The Challenges of Simulating a Hovercraft Ocean Environment

Mark E. Donner
Hughes Training, Inc.
Herndon, Virginia

Abstract

A critical part of the development of a hovercraft simulator is accurately representing an ocean environment. Unlike traditional aircraft simulators, the dynamics of a hovercraft are driven by the forces produced by the sea medium in an ocean environment. The importance of correctly depicting such ocean entities as a sea state, a plunging surf, and a support ship wake becomes evident when one considers that the methods used in modeling these environments directly affect the judgment and actions of the crew. Not only must the details of these ocean entities be readily identifiable, but their dynamics must accurately represent the real world as perceived by the crew. This was accomplished on the Landing Craft, Air Cushion Full Mission Trainer (LCAC FMT) which has the capability of displaying realistic ocean environments. The objective of this paper is to present how sea states 0 to 4, a dynamic surf, and a support ship dynamic wake were modeled and how some of the limitations of these models were overcome. By enhancing the characteristics of these models and developing creative methods of implementation, Hughes Training, Incorporated, is meeting the Navy's need to provide a realistic ocean training environment. This paper discusses some of the design considerations required to provide a real-world ocean environment as perceived by the users of the Landing Craft, Air Cushion Full Mission Trainer.

The Role of the LCAC in Amphibious Operations

From the time that Julius Caesar developed specialized ships for the invasion of Britain (55 B.C.) to the highly mechanized assault of Inchon, Korea (1950), history has documented the triumphs of successful amphibious assaults.[12] In all cases, these successful operations were engineered by well-trained forces who were able to rapidly expedite their armament ashore. Amphibious assaults are typically planned to stun an opponent. The psychological impact of being vulnerable from a seaward front is devastating to the morale of an enemy.[3] Such maneuvers require specialized equipment as well as a trained fighting force.

Today, the U. S. Navy is adopting an Over-The-Horizon philosophy of ship-to-shore assaults. The premise of this operation lies in the ability of air and sea assault vehicles to depart an Amphibious Task Force and converge on any number of predetermined beaches from a stand-off distance.[8,9] The Navy uses many types of assault weapons to perform such operations including: helicopters (CH-53E, CH-46E, AH-1W), aircraft (Harrier, and perhaps the V-22), personnel carriers (LCM, LCU, LCVP), and a high-speed hovercraft known as the Landing Craft, Air Cushion (LCAC). The speed and range of these weapon systems force an enemy to defend an entire coast until the specific location of the attack can be determined.[11] The mission of the Amphibious Task Force may be merely to present an attack threat, thereby keeping the enemy in a defensive posture, as was the case during the Persian Gulf War (1991).[10,11]

After an initial beach assault, a crucial mission of the Amphibious Task Force is to make preparations for supplying offensive troops. This logistical problem requires vehicles that can disembark from the Amphibious Task Force, transport equipment an appreciable distance over sea, travel inland before unloading, and return to the sea for successive loads. The Landing Craft, Air Cushion is a hovercraft designed to transport various resources and personnel from the well deck of a support ship to a landing zone up to one mile inland.[1,2] Capable of being launched from up to five different support ships, the LCAC can carry in excess of 65 tons of cargo (the approximate weight of an M1A1-Main Battle Tank) at 40 knots during calm seas. The hovercraft literally rides on a cushion of air and is less susceptible to mines and water obstructions that can defeat other traditional amphibious landing crafts. The flexible air cushion system of the LCAC (Figure 1) allows this vehicle to operate effectively in sea states 0 to 3 and traverse many different types of terrain, including swamps, mud flats, rocks, and various beach gradients. As such, *tidal conditions do not affect the operation* of the LCAC. The range and speed of this amphibious hovercraft have expanded the potential of amphibious assaults and have contributed to the maneuver-warfare philosophy inherent in the Over-The-Horizon doctrine.

Landing Craft Air Cushion Full Mission Trainer

Hughes Training, Incorporated (HTI) is providing the first Landing Craft, Air Cushion Full Mission Trainer for the Naval Assault Craft Unit 5 (ACU5) *at the Naval Amphibious School in Coronado*, California. This six degree-of-freedom trainer contains complete Group Commander, Operator, Engineer, and Navigator suites. The trainer accurately simulates the performance, maneuvering capabilities, and craft systems of the actual hovercraft. A Hughes CT6 Image Generator with a Wide II display provides an aggregate field of view of 170 degrees horizontal by 40 degrees vertical. Images are displayed at a rate of 50 hertz on a Mylar mirror from four channels each with a horizontal field of view of approximately 45 degrees (allowing for some overlap at the channel boundaries). This visual display system provides a realistic scene of such operational environments as calm to rough seas, a plunging surf at predetermined beaches, numerous types of terrain, rivers, and inner waterways. Other visual cues include military vessels (flotillas, support ships, and landing crafts), civilian vessels (pleasure crafts, oil tankers, and barges), designated landing zones (identified by beach markers, flares, and a beach master), and civilian population centers (cities, houses, and farms). Not only must the FMT trainee be able to operate among these obstacles, but the instructor has the capability to induce craft system malfunctions as well as create meteorological conditions.

Unlike aircraft simulators, the LCAC is always located relatively close to the operating surface (the crew rides approximately 18 to 23 feet above the surface). The LCAC operator commonly uses the undulation of the terrain or sea surface to maneuver the craft. For example, the craft operator may use the slope of a hill or the swell of an oncoming wave to reduce the craft sideslip; allowing the aft of the LCAC to encounter the rise effectively straightens out the track of the hovercraft. Of course, the LCAC crew was familiar *with the visual cues required for training and* approached the design of the ocean gaming area with a preconception that these cues would be pervasive in nature and easy to spot. They felt that emphasizing these cues would not produce false training results. Because of the close proximity of the operator to the terrain, and the familiarity of the crew with different types of ocean attributes, a realistic simulation of the LCAC's operational environment posed a technical challenge not encountered before in the training industry. The remainder of this paper will present the design considerations and the lessons learned in making sea states 0 to 4, a dynamic surf, and a support ship dynamic wake successful visual cues for providing Assault Craft Units 4 and 5 with the correct characteristics for effective hovercraft training.

Training in Open Ocean Environments

Accurately predicting the interaction between the craft and the sea is of paramount importance because the LCAC tends to conform to the contour of the ocean. Without this skill, undesirable hovercraft events may occur, such as plow-in of the LCAC bow with an oncoming wave or slamming the hovercraft superstructure into a trough of a swell. A skilled LCAC operator can anticipate an oncoming wave and adjust the controls to minimize the effects of the sea on the craft. HTI and the Navy spent considerable effort reviewing and fine-tuning the visual and dynamic aspects of these sea state environments. As in many aspects of simulation, the solution of providing realistic sea state cues turned out to be as much of an art as a science.

The elevation profiles of the sea states modeled in the LCAC FMT were derived by a non-real time algorithm, developed by ORI Incorporated, that generates ocean gravity wave elevation spectra. This algorithm calculates sea elevations whose desired characteristics are represented by a

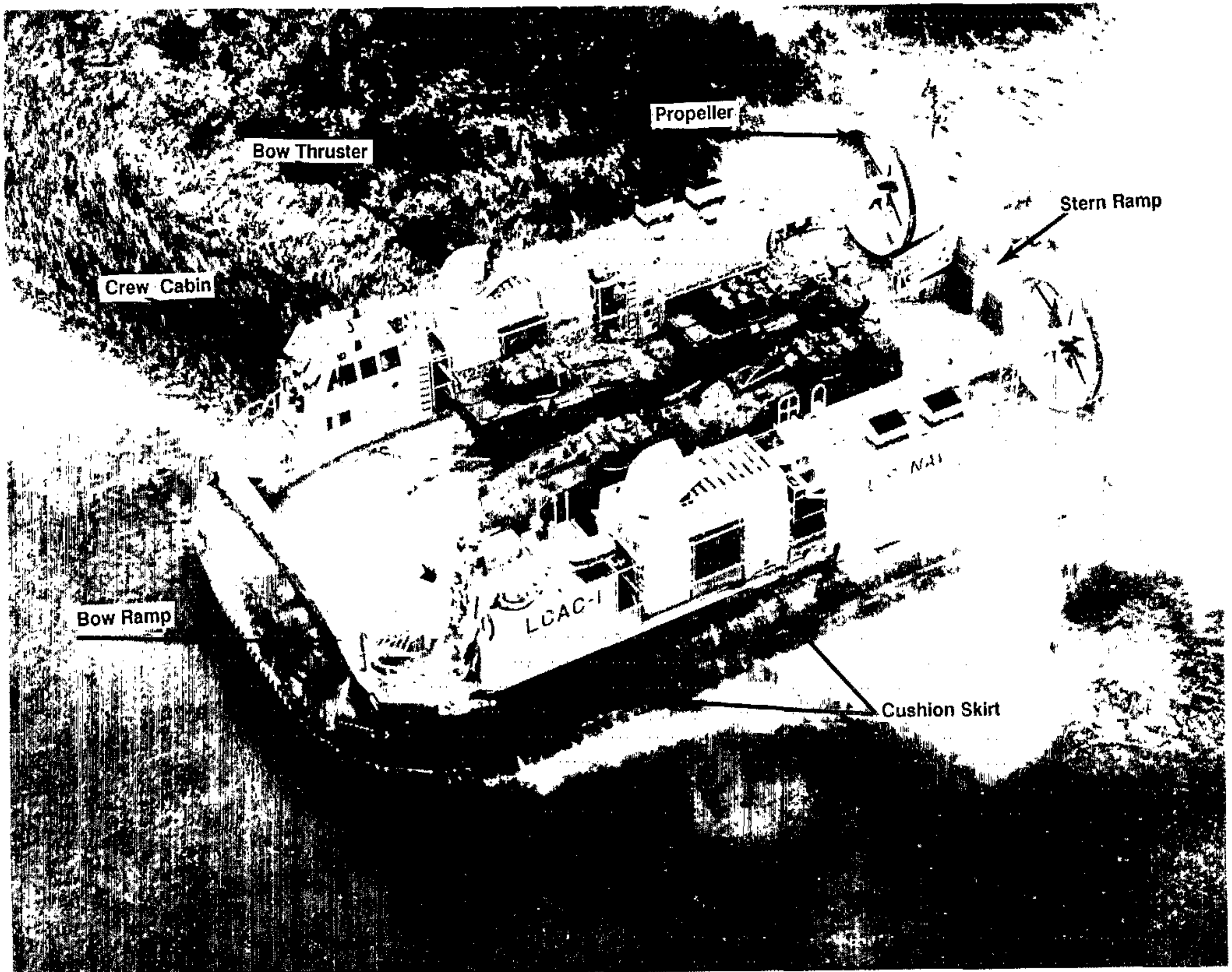


Figure 1 - Landing Craft, Air Cushion - The Landing Craft, Air Cushion is an amphibious hovercraft that is propelled by variable pitch propellers and rotatable bow thrusters. The LCAC is suspended above the operating surface by a flexible rubber air cushion system. The craft is used to deliver armament and personnel from support ships at stand-off distances to predetermined landing zones inland.

primary wave. Additional waves are then introduced at varying frequencies, periods, and directions, which consequently alter the characteristics of the primary wave. The resulting wave elevation is expressed by the following Fourier series:

$$H(x,y,t) = \sum_{\ell=-N_\ell}^{N_\ell'} \sum_{m=-N_m}^{N_m'} [A_{\ell m}(\omega_{\ell m})\, COSINE\{(2\pi\ell/\lambda_o)x + (2\pi m/\lambda_o)y - \omega_{\ell m}t + \phi_{\ell m}\}]$$

Where:

$H(x,y,t)$ - *The elevation at point (x,y) at time (t), feet.*

t - *wave period, seconds.*

i - *wave period indicator.*

x - *x-position along the wave direction of propagation, feet.*

y - *y-position along the wave direction of propagation, feet.*

N_ℓ' - *number of harmonics in x-direction.*

N_ℓ - *number of harmonics in negative x-direction.*

N_m' - *number of harmonics in y-direction.*

N_m - *number of harmonics in negative y-direction.*

$A_{\ell m}$ - *amplitude for* ℓm^{th} *wave, feet.*

$\omega_{\ell m}$ - *frequency for* ℓm^{th} *wave, radians* $second^{-1}$.

$\phi_{\ell m}$ - *random phases for the* ℓm^{th} *wave, radians.*

Sea states 0 to 4 were modeled from these elevation spectra. Each sea state was modeled as a fully developed ocean environment. The gradual build-up of the ocean whenever the instructor changes the sea state or wind velocity was not modeled; the sea direction is driven by the wind heading.

The distortion of the primary wave is controlled by assigning a weight factor to each of the wave components affecting the primary wave, giving them relative importance to the primary wave. The final ocean surface is determined by summing the wave components with respect to the longitudinal and lateral spatial dimensions and time (Figure 2). The distortion of the characteristics of the primary wave was implemented in such a manner as to preserve the directional characteristic of the primary wave. To ensure that the wave spectrum is contiguous at its boundaries, the wave lengths that distort the primary wave length must be integer multiples of the primary wave length.

$$T_j = T_A / j \qquad \text{for } j = 1,2,3,...$$

Such that:

$$\varepsilon_{j\ell} = \text{Minimum } | T_\ell - T'_j | \quad \text{for } \ell = 1,2,3,...$$

$$\omega_m = 2\pi / T_j', \text{ if wave heading} > \pi$$

$$-2\pi / T_j', \text{ if wave heading} \le \pi$$

Where:

T_j - *allowable wave periods, seconds.*

T_A - *wave period (9.6 seconds).*

T_ℓ - *wave period of* ℓ^{th} *wave, seconds.*

$\varepsilon_{j\ell}$ - *difference between wave period in question and nearest allowable wave period, seconds.*

T'_j - *nearest allowable wave period to the wave period corresponding to the gravity wave in question, seconds.*

ω_m - *frequency corresponding to the adjusted wave period, radians* $seconds^{-1}$.

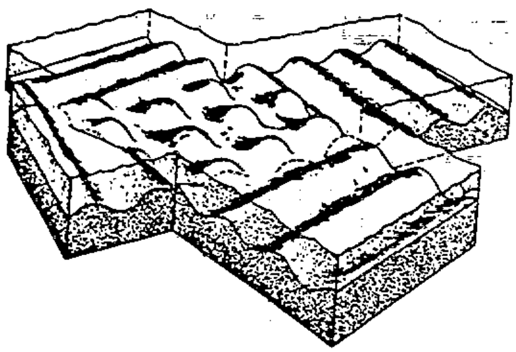


Figure 2 - Wave Interaction Waves propagating from different directions and having unique characteristics are summed to form a resultant sea spectrum. This effect is represented by two such waves at a specific period in time.[6]

The sea state spectra are discretely sampled along their longitudinal and lateral axes with respect to time. This elevation data is then used to generate sets of three-dimensional wave models composed of non-textured polygons whose end points are obtained from the sampled elevation data. The individual wave models are sequentially cycled about the trainee to produce an animated ocean scene. One complete cycle of these models (for a specific sea state) constitutes a complete period of the wave. The specific model currently being displayed in the visual scene is used to synchronize the ocean state vector in the host software with the visual scene.

Sets of the animated sea state models are placed in a 5-by-5 matrix, called a tessellation grid, to give the trainee the perception of a vast ocean. The transition range of the tessellation grid is such that the trainee cannot perceive the boundary of the tessellation grid from the center square. Whenever the LCAC exits the center, the tessellation grid is reconstructed in such a manner as to place the LCAC once again in the center of the 5-by-5 matrix. This method of rearranging the sea states whenever the eye-point exits the center of the tessellation grid is termed "sea-jumping" (Figure 5a). By restructuring the tessellation grid in this manner, the trainee can maneuver throughout the gaming area and perceive an infinite ocean.

The mathematical representation for the sea state spectra can be made as realistic as desired by increasing the number of longitudinal and lateral samples of the resultant wave or by increasing the number of waves that make up the resultant wave. However, the construction of sea state models from the generated elevation spectra is constrained by the number of polygons that can be displayed in real time and the number of models used to represent the sea state. For the CT6 Image Generator, approximately 1500 polygons per channel can be displayed at a time, and the number of models that can be associated with a given sea state is limited to 128. Another factor that affects the creation of the sea scene is the need to preserve the power spectra of the sea state. To obtain reasonable representations of the power spectra of the seas, at least one wave component having a frequency lower than the modal frequency, one wave having a frequency within 10 percent of the modal frequency, and one wave having a frequency higher than the modal frequency were included.* As a result, the wave period required to preserve the power spectra of the seas was determined to be approximately twice that of the modal frequency. These limitations were accounted for in a reduction factor and a power spectra factor used to determine the length of the final wave as follows:

$$\lambda_o = \alpha\beta\,(2\pi g/\omega_m^2)$$

$$K_o = 2\pi/\lambda_o$$

$$T_m = 2\pi/\omega_m$$

* - The modal frequency describes the rate at which the overall sea state spectrum peaks.

Where:

λ_o - *fundamental wavelength, which is also equal to the sea state model length and width, feet.*

g - *gravitational constant (32.174 feet second^{-2})*

α - *reduction factor, 0.83.*

β - *power spectra constant (used to preserve the power spectra of the sea states), 2.*

ω_m - *modal frequency: The frequency at which the resultant sea state spectrum peaks is referred to as the modal frequency, radians second^{-2}.*

K_o - *fundamental wave number, feet^{-1}.*

T_m - *modal period, seconds.*

After the Navy agreed that the ocean scene gave the dynamic cues necessary for training, and the waves were representative of the desired ocean sea states, the wave models were smooth-shaded to give the waves a curved appearance. The smooth shading also eliminated any detection of the individual polygons within a given model of the sea state. The color of the polygons became darker as the polygon normal became horizontal. This effectively lightened the back of the waves and darkened the wave face (the slope of the sea state polygons are more vertical on the front of the waves).

In creating the final oceanic scene, the standard illumination practices of a simulated environment were modified. Diffuse illumination, the illumination that accounts for the reflective energy of the hemisphere making objects brighter irrespective of orientation, was used to simulate the time of day. Direct illumination, the direct energy from the sun that makes objects appear brighter on the side facing the sun, was altered to highlight the specific aspects of the sea state. By keeping the sun angle at a fixed offset from the horizon and setting the heading of the direct illumination to that of the LCAC, the wave contrast is lighter when viewed from the direction of propagation, giving it a froth or white-cap appearance; the waves appear to have more contrast when viewed as oncoming, thereby giving the wave face a more distinguishable dynamic appearance (Figure 3). This, in addition to actual white-caps modeled at higher sea states, enhances the directional characteristics of the ocean and gives the Navy a sea state gaming area that provides the LCAC operator with the optimum realistic sea state training cues.

Some of the difficulty associated with reaching an optimum visual sea scene was in the determination of the wave elevations. Experience shows that an observer on a vessel at sea commonly identifies the significant wave height, the average of the largest one-third of the waves, as the sea state wave elevation.[6] This is due to the difficulty the observer has in distinguishing the movement of the sea from his ownship platform. The sea states were baselined without the advantages of the motion cues of the FMT. HTI, as well as the Navy, had difficulty determining the specific dynamics of the sea state without the motion cues. It should also be noted that the ocean scenes in the LCAC FMT were constructed without benefit of textured polygons. Had textured polygons been used, perhaps the specific attributes needing enhancement would have been more readily identifiable.

Land-to-Sea Transition Training

Most people have gained their experience and knowledge of waves approaching land by watching them from the coast. As waves encounter shallow water, their characteristics begin to change; the wave height increases and wave length decreases. Consequently, as the wave approaches the shore a wave crest curls over a large air pocket and eventually collapses into a smooth splash-up to the shoreline. Under certain circumstances, the energy produced by a breaking wave can cause dramatic damage to the LCAC. To minimize the dynamic effects of the surf on the hovercraft, a craft operator typically examines successive spills of the surf to time the departure from the beach in order to avoid encountering a wave as it begins to break. Such a land-to-sea transition is a skill generally learned through experience, where even well-qualified operators have incurred LCAC damage. Because

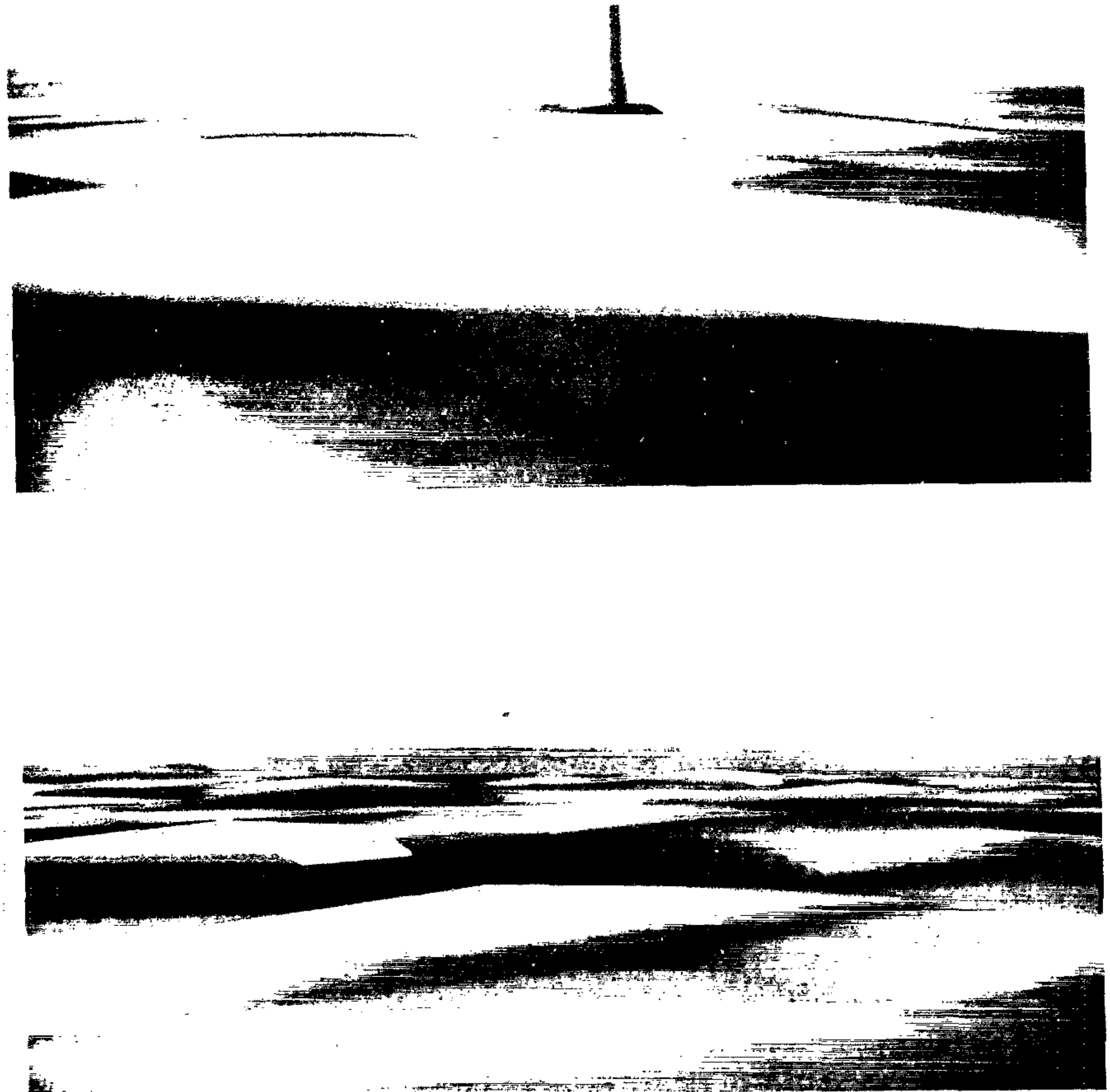


Figure 3 - Modeled Sea State 3 The sea states were modeled by continually cycling sets of three-dimensional wave models about the trainee. The waves appear lighter when viewed in the direction of propagation (top), giving a froth or white-cap effect, and have more contrast when viewed as oncoming (bottom), *highlighting the wave trough and enhancing the sea state dynamics.*

of their frequent occurrence in nature, surf transitions are involved in most land-to-beach operations; consequently, the Navy places a high training value on accurately depicting surf zones in the FMT.

The characteristics of surf zones vary with the tide, sea state, topography under the ocean; as such the analysis of their impact on the LCAC by the operators is subjective. HTI had difficulty identifying the specific attributes of a generic surf which can cause a LCAC Craftmaster to be concerned when attempting to transition through it. At the same time, a surf model so violent that an experienced hovercraft operator would likely elect to abort a mission was avoided. The visual cues of the surf build-up, spill, and splash-up modeled in the FMT had to challenge a Craftmaster and force analysis of the surf prior to performing a land-to-sea transition. Only after reviewing several attempts by HTI at providing a satisfactory representation of a generic surf zone was the Navy satisfied with the model.

The construction of a surf model began with generic digital elevation data that was scaled to represent a sea state 3 open ocean gravity wave evolving into a single 6-foot plunging surf. As with the sea state data, the surf elevation data was used to create sets of individual three-dimensional surf models that were sequentially cycled at specific beaches in the FMT. The surf elevation data was provided at discrete intervals from open ocean to shore with respect to time. This elevation data was used to generate sets of three-dimensional surf models composed of non-textured polygons whose end points were obtained from the sampled elevation data. The individual surf models were sequentially cycled at fixed locations in the FMT to produce an animated plunging surf scene.

Early attempts at modeling the surf used two parallel sets of identical surf profile data separated by the length of the associated sea state (in this case, sea state 3). The surf model was constructed by placing polygons whose end points were defined by coincident points along this profile. This method produced a surf zone that spilled uniformly across the wave face and appeared too mild to cause an experienced LCAC operator to hesitate at a land-to-sea transition. The final model of the surf zone used an additional modified surf profile that was introduced between the previous two digitized profiles. This modified surf profile was created such that it evolved faster than the digitized data profiles. The surf was then constructed by placing polygons whose end points were defined by the digitized data and the enhanced surf profile.

The introduction of the enhanced surf profile increased the number of polygons required to construct the surf model, thereby enhancing the detail of the surf. Additionally, the wave slope (the ratio of the wave height to wave length) was increased. This affected the orientation of the polygons that made up the surf such that normals to the polygons became more horizontal as the wave spilled. As a result, the contrast of the wave face increased, giving it a more violent appearance as the wave began to curl. By temporarily and spatially offsetting the enhanced surf elevation profile, the surf lost its uniform appearance. This provided additional cues that forced the LCAC operators to predict the surf dynamics prior to attempting a land-to-sea transition.

Separate polygons were added to the surf model independent of the profile data to highlight the froth associated with a plunging wave. White polygons were introduced as the surf curled and spilled up to give the surf a more realistic appearance. The surf curl which started as a modified profile began to spill, and spread laterally along the surf face until the entire surf was plunging. The spill-up polygons became transparent as they receded toward the ocean. This gave the effect of the surf froth disappearing into the sand, beach cusps appearing on the shore, and enhancing the terrain cues near land(Figure 4). This also helped the crew to identify the surf spill and splash-up from a seaward perspective (crucial in sea-to-land transitions).

In nature, ocean waves diminish in amplitude and form a wave parallel to the shoreline as they evolve into a surf.[6] To create a natural scene between the open ocean sea state and the surf zone, adjustments to the surf elevation had to be made in the surf profile to account for the spatial and temporal continuity between the animated sea state 3 model and the surf zone. A transition zone was modeled between the open ocean sea state 3 and the area of the surf where the surf actually curls and spills. In this transition zone,

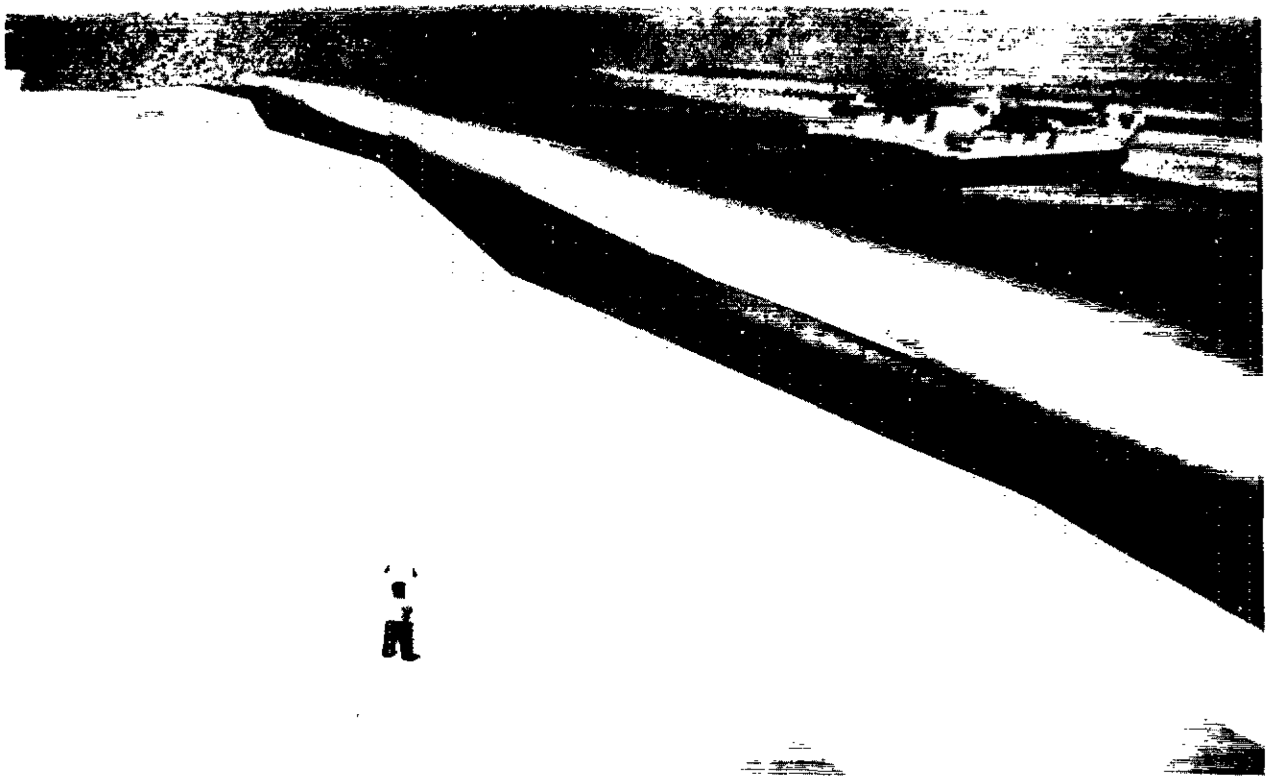


Figure 4 - Modeled 6-Foot Plunging Surf The open ocean sea state 3 gravity wave evolves into a 6-foot plunging surf at predetermined beaches. The dynamics of the surf are highlighted by the addition of froth polygons that make up the surf curl.

surf elevations and open ocean elevations are blended so that the visual continuity between open ocean and the breaking zone was maintained. The elevation of the sea state to surf transition zone was determined as follows:

$$H_T(x,y,t) = W_{\infty} H(x,y,t) + W_s H_s(x,y,t)$$

Where:

$H_T(x,y,t)$ - *elevations in the transition zone, feet.*

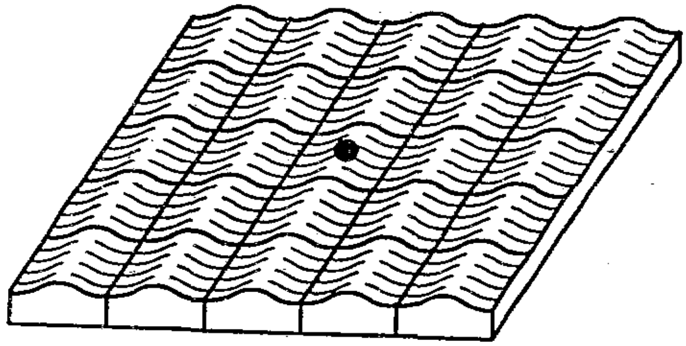
W_{∞} - *open ocean weighting factor.*

W_s - *surf zone weighting factor.*

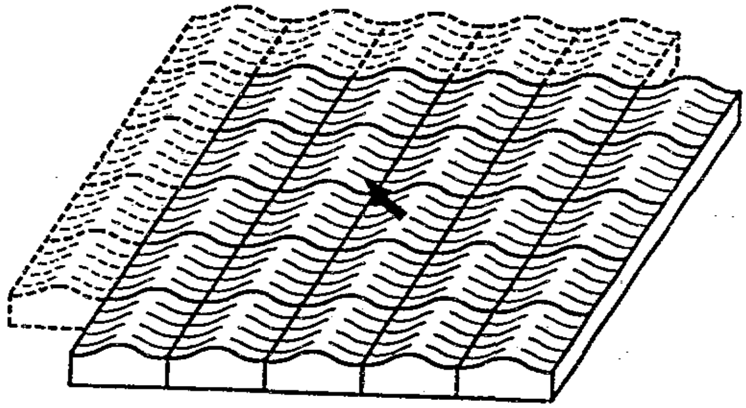
$H(x,y,t)$ - *open ocean elevations, feet.*

$H_s(x,y,t)$ - *elevations in the surf tessellation area, feet.*

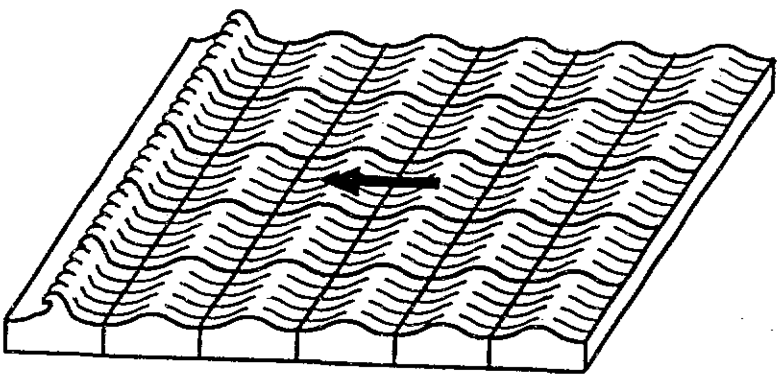
When the LCAC travels within a fixed distance of shoreline where the surf exists, the sea-jumping algorithm associated with the sea state tessellation grid was altered. The sea state was no longer reconfigured in the direction of the surf zone. Whenever the LCAC exits the center grid in any direction other than that of the shoreline, the tessellation grid is reconstructed in such a manner as to place the LCAC in the center of a 5-by-6 matrix, where the sixth row/column is the surf. In this instance the surf acts as an additional row or column and moves laterally up and down the beach in association with the movement of



(a)



(b)



(c)

Figure 5 - Sea State Jumping The open ocean repeatable sea models are placed in a 5-by-5 matrix about the trainee such that the outer boundaries cannot be readily distinguished (5a). As the LCAC exits the center square (5b), the columns and/or rows furthest from the craft are effectively rearranged to form the 5-by-5 grid. This restructuring is eliminated in the direction of a shoreline (whenever surf exists) to preserve the sea-to-surf boundary (5c). Here, lateral reconfiguration is permitted where the surf is sixth row/column.

the LCAC. This method of rearranging the sea states in all directions except that of the shoreline is termed "lateral sea-jumping" (Figure 5b). By restructuring the tessellation grid in this manner, the trainee perceives a contiguous boundary between the sea state and the surf as the LCAC traverses to land.

The simulation of the surf areas for the Landing Craft, Air Cushion Full Mission Trainer proved to be a major hurdle in creating a complete oceanic environment. The problems of meeting the visual cues necessary for a generic surf zone were satisfied by introducing a massaged surf profile from the digitized data. The final surf scene contained the chaotic, violent nature expected by the hovercraft operators.

Support Ship Dynamic Wake

During an amphibious assault mission, the Landing Craft, Air Cushion is constantly bringing troops and equipment ashore. To minimize the time between successive beach deliveries, the LCAC operator must be able to efficiently enter/exit the well deck of a support ship.* The LCAC crew must work as a team during this maneuver to monitor the distance between the hovercraft to the support ship and adjust the encounter speed of the LCAC to the stern of the support ship.[2] Rough seas, fog, ocean spray, and nighttime well deck operations often make this a difficult maneuver. Instances of damage to the LCAC as it collides with the support ship during high seas are not uncommon. The visual cues modeled in the LCAC FMT include an illuminated well deck for day, night, or wartime operations, an animated signalman and moire lens to provide the LCAC with directional signals, and a flag mounted above the well deck to provide wind directional cues. Although the Navy agreed that these support ship attributes were beneficial during well deck entry missions, they did not provide the distance cues necessary for such operations. Only when a dynamic support ship wake was added to the visual scene was the crew able to consistently judge this distance.

* - Each of the support ships contain a large platform, or "well deck", within its hull to load or unload various resources to or from the LCAC. The well deck is accessed from the support ship stern.

Experience shows that a propeller-driven steaming vessel generally leaves a series of waves that are emitted from its bow, and an area of immense water turbulence at its stern. Wakes are a complex phenomenon that are generally affected by the sea state, wind, and ship's attitude.[7] In the LCAC FMT, a 10-knot steaming support ship dynamic wake was modeled. The bow wake, a V-shaped series of parallel waves generated as the bow of the ship slices through the sea, was modeled as a churning white animation directly at the bow of the support ship. Because the LCAC is seldom within view of the support ship bow (well deck operating procedures state that the LCAC must approach the support ship from the support ship stern), the bow wake proved to be a less significant cue and the details of the series of parallel waves from the bow were omitted. The churning froth near the bow was modeled to aid in identifying the ship as steaming when viewed from a profile perspective.

It was determined that the aft wake was a significant factor in judging the distance of the LCAC to the support ship, thereby creating a successful well deck scene. The aft wake was modeled as an area of turbulent, disturbed water directly behind the support ship created by the ships propellers. This wake contained a "collapsing" area of water to fill the volume of water displaced by the steaming ship's hull immediately at the support ship stern. The turbulence was modeled as a series of transparent animating polygons moving in a chaotic sequence at the ramp of the support ship (Figure 6). Unlike the sea state and surf, the stern wake was modeled as a chaotic froth of water. To maintain this froth-like appearance, the dynamic wake polygons did not change in contrast as the polygon normal became horizontal. As the wake moved away from the support ship, the turbulence became less chaotic and transparent polygons were used to model the wake. This allowed the wake to blend in with the sea.

The dynamic wake was built as a part of the

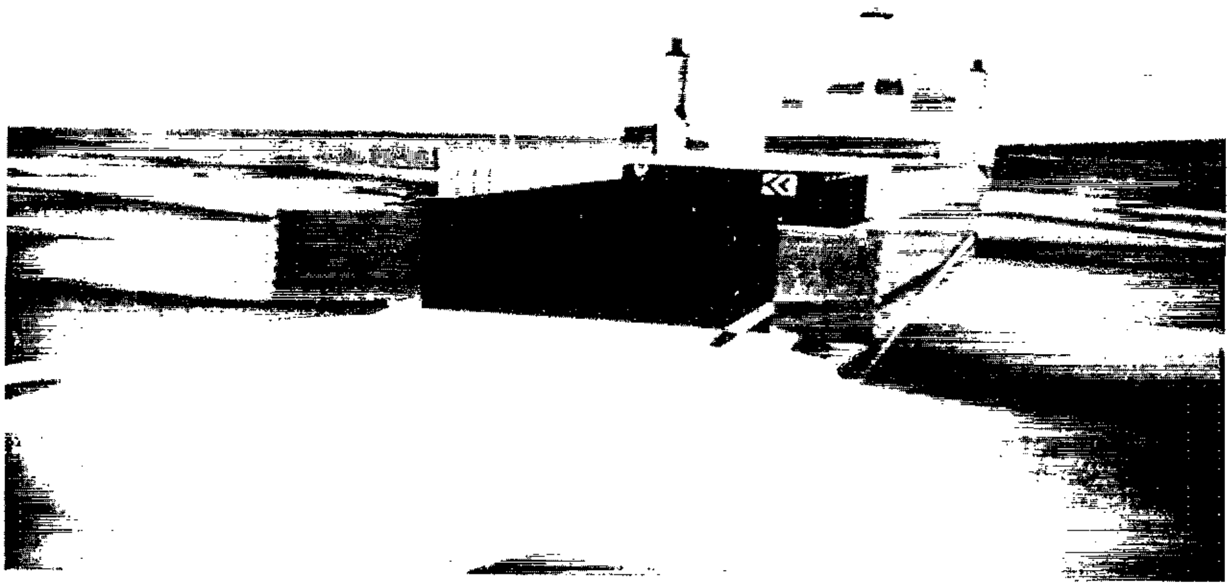


Figure 6 - Support Ship Dynamic Wake The complexities of the stern wake gave the Navy the proper depth cues necessary for a well deck operation. The dynamic wake of a steaming LSD-36 Anchorage class support ship is shown above.

support ship model such that its origin is coincident with the support ship and its attitude is defined from the support ship body-axis system. The dynamic wake's pitch and roll are determined such that the wake remains flat on the surface of the sea. The state vector of the dynamic wake is defined as follows:

$$w = \begin{bmatrix} X_{ship} \\ Y_{ship} \\ Z_{sea} \\ \Psi_{ship} \\ -\theta_{ship} \\ -\Phi_{ship} \end{bmatrix}$$

Where:

w - dynamic wake state vector.

X_{ship} - support ship longitude, feet.

Y_{ship} - support ship latitude, feet.

Z_{sea} - sea level, feet

Ψ_{ship} - support ship heading, degrees.

θ_{ship} - support ship pitch, degrees.

Φ_{ship} - support ship roll, degrees.

To observe an LCAC crew performing a well deck operation in high sea states is perhaps the most striking training aspect of the LCAC FMT. All of the hovercraft crew members must accurately perform their specific tasks, and the group must act as a unit to successfully complete this operation. The Craftmaster requires a correct visual scene as the Engineer and Navigator provide ownship state and distance information. The dynamic wake greatly increases the fidelity of the well deck operation and gives the LCAC crew the ability to perceive the proper depth cues required to perform a well deck entry.

Conclusion

Amphibious Task Forces are a cornerstone of the U.S. Marine philosophy of rapidly responding to global conflicts. In any analysis of Naval power, one fact should not be overlooked: virtually no coastal region on earth is immune from an attack from the sea. Weapon systems, flotillas, and specialized assault crafts would prove ineffective without proper training and familiarization with the capabilities of such systems. Without effective training, putting men and equipment ashore would prove an unpredictable and complex job. The Landing Craft, Air Cushion Full Mission Trainer allows an instructor to place a crew in a controlled environment where seaward hovercraft skills can be enhanced. The physical characteristics of the sea and surf are successfully modeled by a combination of mathematical analysis and on-the-spot creativity. By massaging the sea and surf elevation profiles to enhance the desired oceanic properties required by the Navy within the limits of the visual system used, Hughes Training, Incorporated has provided an oceanic environment suitable for hovercraft training.

References And Suggested Readings

1) Class, J., "The Implementation of the Landing Craft, Air Cushion (LCAC) Full Mission Trainer (FMT) Land Dynamics Reaction to Terrain", Proceedings of the 12th I/ITSC Conference, November 1990, pp. 144-149.

2) Donner, M., "The Simulation of the Dynamic Interaction of a Hovercraft Entering a Support Ship Well Deck", Proceedings of the 12th I/ITSC Conference, November 1990, pp. 136-143.

3) Fioravanzo, G., Naval Tactical Thought, Naval Institute Press, Annapolis, Maryland, 1979.

4) Ganguly, D., "Bangladeshis Hail Arriving 'Angels'; U.S. Marine Flotilla Joins Relief Effort for Survivors of Cyclone", Washington Post, May 17, 1991 section A, p. 20.

5) Graham, P., and Norton, J., "LCAC Medevac Considerations", Proceedings of Naval Review, Annapolis, Maryland, February 1990.

6) Grant, M. G., Oceanography, A View of The Earth, Prentice-Hall Incorporated, Englewood Cliffs, New Jersey, 1977.

7) Gross, M. E., "A Real Time Particle System for Display of Ship Wakes", IEEE Computer Graphics and Applications, May 1990, pp. 30-35.

8) Ladd, J. D., Amphibious Techniques, Learner Publications, Minneapolis, Minnesota, 1985.

9) Maroon, F., and Beach, E., Keepers of the Sea, United States Naval Institute, Annapolis, Maryland, 1983.

10) Moore, M., "Navy's 'Imminent Thunder' Assault Washes Out: Waves to Gunwales Deflate Air-Cushioned Crafts' Mock Attack on Beach Near Kuwait", *Washington Post*, November 18, 1990.

11) Schwarzkopf, H. N., Persian Gulf war press briefing by General H. Norman Schwarzkopf in Riyadh, Saudi Arabia. A complete transcript can be found in numerous sources, including: Washington Post, February 28, 1991, section A., pp 35-37.

12) Whitehouse, A. ,Amphibious Operations, Doubleday and Company, Garden City, New York, 1963.

Acknowledgments

The author would like to acknowledge the non-real time sea and surf elevation profile work done by ORI, Incorporated during the early stages of the LCAC project, and the work performed by Hughes Training, Incorporated, Arlington, Texas in the construction of the sea and surf polygon models. Their efforts were critical in the development of the LCAC FMT visual scene.

About The Author

Mark E. Donner is a Systems Analyst on the LCAC-FMT program at Hughes Training, Incorporated. He is responsible for the design, test, and integration of all visual related software. He has also contributed to the development of the dynamic software, particularly in areas related to the visual system interface. Mark has 5 years experience in his current position and holds a Bachelor of Science in Chemical Engineering and a Masters of Computer Science, both from New Jersey Institute of Technology.