Advanced Hydro-Ski Vehicles for Amphibious Warfare

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The Lockheed hydro-ski vehicle is one of several new concepts being examined to meet a Navy requirement for advanced, high-speed, assault landing craft. The hydro-ski is a variable geometry planing hull capable of speeds ranging from 35 to 60 knots and maintenance of this speed in a seaway. The hull design is a normal, essentially flat, planing bottom; however, a pair of skis have been added which, when retracted, fit into recesses in the hull. Beyond hump speed the skis are hydraulically extended to provide two narrow planing surfaces, thus lifting the basic hull well above the water surface. In this fashion the flat-plate area that is exposed to wave impact is greatly reduced. A 25-ft test craft has been built to prove the concept. The preliminary design of a family of assault craft has been completed, all powered by waterjet propulsion systems. With gross weights varying from 4500 to 200,000 lb, these craft have been configured as suitable replacements for current landing craft. A very simple design, the hydro-ski boat may be configured for any mission for which high speed in a seaway is a fundamental requirement.

During World War II, and again in Korea, our military forces were required to make assault landings on enemy-held shores in order to gain and hold a beachhead. Landings were accomplished in barge-like vehicles with a maximum speed capability of 9 knots. The ride to the beach was usually rough, slow, and often hazardous, particularly when conducted under enemy fire from the shore. The U. S. Navy is currently embarked upon a program to improve all facets of their ability to conduct amphibious warfare. Several different vehicle concepts are being evaluated for the most practical design approach to various sizes of high-speed landing craft which will improve this situation in the future. The Lockheed hydro-ski is one of the concepts being considered.

The hydro-ski described in this paper is basically a variable geometry planing hull. Very high speeds have been obtained over the years by utilizing the planing hull; unfortunately, however, these speeds are attainable in smooth water only. All such craft must restrict their speed when waves are encountered because of the severity of slamming loads caused by wave impact on the flat-plate surface of the hull. The hydro-ski provides a means of reducing the flat-plate area exposed to wave impingement, thus permitting the craft to remain at high speed in a seaway, within the limits of the design. One naval officer, drawing upon his experience as a sailing man, has described this concept as "reefing the beam" when encountering rough (weather) water.

Figure 1 is presented to describe the variable geometry hull. Shown is a 25-ft test craft, built by the Marine Vehicles Department of the Lockheed-California Company to prove the basic concept of impact load alleviation. The hull is a normal, essentially flat, planing bottom; however, a pair of skis have been added which, when retracted, fit into recesses in the hull. When planing at high speed, the skis may be extended by hydraulic actuators, as shown in the figure, and the craft will plane on the ski surfaces only, with the remainder of the hull held clear of the water surface. The craft shown here has been designed to represent a landing craft, with a box-like well and a simulated ramp bow. The power package has been placed on the rear of each ski and consists of an appropriate prime mover driving a waterjet pump. Control is provided by vectoring the water jets, plus the employment of reversing gates similar in principle to the thrust reversers utilized on modern jet engines.

The principle of load alleviation is best described by Fig. 2. The boat shown on the left is a conventional planing hull, grossing 4500 lb and operating at 30 knots. The test craft size, weight, and design speed are used for this example. In smooth water the wetted area of the hull is shown by the darkened area on the aft hull. When this hull strikes a wave of only 0.8 ft in height, the remainder of the flat-plate area is wetted. A slamming load is the result. The boat shown on the right, however, is of the same size and weight and operating at the same speed in the ski-borne mode. The smooth water wetted area again is shown in the dark color. The additional wetted area, when striking the same 0.8-ft wave, also is shown. The difference between the wave action on the two hulls is quite apparent. Analytically, it can be shown that the normal hull on the left will suffer a slamming load 3.46 times greater than will the hydro-ski hull under identical conditions. This fact has been verified by instrumented test results.

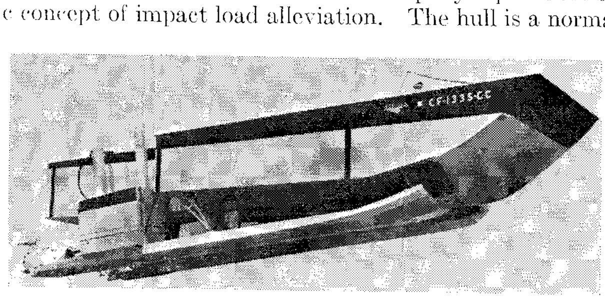

Fig. 1 Hydro-ski test craft.

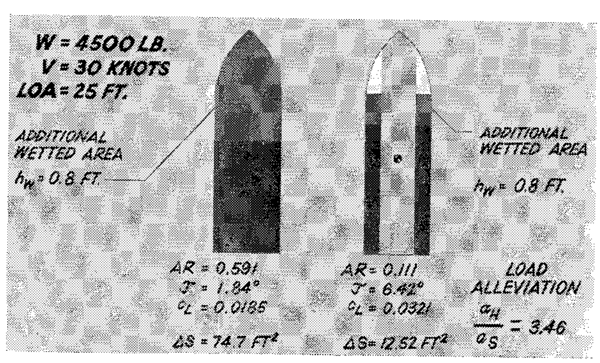

Fig. 2 Hydro-ski concept, load alleviation in waves.

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Fig. 3 LOWTS testing hydro-ski assault craft.

Also of interest to the designer are the differences in aspect ratio, angle of attack, and lift coefficient which are realized. These values are indicated on Fig. 2 for both cases. It is readily apparent that the ski is more heavily loaded and must operate at a higher angle of attack than the larger planing surface. These characteristics contribute to the smoothness of the ride, since the more heavily loaded lifting surface (ski) will provide less response to wave action. This characteristic is similar to that demonstrated in aircraft; the heavily loaded wing of a fighter or modern transport will provide a much smoother ride through heavy turbulence than will the light plane or trainer that is normally designed with a light wing loading. Another significant point is the effect of aspect ratio. The ski has a comparatively low aspect ratio, resulting in a lower slope to the lift curve. For a given incremental increase in angle of attack, the increase in lift coefficient is less than for the planing hull. This design feature is a strong factor in reducing the variation in lift during wave encounter.

The test craft shown was initially intended to prove the basic theory of the load alleviation concept and development testing commenced in January 1964. The use of retractable skis permitted a direct comparison between a conventional planing hull and the hydro-ski hull, operating at the same gross weight, same size, identical power, and the same sea condition. Three accelerometers were installed to record vertical accelerations: in the bow, at the center of gravity, and in the stern. The design wave height for this craft is 20 in. Tests have been conducted in smooth water and in various size waves. The difference between the vertical accelerations experienced by the normal planing hull and the hydro-ski configuration has been adequately demonstrated in a spectrum of seas, up to and in excess of the design sea state. Theory has been closely substantiated.

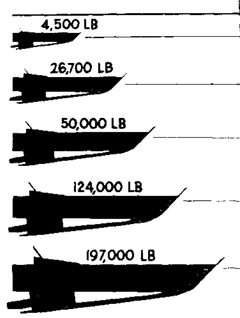
The test craft hull, 25 ft in over-all length, was constructed of wood with a fiberglass overlay. The skis also were made of wood initially, but turned out excessively overweight; accordingly, they were rebuilt using aluminum and typical aircraft structural techniques at a weight saving of approximately 500 lb. The initial power packages consisted of a Chrysler Valiant engine, developing 130 hp, driving a Buehler axial flow pump. These were later changed to Eaton Interceptor V-8 engines, each developing 190 hp and driving Berkeley 12JA-C mixed flow waterjet pumps. The second configuration resulted in the following characteristics: weight empty = 4000 lb, design gross weight = 5000 lb, maximum displacement, ski-borne = 5300 lb, useful load, maximum = 1300 lb, length over all = 25 ft, beam = 7.5 ft, draft, displacement, design GW, skis retracted = 9 in., maximum speed, design GW, ski-borne = 41.6 knots, maximum speed, design GW, hull-borne = 37.4 knots, and minimum speed, ski-borne = 22.6 knots.

Lateral stability is described as good, as might be expected, since the ski-borne craft has the characteristics of a catamaran configuration. Pitching response to waves is considerably reduced in the ski-borne mode; further improvement in this characteristic is being explored during the development program now under way. Directional control, ski-borne, was initially unsatisfactory but has been greatly improved by the use of spray control devices, with still further improvements currently on the drawing board. Steps also have been taken to improve the pump discharge nozzle and thrust reversing capability. Directional control at low speeds, displacement mode, is outstanding, as would be expected with the widely offset thrust vectors of the waterjet propulsion system. The lift/drag ratio realized is approximately 6, which is as good as can be realized with a conventional planing surface. The useful load of the experimental vehicle is 25% of maximum gross weight; however, this can be expected to grow to approximately 60% in larger operational landing craft if aircraft structural techniques and gas turbines are employed.

The second phase of the development program began in November 1964, with the incorporation of several improvements in the configuration. A test program has been funded by the Advanced Research Projects Agency (ARPA), administered by the Bureau of Ships, to thoroughly evaluate the test craft under the following conditions: 1) smooth water; 2) rough water, varying the sea state; 3) weed-infested shoal waters; and 4) surf penetration, beaching, and retraction. The test craft has been thoroughly instrumented for this program. The results and data are not available at the time of this writing and hence must be held for a later report.

In addition to the test and development program described previously, a design study for a family of landing craft, each varying in size and power, has been undertaken. To assist in this effort a hydrodynamic test program was initiated, utilizing the Lockheed Open Water Test System (LOWTS) shown in Fig. 3. This testing facility consists of a scaled, dynamically similar model towed at varying speeds over scaled sea conditions by a 17-ft boat equipped with a controllable boom. This relatively inexpensive procedure permits the recording of resistance, by a strain gage in the towing bridle; water speed, by the towing craft; model trim, photographically; vertical accelerations, recorded on an oscillograph in the towing craft; and dynamic behavior, by visual and photo observations; for any given model, while varying the gross weight, center of gravity, and ski geometry between runs. A quick and inexpensive method, LOWTS has proven invaluable since results can be reflected immediately on the drawing board. This rather unsophisticated testing procedure has been augmented by towing basin testing of models under more controlled conditions.

From these research programs sufficient data have been obtained to conduct preliminary designs of a family of craft, illustrated in Fig. 4. Gross weights vary from 4500 lb to approximately 200,000 lb, with design speeds running from 35–60 knots. The height of the design wave (i.e., the wave that may be penetrated without any impingement upon the hull bottom) also will vary from 20 in. to 10 ft for the vehicles shown. Note that all vehicles except the smallest will be powered by gas turbine engines in order to provide the power required for the speeds specified and at a weight that is ac-



	PAYLOAD LB	THP/SHIP	LOA/BEAM FEET
4,500 LB	1500	129	25/7.5
26,700 LB	12,000	672	36/10.5
50,000 LB	27,000	1343	51/15
124,000 LB	86,000	3660	61/18
197,000 LB	126,000	6800	75/22

Fig. 4. Assault craft family.

ceptable. The hydro-ski, like the hydrofoil, the Air Cushion Vehicle, and the airplane, is weight sensitive. Aerospace technologies, materials, and construction philosophy must be utilized if an acceptable payload fraction is to be realized. Note that the estimated payload fractions shown on Fig. 4 vary from 33–69%, although these must be recognized as approximations and may change with the issuance of detailed specifications.

The second vehicle shown on Fig. 4 has been sized to the same gross weight (26,730 lb) and physical envelope as the present day Landing Craft, Vehicle Personnel (LCVP) landing craft. The preliminary design is shown as a rendering in Fig. 5. Note that the speed of 9 knots has been increased to 35 knots (this is being further increased in later designs), and the present-day payload of 8595 lb can be increased to approximately 12,000 lb by using aircraft structural techniques. Both fiberglass and aluminum are being examined for this size craft, although the larger sizes will probably be aluminum for all basic load carrying structures. In the case of the LCVP craft, the power packages will be two Pratt & Whitney ST-6 gas turbine engines, each developing 550 shp, and each driving a waterjet pump. The payload normally carried consists of combat troops, jeeps, and trailers as depicted. Note that the configuration of the cargo well permits a stern ramp as well as a bow ramp or side ramp, if desired. Another important characteristic is the very shallow draft at design gross weight: 1.75 ft as opposed to 3 ft 5 in. for the present-day craft. A final item that is expected to be important is the use of the skis as built-in hydraulic jacks. These will be discussed later as aids in beaching. They also may be considered as a cradle for maintenance and/or repairs, and should be useful for intentionally grounding the craft within the hold of the LPD amphibious transport dock.

In addition to the LCVP described previously, larger craft are now on the drawing board. The controlling criterion for size, at the present time, is the gas turbine powerplants that are available and considered by the Bureau to be qualified marine powerplants. Two sizes currently being examined are powered by the 1500-hp Lycoming TF20 and the 3000-hp Pratt & Whitney JFTD-12 gas turbine engines. In each instance the waterjet pump must be optimized to the chosen design speed. New or unique pump designs have not been found to be necessary.

The problems of surf penetration, beaching, and retraction from the beach are unique to assault landing craft, but are of such significance that the contractor must design specifically for this function. Figure 6 is presented to dramatically illustrate this problem. Shown is a present-day LCVP that broached and was demolished during a landing exercise conducted in 1963. According to the press accounts of this exercise, 21 craft were involved in the landing, and 15 were lost in the manner shown here. One must remember that the surf is oftentimes higher than shown and is accompanied by a

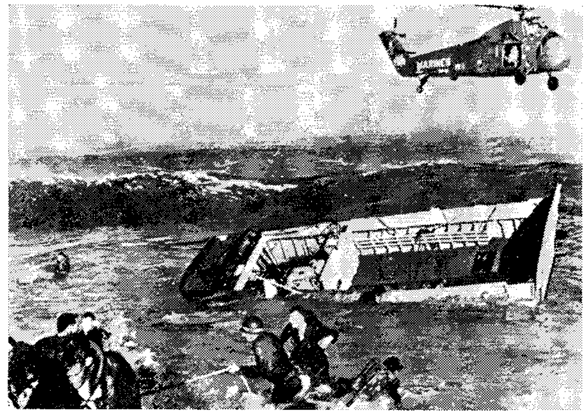


Fig. 6 Surf penetration, problem.

strong undertow, and that the troops are combat-equipped. Enemy fire may be an additional hazard.

Figure 7 is presented to diagrammatically illustrate the cause of landing accidents using present-day craft, and the manner in which the hydro-ski landing craft has been designed to solve the problem. The current LCVP has a 9-knot maximum speed capability; in attempting to penetrate the surf line the coxswain will often experience a following sea, with a resultant rudder reversal. Having limited power, a water rudder, and a single screw, he must be highly skilled to get through the surf without broaching. Furthermore, today's LCVP has a slight deadrise, plus a skeg at the keel to protect the propeller and rudder. Upon touchdown the craft will invariably heel over to one side or the other. This in itself is sufficient cause for trouble. Add to this the constantly breaking surf which tends to pound the transom, cause the craft to broach, and drown out the engine.

The hydro-ski landing craft will approach the beach with skis retracted to minimize the draft. Having an excess of speed available, the operator may select a swell and ride it in on the back side. With a constant flow of water through the waterjet system, made possible by selecting partial forward and reverse thrust simultaneously, dynamic steering is always available. This, plus the widely separated thrust vectors, makes steering easy and positive. Maintaining the craft perpendicular to the wave front, the coxswain can readily ride one wave onto the beach and touch down. At this point (or at the choice of the operator, depending upon beach conditions), the skis may be partially lowered to contact the slope of the beach, thus permitting a firm, 3-point footing. A small amount of forward thrust is maintained to keep the bow in and grounded. Water suction for the pumps may be shifted to a plenum located on the upper surface of the ski to prevent a fouled intake or ingestion of sand, if required. At this point the ramp is lowered and the payload discharged, with hydraulic pressure still applied to the skis to assure a continued firm footing. After reducing the weight by the amount of the payload (and closing the ramp), the skis may be retracted and the craft should be floating because of the reduced dis-

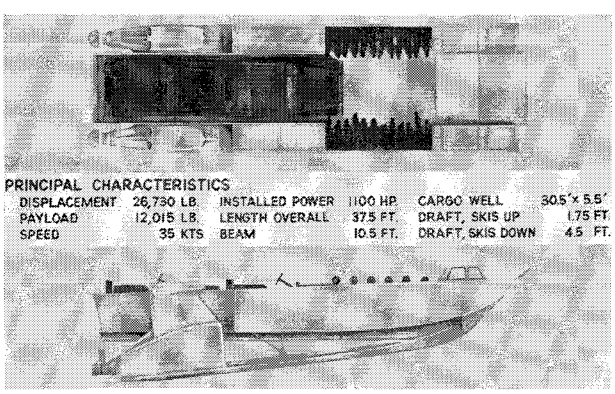


Fig. 5 Hydro-ski assault craft, LCVP.

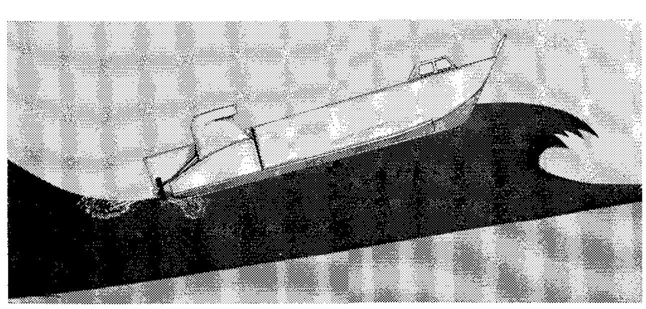


Fig. 7 Surf penetration, solution.

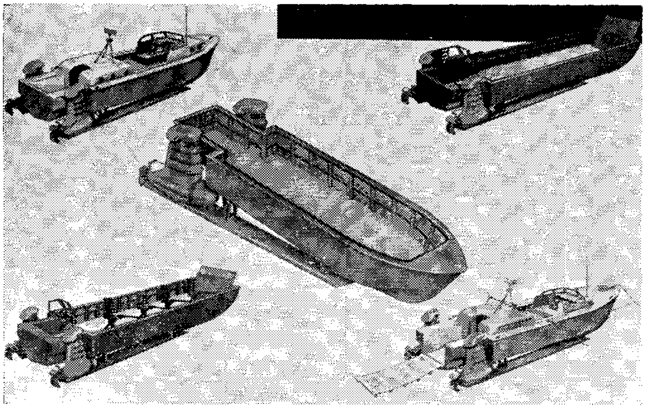


Fig. 8 Multiple-mission design concept.

placement. Reverse thrust must be applied immediately to start the retraction process.

Not shown on the sketch is a special transom design that is more sea kindly than a normal flat-plate transom. The lines are shaped to deflect the water of the breaking surf downward and outward, at the same time providing an upward lift to the stern of the craft. Attention also is being given to intake and exhaust duct design for the turbines to prevent entry of water and drowning of the engines. Retraction from the beach is accomplished by backing through the line of the surf, quickly turning the craft by differential thrust control, and then proceeding to seaward in a normal fashion.

Although the design effort initially was directed toward the basic landing craft and its own unique problems, it has become apparent that the same basic hull lines can readily be adapted to other missions if the speed and displacement are compatible. With superficial changes, such as adding a pointed (more sea kindly) bow, changing the design of the stern sheets, and adding an appropriate superstructure, the craft may be utilized for: 1) the assault command boat, 2) the swimmer retrieval and reconnaissance mission of the LCSR, 3) high-speed shore bombardment missions, 4) personnel or utility boats, and 5) commercial craft with a variety of functions. In this fashion the tooling for high volume production of the basic hull(s) may be identical. The skis with power packages installed will be interchangeable for any given size, thus reducing initial costs as well as logistic support problems and costs. A single ski may be removed easily, for example, and a spare attached in its place while the original ski structure is repaired or the power package is overhauled. The basic concept of multiple-mission design is illustrated by Fig. 8. Cost effectiveness, although not covered in this report, will be enhanced considerably by this design approach.

Additional flexibility for the amphibious forces is provided by the use of the basic landing craft as a high-speed shore bombardment vehicle. A design study is under way to provide a portable battery of improved, lightweight ship-to-shore rockets, fired at a high cyclic rate by recoilless weapons. The objective is a battery, up to the full payload weight of a given sized landing craft, that can be hoisted into the cargo well and tied down with quick-disconnect fittings. A large fleet of such craft could be deployed to a beachhead for a high-speed bombardment attack, return to the landing ships offshore, unload the rocket batteries, load with combat troops, and return to the beach for a normal landing. An alternate configuration that is adaptable even to the small LCVP-sized craft is a small battery of one or two rifles, with automatic feeding of rockets, mounted in the stern sheets, and firing forward over the heads of the troops during the actual landing run. Details of these designs still have to be coordinated with the military planners.

In summary, the hydro-ski vehicle is basically a design that provides wave impact load alleviation. Retractable skis provide an additional feature of minimum draft for a given displacement, where this is considered an operational requirement. Waterjet propulsion is not fundamental to the hydro-ski design concept, but has been incorporated into the landing craft configurations to solve some basic problems associated with this mission. This type of vehicle is less susceptible to damage from surface or submerged debris than is the hydrofoil. It will be less expensive to build and to maintain than will the various types of air cushion vehicles. A very simple design, the hydro-ski boat may be configured for any mission where high speed in a seaway is a fundamental requirement.