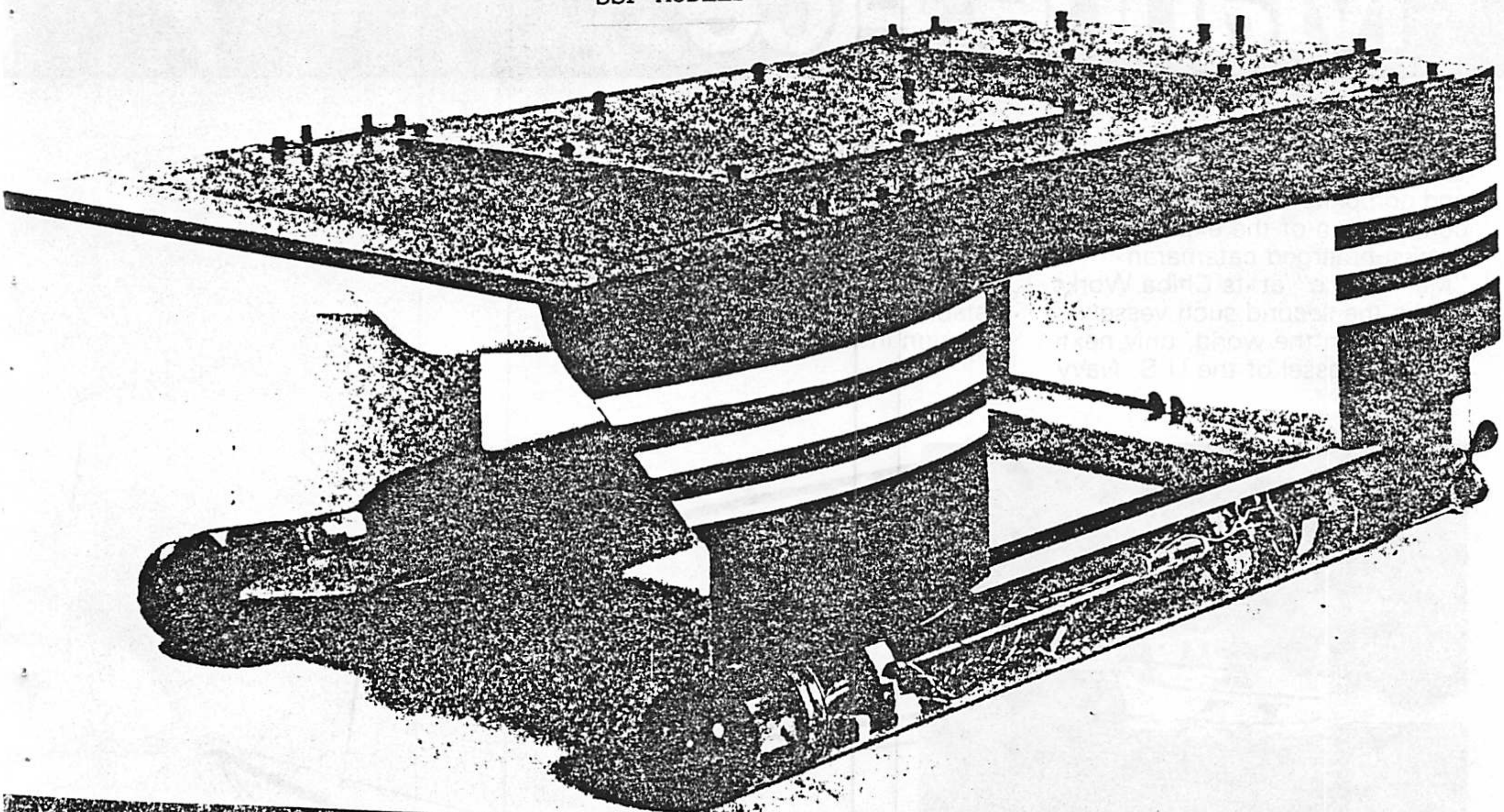
Length Overall	88 ft 4 in.
Beam Overall	46 ft 6 in.
Well Dimensions	23 × 12.5 ft
Draft (Normal)	15 ft 3 in.
Gross Payload	34.9 long tons (includes fuel)
Mission Payload*	16 long tons
Main Propulsion	T64-GE-6B turbines (2), 2204 hp each
Auxiliary Propulsion	8V-71T Detroit diesels (2)
Propeller System	4 blade, 6.5 ft diameter
Maximum Speed	19 knots
Cruise Speed	13-15 knots
Auxiliary Speed	0-5 knots
Hydraulic Capacity*	60 gpm at 2,000 psi
Electrical Capacity*	250 kW, (480, 240, 120 VAC, 3 phase, 60 Hz)
Deck Area	3,400 sq ft (with well covered)
Displacement	228 long tons
Berthing Capacity	10 crew, 6 scientists
Lower Hull Diameter	6.5 ft
Range on Turbines	300 mi at 13 knots
Range on Auxiliary Propulsion	1000 mi at 4 knots

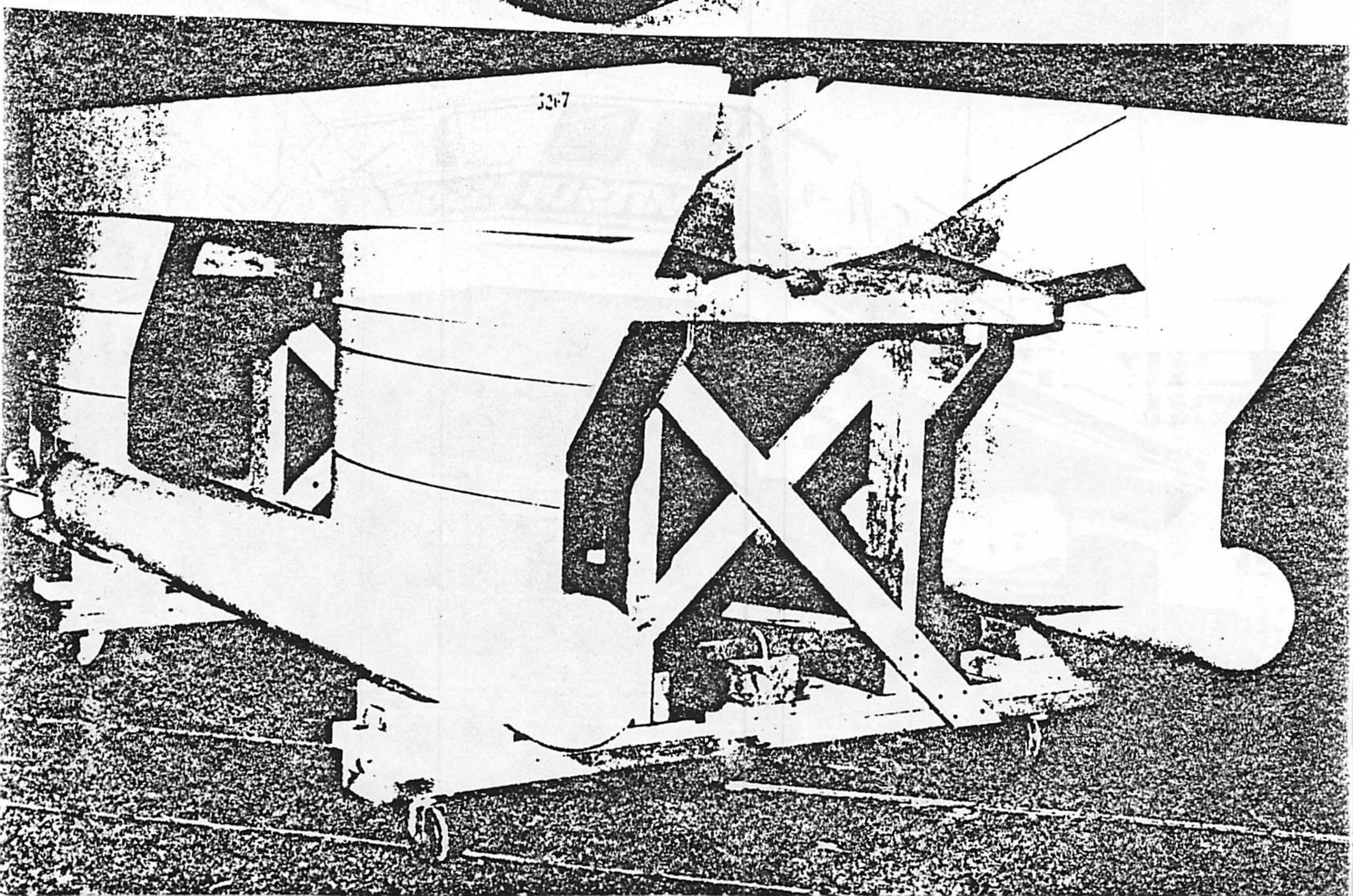
*Available for Customer Support Equipment

ANCILLARY EQUIPMENT

Sperry Doppler Speed Log (±0.1 knot resolution)
Raytheon Pathfinder (0-64 mi range)
Raytheon RAYNAV-6000
Magnavox Satellite Navigator
VHF, UHF, and HF Military and Civilian Frequencies
Depth Recording Fathometer (0-1250 fathom range)
Propeller Shaft Torque and Speed Indicators
Underwater Cameras and Observation Ports
Automatic Motion Control System (with motion outputs)
Mark-27 Gyrocompass
Wind Speed and Direction Indicators

SSP MODELS

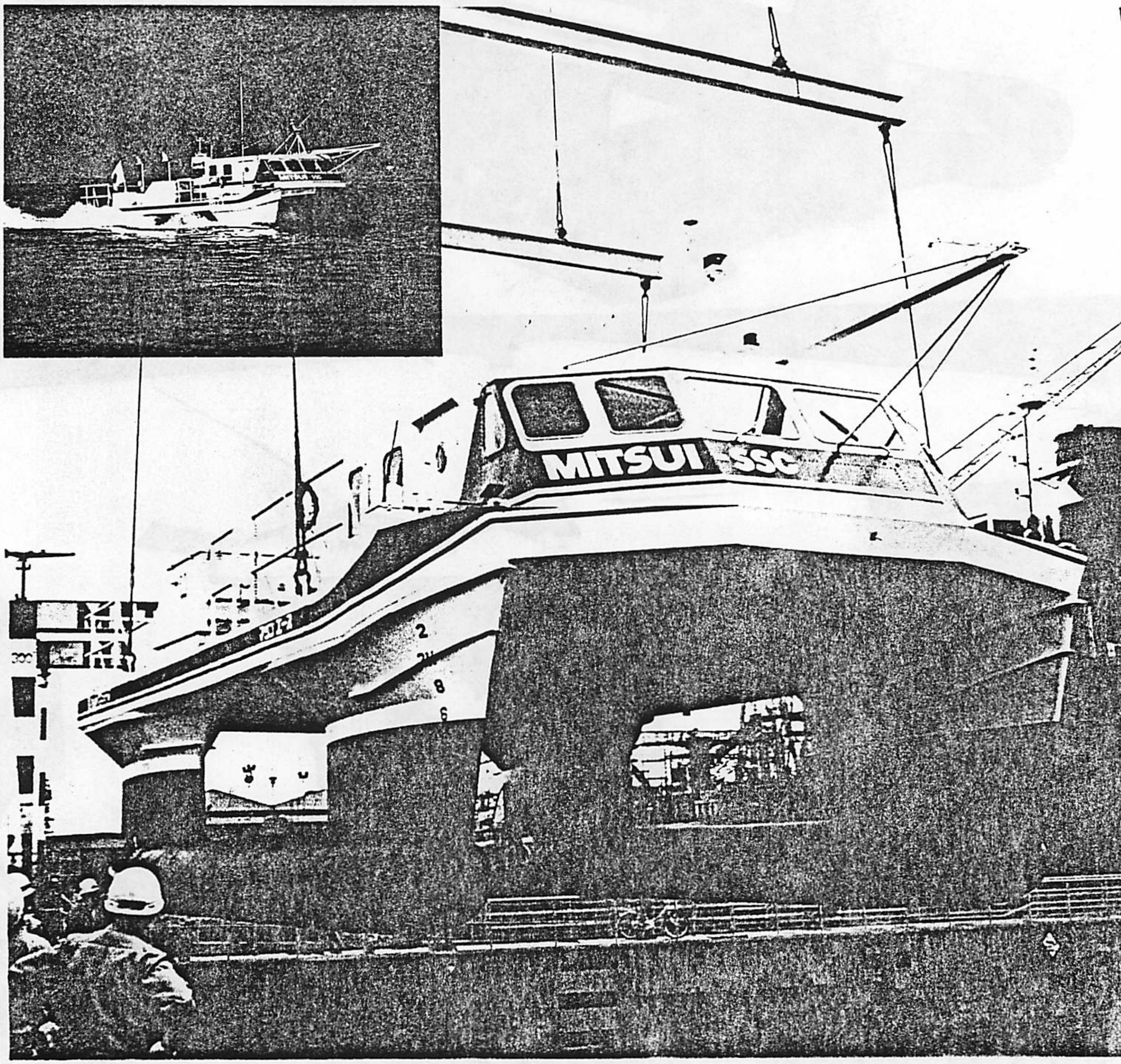




The Experimental Semi-Submerged Catamaran "Marine Ace"

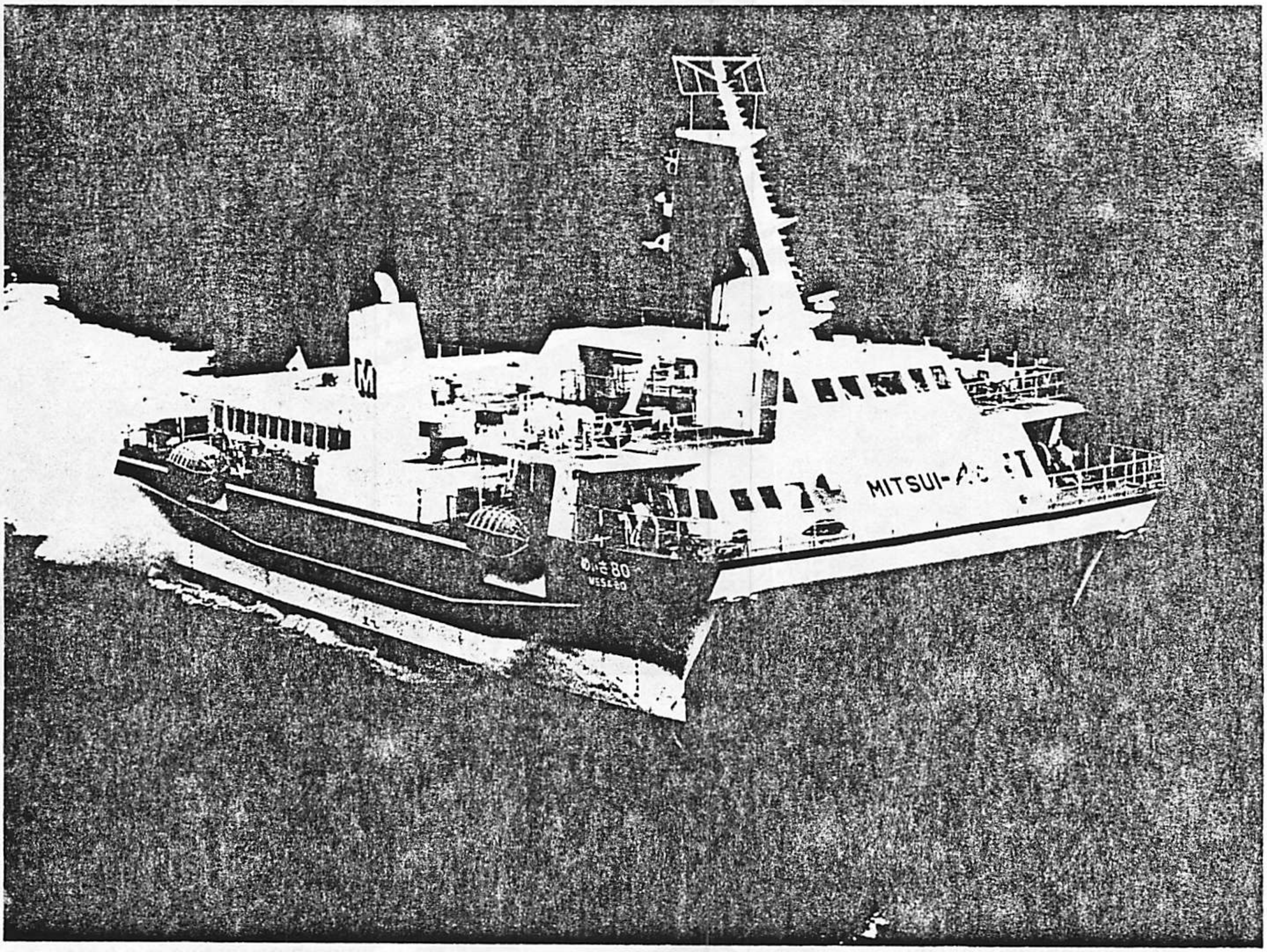
Mitsui Engineering & Shipbuilding Co., Ltd., started in April 1977, and completed in October the construction of the experimental semi-submerged catamaran "Marine Ace" at its Chiba Works. She is the second such vessel ever built in the world, only next to a test vessel of the U.S. Navy.

The 11-meter long catamaran, built of anticorrosive aluminum alloy, develops a maximum speed of about 18 knots, and can readily navigate wavy seas of sea state 2-3. Her automatically controlled fin stabilizers help further reduce ship motion in waves.



"MESA 80"

High-Speed Semi-Submerged Catamaran (SSC) Passenger Craft



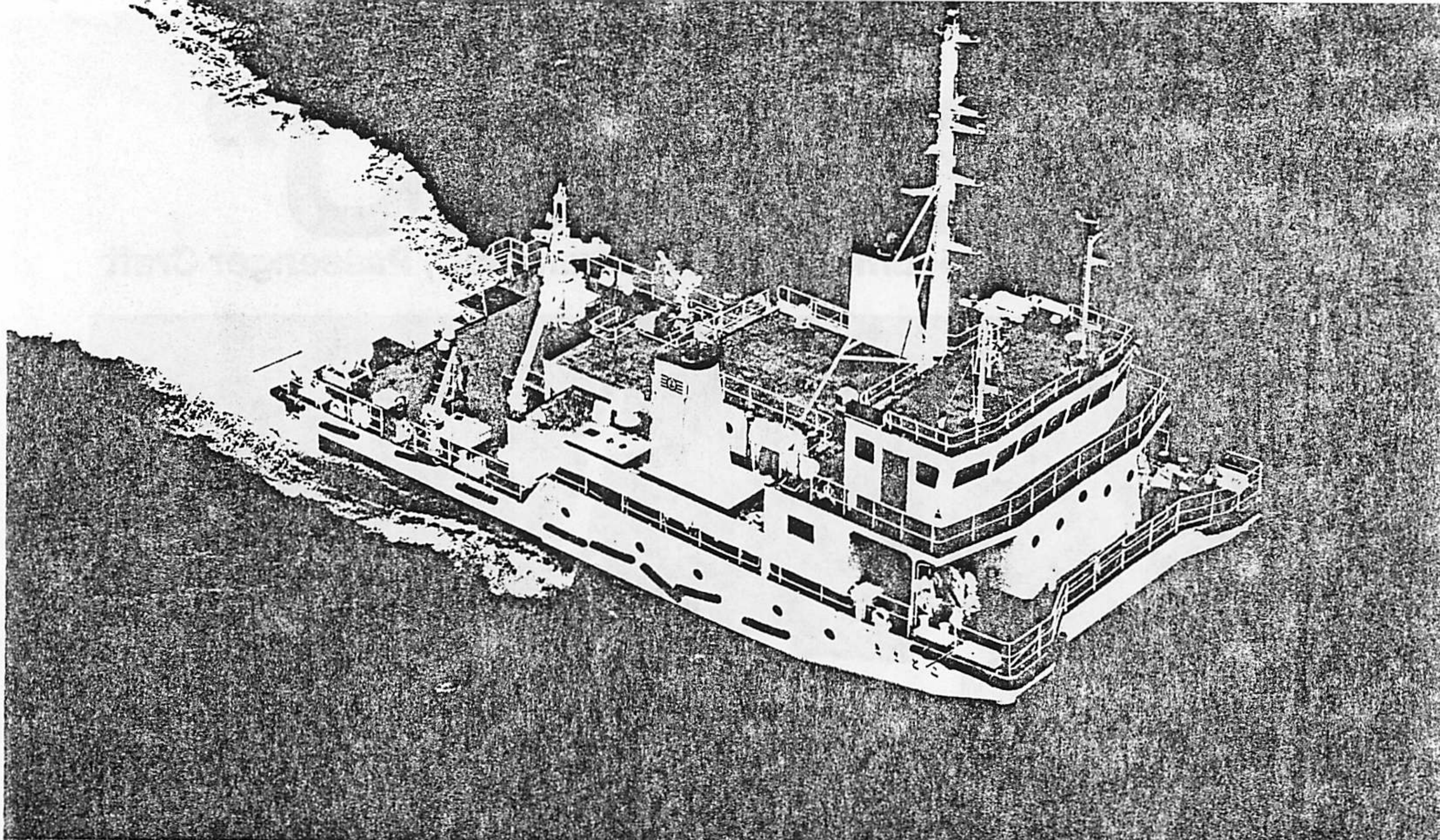
The "MESA 80" is the world's first commercial SSC, jointly developed by Mitsui Engineering & Shipbuilding Co., Ltd. and the Japan Marine Machinery Development Association (JAMDA) (as a new type of promising marine craft) to break the various limitations on the performance of conventional ships.

Work to develop SSC was started in 1970. Mitsui conducted extensive research on the design as well as with many model tests, and in 1977 built the experimental ship "Marine Ace" for the purpose of accumulating sufficient technologies to achieve practical application of this hull form. The fruits of all these research and development endeavors have been embodied in the "MESA 80", the first SSC type high-speed passenger craft for practical use.

Although the "MESA 80" is designed as a high-speed passenger craft, the Mitsui-developed SSC technology can be effectively applied to many other types of ships.

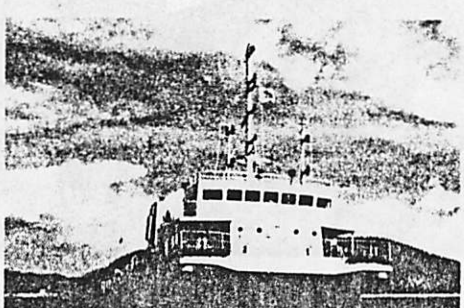
The excellent performance of the SSC in waves and her ample deck space make this type ideal for service in the 1980s, applicable not only to passenger crafts but also to ferries, oceanographic survey ships and offshore work vessels.

MITSUI ENGINEERING & SHIPBUILDING CO., LTD.



Hydrographic Survey Vessel
"KOTOZAKI"

The world's first hydrographic survey vessel of the SSC (Semi-Submerged Catamaran) type, "KOTOZAKI" was successfully built by Mitsui Engineering and Shipbuilding Co., Ltd. and delivered to the Fourth District Port Construction Bureau, Ministry of Transport of Japan in March 1981.



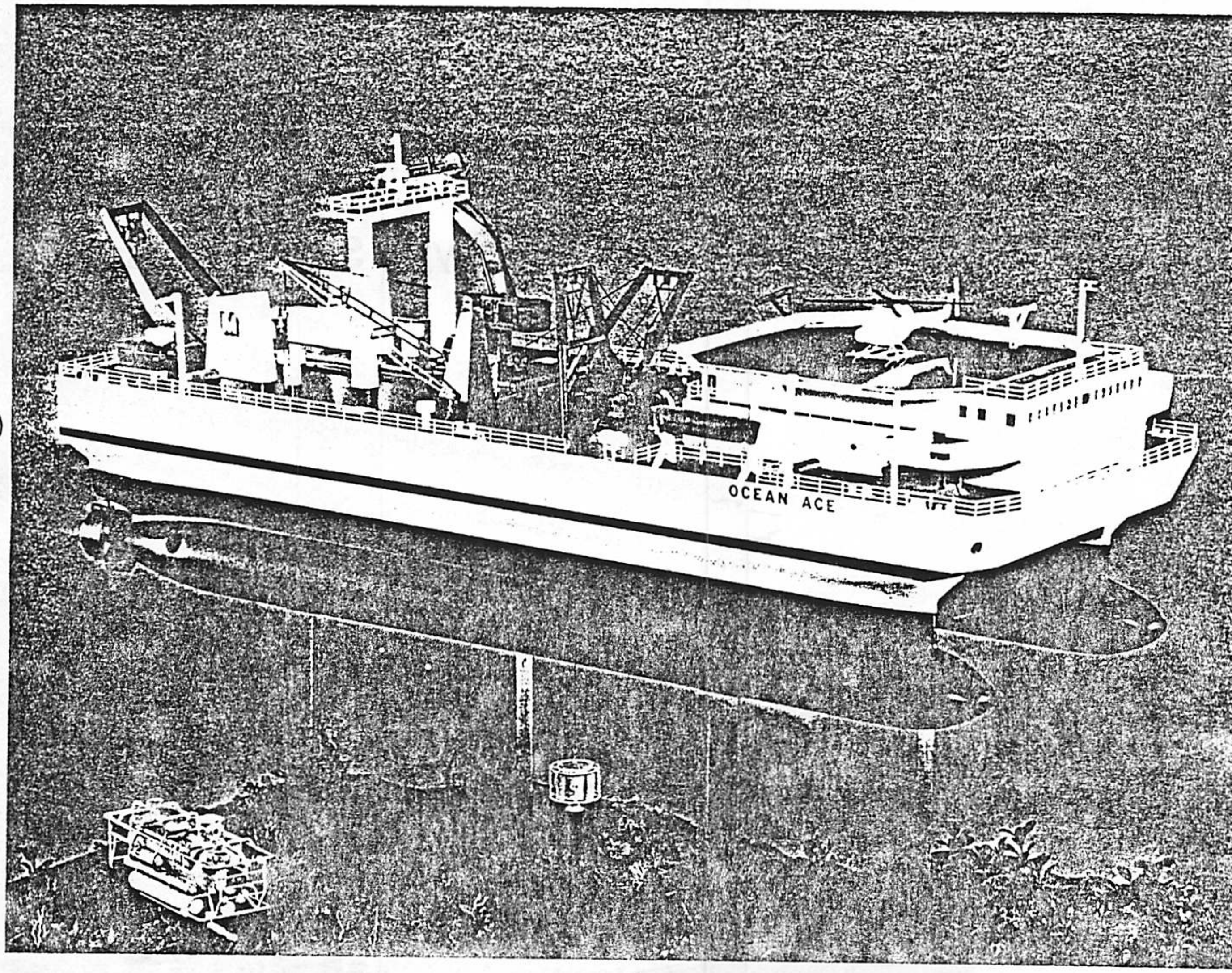
The SSC has a pair of torpedo-shaped lower hulls which are connected to the deck structure by means of streamlined struts. Due to this unique configuration, the SSC is less susceptible to ship motions in waves at rest and underway, suffers less from speed drop in waves, and has spacious work area on a flat deck level.

Main hulls and deck of "KOTOZAKI" are of hybrid structure made of steel and aluminum alloy to ensure maintenance ease and high service speed. The vessel is specially equipped with controllable-pitch propellers and fin stabilizers manually operated for smooth navigation in a wide speed range, as well as for excellent maneuverability and stability.

As a hydrographic survey vessel, "KOTOZAKI" provides a stable platform from which data can be taken as well as a deck area sufficient to set equipment and conduct work effectively, laboratory facilities suitable for scientific researches, and comfortable living space for the crew and research personnel.

MITSUI ENGINEERING & SHIPBUILDING CO., LTD.
Ship & Ocean Project Headquarters 6-4, Tsukiji 5-chome, Chuo-ku, Tokyo, Japan
Phone: 03-544-3462 Telex: J22821, J22924

MITSUI SSC Type
DIVING SUPPORT VESSEL



(UNDER CONSTRUCTION)

This diving support vessel, developed by Mitsui Engineering & Shipbuilding Co., Ltd., fully incorporates the features of semi-submerged catamaran which the Company has been experimenting with considerable success since April, 1977.

The vessel, being of the semi-submerged catamaran type, is virtually free from motion in waves, and has a large deck space which allows for comfortable accommodations to divers.

Furthermore, good and safe maneuverability even in rough seas is assured, while handling of various underwater equipment are also rendered quite safe and smooth.

MITSUI ENGINEERING & SHIPBUILDING CO., LTD.
Head Office: 6-4, Tsukiji 5-chome, Chuo-ku, Tokyo, Japan Telex: J22821, J22924
Overseas Offices: New York, Los Angeles, Mexico, London, Düsseldorf, Vienna, Singapore,

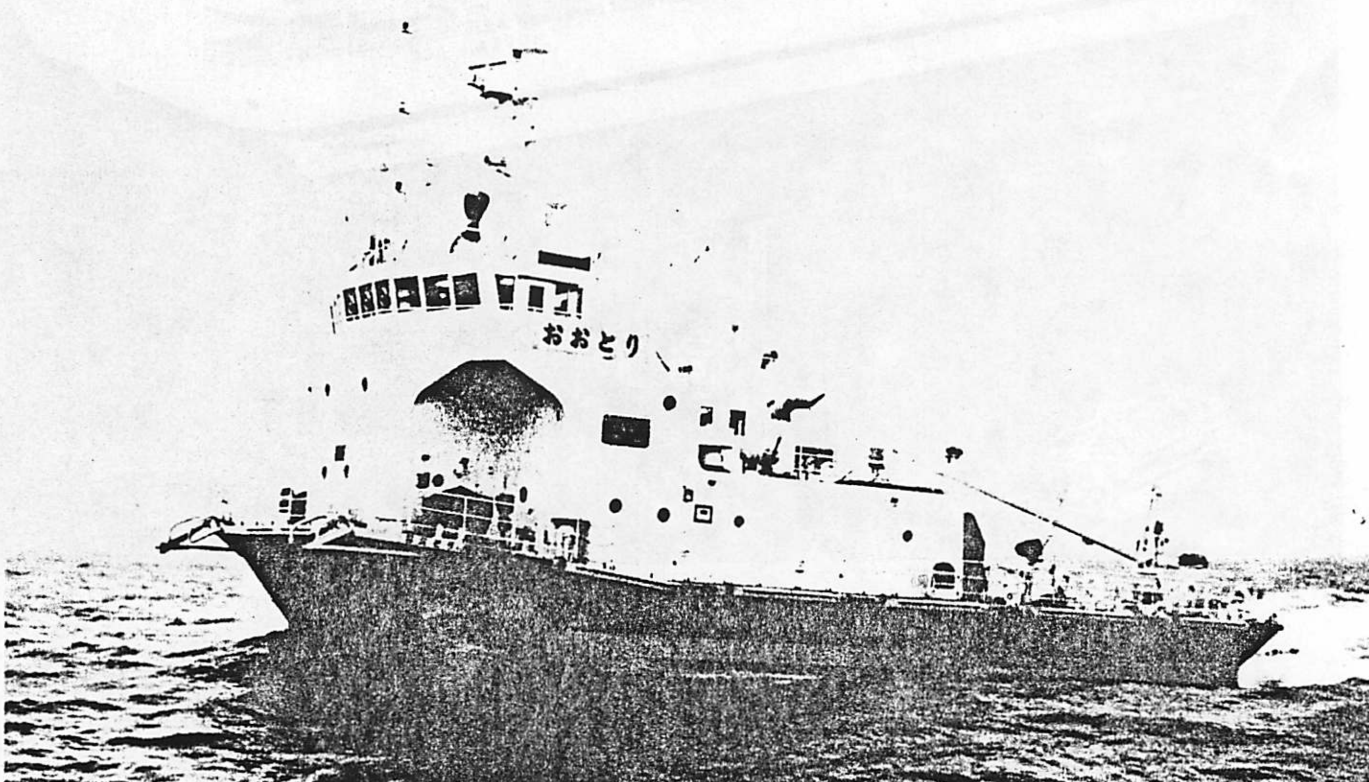
SHIPBUILDING REPORT

MITSUBISHI
HEAVY INDUSTRIES, LTD.

Shipbuilding & Steel Structures Headquarters: 5-1, Marunouchi 2-chome, Chiyoda-ku, Tokyo, Japan

June 25, 1981 No. 188

"OHTORI" —
Semi-Submerged Catamaran Type Survey Vessel



Built at the Kobe Shipyard & Engine Works of Mitsubishi Heavy Industries, Ltd., the "OHTORI" was delivered to her owner, the Third District Port Construction Bureau in the Japanese Ministry of Transport, on March 25, 1981. She is the first semi-submerged catamaran in the world put into real service.

Intended for surveying water and seabed condition as part of the step to purify Seto Inland Sea, the vessel is equipped for collection and analysis of seabed and water samples, exploration of seabeds and observation of sea and weather conditions.

She is also equipped with precision position finders to accurately determine her position at sea.

SPECIFICATIONS

Length: 64'11" (19.7 M)

Beam: 30'0" (9.1 M)

Draft (FLD): 6'6" (1.9 M)

Main Engines: 2 GM Diesel Turbo V-8; 375 bhp

Fuel: 3,500 Gallons

Accommodations: 4 Bunks, Galley

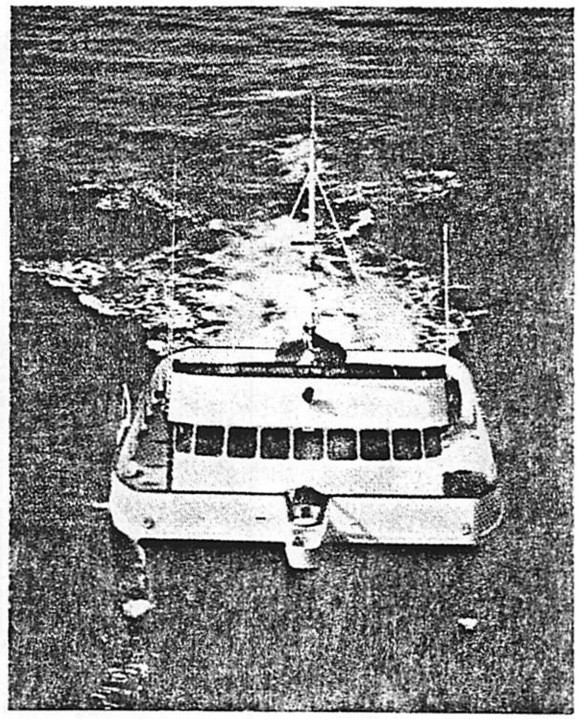
Full Load Displacement (FLD): 45.8 Long Tons

Light Ship Displacement: 39 Long Tons

Instruments: 2 Radar Sets, LORAN, Fathometer, Autopilot, SSB/VHF Radio

Cruising Speed: 18 Knots

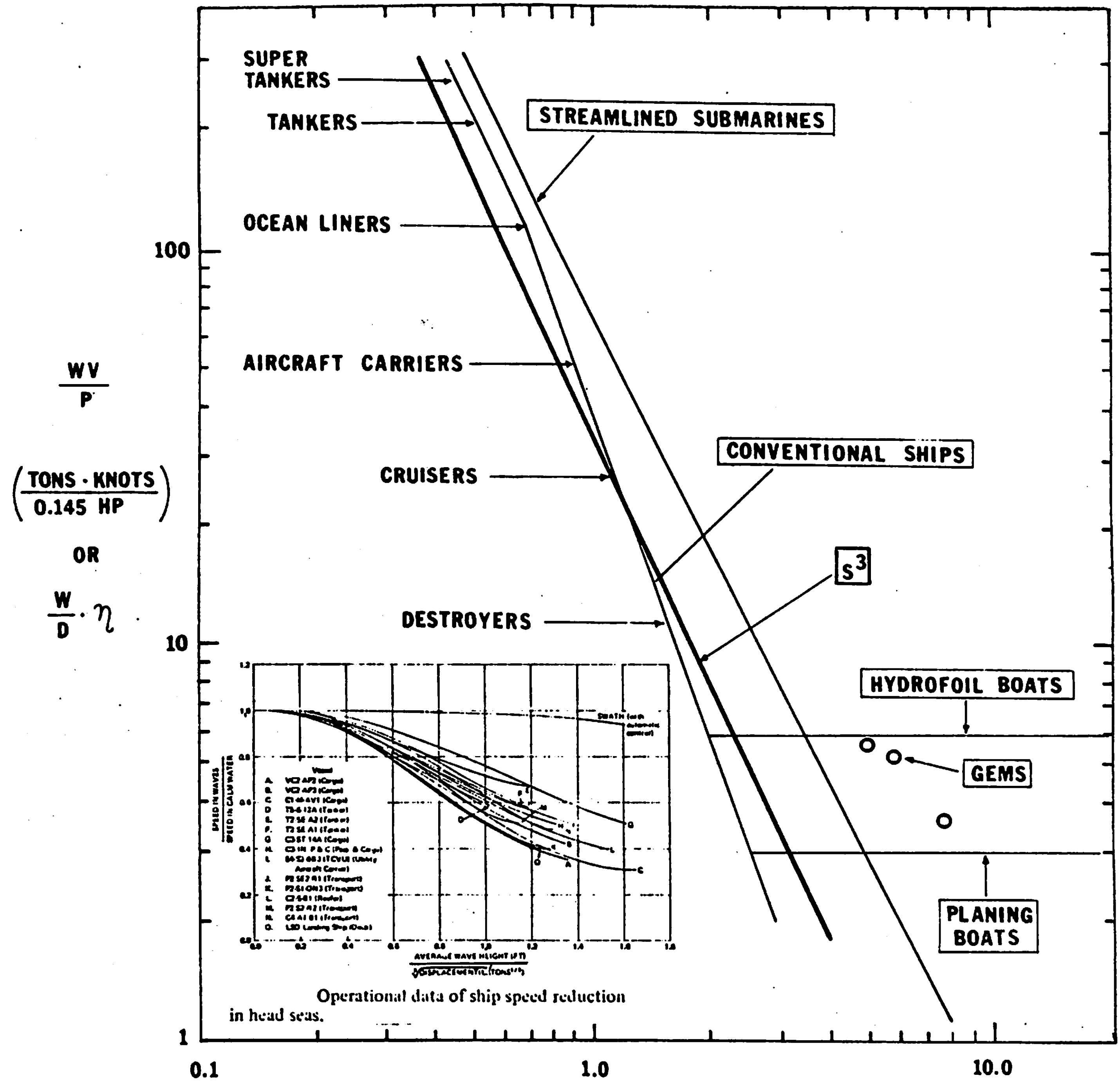
Fully operational in seas up to and including Sea State 4



For information on leasing the Suave Lino
or other SWATH ships, contact:

SEACO [illegible] 328 [illegible]et Ale[illegible] [illegible]A 22314 ([illegible]) 548-6146	SEACO, INC. 146 Hekili Street Kailua, HI 96734 (808) 261-7955	SEACO, INC. 2845-D Nimitz Blvd. San Diego, CA 92106 (714) 225-8631

OVER



$$F_\nabla = \frac{V}{\sqrt{g\nabla^{1/3}}} = \frac{\rho^{1/6}\,V}{g^{1/3}\,W^{1/6}} = 0.164\,\frac{\text{KNOTS}}{\text{TONS}^{1/6}}$$

VESSEL WP/V VERSUS DISPLACEMENT FROUDE NUMBER

Seakeeping

Captain James W. Kehoe, Jr., U. S. Navy (Retired), Kenneth S. Brower, and Edward N. Comstock

Proceedings / September 1983

Figure 1 *Maximum Ship Speeds in Various Sea States*

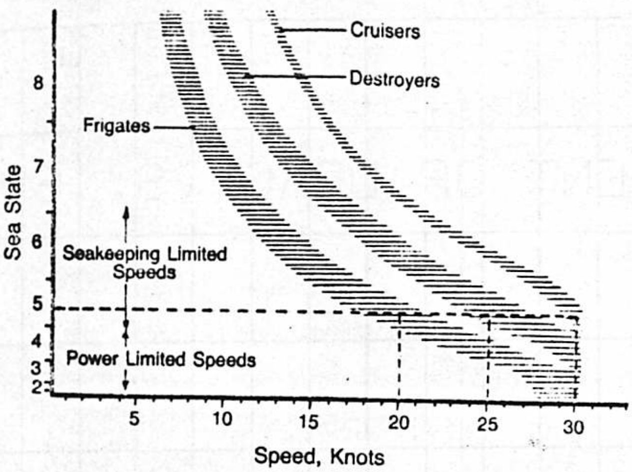


Figure 2 *Full Power Operations*

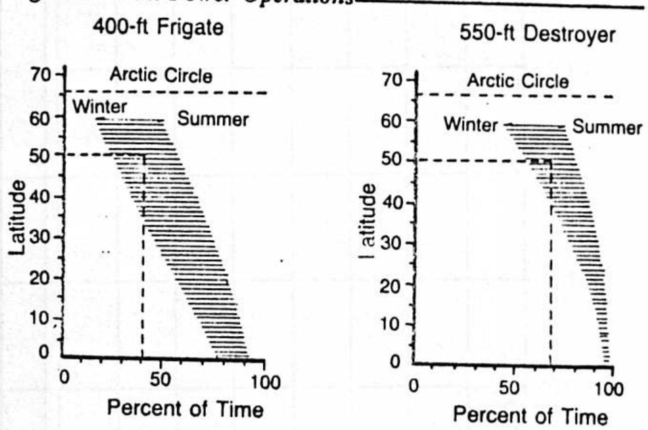


Figure 3 *Sonar Operations*

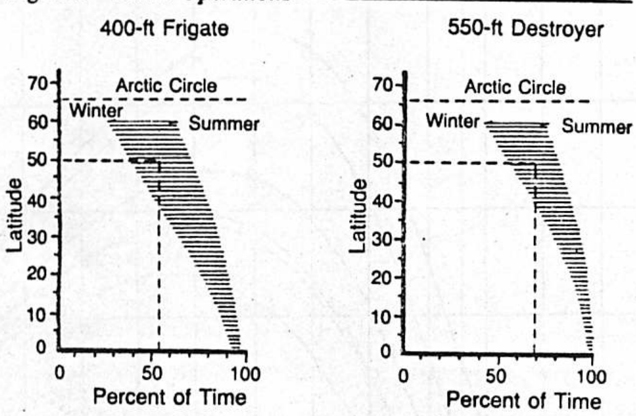


Figure 4 *Helicopter Operations*

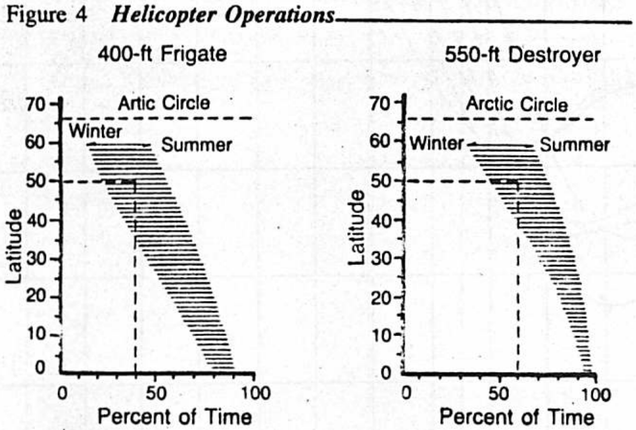


Figure 5 *Replenishment at Sea Operations*

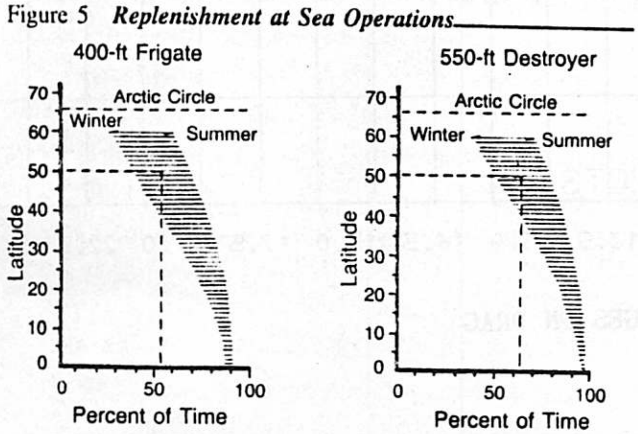
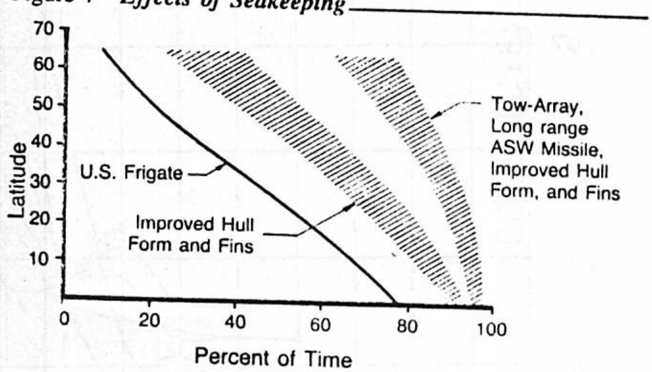
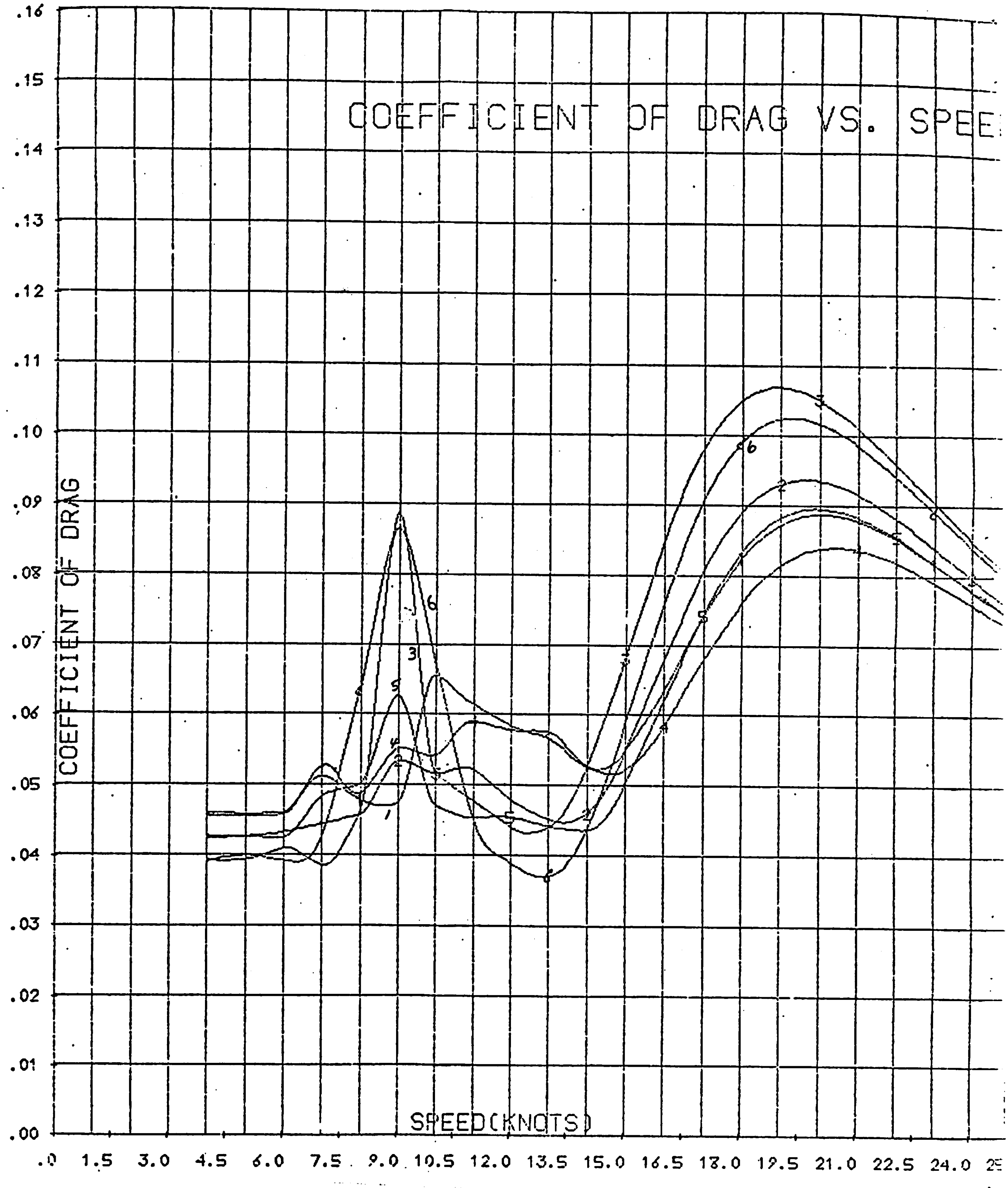


Figure 7 *Effects of Seakeeping*



	Limiting Latitude (North or South)	
	Frigates	*Destroyers/Cruisers*
Hull-Mounted Sonar	30°	45°
Helicopter	15°	35°
Replenishment at Sea	35°	40°



EFFECT OF FORM CHANGES ON DRAG

data reduction from motion picture film, NUC DA-LHM-75-14, dated March 1975

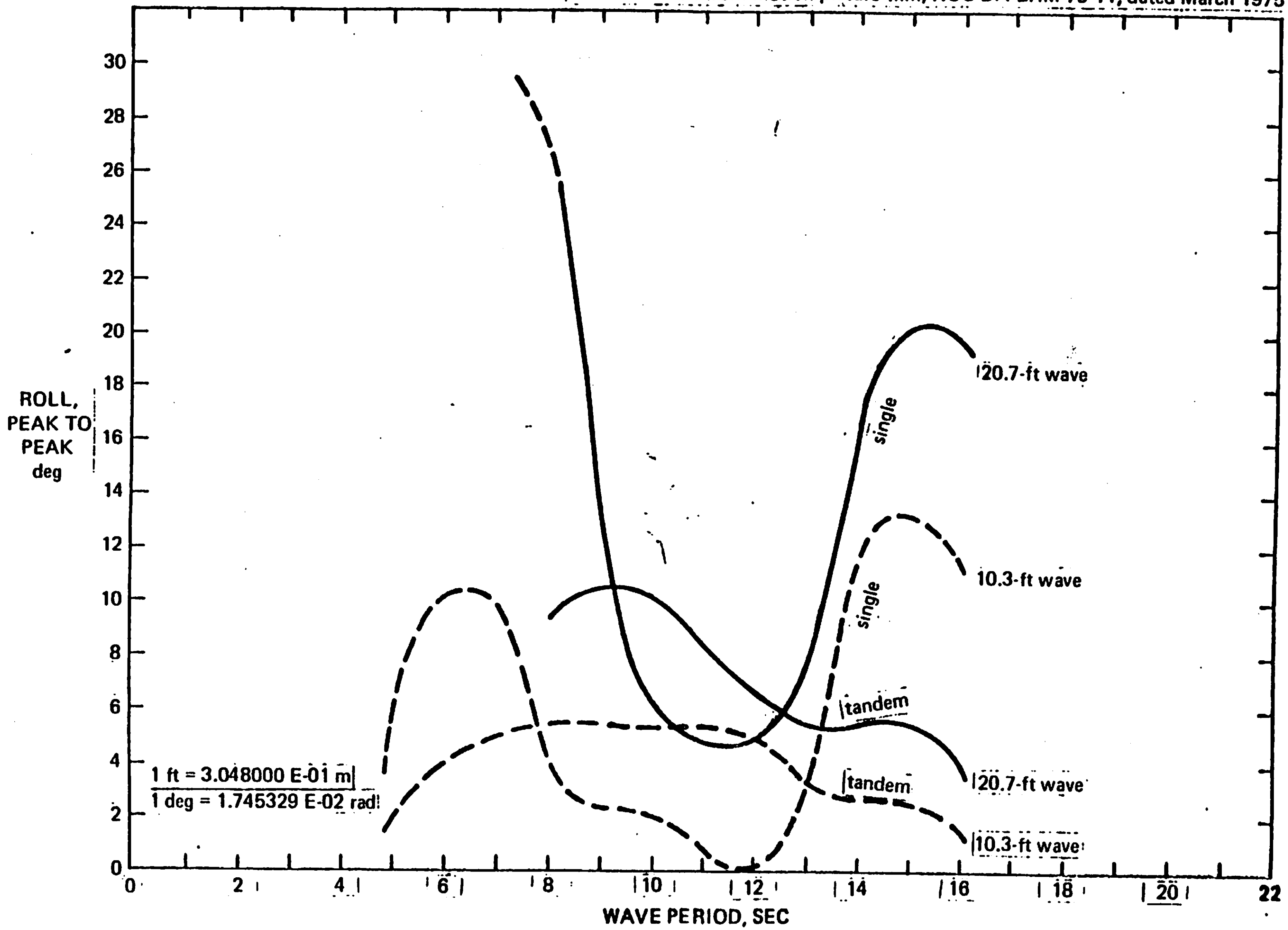


Figure 4. SWATH model roll data scaled to 1800 long tons.

Ref: Sturgeon, "Analysis of Motion Picture Data on Motions in Beam Waves for Single and Tandem Strut SWATH Ship Models", Internal Report, NOSC Code 631, Sept 1977.

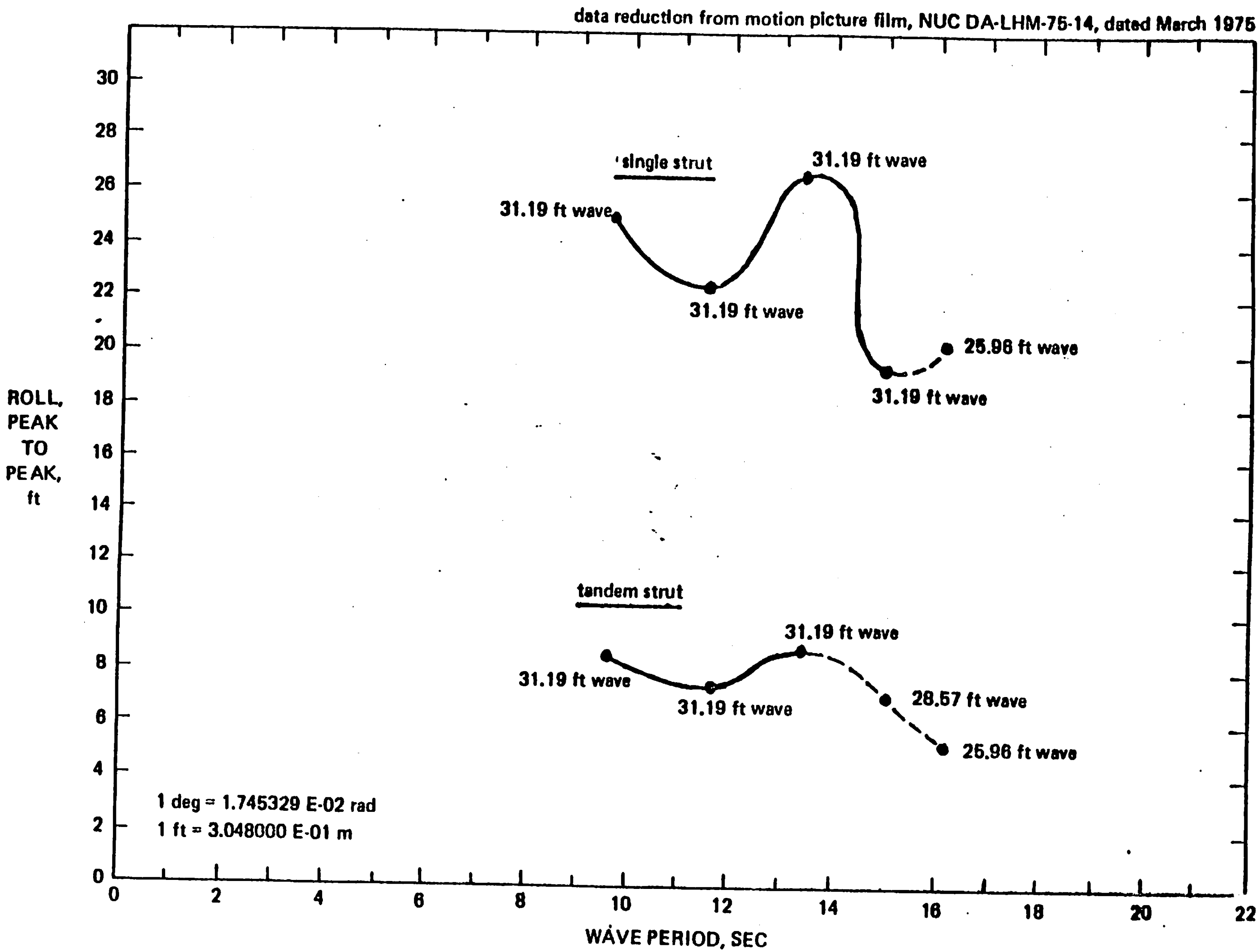


Figure 6. SWATH model roll data, scaled to 1800 long tons.

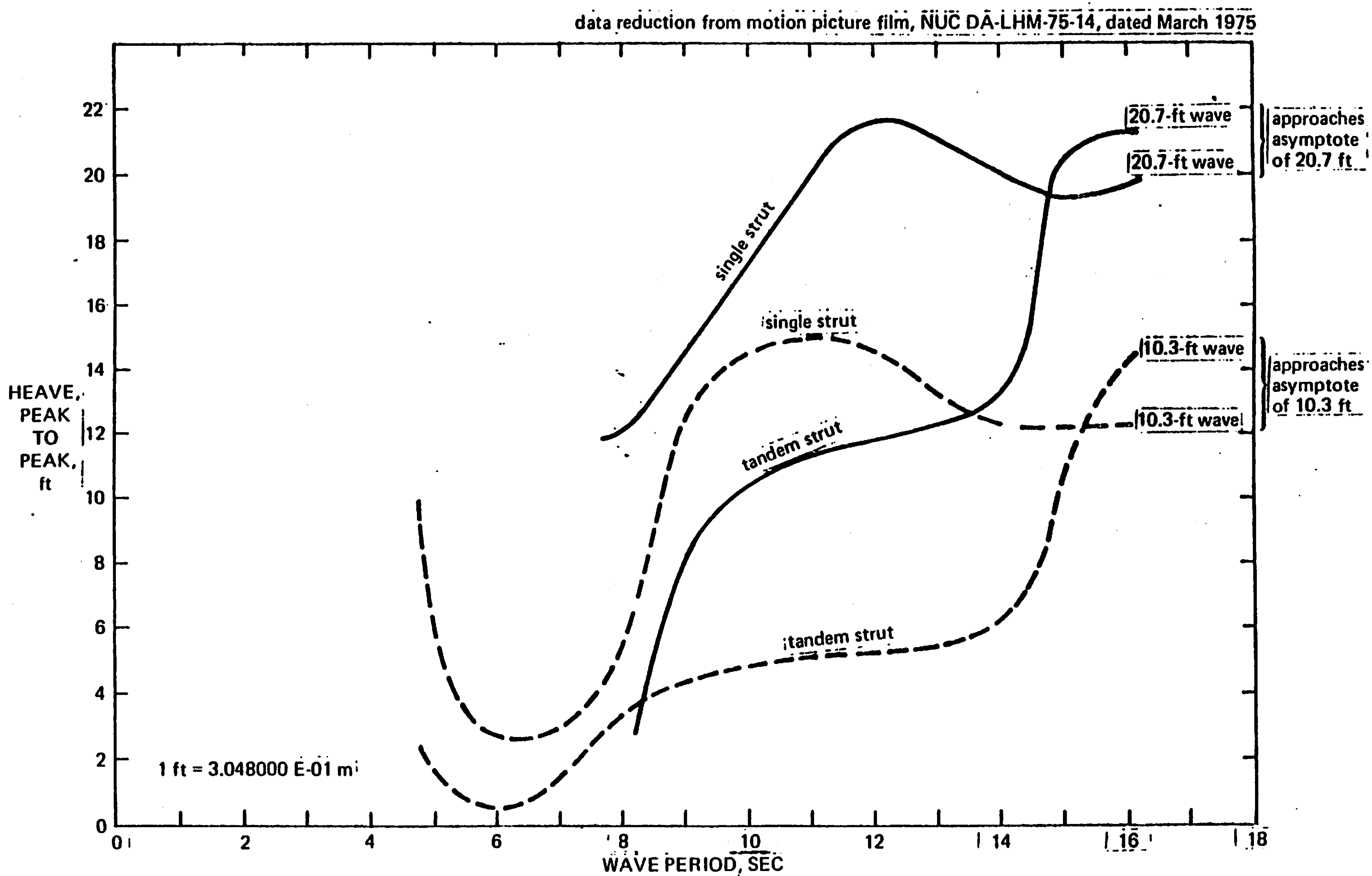
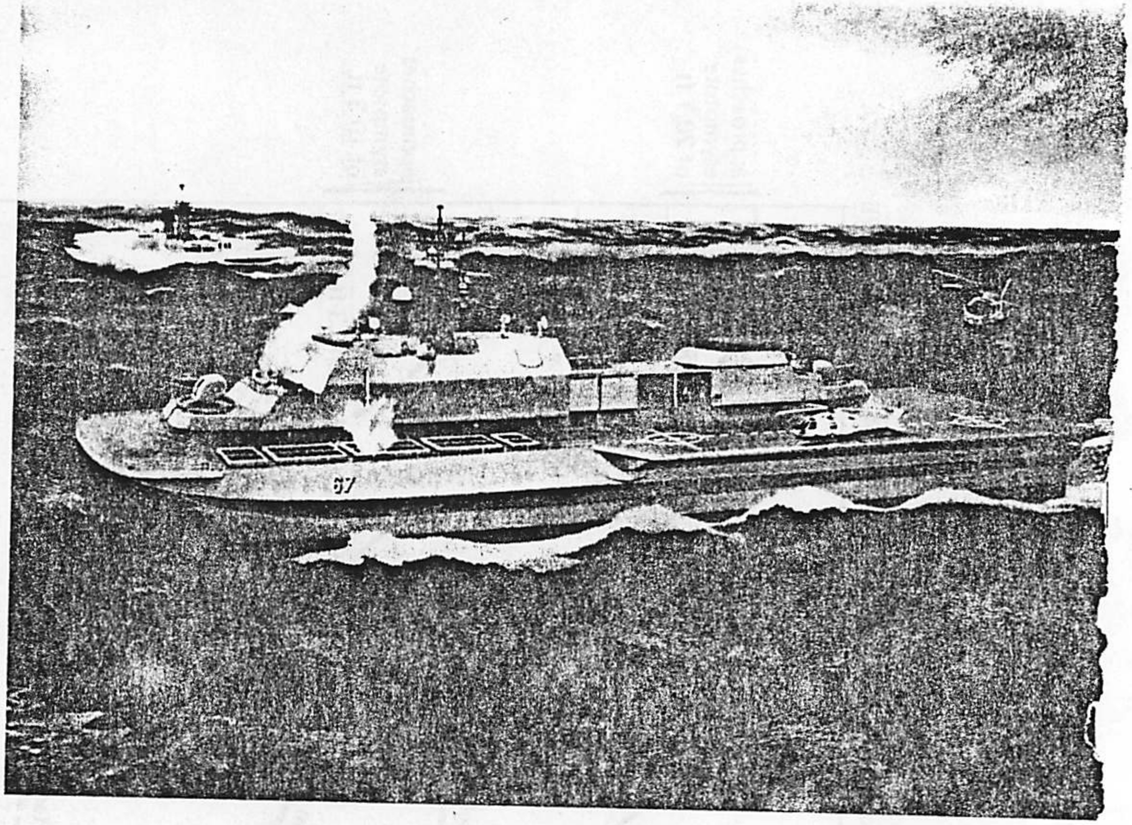


Figure 3. SWATH model heave data, scaled to 1800 long tons.

Navy aviation planners, preparing for a new era of precision weapons and a wider range of action, must employ new technology, mainly in electronic systems

by Robert A. Frosch
General Motors Research Labs



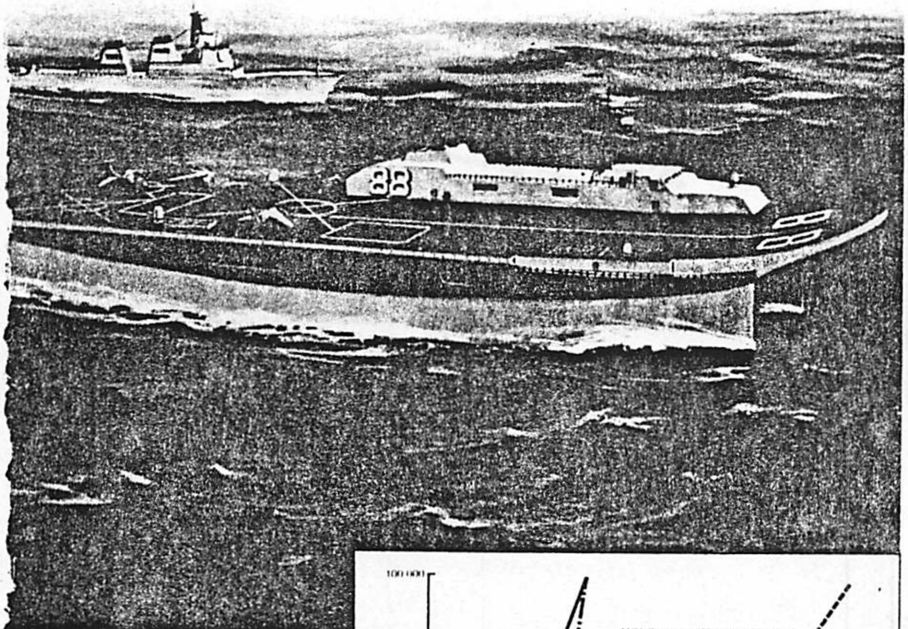
The right stuff for the Navy

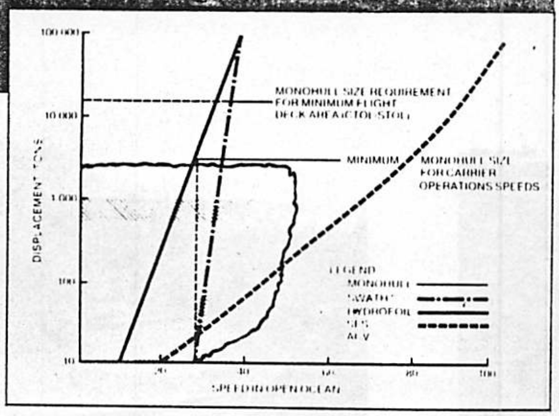
Robert A. Frosch is VP of General Motors in charge of its Research Labs since 1982. The field knows him best for his leadership of NASA from 1977 to 1981, a term from 1963 to 1965 at DARPA as director of Nuclear Test Detection and then deputy director, and his appointment as assistant secretary of the Navy for R&D, from 1966 to 1973.

This article is extracted from the executive summary of a report on "The Implications of Advancing Technology for Naval Aviation," prepared by a panel of the Naval Studies Board of the National Academy of Science's Commission on Physical Sciences, Mathematics, and Resources. The panel was established by request of the Chief of Naval Operations on January 16, 1980. Its task was to devise recommendations, based on the most important technical trends, to assist the Navy in developing its future R&D programs and suggestions for new systems concepts, derivable from expected technological advances, that would enhance the Navy's effectiveness. The panel made no attempt to forecast future scientific discoveries or inventions, but limited itself to the extrapolation of known capabilities. Rather than pursue a rigorous analysis, the panel examined technological trends and systems implications to help guide subsequent detailed Navy studies and analyses. The key points of the full report presented here have been selected by the author without consulting other panel members.

What planes, weapons, and ships should outfit a modern navy deployed around the globe, ready to engage in either nuclear or conventional warfare? What technical trends will shape R&D programs of the U. S. Navy as it looks to the future? In more narrow terms, what should be the future of the carrier? The impact of V/STOL aircraft on the carrier and the form of the Navy? The impact of cruise missiles?

The story begins with naval aviation missions. Naval aviation missions already defined and accepted are to assist in the use of the seas by the United States and its allies, to control the seas in wartime, and to project military power ashore. These





SWATH ships would be small enough to be economical but could keep up with carriers at sea, as graph shows. By carrying missiles and V/STOL aircraft they would better distribute the punch of a task force among its components.

broad mission areas include specific military tasks in which aviation participates: acquiring and distributing intelligence; attacking enemy surface ships and submarines; attacking targets on land, defending friendly assets (of all kinds) at sea, landing ground and air forces from the sea, and defending friendly forces and related assets ashore or over enemy territory. Although these tasks may be carried out against a spectrum of opposition varying from third countries to Soviet forces, they must be formulated with the maximum threat in view.

The threat

The main—and growing—threat to the Navy at sea is from missiles. Missiles can be launched from the air, from the surface, and from under the sea. Future missiles can be expected to have longer ranges, to approach their targets from unexpected angles at high speeds with short intercept times, and to utilize saturation tactics. The Soviet navy is now supported by a worldwide information and targeting system, which will inevitably improve in the future. Delivery platforms will be able to approach U. S. ships, wherever they are, from 360° azimuth. The long reach of the threat and the short time available to react will mean that our current long-range defenses, such as F-14/Phoenix, will no longer be able to reach the launch platforms, and shorter range defenses in heavy electronic countermeasure environments can potentially be saturated. Shorter response time and longer defense reach are essential.

The present missile threat has already forced the Navy to bias its aeronautical resources toward defense of the battle group, to the detriment of its offensive capability. If new technologies and the resulting systems concepts can assist the defense of the fleet and free more aviation assets for offensive missions, a major contribution to Navy effectiveness will have been achieved.

Ashore, attack will face increasingly capable missile-firing air defenses. Thus, any land-attack mission concept must include elements to find and defeat defenses in the target area.

Technology's role

The strong systems nature of evolving technology makes it impossible to consider aviation without examining how it is embedded in the larger Navy.

Naval aviation is, by its very nature, a dispersable force. Advances in nearly all traditional aeronautical technologies now require a system structure that takes better advantage of its dispersability than current Navy systems do. Implicit in the success of such a dispersed force of ships, aircraft, and missiles is the effective flow of signals both within and from outside the battle group, and the ability of this command structure to be disguised so as to make it more difficult to find and attack effectively. Hence, although R&D in naval aircraft is important and should be continued, the major contributions of technology to "naval aviation" in the broad sense will not be in the traditional technologies such as aircraft, airframe, and propulsion. Existing and planned naval tactical aviation airframes, the F-14, A-6, and F/A-18, will continue to be adequate for the tasks envisioned. The leverage of technology will accrue in the application to surveillance, sensors, commu-

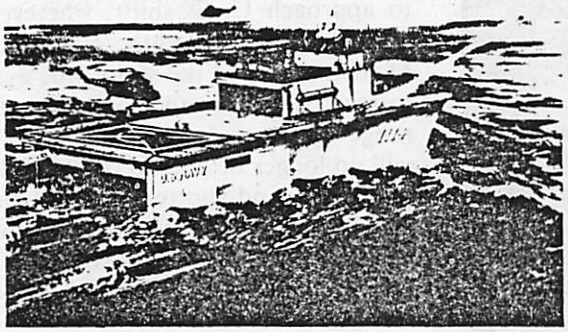


Figure 24. 2,500-ton SWATH frigate.

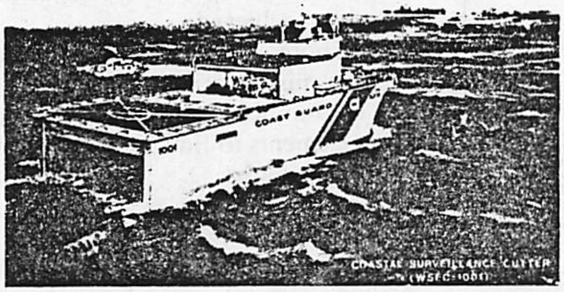


Figure 25. 2,500-ton SWATH coastal surveillance cutter.

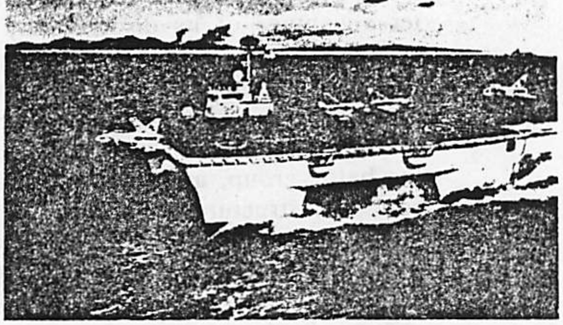


Figure 26. 3,500-ton SWATH V/STOL carrier.

The 12,000-ton artist's version shown in figure 27* could provide permanent basing for 10–20 V/STOL aircraft and helicopters. Modular outfitting of support systems would permit

*Courtesy of DTNSRDC

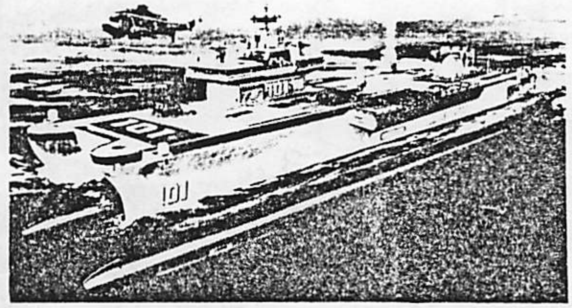


Figure 27. 12,000-ton SWATH V/STOL carrier.

different types of aircraft to be changed quickly to meet mission requirements. A smaller, 7200-ton "ski jump" carrier is shown in figure 28* which would be designed to support type A V/STOL aircraft and helicopters. It would have a flight deck length of 325 feet and a beam of 106 feet.

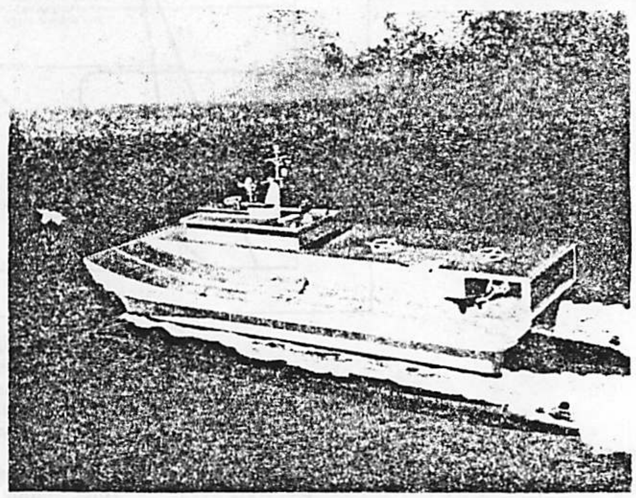
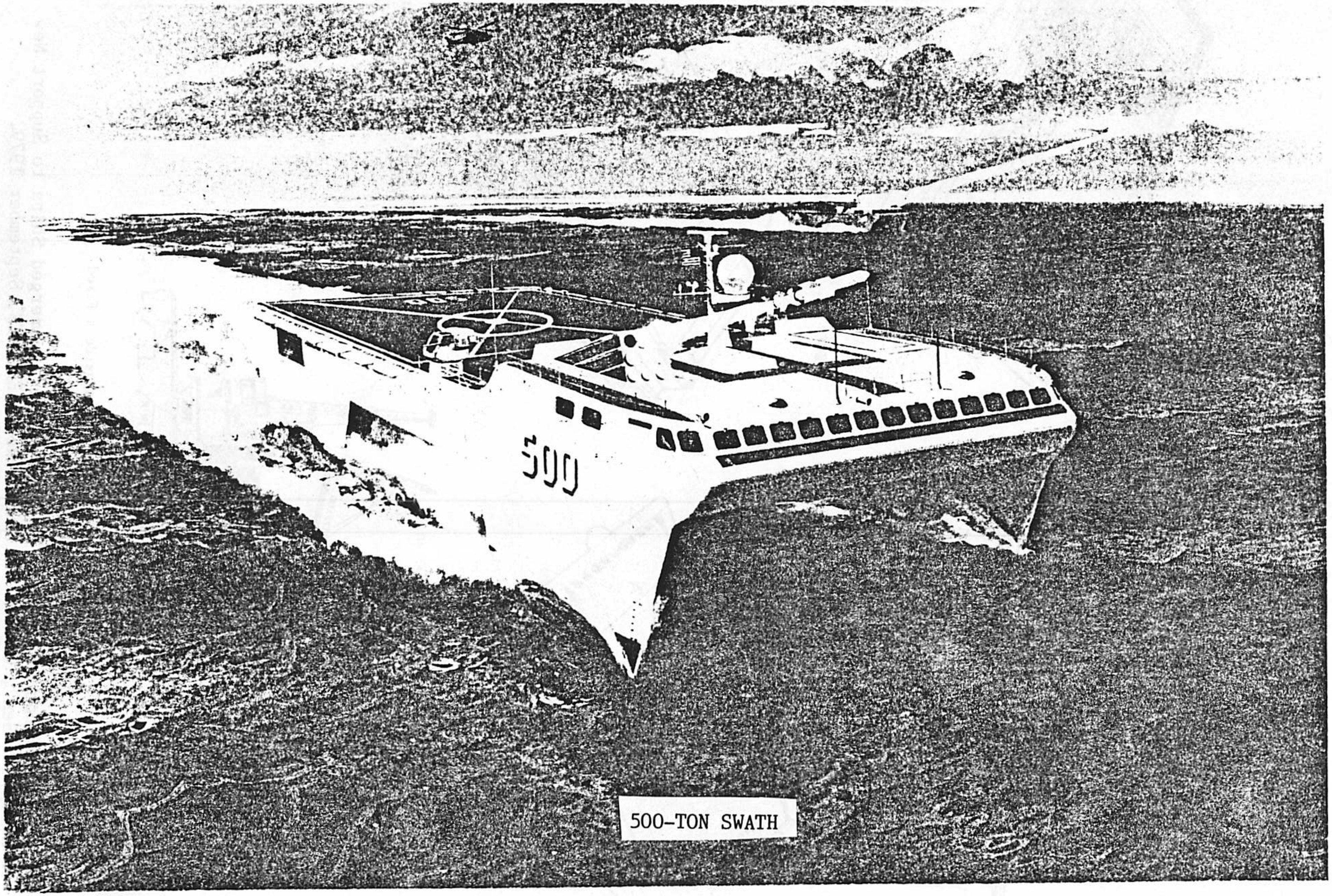


Figure 28. SWATH V/STOL carrier (ski-jump deck).

The 500-ton SWATH shown in figure 29 is another potential application which could be armed with vertically launched surface-to-air missiles and the latest cruise missile system. It would be a potent adversary in open-ocean or inshore surface warfare. The 1,000-ton SWATH shown in figure 30 demonstrates another unusual capability of SWATH ships, namely that of towing very large pods, as conceived by Warnshuis,[50] which might contain ordnance, surveillance equipment, or fuel.

Since basically the only new feature is the shape, current technology can be used to construct these SWATH ships. The large above-water cross structure is readily accessible and lends itself to modular outfitting. Using the modular approach for outfitting, the basic design of figure 26 has been investigated for a variety of naval applications.[49]

Ref: Lang, "The SWATH Ship Concept and its Potential", AIAA/SNAME Advanced Marine Vehicles Conference, Paper 78-736, April 17-19, 1978.



500-TON SWATH

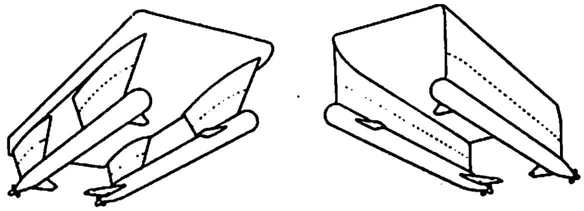


Figure 10. SWATH concept.

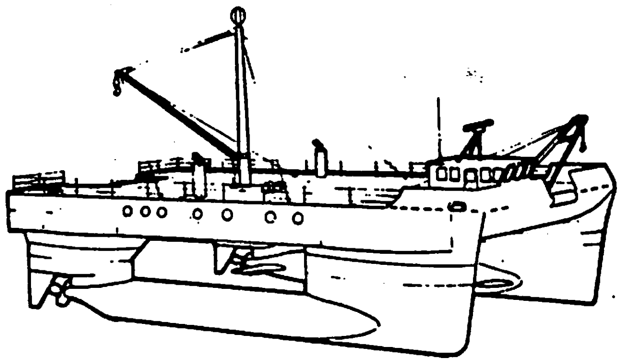


Figure 13. 200-ton S^3 Fishing Vessel

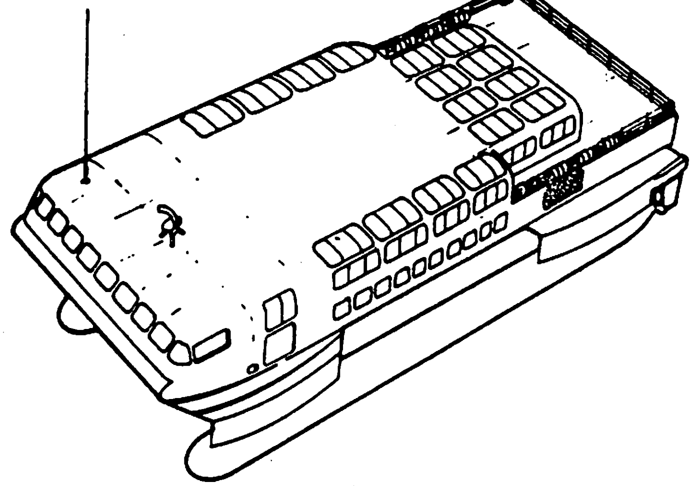


Figure 10. 300-ton S^3 Passenger Excursion Vessel

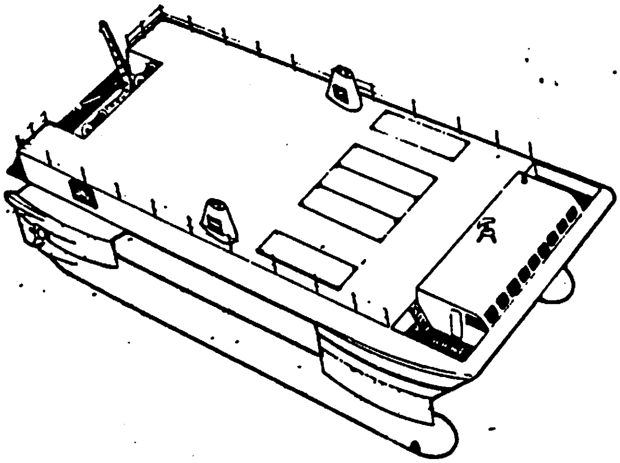


Figure 5. 400-ton S^3 Coastal Zone Oceanic Research Vessel

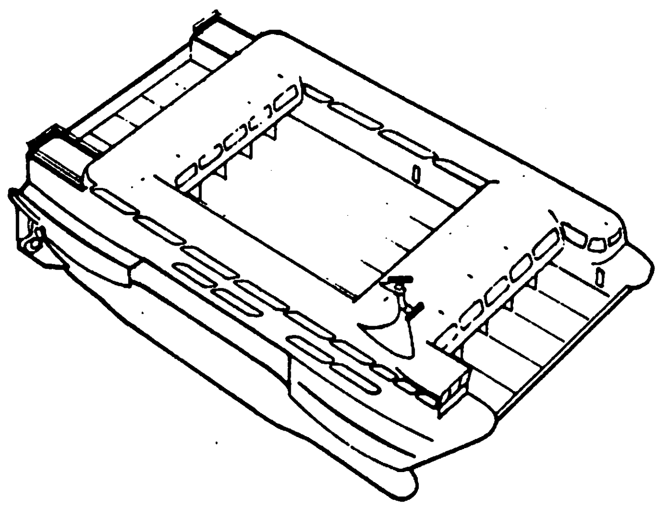


Figure 11. 500-ton S^3 Passenger/Auto Ferry

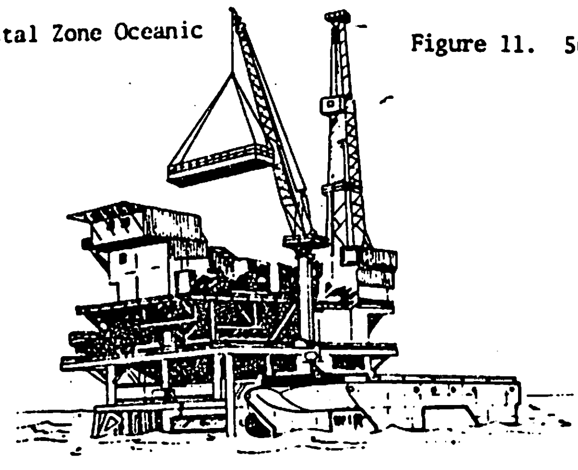


Figure 8. S^3 Crew-boat Alongside a Fixed Production Platform

Ref: Lang, Bishop, Sturgeon, "The Use of Semi-Submerged Ships to Support New Technology at Sea", Oceans '79 Conference, IEEE/MTS, September 1979.

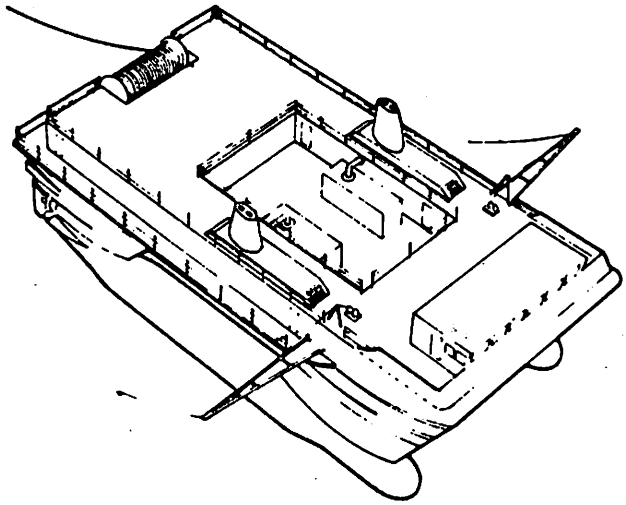


Figure 3. 900-ton S^3 Seismic Survey Vessel

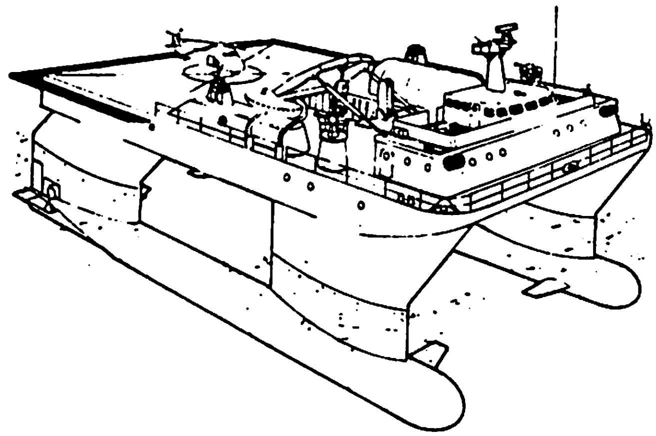


Figure 7. 2000-ton S^3 Undersea Vehicle and Diver Support Vessel

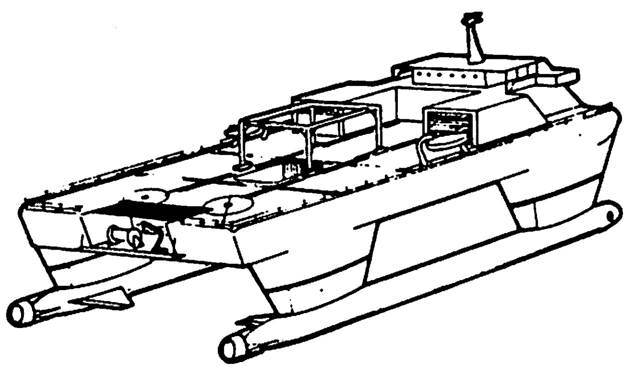


Figure 6. 3000-ton S^3 Oceanic Research Vessel

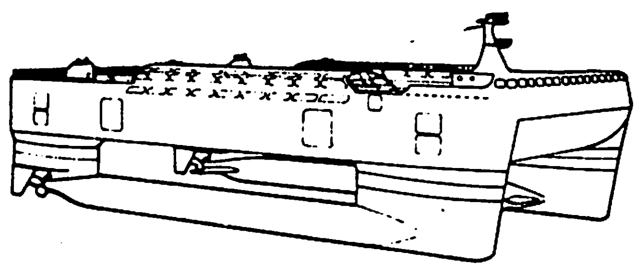


Figure 12. 3200-ton S^3 Passenger/Vehicle Ferry

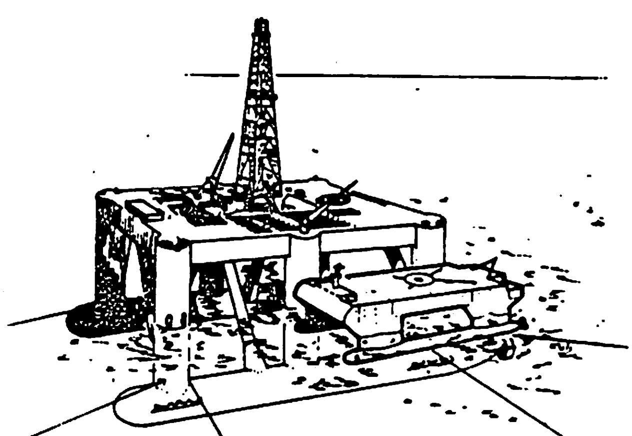


Figure 9. S^3 Supply Ship Alongside a Semi-submersible Drilling Rig

APPENDIX C

<u>SWAGOS Ship Characteristics</u>

Displacement = 1450 long tons

LOA = 213.0 ft. (superstructure)

LWL = 190.0 ft

B_{max} = 87.0 ft. (across lower hulls)

DWL = 22.0 ft. above B_L

Cross Structure water clearance = 16.0 ft.

Strut Spacing:

Transverse = 70.0 ft C_L to C_L

Longitudinal = 125.0 ft. C_L to C_L

Range = 5000 nm at 14 knots (transit)

Endurance = 45 day mission:

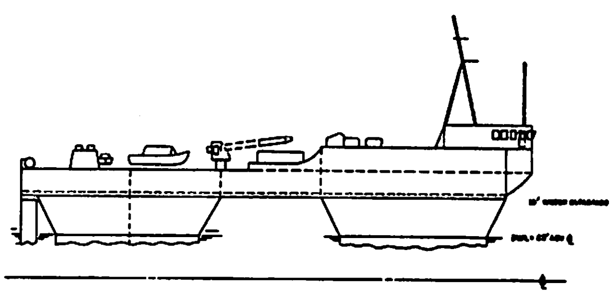
1500 nm at 14 knots cruising speed,
20% of balance at station keeping (0 net speed),
balance at 3.5 knots trawling speed

Complement:

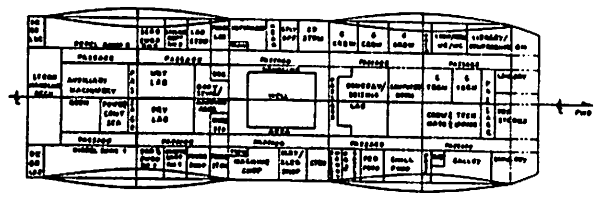
5 Officers
10 Petty Officers
14 Crew
17 Scientists
8 Technicians

54 Total

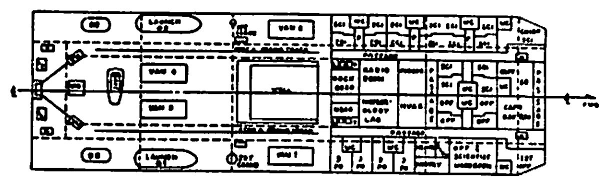
Appendix D - SWAGOS Arrangement
(1 of 4)



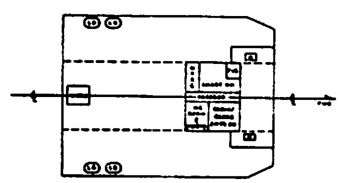
Appendix D - SWAGOS Arrangement
(2 of 4)



Appendix D - SWAGOS Arrangement
(3 of 4)



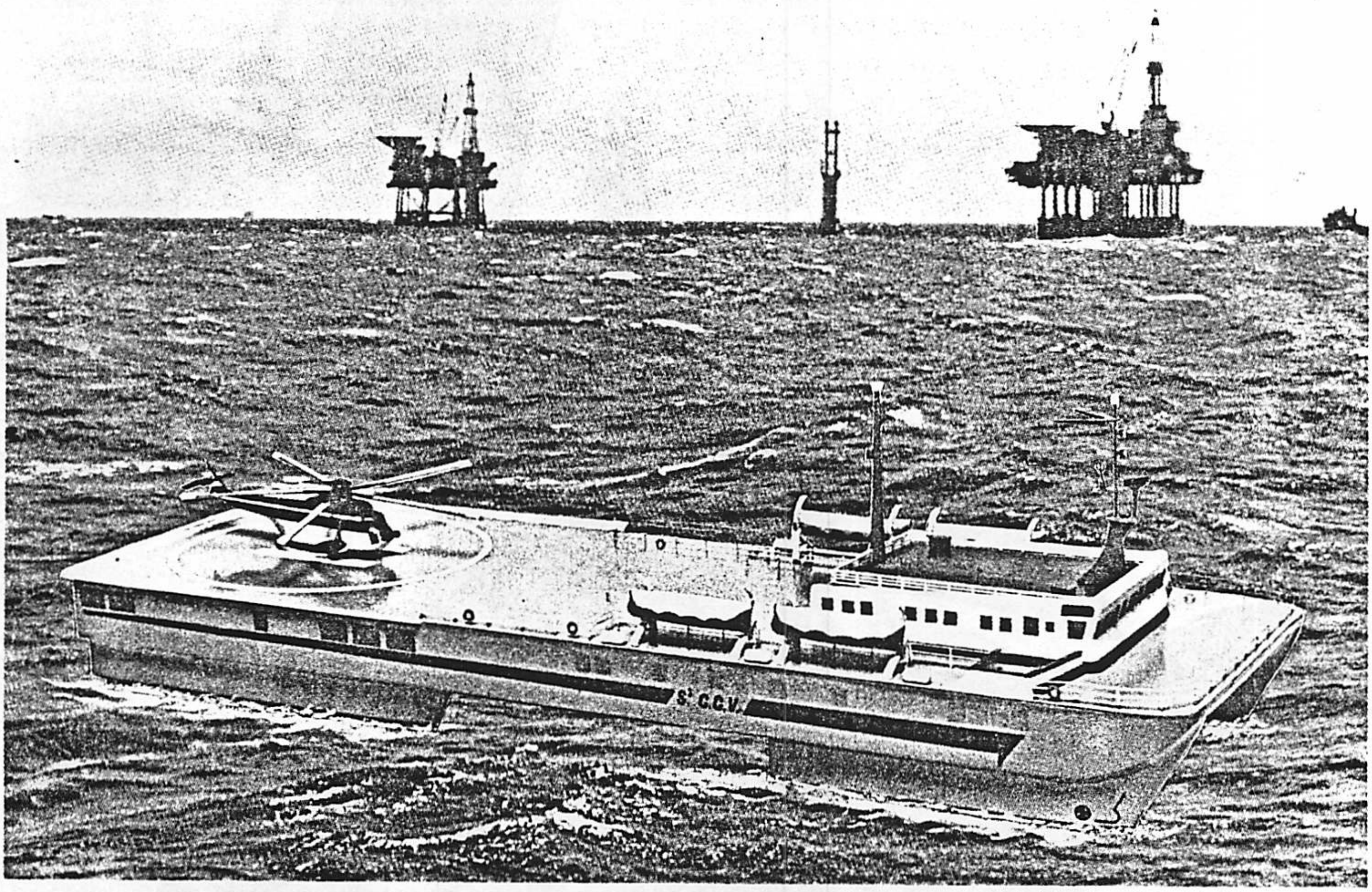
Appendix D - SWAGOS Arrangement
(4 of 4)



Ref: Lang, Becker, Kaysen, Price, "Raytheon/SSSCO Oceanographic SWATH Ship Design", Oceans '82 Conference, IEEE/MTS, Sept 1982.

S^3 C.C.V.

SEMI-SUBMERGED SHIP CREW CHANGE VESSEL



Modelmaker: D. Smith, Photo: T. Wilks.

This illustration shows a 2100-ton S^3 CCV, designed to operate as a Crew Change Vessel servicing offshore complexes. Her high speed capability (35-knots cruising, 38-knots maximum) would also help the vessel to participate in the emergency evacuation of personnel.

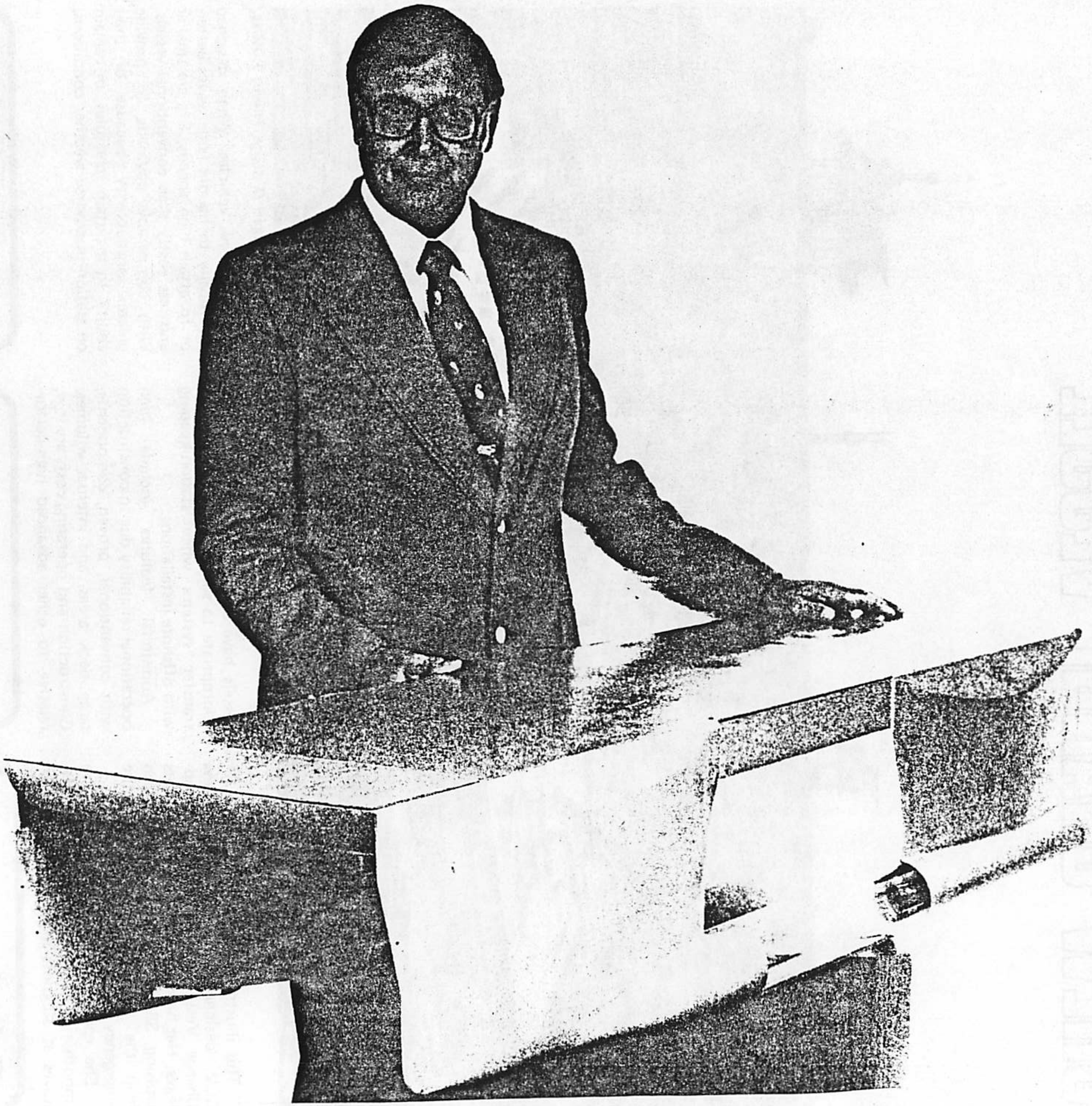
She can carry 400 passengers and a smooth ride is to be expected in 22-ft. waves at 30-knots in the North Sea. S^3 vessels have characteristics exceptionally appropriate to simple and safe passenger transfer systems when station-keeping with offshore installations.

Additional features include high operational reliability due to construction with conventional, proven, components, large deck areas, and internal volumes. Construction and operating costs are low, relative to other advanced high-performance marine vehicles. When designed specifically to handle large waves better, or to attain high speeds, S^3s are smaller and less costly than conventional vessels. With comparable payloads, S^3 provide greater productivity because of their ability to maintain schedules, or remain on station in adverse weather conditions.

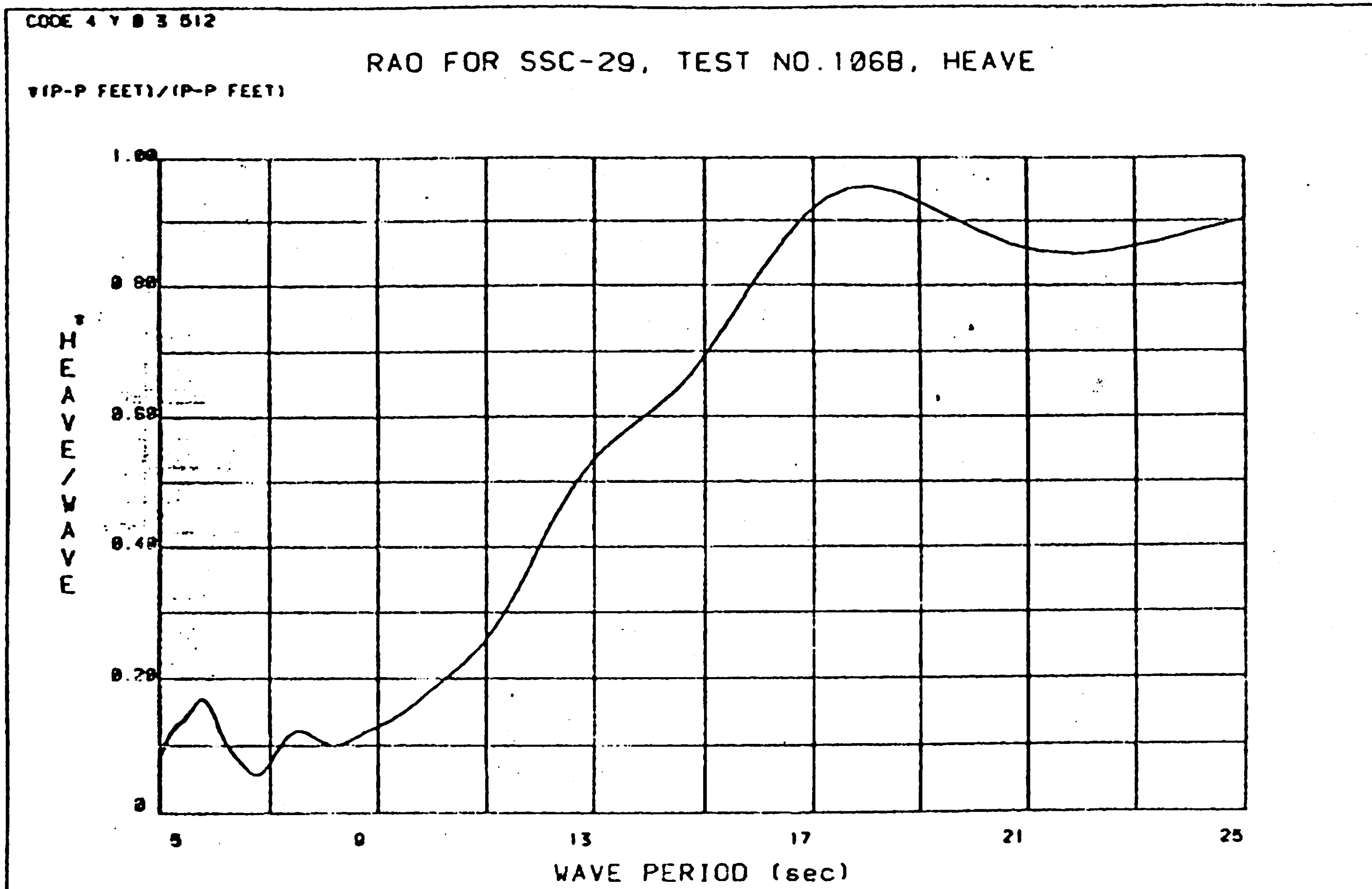
British Shipbuilders

SEMI-SUBMERGED SHIP CORPORATION
SSSCO

MANDERSTAM TECHNICAL SERVICES LTD



BS/SSSCO MODEL OF 2,000 LT CREW CHANGE VESSEL (CCV)



Graph 20 Heave RAO for Point B, Test No. 106

HEAVE RAO OF CCV MODEL

Ref: Lang, "The SWATH Ship Concept and its Potential", AIAA/SNAME Advanced Marine Vehicles Conference, Paper 78-736, April 17-19, 1978.

Design Tradeoffs

Discussion

An important aspect of the design process is to determine the effect of changing various design parameters. For example, how does a change in speed trade off against displacement? Alternatively, how does range affect payload, or how does structural weight affect range? The following is a simplified analytical approach which provides approximate answers to these kinds of questions. This approach is based upon the generalized design procedure by Lang,[47] and can be extended to cover the more complex design cases.

Basic Equations

Let the displaced weight W of a ship be defined as

$$W = W_a + W_s + W_p + W_f \qquad (1)$$

where,

W_a = weight of all items which are essentially independent of the displacement, speed, or range. W_a includes such items as payload, men, outfitting, supplies, and auxiliaries.

W_s = weight of all structural-like items that vary essentially with displacement, including primary and secondary structure, anchors, and rudders.

W_p = weight of propulsion items that vary with power, including engines, shafts, and propellers.

W_f = weight of the fuel.

$$\text{Let } W_p = \alpha P = \frac{\alpha C_d}{\eta}\left(\frac{W}{\rho g}\right)^{2/3}\frac{\rho}{2}V^3 \qquad (2)$$

$$\text{and } W_f = \beta\frac{PR}{V} = \frac{\beta C_d}{\eta}\left(\frac{W}{\rho g}\right)^{2/3}\frac{\rho}{2}V^2 R \qquad (3)$$

where α is the weight per unit of installed power P, C_d is the drag coefficient based on volume, ρ is the mass density of seawater, g is the acceleration of gravity, V is ship speed, β is the fuel weight per unit power and time, R is the range, and η is the propulsive efficiency times the transmission efficiency.

Substituting equations (2) and (3) into (1), dividing by W, and defining $W_s/W = W_s'$,

$$1 = \frac{W_a}{W} + W_s' + \frac{C_d\rho^{1/3}V^3\alpha}{2\eta g^{2/3}W^{1/3}} + \frac{C_d\rho^{1/3}V^2\beta R}{2\eta g^{2/3}W^{1/3}} \qquad (4)$$

modifying equation (4),

$$\frac{W_a}{W} + \left(\frac{W_a}{W}\right)^{1/3}\gamma = 1 - W_s' \qquad (5)$$

where

$$\gamma = \frac{C_d \rho^{1/3} V^2}{2\eta g^{2/3} W_a^{1/3}} \left[V\alpha + \beta R\right] \tag{6}$$

This equation is plotted in figure 18. The results show, for example, that if $W/W_a = 6$ and $W_s' = 0.4$, then $\gamma = 0.8$. Now, if γ were increased by 25%, due to changes in C_d, η, V, R, α, or β, then the displacement would increase 50%. Alternatively, if γ reduced by 25%, the displacement would reduce by 33%. Similarly, reducing W_s' to 0.2 would reduce displacement by 45%.

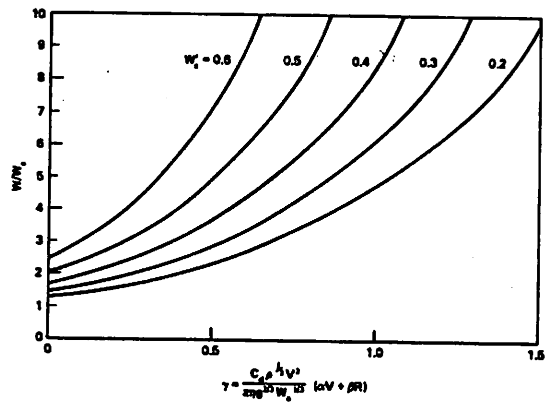


Figure 18. Displacement to W_a ratio for ships.

Figure 18 can also be used to compare monohull and SWATH ships. For example, assume that a monohull and a SWATH are designed for the same values of W_a, V, R, α, and β. Let the monohull have $W_s' = 0.3$ and $\gamma = 1.0$. Assume the equivalent SWATH has $W_s' = 0.4$, C_d = 5% less, and η = 10% greater than the monohull. Figure 18 shows that the SWATH will displace 3% less than the monohull. Alternatively, if the C_d for SWATH had been 5% greater rather than 5% smaller than for a monohull, the SWATH displacement would have been 15% greater than the monohull.

A method for more directly determining the effect of a change in one parameter on another is to modify equation (4) by multiplying and dividing each variable term by the same term having the subscript 0 to designate a baseline design, and then adding the subscript 1 to the original term to designate a new design. Thus, equation (4) becomes

$$1 = \frac{\dfrac{W_{a1}}{W_{a0}} \cdot \dfrac{W_{a0}}{W_0}}{\dfrac{W_1}{W_0}} + \frac{W'_{s1}}{W'_{s0}} W'_0 + \frac{\dfrac{C_{d1}}{C_{d0}}\left(\dfrac{V_1}{V_0}\right)^2}{\dfrac{\eta_1}{\eta_0}\left(\dfrac{W_1}{W_0}\right)^{1/3}} \left(\frac{\rho^{1/3} C_{d0} V_0^2}{2g^{2/3}\eta_0 W_0^{1/3}}\right)$$

$$\left(\frac{\alpha_1}{\alpha_0}\frac{V_1}{V_0} V_0\alpha_0 + \frac{\beta_1}{\beta_0}\frac{R_1}{R_0}\beta_0 R_0\right) \tag{7}$$

Substituting the baseline design values for equations (2) and (3) into (7), and letting primes denote weight fractions,

$$1 = \frac{W_0}{W_1}\frac{W_{a1}}{W_{a0}} W'_{a0} + \frac{W'_{s1}}{W'_{s0}} W'_{s0} + \frac{\eta_0}{\eta_1}\frac{C_{d1}}{C_{d0}}\left(\frac{W_0}{W_1}\right)^{1/3}\left(\frac{V_1}{V_0}\right)^2$$

$$\left[\frac{\alpha_1}{\alpha_0}\frac{V_1}{V_0} W'_{p0} + \frac{\beta_1}{\beta_0}\frac{R_1}{R_0} W'_{f0}\right] \tag{8}$$

Equation (8) can be used to show how a change in any one variable can affect any other variable. For example, the change in displacement resulting from a change in any one variable, while keeping all the remaining terms fixed, is shown in figure 19 for the case of $W'_{s0} = 0.40$, $W'_{p0} = 0.10$, and $W'_{f0} = 0.15$ where $W'_{a0} = 1 - W'_{s0} - W'_{p0} - W'_{f0} = 0.35$. The result shows that an individual increase of 20% in each of W_a, W_s', η, C_d, V, R, X, α, and β will change the displacement by 15, 25, −8, 12, 42, 10, 6, and 10%, respectively. Alternatively, reducing W_s' from 0.40 to 0.30, such as by using more aluminum, would reduce displacement by 20%.

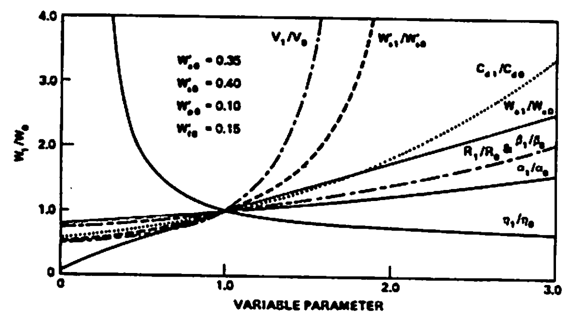


Figure 19. Displacement change as a function of design parameter changes ($W'_{s0} = 0.40$).

Figures 20 and 21 also originated from equation (8), and show the effects of the variables on range and payload, respectively, for the same baseline design as in figure 19. The results show that both range and payload are greatly affected by speed and displacement. The figures can also be used to determine the effects of simultaneous changes in the parameters, such as an increase in range and a reduction in structural weight.

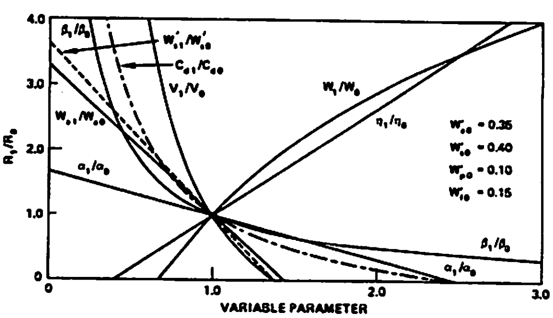


Figure 20. Range change as a function of design parameter changes ($W'_{s0} = 0.40$).

Figure 22 shows that speed is not affected by changes in the design parameters as much as W, W_a, and R were. However, changes in W, η, W'_s, and W_a have the greatest effect on speed.

Changing the baseline design from $W'_{s0} = 0.40$ to 0.30, as in figure 23, appears to produce little change from figure 19, except for the curve of W'_{s1}/W'_{s0} which has become less critical.

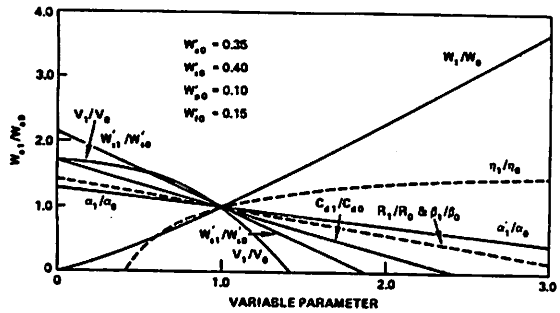


Figure 21. Payload change as a function of design parameter changes ($W_{s}{}'_{o} = 0.40$)

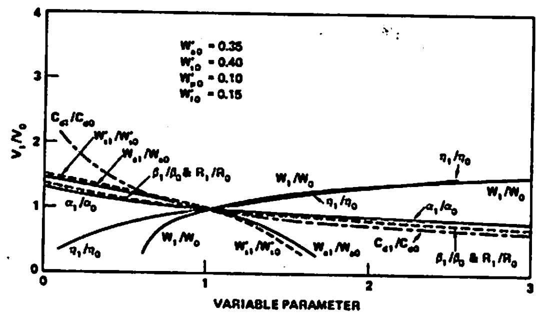


Figure 22. Velocity change as a function of design parameter change ($W_s{}' = 0.40$).

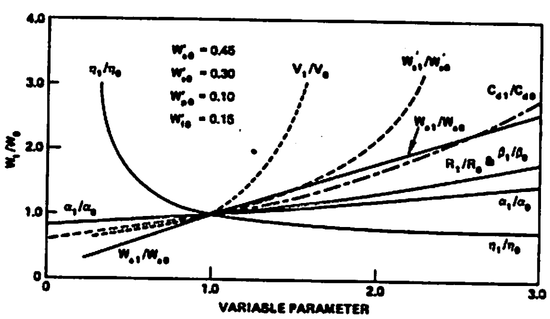


Figure 23. Displacement change as a function of design parameter changes ($W_{s}{}'_{o} = 0.30$).

The new values of $W_p{}'$ and $W_f{}'$ resulting from a design change can be calculated from the following equations which were derived from equations (2) and (3):

$$\frac{W'_{p1}}{W'_{p0}} = \left(\frac{C_{d1}}{C_{d0}}\right)\left(\frac{V_1}{V_0}\right)^3\left(\frac{\alpha_1}{\alpha_0}\right)\left(\frac{\eta_0}{\eta_1}\right)\left(\frac{W_0}{W_1}\right)^{1/3} \quad (9)$$

$$\frac{W'_{f1}}{W'_{f0}} = \left(\frac{C_{d1}}{C_{d0}}\right)\left(\frac{V_1}{V_0}\right)^2\left(\frac{\beta_1}{\beta_0}\right)\left(\frac{\eta_0}{\eta_1}\right)\left(\frac{W}{W_1}\right)^{1/3}\left(\frac{R_1}{R_0}\right) \quad (10)$$

Modified Equations

For propulsion systems in which one power source is used for cruising and another for maximum speed, two power and two fuel terms are needed in the weight equation. Using the subscripts c and m to correspond to the cruise and maximum speed conditions, respectively, equations (2) and (3) become

$$W'_p \doteq \frac{C_{dc}}{2\eta_c} \cdot \frac{V_c^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \cdot \alpha_c V_c + \frac{C_{dm}}{2\eta_m} \cdot \frac{V_m^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \cdot \alpha_m V_m \quad (11)$$

$$W'_f \doteq \frac{C_{dc}}{2\eta_c} \cdot \frac{V_c^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \beta_c R_c + \frac{C_{dm}}{2\eta_m} \cdot \frac{V_m^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \beta_m R_m \quad (12)$$

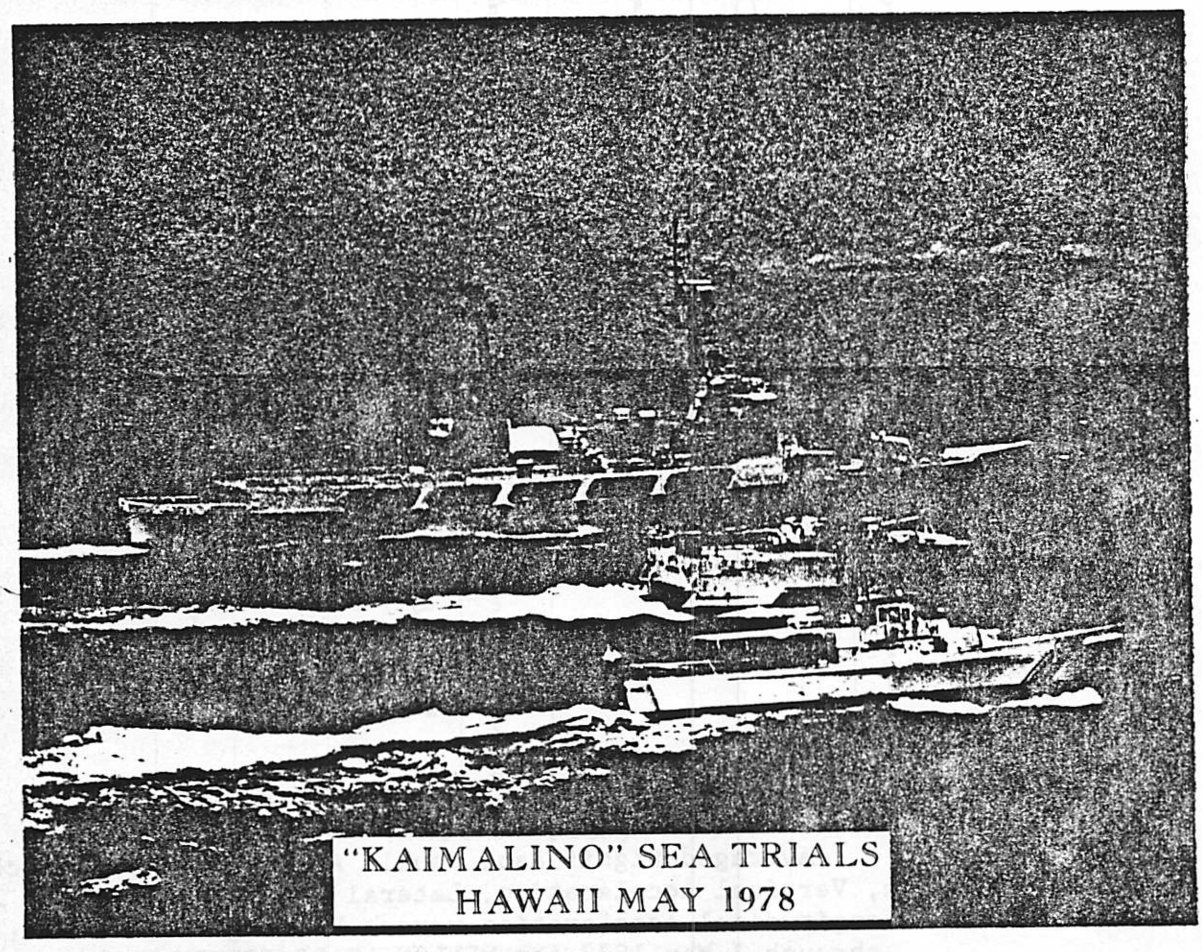
Modifying these equations,

$$W'_p = \frac{C_{dm}}{2\eta_m} \cdot \frac{V_m^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \cdot \alpha_m V_m \left[1 + \frac{C_{dc}}{C_{dm}} \cdot \frac{\eta_m}{\eta_c} \left(\frac{V_c}{V_m}\right)^3 \cdot \frac{\alpha_c}{\alpha_m}\right] \quad (13)$$

$$W'_f = \frac{C_{dm}}{2\eta_m} \cdot \frac{V_m^2 \rho^{1/3}}{g^{2/3} W^{1/3}} \cdot \beta_m R_m \left[1 + \frac{C_{dc}}{C_{dm}} \cdot \frac{\eta_m}{\eta_c} \left(\frac{V_c}{V_m}\right)^2 \frac{\beta_c}{\beta_m} \frac{R_c}{R_m}\right] \quad (14)$$

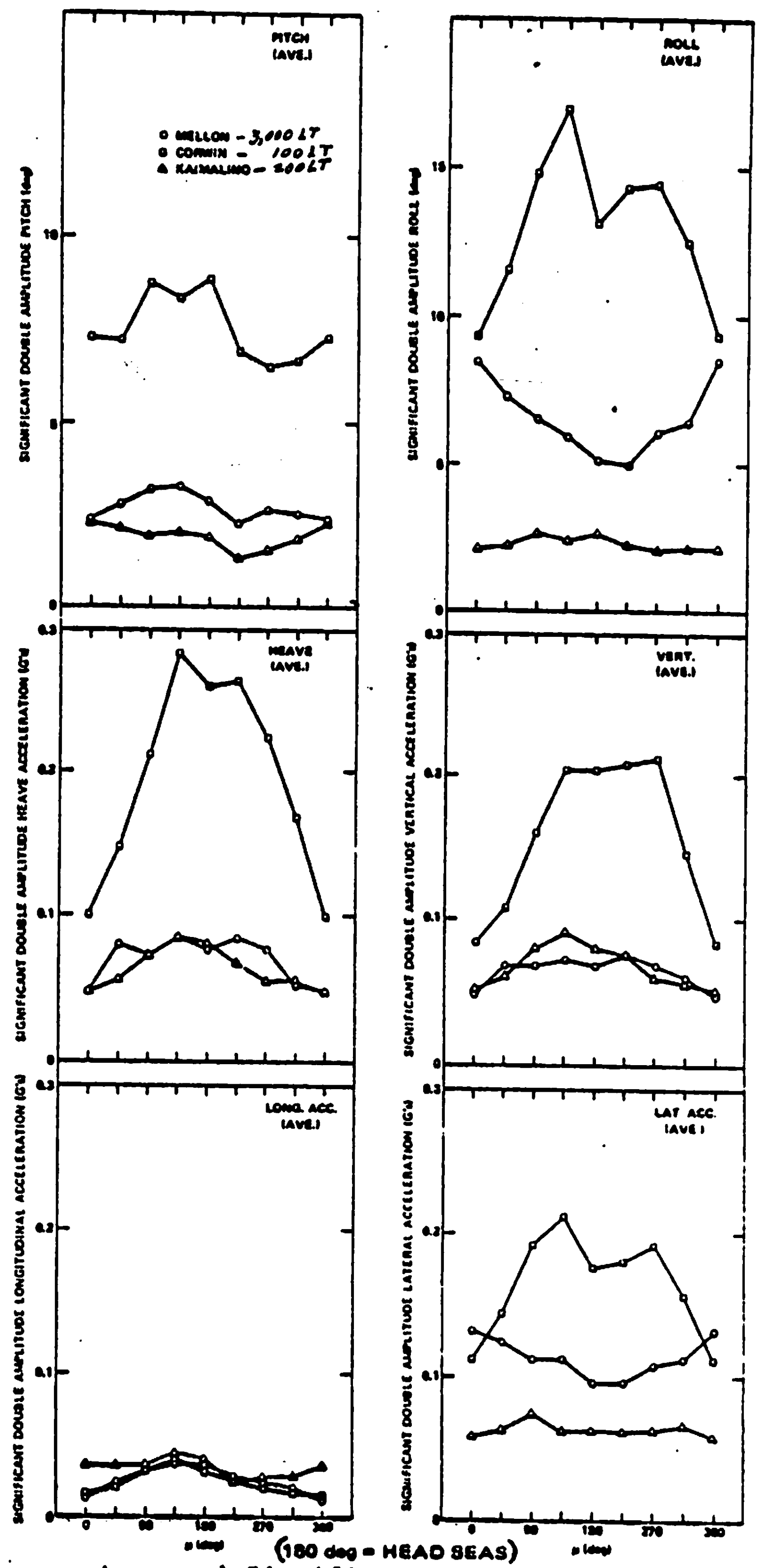
Equations (13) and (14) can be substituted into their corresponding terms in equations (4) through (8) and then used for answering a more complex set of design questions relating to tradeoffs with the cruise and maximum speed propulsion systems. However, for some such questions, the original equations (4) through (8) can still be used. For example, if the cruise system and ship displacement were to be fixed in a design tradeoff, the maximum speed system could be treated as the sole propulsion system, wherein the cruising power plant and its associated fuel would be combined into the W_a term.

*Courtesy of DTNSRDC



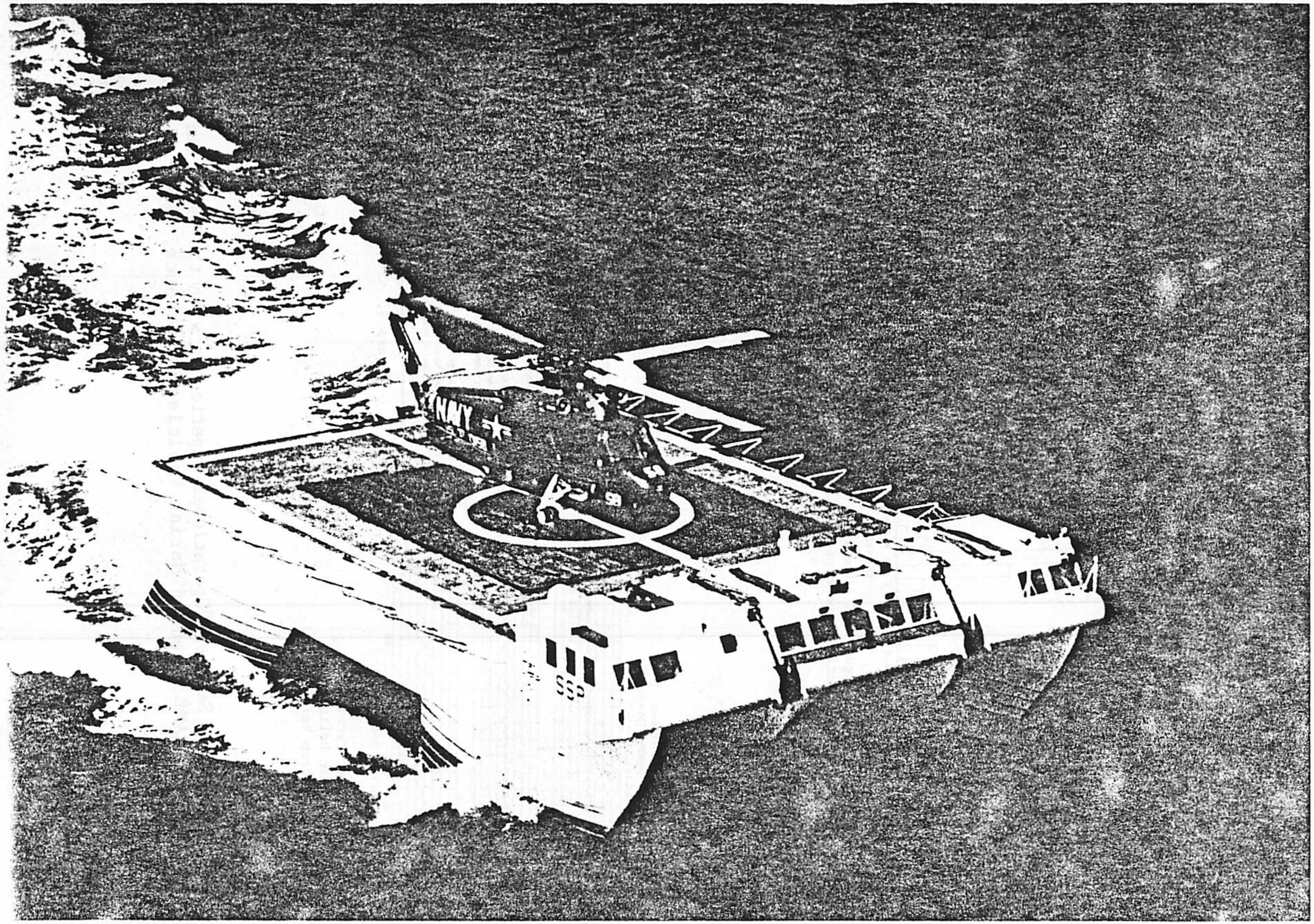
"KAIMALINO" SEA TRIALS
HAWAII MAY 1978

Comparative Motions Tests
Conducted by the USCG



Averaged Significant Double Amplitude Roll, Pitch, Heave, Vertical Acceleration, Lateral Acceleration, and Longitudinal Acceleration versus Heading for 1 through 3 May 1978 for MELLON, CAPE CORWIN, and KAIMALINO

Reference: DTNSRDC REPORT 80/037 "Comparative Ship Performance Sea Trials for the USCG Cutters MELLON and CAPE CORWIN and the U.S. Navy Small Waterplane Area Twin Hull Ship SSP KAIMALINO," by D.A. Woolover and J.B. Peters. March 1980.


NAVY

High Speed	13 to 22	knots
Medium Speed	2 to 9	knots
Low Speed/DIW	0 to 2	knots

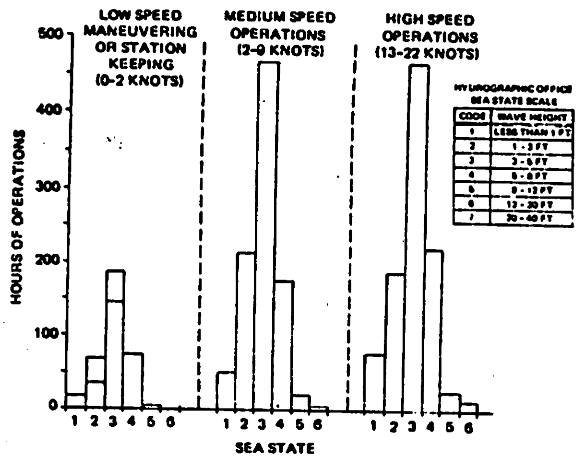


Figure 16. Operating histograms at various speed regimes.

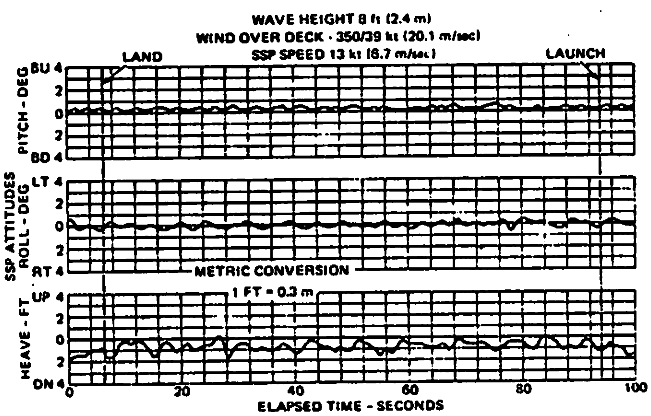


Figure 21. Strip chart recordings showing SSP motions for helicopter launch and recovery (from Reference 7).

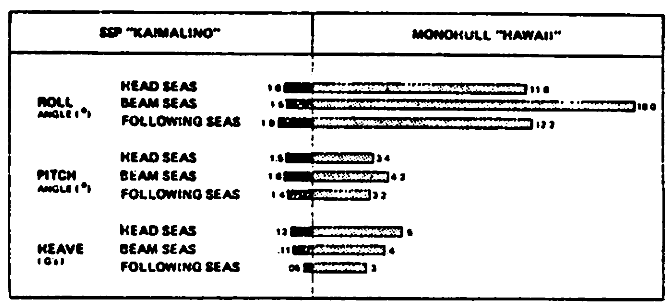


Figure 9. Comparative motions.

Ref: Hightower and Seiple, "Operational Experiences with the SWATH Ship SSP KAIMALINO", AIAA/SNAME Advanced Marine Vehicles Conference, Paper 78-741, April 17-19, 1978.

DYNAMIC INTERFACE TESTS WERE CONDUCTED ABOARD THE SSP KAIMALINO WITH AN SH-2F (LAMPS) HELICOPTER ON 9-16 SEP. THE EVALUATION INVOLVED 78 LAND/LAUNCH EVOLUTIONS AND DETERMINATION OF SSP MANEUVERING AND HELICOPTER ENGAGE/DISENGAGE ENVELOPES ALL IN CONDITIONS UP TO SEA STATE FOUR. TESTS WERE SAFELY COMPLETED AND RESULTED IN AN UNUSUALLY LARGE OPERATIONAL ENVELOPE FOR THE AIRCRAFT AND SSP (WHILE CONDUCTING FLIGHT OPERATIONS). THE UNPRESCEDENTED STABILITY CHARACTERISTICS AND UNOBSTRUCTED DECK HENCE LACK OF WIND TURBULENCE OF A SWATH VESSEL PROVIDE OUTSTANDING POTENTIAL AS AN OPERATIONAL PLATFORM FOR VTOL/HELICOPTER OPERATIONS.

THE FOLLOWING ARE THE MAJOR CONCLUSIONS OF THE EVALUATION:

A. A LARGE DAY VMC LAND/LAUNCH ENVELOPE WAS DEVELOPED. THE FORWARD AND AFT QUADRANTS WERE LIMITED ONLY BY WINDS AVAILABLE. LATERAL QUADRANTS OF THE ENVELOPE WERE LIMITED BY AIRCRAFT CONTROL (WHICH WOULD NOT APPLY TO LARGER DECKS WHERE LANDINGS INTO THE RELATIVE WIND WOULD ALWAYS BE POSSIBLE).

B. A LARGE ROTOR ENGAGE/DISENGAGE ENVELOPE WAS ESTABLISHED IN SEA STATES UP TO 4, AND IS LIMITED ONLY BY THE ATTAINABLE WINDS DURING THE TESTS.

C. THE SSP IS PERMITTED UNRESTRICTED MANEUVERING IN SEA STATES UP TO 4 WITH HELICOPTER ROTORS ENGAGED ON DECK.

Ref: Abstracts from "Dynamic Interface Evaluation of the SSP with SH-2F Helicopter" by Woomer and Edris, Naval Air Test Center Technical Report RW-65R-76, Dec 1976.

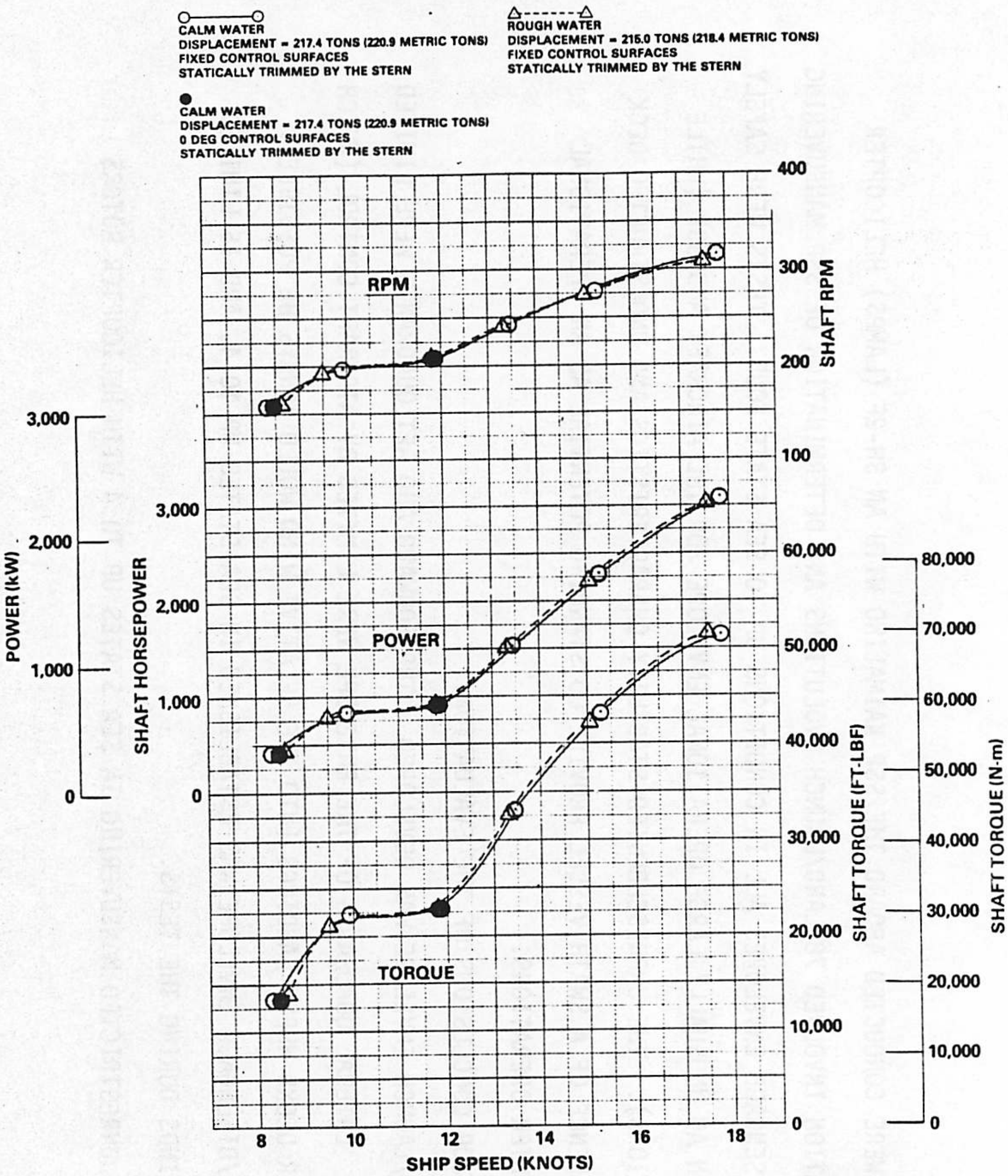


Figure 6 - Comparison of Rough and Calm Water Standardization Trial Results

Ref: Woo and Mauck, "Standardization Trials of the SSP with a Modified Buoyancy Configuration", DTNSRDC Report 80/049, April 1980.

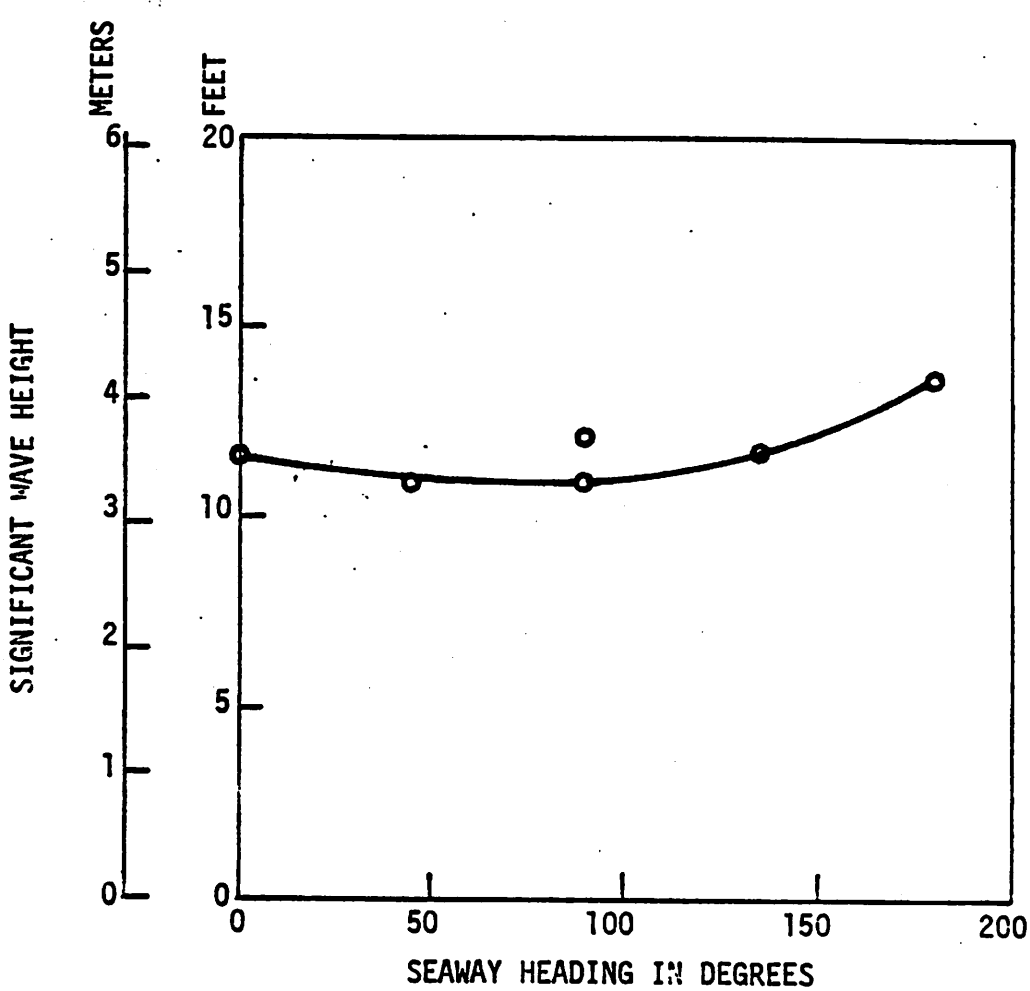


Figure 3 - Variation of Significant Wave Height with Seaway Heading for the Series of Seakeeping Runs at a Nominal Speed of 5 Knots.

Ref: Fein, "Low Speed Seakeeping Trials of the SSP", DTNSRDC Report SPD-0650-04, March 1978.

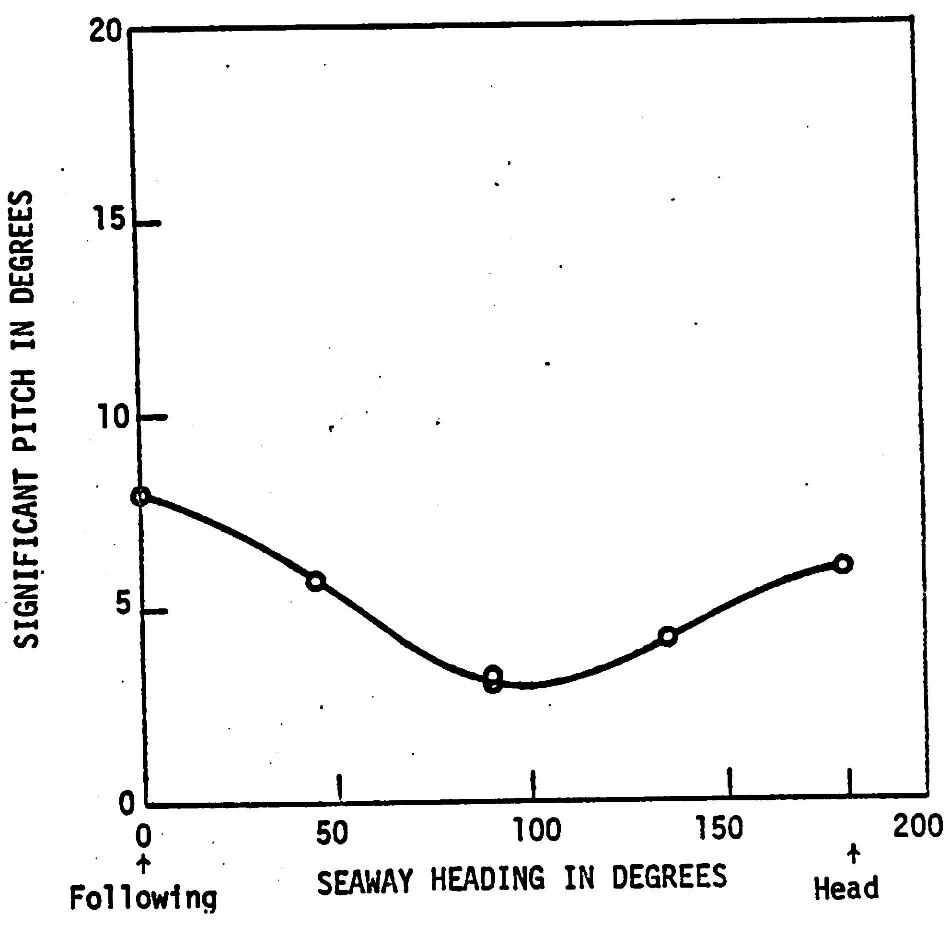


Figure 4 - Variation of Significant Pitch Double Amplitudes with Seaway Heading for the Series of Seakeeping Runs at a Nominal Speed of 5 Knots.

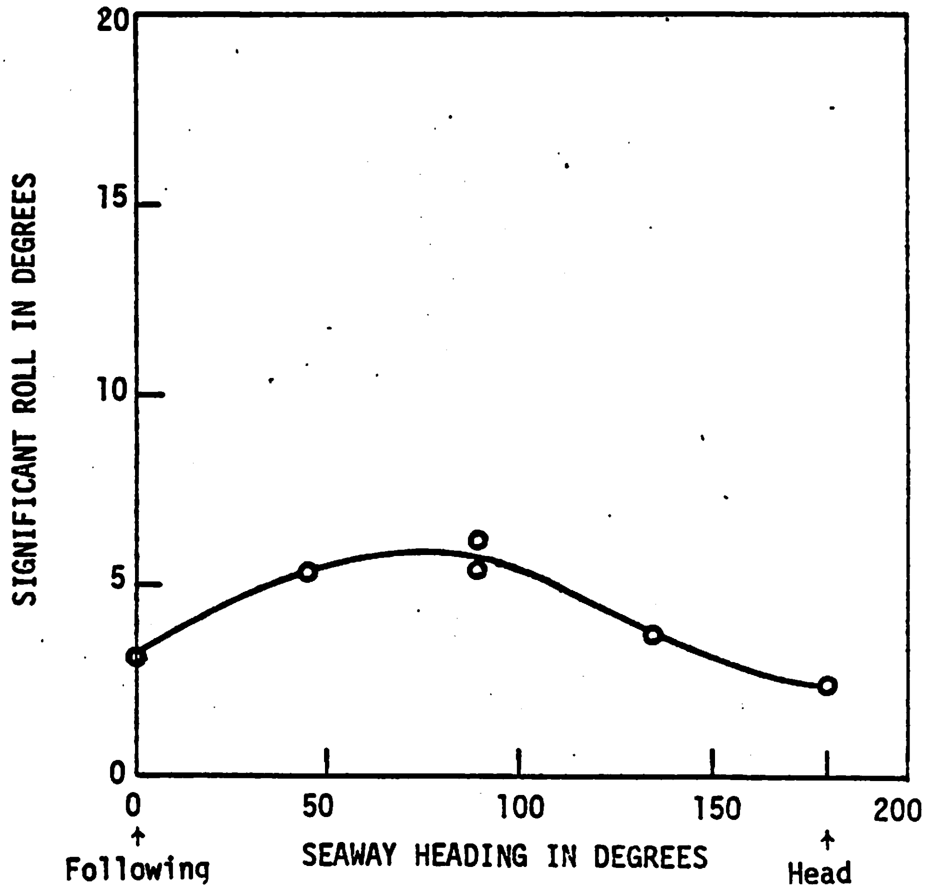


Figure 5 - Variation of Significant Roll Double Amplitudes with Seaway Heading for the Series of Seakeeping Runs at a Nominal Speed of 5 Knots.

4. MOTIONS RESULTS FOR SSP KAIMALINO

The results of seakeeping experiments are describable in several ways. One is in the form of the ratio of significant responses to significant wave height. A significant value is the average of the one-third highest values and may be obtained from a time history of the motions or wave excursions. Another method of analysis is the power spectral density distribution which relates the energy of the motion or wave to the frequency. SSP KAIMALINO full scale trials spectral data are presented in the next section. A third method of analysis used in Section 6.3 involves the transfer functions. The transfer functions provide the unit response of a motion to a unit wave height throughout the frequency range.

The ratios of significant responses to significant wave height are presented in Figures 4 to 13 for the model and full scale ship. The data were obtained in Sea States 4 and 5. The wave spectra for the model experiments were different from those in the full scale trials. The effect of control at high speed is also included for pitch and roll in Figures 10 through 13.

Figures 4 through 7 show the effect of speed on free body motions without any form of control in head seas. The results show linearity throughout the wave height range examined. Correlation between model and full scale is good for pitch throughout the speed range. The model results were obtained from the 1971 and 1973 experiments. From a maximum at zero speed, pitch decreases to a minimum at 10 knots, then peaks at about 14 knots. Between 10 and 14 knots the wave drag hump occurs. At 10 knots the ship is "climbing" its self-generated bow wave and thus it is heavily damped in pitch. At 14 knots the ship-generated wave is behind the ship and may act in a destabilizing manner. Trial conditions after the addition of the buoyancy blisters are indicated by solid points. The data with buoyancy blisters show good agreement with the earlier data which indicates that the blisters, which are centered at the longitudinal CG, have little effect on pitch motion.

Figure 5 presents roll in head seas. The model experiments which were conducted in a unidirectional head sea show minimal roll motion while the full scale trial results show significant roll. This may be attributed to the fact that wave components are present in the real environment from other than the direction of the predominant energy. The vertical acceleration in Figure 6 remains relatively constant with speed, slightly increasing at the higher speeds. The ratio of significant relative bow motion to significant wave height in Figure 7 shows almost no speed effect. Except for a single point near 16 knots, the model data agree quite well with the full scale results.

Figures 8 and 9 show speed dependence of the pitch and roll motions in beam seas. Pitch in beam seas at speeds below 5 knots is slightly higher for the full scale trials than for the model results. The difference is probably due to uncertainties in heading and wave direction, but even so the model data do show the presence of pitch in beam seas. The pitch is probably due to the fore and aft asymmetry of the ship. The large aft foil excites pitch as the ship responds to the beam waves, and since there is no area forward to cancel this effect a net pitch motion ensues. The model roll motions agree quite well with the full scale over the speed range in Figure 9. Again the blisters seem to have little effect on significant roll. The peak in pitch and roll at about 14 knots is again present in beam seas. Roll follows the same trend with speed as pitch, decreasing to about 10 knots and then showing an increase in the wave drag hump regime.

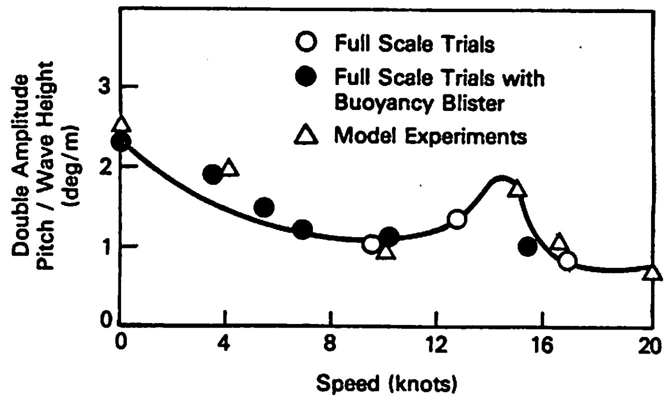


Fig. 4 Pitch Motion for SSP KAIMALINO in Head Seas

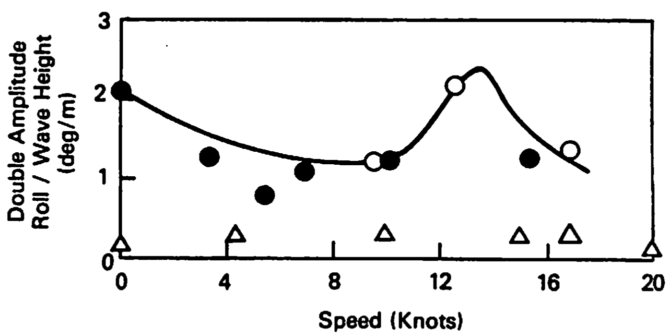


Fig. 5 Roll Motion for SSP KAIMALINO in Head Seas

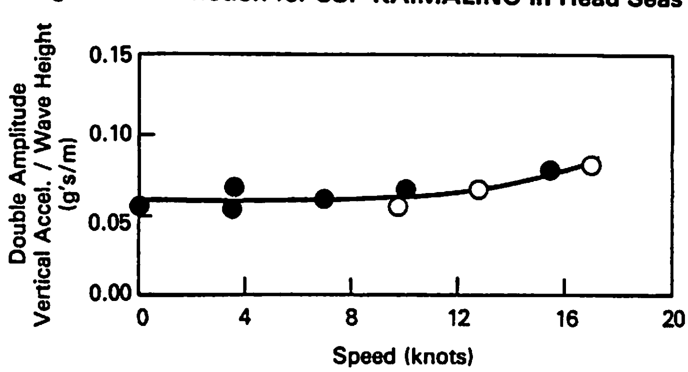


Fig. 6 Vertical Acceleration for SSP KAIMALINO in Head Seas

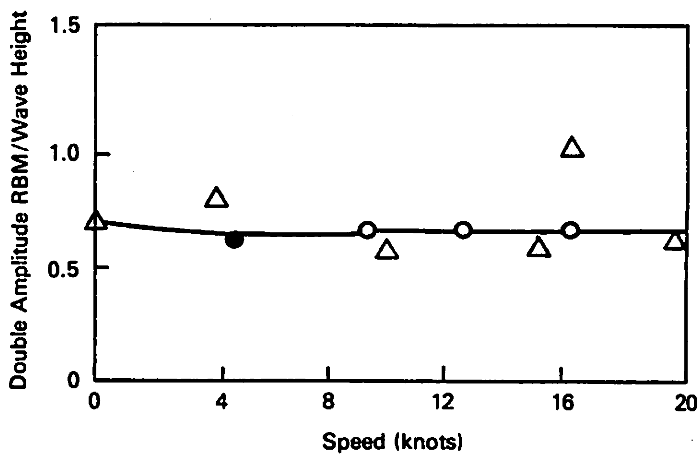


Fig. 7 Relative Bow Motion for SSP KAIMALINO in Head Seas

Ref: Fein, Ochi, McCreight, "The Seakeeping Characteristics of a Small Waterplane Area, Twin Hull (SWATH) Ship", Thirteenth Symposium on Naval Hydrodynamics, Paper V-4, ONR/NAS/SRAJ, Oct 6-10, 1980.

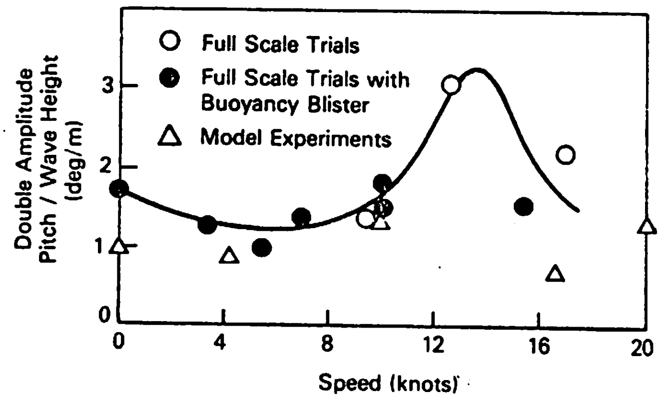


Fig. 8 Pitch Motion for SSP KAIMALINO in Beam Seas

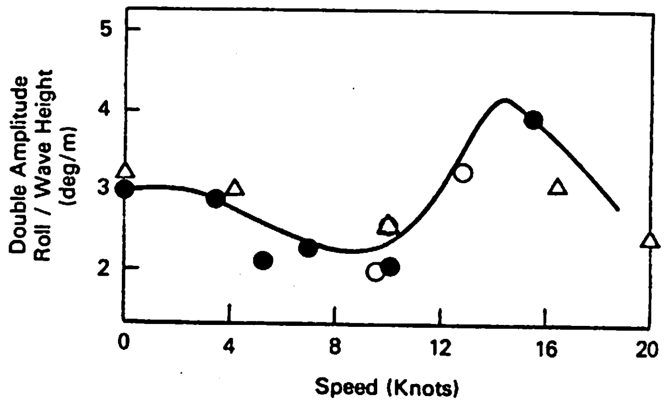


Fig. 9 Roll Motion for SSP KAIMALINO in Beam Seas

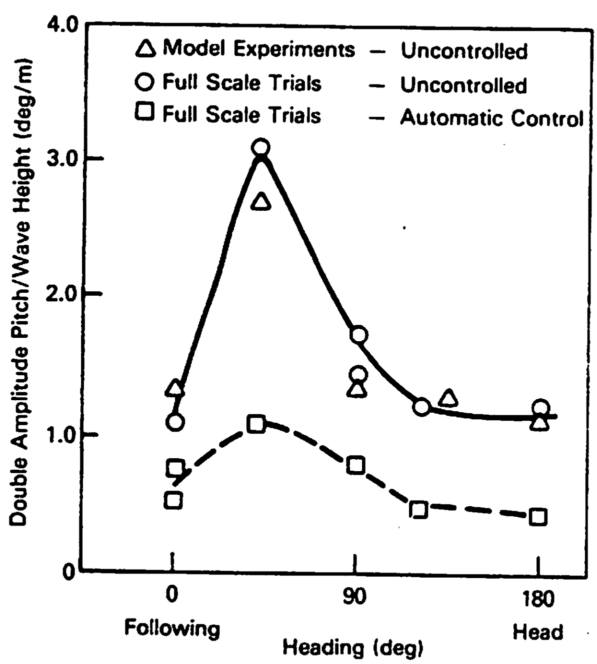


Fig. 10 Pitch Motion for SSP KAIMALINO at 10 Knots

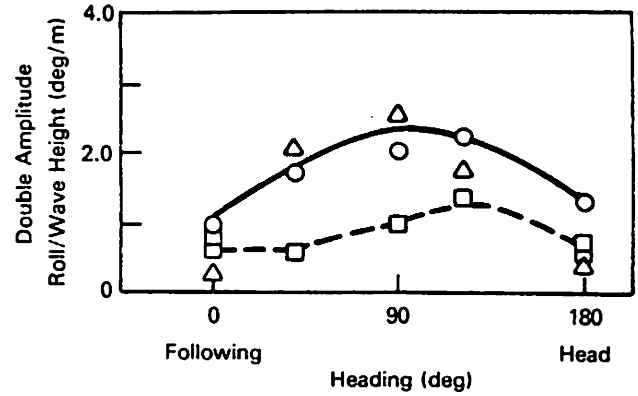


Fig. 11 Roll Motion for SSP KAIMALINO at 10 Knots

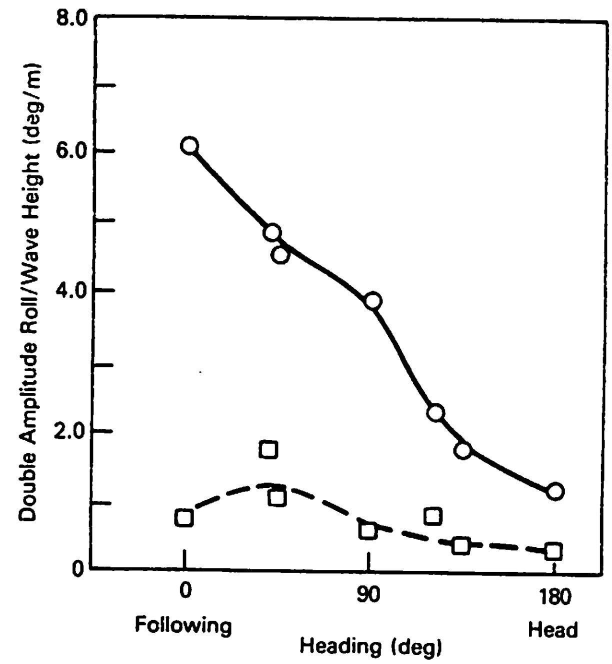


Fig. 13 Roll Motion for SSP KAIMALINO at 15.5 Knots

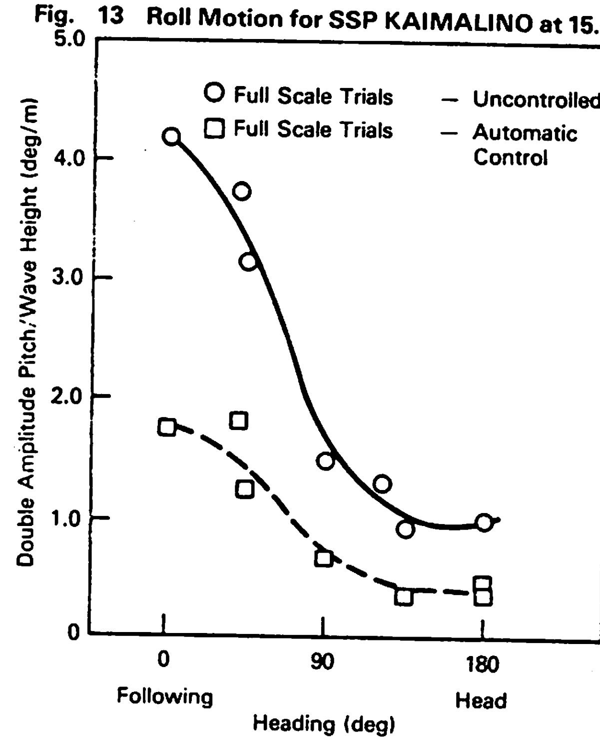
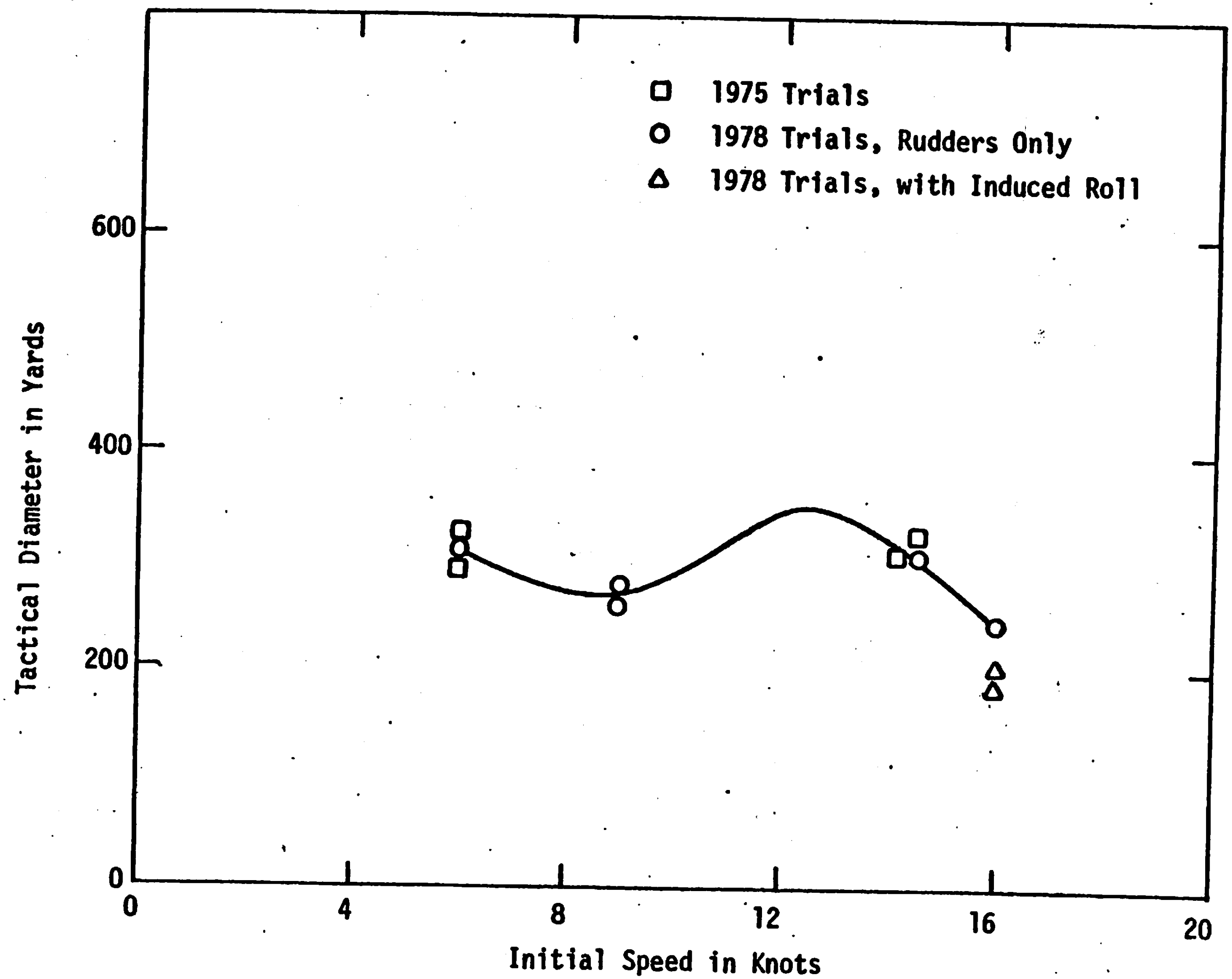


Fig. 12 Pitch Motion for SSP KAIMALINO at 15.5 Knots

Figure 1 - TURN DIAMETER VERSUS SPEED



Ref: Fein, "Turning Trials on SSP KAIMALINO During Feb 1978", DTNSRDC Report TM 15-78-91, Feb 1978.

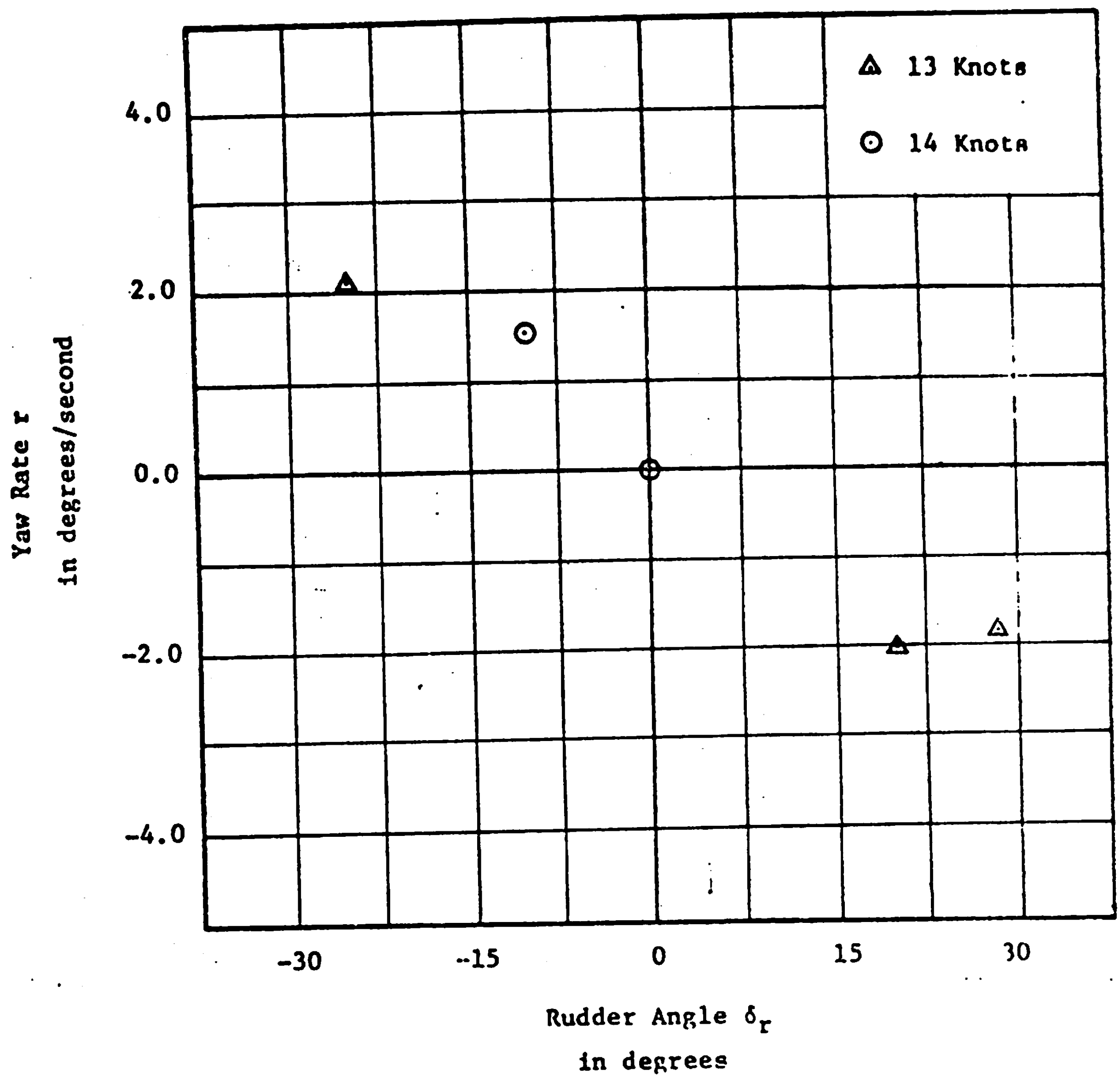


Figure 25 - Variation of Steady State Yaw Rate with Rudder Deflection at the Speeds of 13 and 14 Knots

Fein and Waters, "Control Response Trials of the SSP", DTNSRDC Report SPD 650-02, April 1976.

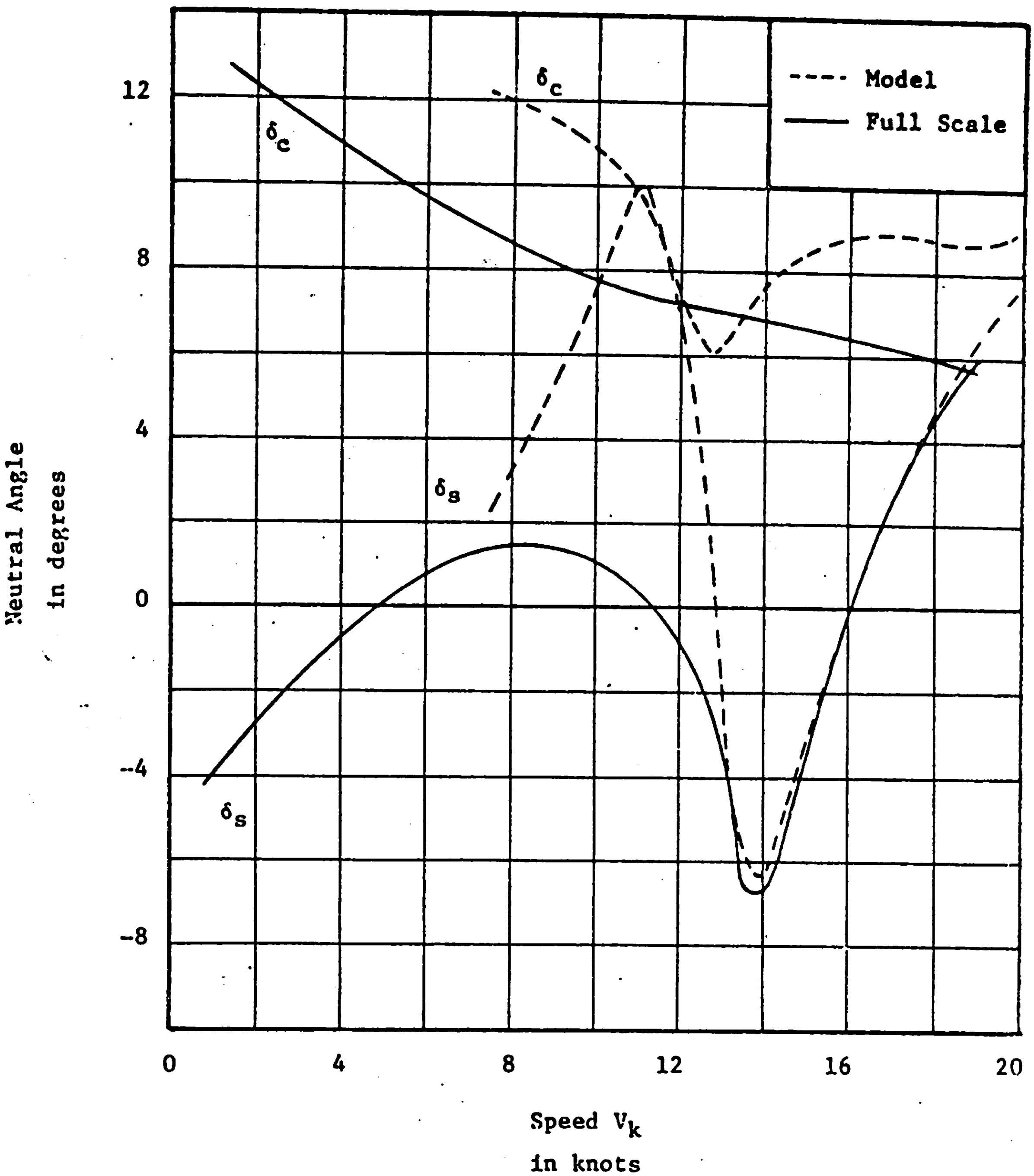


Figure 4 - Variation of Neutral Canard and Flap Angles for Level Trim with Speed Comparing Model and Full Scale Results

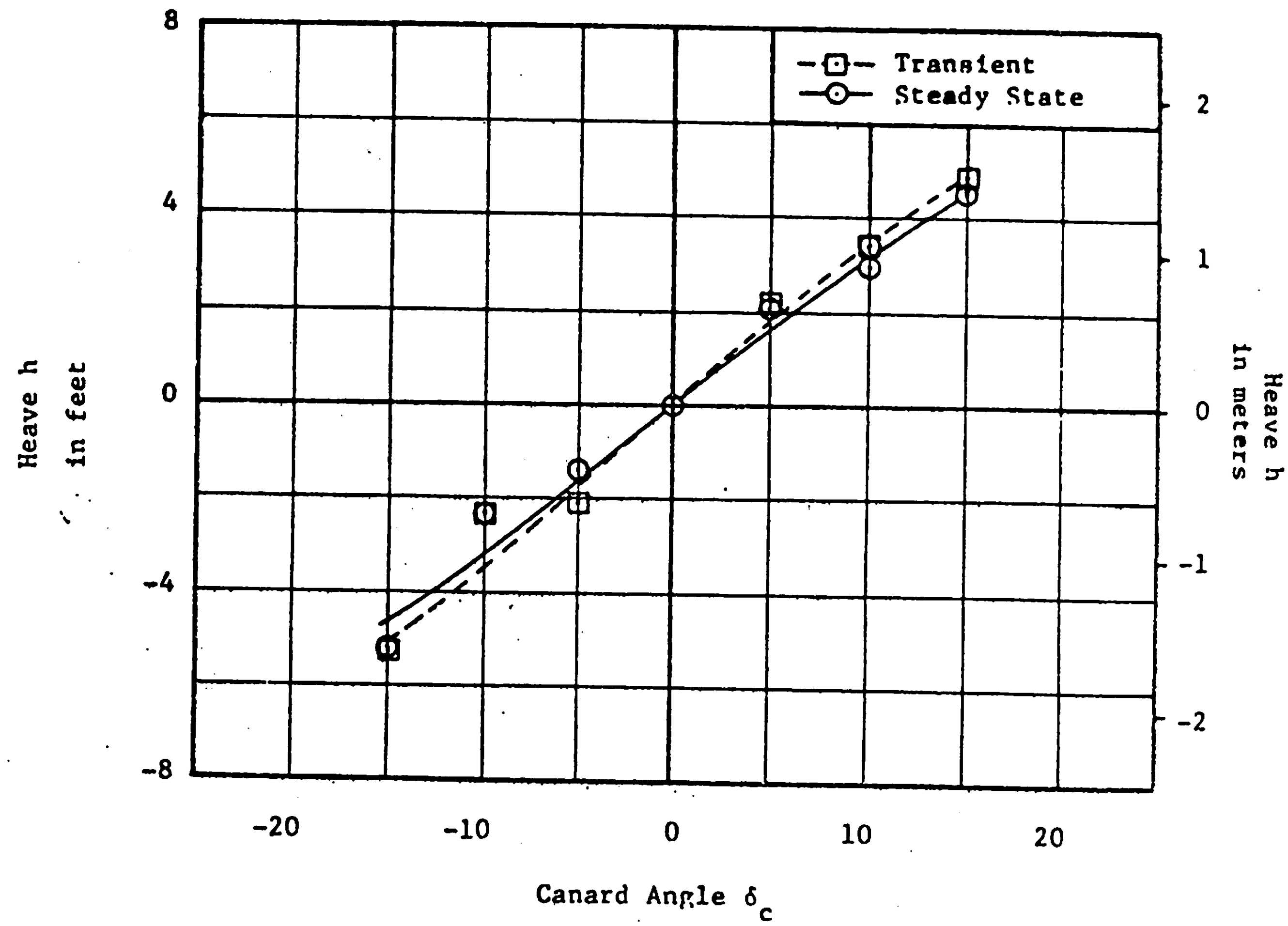


Figure 13 - Variation of Transient and Steady State Heave with Canard Deflection Angle at a Speed of 14 Knots

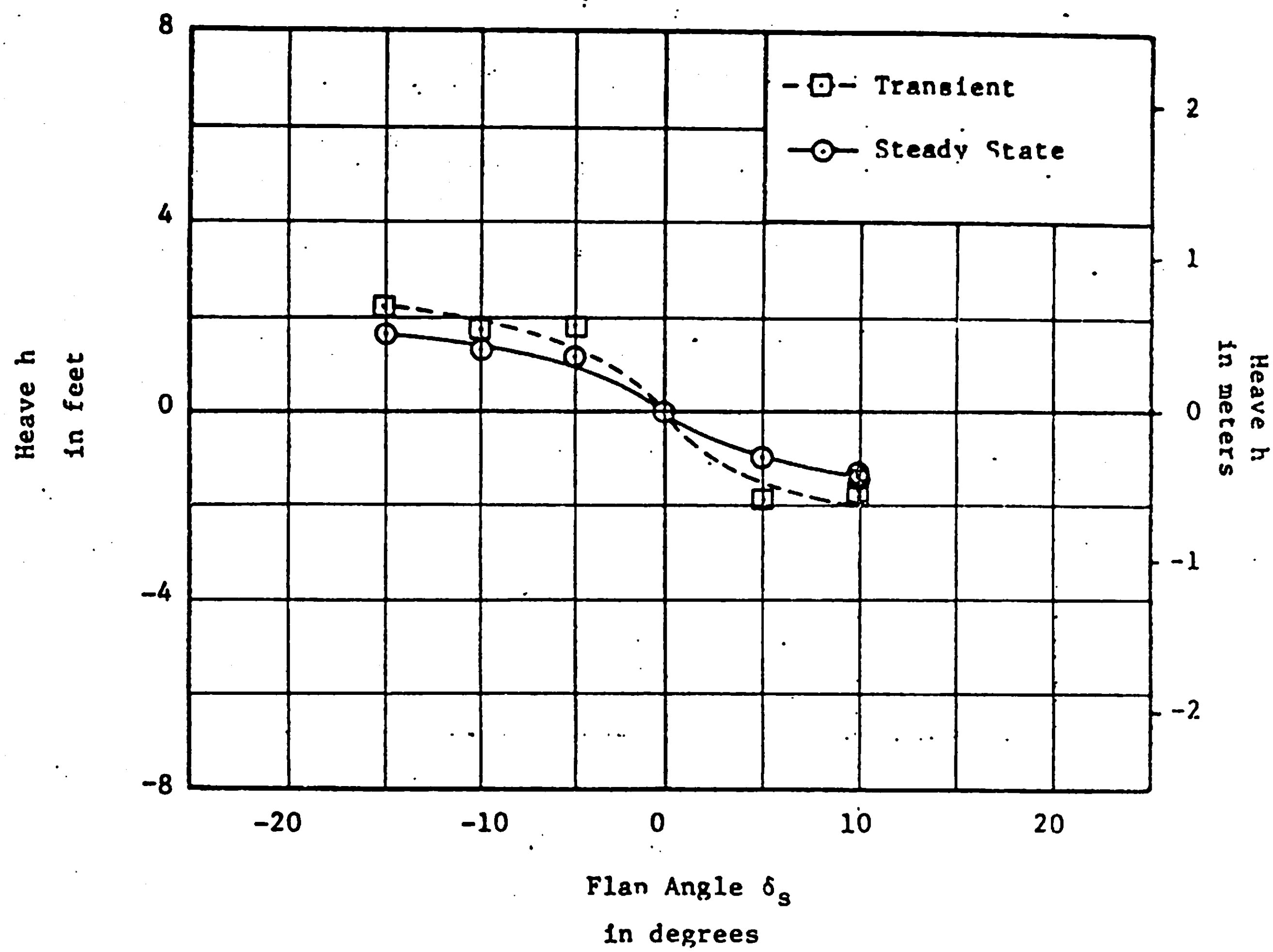


Figure 16 - Variation of Transient and Steady State Heave with Flap Deflection Angle at a Speed of 14 Knots

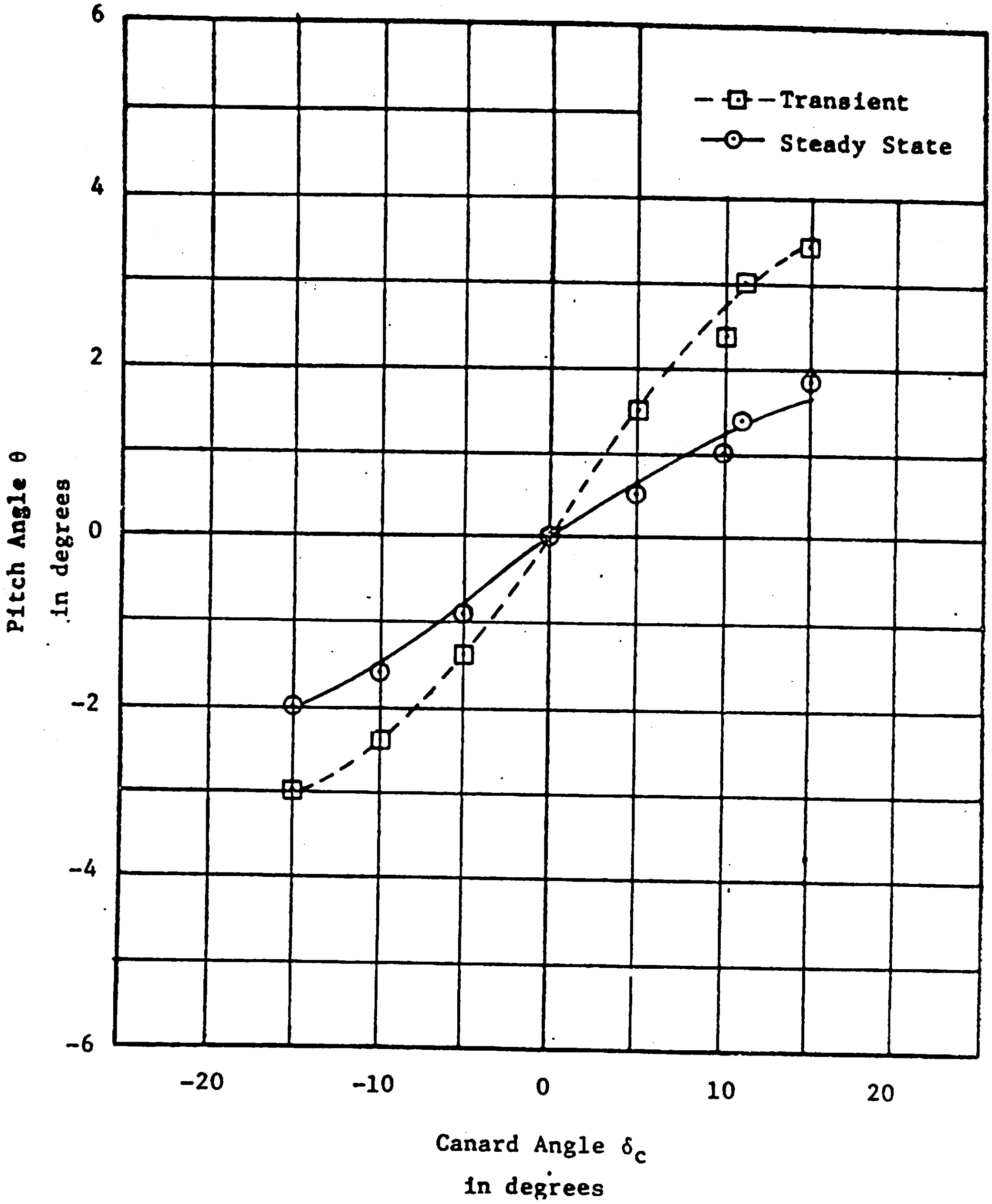


Figure 6 - Variation of Transient and Steady State Pitch Angle with Canard Deflection Angle at a Speed of 14 Knots

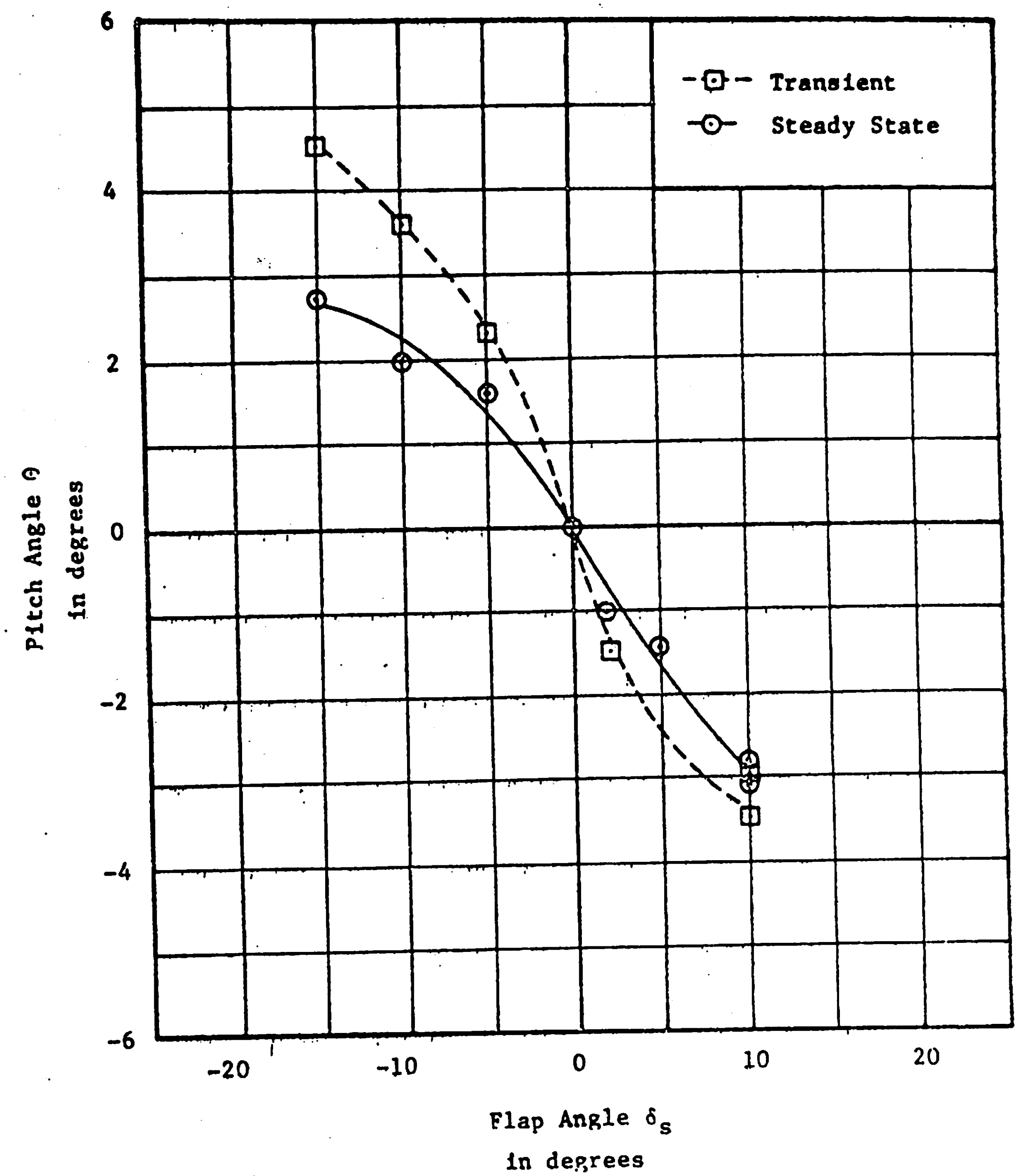


Figure 9 - Variation of Transient and Steady State Pitch Angle with Flap Deflection Angle at a Speed of 14 Knots

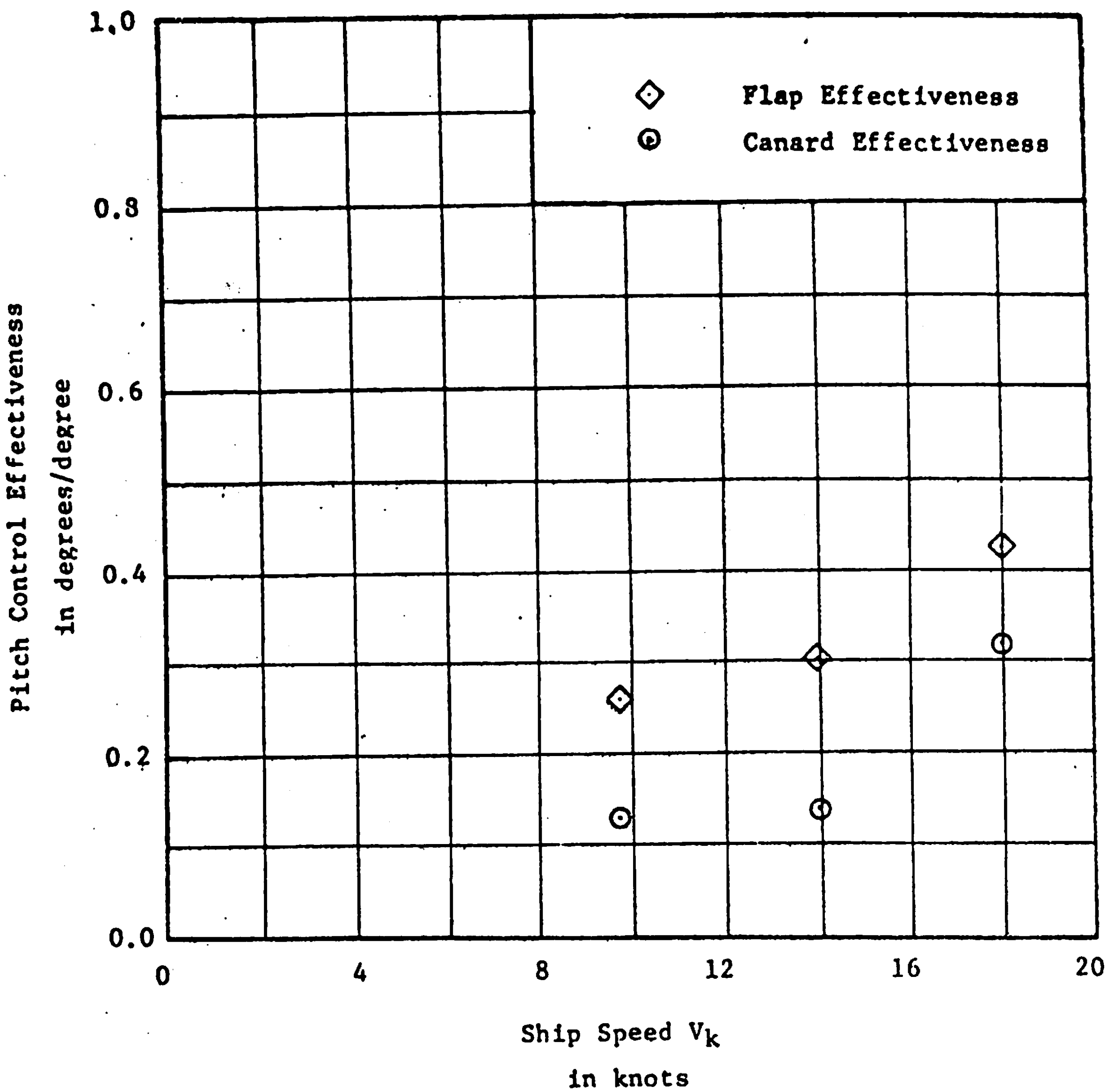


Figure 11 – Variation of the Absolute Value of Pitch Control Effectiveness with Speed for Canards and Flaps

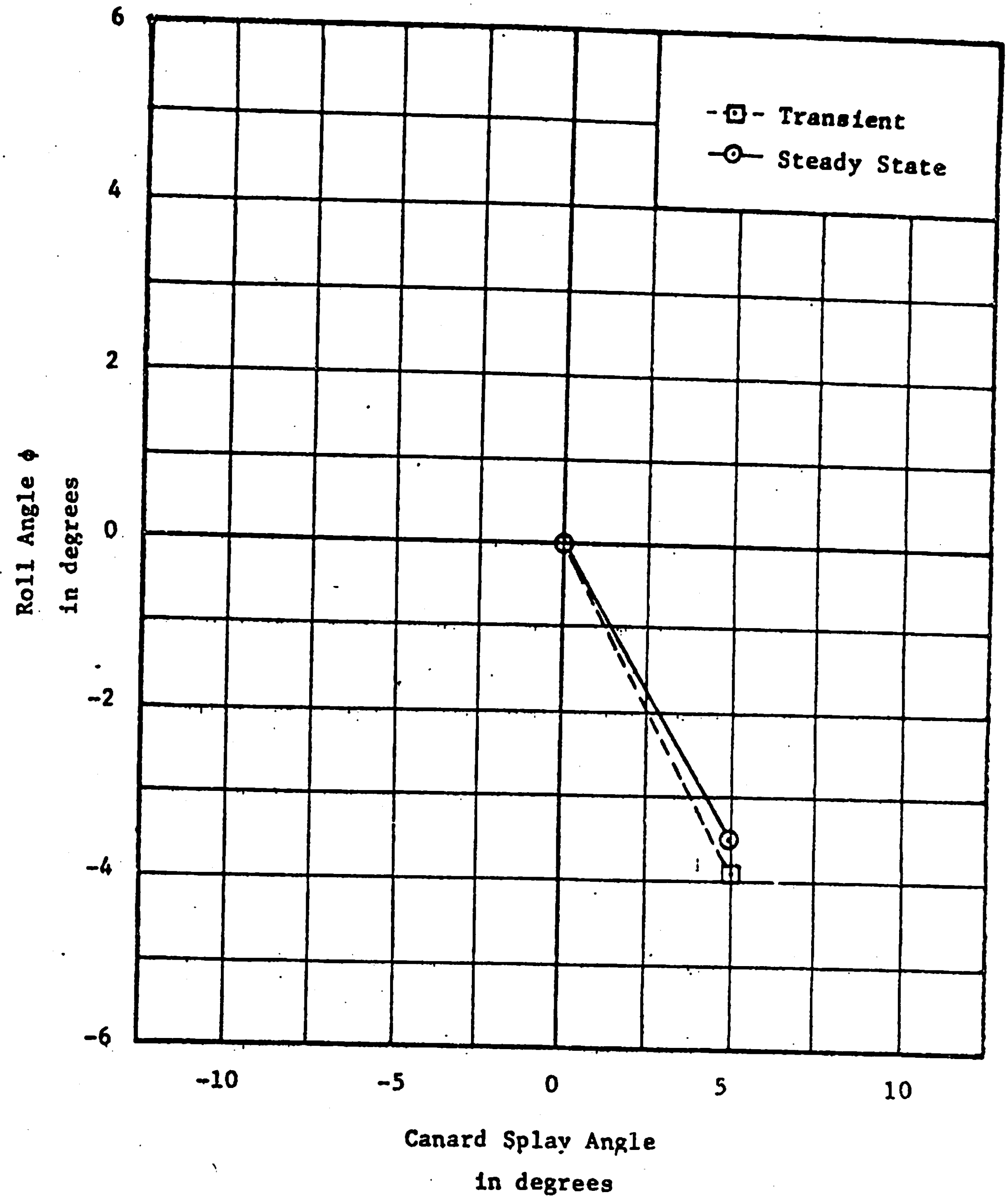


Figure 19 - Variation of Transient and Steady State Roll Angle with Canard Splay Angle at a Speed of 14 Knots

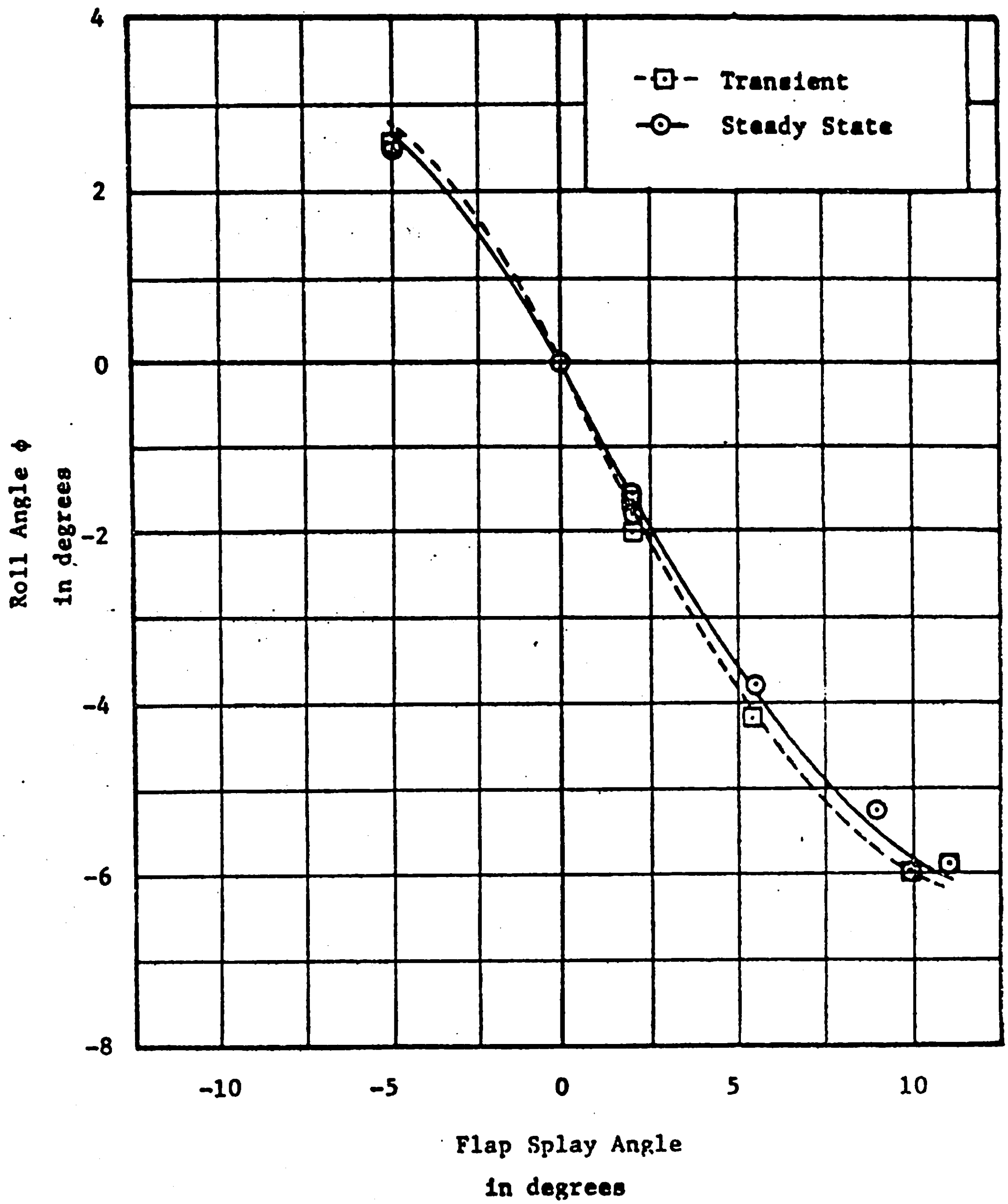


Figure 22 - Variation of Transient and Steady State Roll Angle with Flap Splay Angle at a Speed of 14 Knots

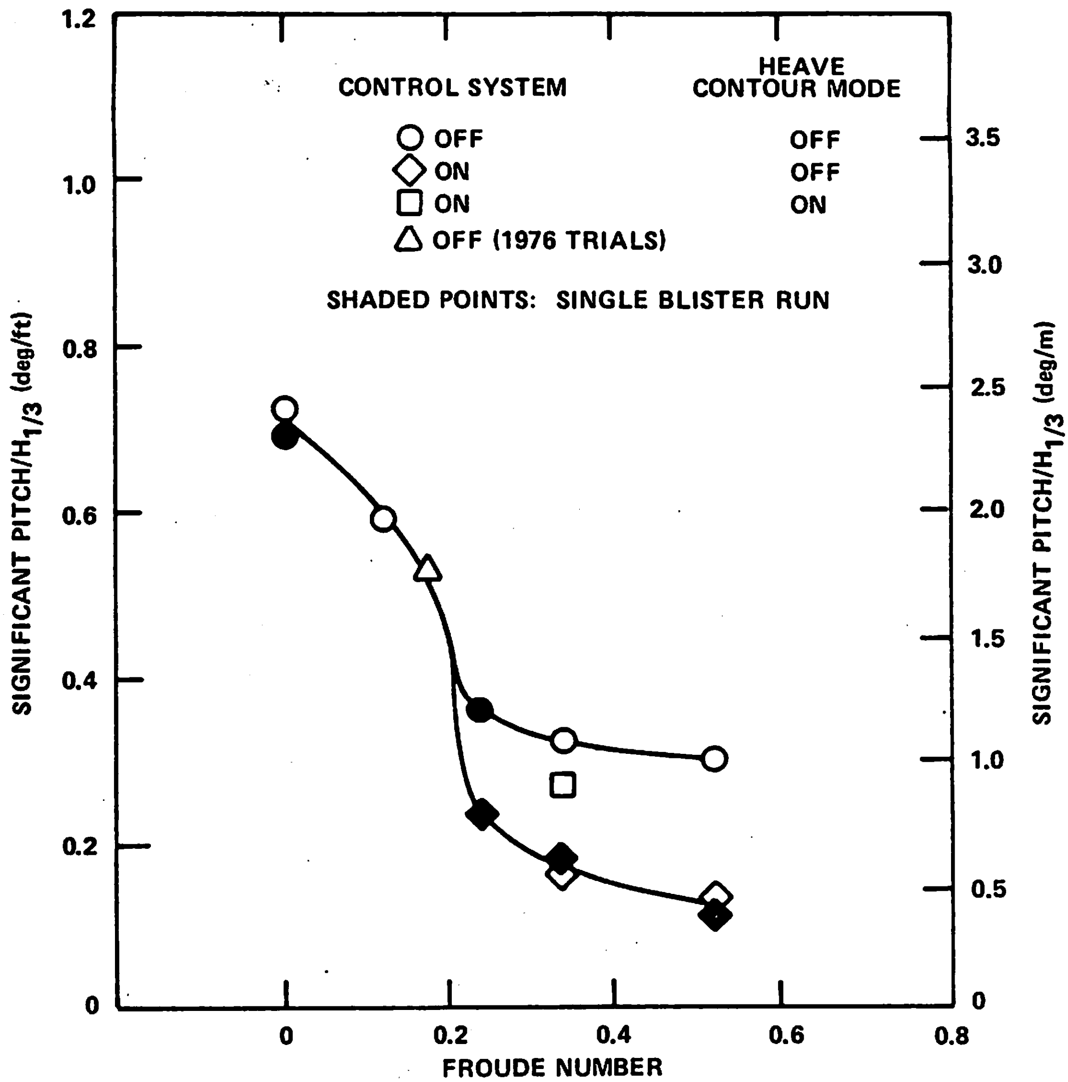


Figure 3 - Variation of Significant Pitch/Significant Wave Height with Froude Number for 1979 and 1976 Trials of the SSP KAIMALINO in Head Seas

Ref: Fein, "Seakeeping and Motion Control Trials of SSP KAIMALINO in Sea States 4 and 5", DTNSRDC Report 81/015, Feb 1981.

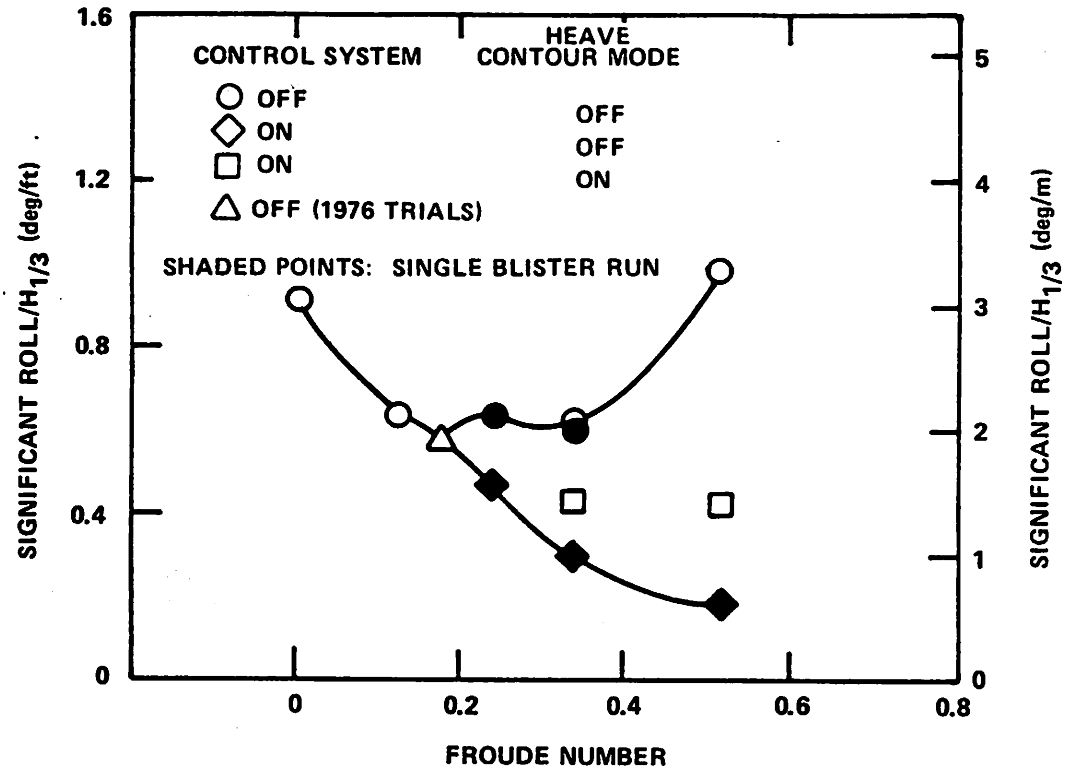


Figure 14 - Variation of Significant Roll/Significant Wave Height with Froude Number for 1979 and 1976 Trials of SSP KAIMALINO in Beam Seas

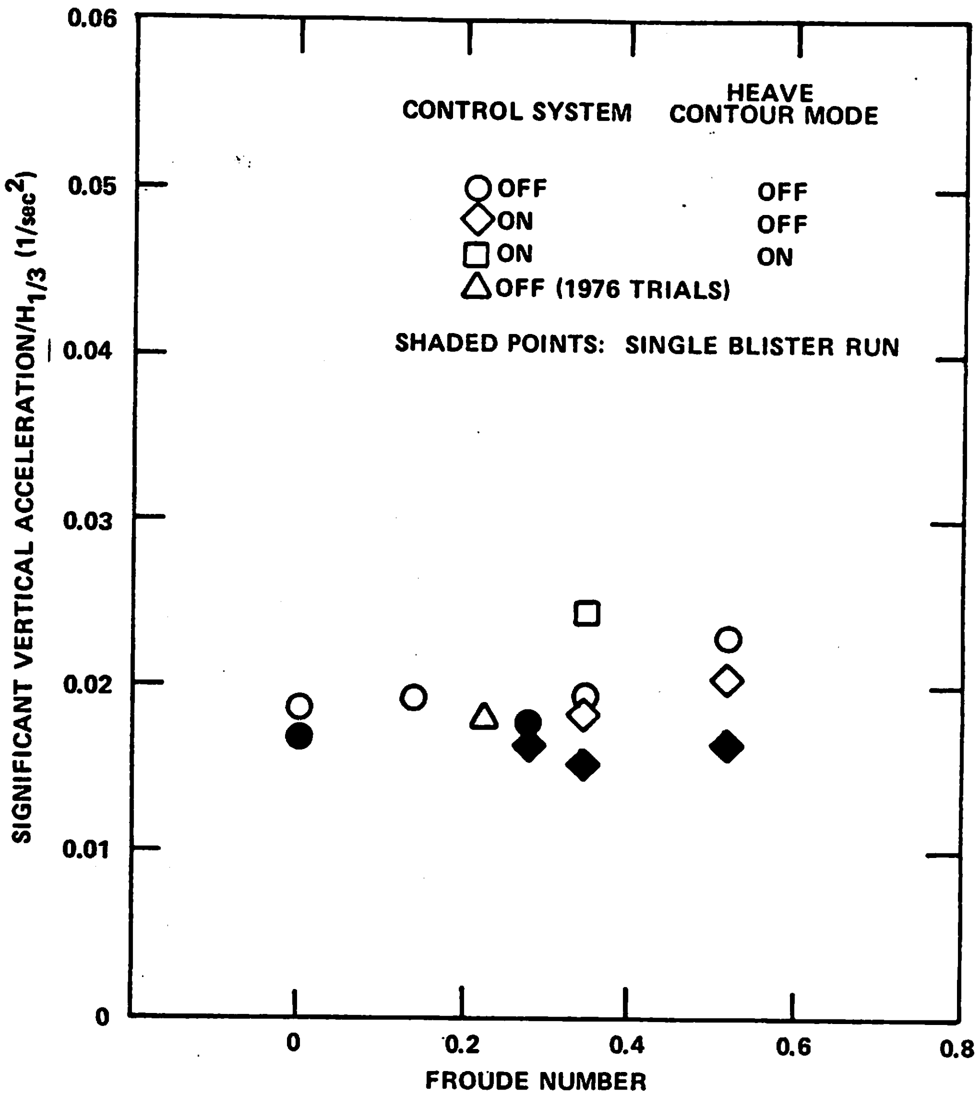


Figure 5 - Variation of Significant Vertical Acceleration/Significant Wave Height with Froude Number for 1979 and 1976 Trials of SSP KAIMALINO in Head Seas

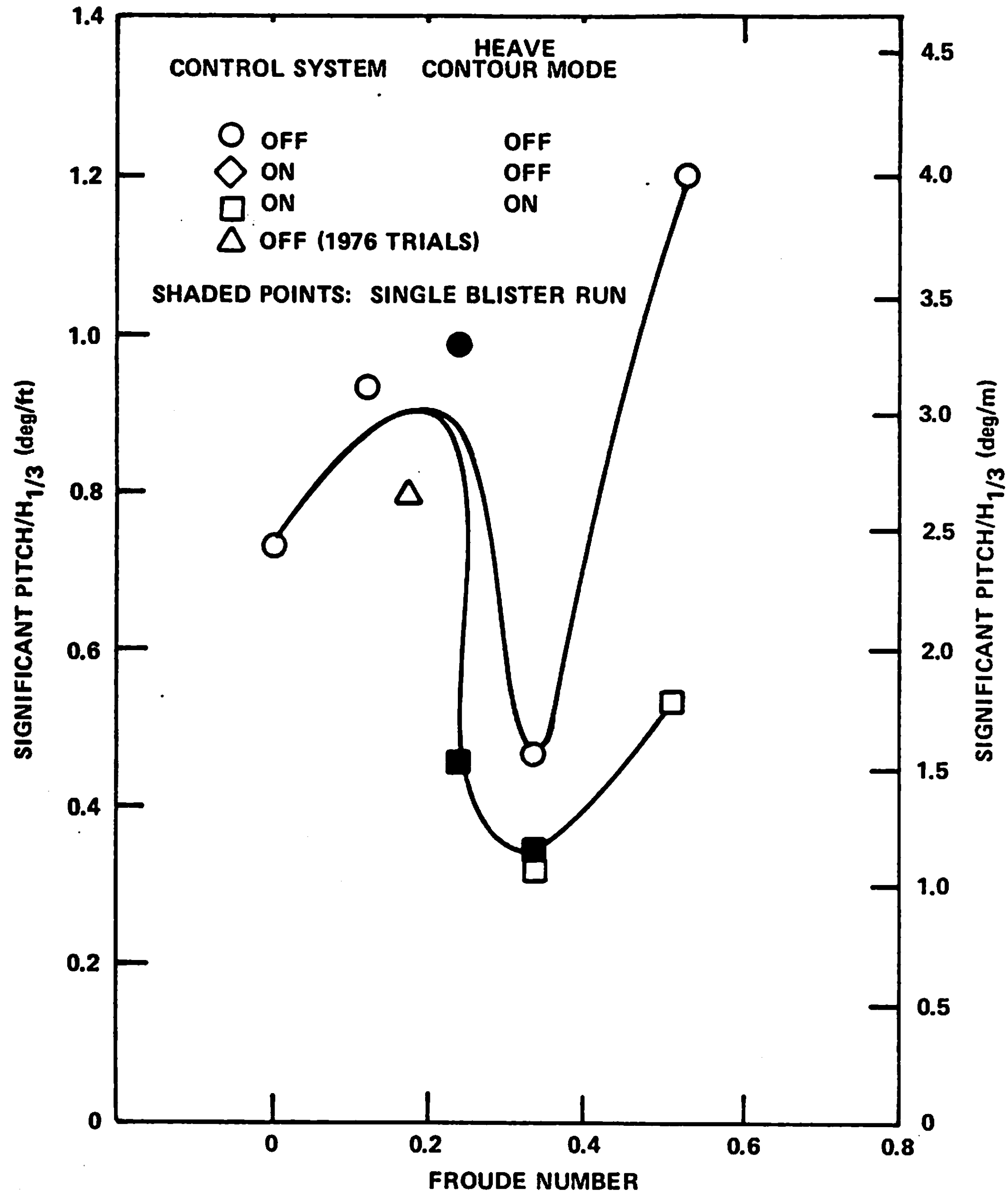


Figure 19 - Variation of Significant Pitch/Significant Wave Height with Froude Number for 1979 and 1976 Trials of SSP KAIMALINO in Following Seas

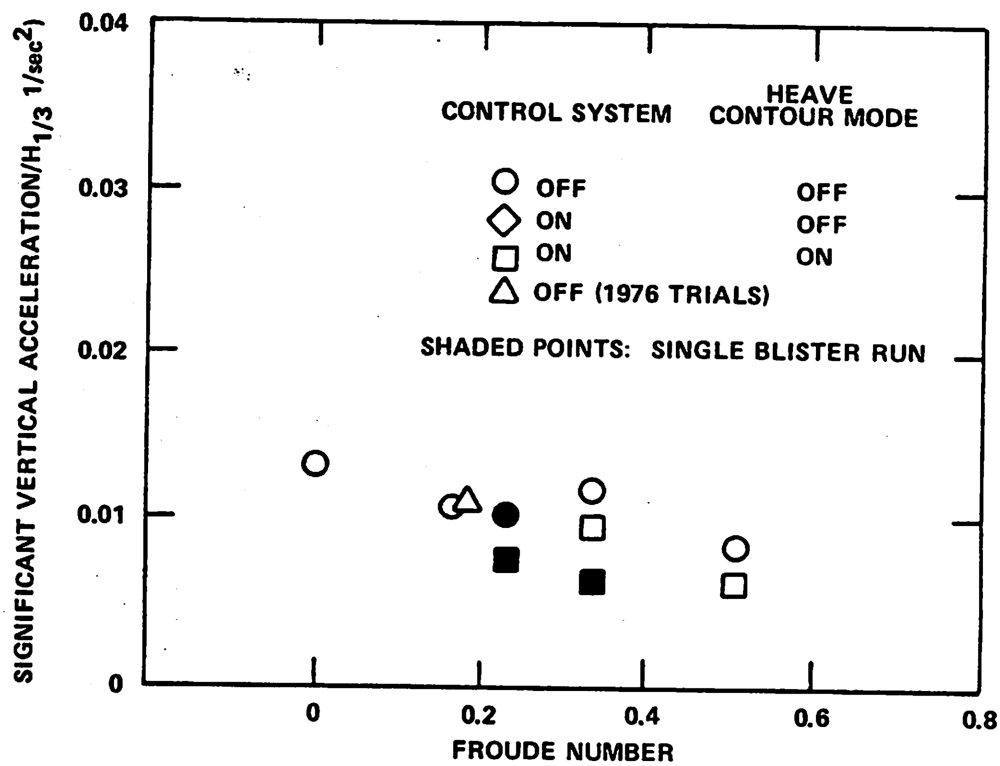


Figure 21 - Variation of Significant Vertical Acceleration/Significant Wave Height with Froude Number for 1979 and 1976 Trials of SSP KAIMALINO in Following Seas

SEAKEEPING AND MOTION CONTROL TRIALS OF SSP KAIMALINO IN SEA STATES 4 AND 5

by

James A. Fein

CONCLUSIONS

1. The control system of SSP KAIMALINO is capable of reducing motion significantly at all headings. In head, bow, and beam seas, a normal control mode which minimized pitch and roll motions is utilized. In stern quartering and following seas, the normal mode is used in conjunction with a control mode that contours the waves by inducing heave to maintain a constant height over the waves. This combination of controls helps prevent propeller broaching in long encounter period conditions. Motions can be appreciably reduced at speeds of 7 knots (Froude Number of 0.24) and above. The current analog control system with fixed gains appears adequate for the SSP, although motion characteristics and control effectiveness do vary with speed.

2. The blisters mounted on the SSP lower hulls to increase displacement do not have a significant influence on SSP KAIMALINO pitch and roll motions. The absence of one blister did not significantly affect the magnitude of the responses or the trends for pitch and roll, although heave motion was affected in bow seas.

3. Slamming did not occur in bow, beam, stern quartering, or following seas either with or without control. In head seas, impacts at high speed without automatic control were effectively eliminated by dynamically trimming the ship bow up by manual control surface deflections. This lack of slamming is significant, because in Sea State 5, the wave heights were large compared to the bridging structure clearance of the ship which was 1.8 m.

4. The SSP did not exhibit any problems in a Sea State 5 nor any conditions that required slowing down or changing heading (except inability to maintain a stern quartering heading at zero speed). Motion characteristics even without control did not induce discomfort or difficulties for the crew.

Ref: Narita, Mabuchi, Kunitake, Nakamura, Matsushima, "Design and Full Scale Test Results of Semi-Submerged Catamaran (SSC) Vessels", IM SDC 82 Conference, London, Paper No. 11, April 22-24, 1982

calculations using a computer program and conducting model tests, and its superior characteristics in the design wave conditions made it possible to adopt a fin stabilizer system which is not automatically but manually operated.

2.4 Full Scale Trial Results

Extensive full scale trials were conducted using these SSCs to investigate powering, seakeeping, maneuvering, structural loads, and fin control response. A comparative trial with conventional monohulls was also carried out by side-by-side running tests in waves. Some typical test results are presented here in order to show the SSC's performance.

To check the seakeeping characteristics of the SSC including fin control and deck impact, extensive seakeeping tests on the 'SEAGULL' were carried out in the sea near Oshima island and off Nojimazaki as shown in Fig. 5, changing the ship's speed and ship's heading to the waves. During these test periods, waves of 2.6 meters significant height were measured by a wave-rider buoy and also a wave height of about 3 meters in significant value was visually observed in another test.

Fig. 7 shows the significant values of the measured pitch and roll motions and vertical accelerations in waves corresponding to Sea State 4 with a 2.4 meter significant wave height at ship's speed of 24 knots. The fins were automatically controlled during these tests.

The significant value of the vertical acceleration was less than 0.1 G and the significant pitch and roll motions were less than

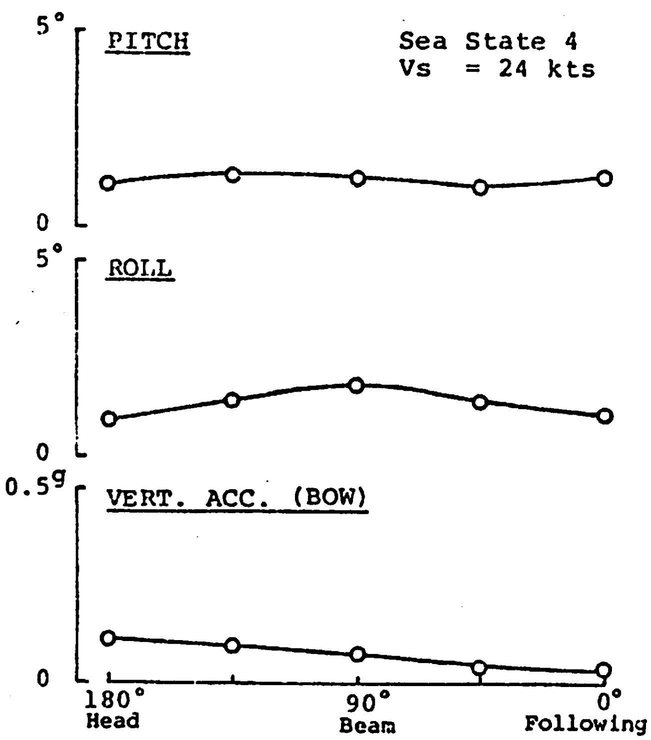


Fig. 7. Pitch, Roll Motions and Vertical Accelerations for 'SEAGULL'

Sea State
board is
vertical
of ship
motions, in fact, the acceptable level of vertical acceleration for passengers' comfort is considered to be less than about 0.2 G.

The above results demonstrated that the 'SEAGULL' could be operated at her service speed in wave conditions up to Sea State 5 (significant wave height from 2.5 meters to 4 meters), providing a smooth and stable ride and real comfort for her passengers in spite of her small size measuring only 31.5 meters in length.

In April 1980, side-by-side running tests with four different monohulls were carried out in wave conditions of Sea State 3 to 4 in order to directly compare the seakeeping performance of the SSC with these monohulls. Ship's motions were observed both on board and from a helicopter and especially pitch, roll motions and vertical acceleration at the bow were measured at a ship's speed of 24 knots both on the 'SEAGULL' and one of the high speed monohull vessels with a length of 35 meters.

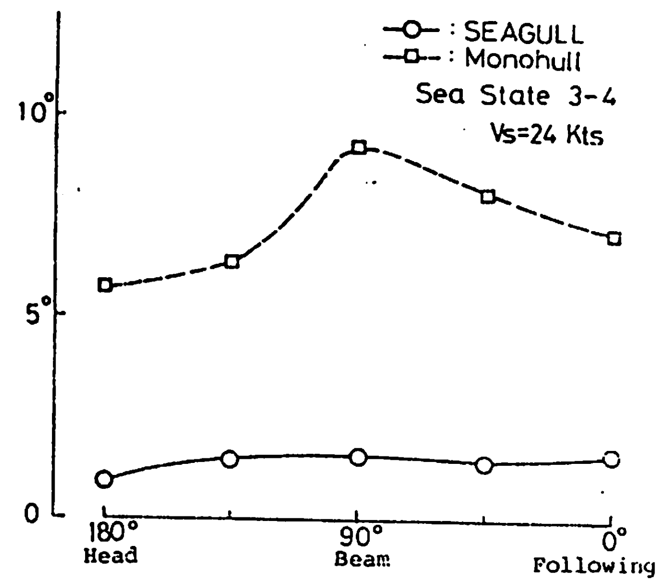


Fig. 8. Comparison of Roll Motion between 'SEAGULL' and Monohull Ship

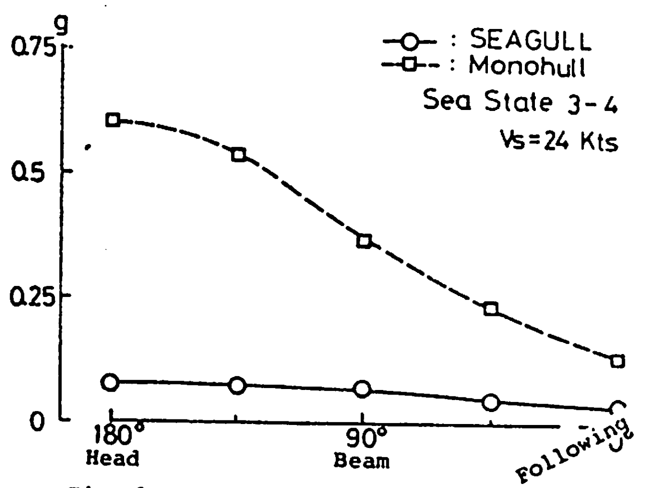


Fig. 9. Comparison of Vertical Acceleration at the Bow between 'SEAGULL' and Monohull Ship

As can be seen in Fig. 8, the significant roll angle of the 'SEAGULL' is less than about 1.5 degrees for all headings while that of the monohull is about 9 degrees in a beam sea condition. Also the superiority of the 'SEAGULL' in seaworthiness is clearly demonstrated in the results of the measured vertical accelerations shown in Fig. 10. The measured accelerations of the 'SEAGULL' are less than 0.1 G for all headings while that of the monohull is about 0.6 G in a head sea condition. Consequently during the tests on all headings the 'SEAGULL' experienced about 1/4 to 1/6 the roll angles and about 1/3 to 1/7 the vertical accelerations at the bow compared with the monohull Motion sickness and a reduction in job performance efficiency were also experienced by several crew members and by the measurement staff on board the high speed monohull, while no person felt motion sickness on the 'SEAGULL'.

The speed trials were conducted using the mile-post in Tokyo Bay, changing the ship's draft, trim and engine loads. The maximum recorded speed at the design draft was 27.1 knots. Speed in different sea conditions were measured at a deeper draft of 3.65 meters by means of an electromagnetic type log. The measured average speeds at service power in waves are shown in Fig. 10 as a function of the Sea State. As a result, the speed loss of the 'SEAGULL' was less than 2 percent in a high Sea State 4. These results have proved that the SSC can maintain a service speed even in rough sea in addition to its superior comfortable ride at high speed.

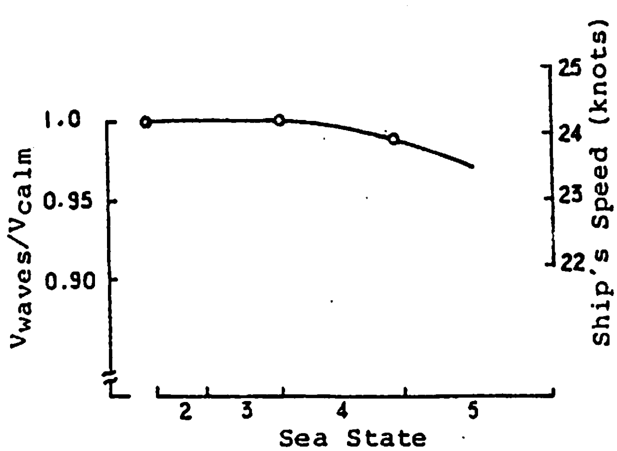


Fig. 10. Speed Loss in Waves for 'SEAGULL'

In the field of maneuverability, turning tests, spiral tests, zig-zag maneuvering tests, new course tests, stopping tests, crash stop and astern tests and on-the-spot turning tests were conducted. Through these tests, the 'SEAGULL' demonstrated her easy maneuver with not only immediate response to the rudder and a good course keeping capability at moderate to high speed, but also positive control by the differential thrust of each propeller at low speed and easy turn on the spot by contraturning of the port and starboard propellers.

3. TECHNOLOGICAL BACKGROUND OF SSC DESIGN

In designing an SSC, there exists more freedom than with a conventional monohull, and as a consequence a wide range of performance requirements can be very satisfactorily fulfilled by choosing an appropriate design.

Although the design technology established for conventional ships is mostly applicable to design of the SSC, it is extremely important to understand the inherent design characteristics of the SSC. In particular, all aspects of performance are sensitively affected by a small variation in the value of any one design parameter, and therefore a careful overall optimization process is always required in designing a high performance SSC. In order to design a commercially acceptable economical SSC with high performance, not only the hydrodynamic performance, but also structural strength, propulsion system, safety and operational capability etc. have to be carefully studied, together with the cost, for overall design optimization.

In this chapter, several technological bases for SSC design such as resistance and propulsion, motion and control, maneuverability, trim and stability, structural design and power transmission system are briefly presented.

3.1 Resistance and Propulsion

Although the SSC has a high performance in waves with regard to motion and the ability to maintain speed, the required power for the design speed in calm water needs to be minimized in order to further enhance its operational economy and to extend the application area of the SSC. As an SSC has almost twice the wetted surface area of a monohull of equal displacement, it has nearly double the friction drag. Accordingly,

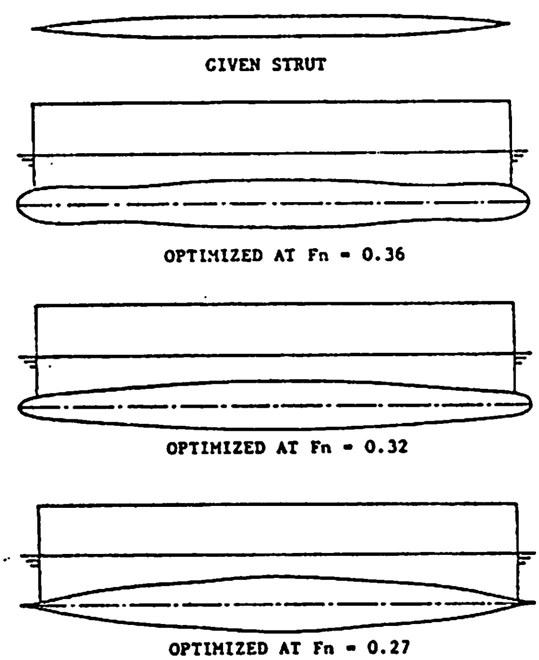


Fig. 11. Optimized Lowerhull with Given Strut for Different Speed

considerable attention must be paid to minimizing the residuary resistance, especially the wavemaking resistance as well as to attaining high propulsive efficiency.

The wave resistance of the SSC is calculated by a computer program based on the thin ship theory applying Michell's source distribution for struts and the line doublet distribution for lowerhulls. In this computer program, correction factors both in phase and magnitude are put into equations in order to predict wave resistance more accurately.(5) By using this prediction, a hull form with minimum wave resistance is calculated on the variatoinal principle. The optimized hull forms of the lowerhull under a given strut at Froude number 0.27, 0.32 and 0.36 respectively, are shown in Fig. 11.

At an initial design stage, it is of importance to understand the components of the wave resistance. Fig. 12 shows the breakdown of the wave resistance of a typical SSC designed at Froude number 0.7. In this figure, the wave resistance of the lowerhulls is the largest among other components because lowerhull submergence is limited by the water depth of the port. The magnitude of the wave resistance caused by interaction between struts and lowerhulls is nearly the same as that of the lowerhulls, while the port-starboard interference is almost negligible at design Froude number 0.7.

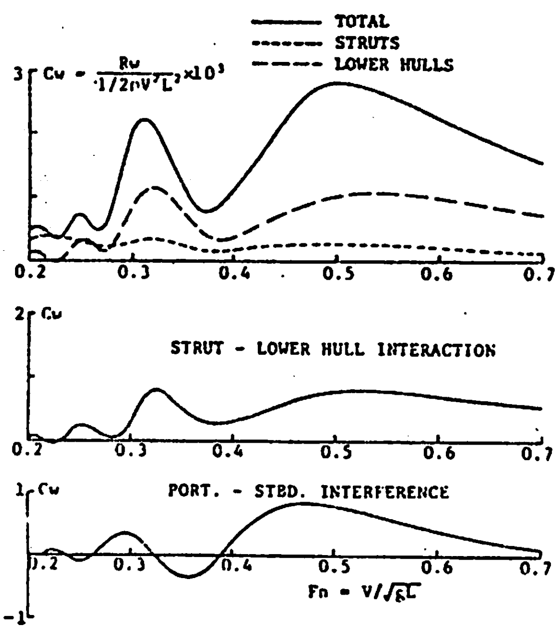


Fig. 12. Wave Resistance Components for SSC

The wave resistance of the hull element is greatly influenced by dimensions and proportions such as the lowerhull submergence to diameter ratio f/D, lowerhull length to diameter ratio L/D as can be seen in Fig. 13 and Fig. 14 respectively. In this way, the total wave resistance is made up of a complicated combination of resistances from all the components, so that an accurate theoretical prediction of the wave resistance is one of the most important tools for the design of the SSC.

Besides it is also of importance to know the effect of a hull form to propulsive efficiency in hull form optimization studies for the SSC. Self-propulsion factors of an SSC are greatly affected to the ratio of the propeller diameter to the lowerhull diameter as well as the fullness of the aft part of the lowerhull, due to relatively large propeller size to the hull as compared with a conventional ship. Generally, as the lowerhull becomes slender, the propulsive efficiency decreases while the wave resistance becomes smaller at high speed,and there may exist an optimum combination of propeller diameter and L/D ratio of the lowerhull which minimize the required power at the design speed. Therefore the hull form design have to be made considering both wave resistance and propulsive efficiency.

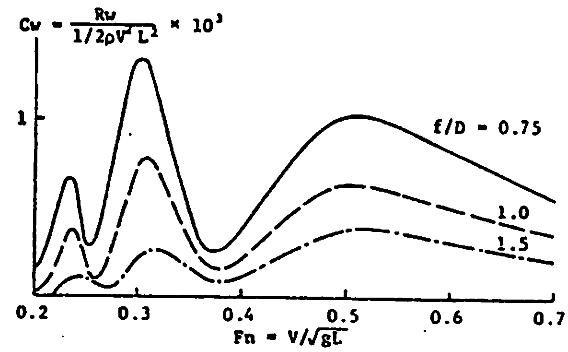


Fig. 13. Effect of Lowerhull Submergence on Wave Resistance of Lowerhull

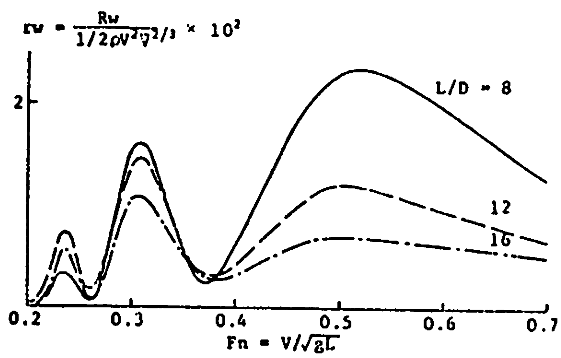


Fig. 14. Effect of Length to Diameter Ratio on Wave Resistance of Lowerhull

3.2 Motion and Control

In the initial design stage of the SSC, basic hull configuration and some design parameters such as the size of the waterplane area, etc. are determined, taking into consideration natural periods of motion in heave, pitch and roll and the interrelationships among these natural periods.

An SSC has essentially longer natural periods of motion than a conventional ship in addition to smaller wave exciting forces acting on the hull because of its unique configuration. Therefore the natural periods of motion which influence seakeeping peformance dominantly can be chosen long enough to avoid synchronous motions in mostly encountered waves. Furthermore, the trend and magnitude of the motion responses have to be obtained by model experiments or theoretical prediction, in order to predict not only the significant motion and acceleration amplitudes in the given wave conditions (which are useful for evaluating operational capability, work effectiveness, ride comfort, etc.), but also the maximum motion amplitudes during the life of the ship (which are necessary in deciding the structural strength and the adequate height of the upper deck clearance above the water's surface).

Typical pitch and heave motions for the SSC are shown below. Fig. 15 shows pitch and heave motion response functions for a typical twin strut configuration at Fn=0 in relation to the wave length to the ship length ratio λ/L. In these figures, pitch and heave resonances appear markedly at around 1.9 and 3.5 of λ/L respectively. A complicated motion coupling between pitch and heave is also seen on both response curves.

Motion response function at Fn=0.55 are shown in Fig. 16. At such a high speed, the lift of the fins generates large damping forces, so that the response functions of both motions with fins gradually increase with λ/L and tend to 1.0 of nondimensional pitch and heave. As can be seen in these figures, motion damping by the fins is effective in reducing resonant motions, especially at Fn=0.55.

In these figures, the motions including the effect of the fins are calculated by a computer program based on a strip theory. (6) Correlation of theory and model experiments shows fairly good agreement for both cases with and without fins at a wide range of speeds, as shown in Fig. 15.

This calculation program for motion and wave loads for the SSC was developed by Mitsui, taking into consideration the effect of the lift both of fins and main hulls. (7) (8)

The basic equation of motion is described as follows;

$$(M + A)\ddot{X} + B\dot{X} + CX = F + F_1 + F_f + F_c$$

Here X, $\dot{X}$, $\ddot{X}$ are linear and angular displacement, velocity and acceleration vector from its mean position respectively. M, A, B, C are Mass, added inertia, damping coeff. and restoring coeff. matrix respectively. F is vector of wave exciting force and moment acting on the main hulls, and F_1, F_f, F_c are force and moment generated by the lift of the main hulls, by the lift of the fins and by the fin control respectively.

The effect of the fin control is calculated in this computer program by a simplified prediction method using the above term of F_c in the right hand side of the equation. The so-called P-D control is adopted as the fin control system for the SSC, and F_c is described as follows;

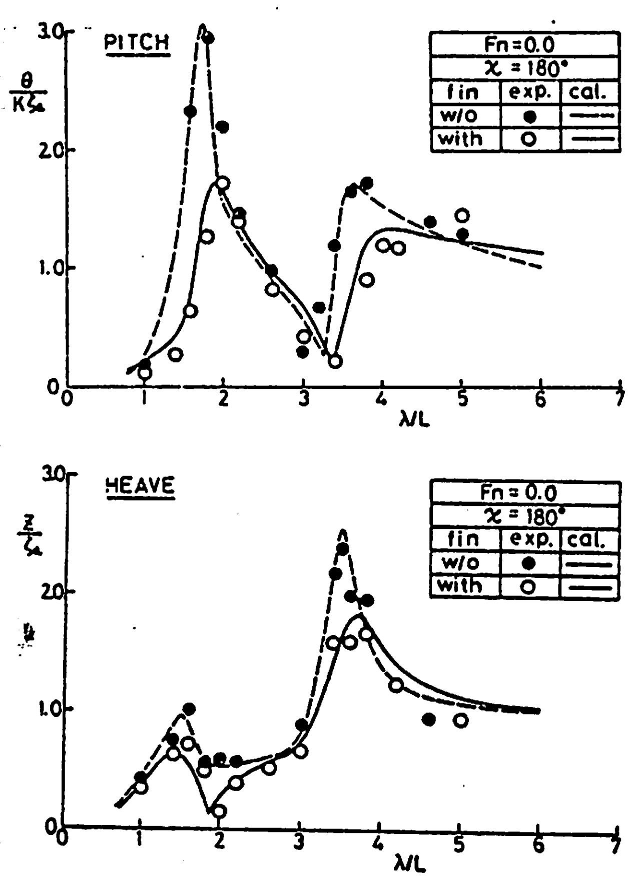


Fig. 15. Pitch and Heave Motions for Twin Strut SSC at Fn=0.0.

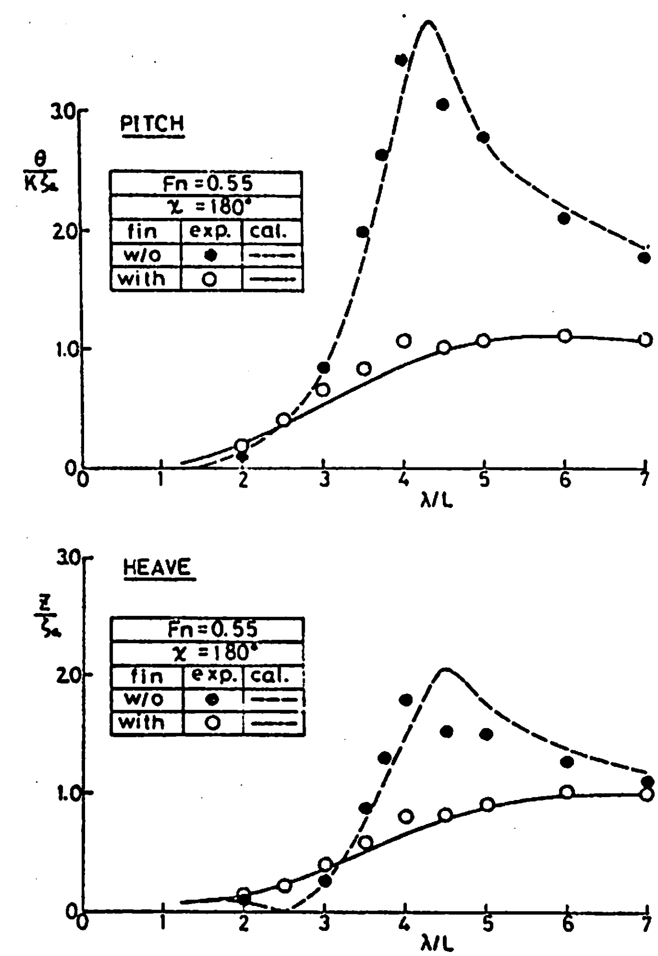


Fig. 16. Pitch and Heave Motions for Twin Strut SSC at Fn=0.55.

$$F_c = (1/2)\rho U^2 \sum_i A_f(i) C_{l\alpha}(i)\alpha(i)$$

$$\alpha(i) = C1(i)\ddot{x} + C2(i)\dot{x} + C3(i)x$$

Where ρ is density of seawater. U is ship's speed. A_f, $C_{l\alpha}$ and α are effective projected area, lift curve slope and fin control angle of the i-th fin respectively. C1 , C2 and C3 are gain constants of control. The gain constants of the control are empirically derived from results of full scale fin control tests and simulation studies.

Fig. 17 shows a block diagram of the fin control system. Ship motion and accelerations sensed by means of gyros and accelerometers on board are fed into a computer, then the fin actuators are independently driven in accordance with each command signals from the computer. This feed back system is also useful in keeping the ship's trim and heel favorable when turning and changing speed drastically.

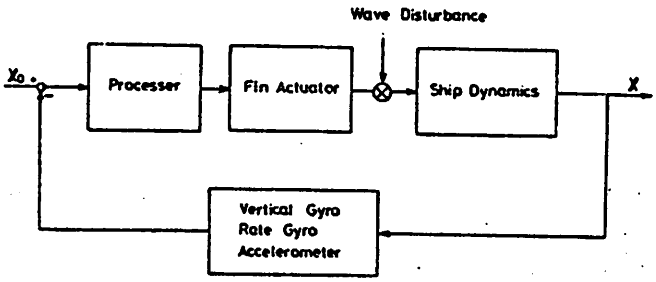


Fig. 17. Block Diagram for Fin Control

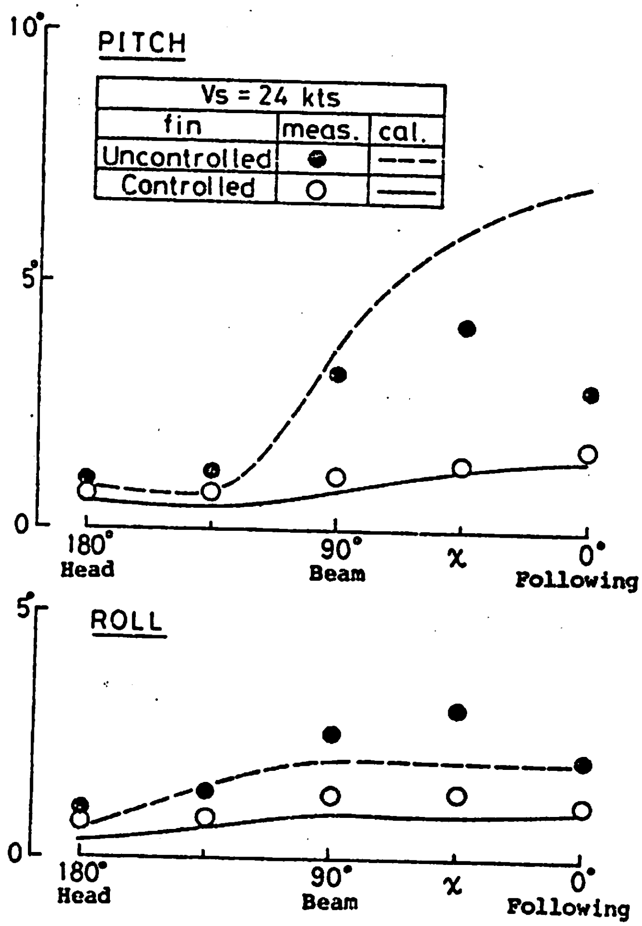


Fig. 18. Pitch and Roll Motions with and without Fin Control for 'SEAGULL'

Remarkable reduction of motions due to automatic operation of fins is demonstrated in Fig. 18 by using the full scale trial results for the 'SEAGULL' at the speed of 24 knots in Sea State 5, showing that both pitch and roll angles were reduced to about 1/3 and 1/2 respectively in beam and stern quartering seas.

Also, calculated motion amplitudes in irregular seas corresponding to the trial condition obtained from linearly superposing responses in regular waves are compared to the trial results in these figures.

In case of fins uncontrolled, there are somewhat differences between the predicted values and the measured one due to the difficulty of estimating motions in regular following waves in which the wave speed is quite close to the ship speed. This discrepancy in motions is also cnsidered to be caused by the complexity of real sea conditions and the nonlinearity in long periodic large motions due to the large flare of the upper part of the struts. Although the motion prediction of long period and large angle should be somewhat improved, the correlation of theory with full scale trial results has shown a generally good agreement for both pitch and roll motions including automatic fin control.

3.3 Maneuverability

Maneuverability of ships consists of three fundamental abilities, i.e. course keeping, course changing and turning ability.

The course keeping ability is investigated by spiral tests, and Fig. 19 shows typical results of the relation between the rudder angle δ and r' (nondimensional turning rate) of the 'SEAGULL'. As can be seen in these figures, the continuous δ-r' curves without hysteresis both at low speed and high speed show the SSC has a good course keeping ability.

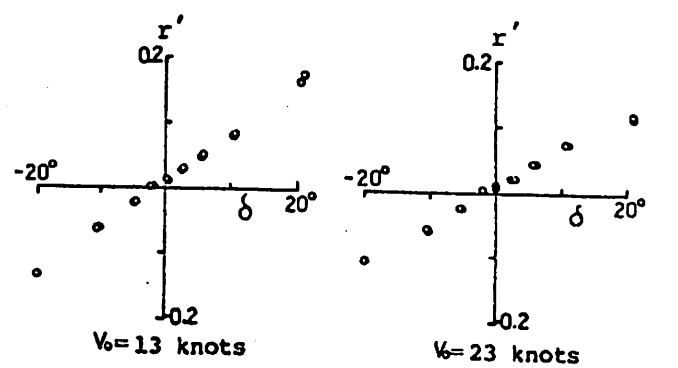


Fig. 19. δ-r' Curves of 'SEAGULL'

With respect to the turning ability, Fig. 20 shows the tactical turn diameters at various approach speeds,for rudder angles of between 30° and 35° for the 'SEAGULL'. The turn diameters are markedly varied for different approach speeds at moderate to high speed as shown in the figure. As the speed increases, the tactical turn diameter increases and at 23 knots becomes twice that at 13 knots.

A theoretical calculation method for the SSC's maneuvering motion, is basically same as that for a conventional ship. But hydrodynamic

SUMMARY

Semi-submerged vessels (SWATH ships) have been under active development since 1968. Considerable research, design, and operating experience has since been accumulated.

The results indicate that such vessels provide greatly reduced motion in waves, both at rest and when underway, relative to conventional vessels, together with greater deck areas, topside weight-carrying capability, and outfitting verstility. Their disadvantages may include a greater draft, beam, or structural weight.

There appear to be many areas of application. A comparison of alternative vessel and semi-submerged vessel characteristics is needed in most cases to determine which type is best suited for a specific application. The wide variety of semi-submerged ship designs and the resulting differences in design options provide the designer with many choices in order to optimize his design.

It is predicted that monohulls will continue to dominate the marine field in the foreseeable future, but that large numbers of semi-submerged vessels will also be built along with new versions of other kinds of advanced marine vessels. Each type of vessel will tend to be best suited for a particular set of applications.