

# **Nonlinear Problems in Ocean Engineering: On the Evolution of Energetic Ocean Waves and Their Interaction With Structures**

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## **LONG-TERM GOALS**

Improve and develop new scientific understanding of nonlinear water waves, including effects of wind and breaking, and their consequence for naval operations; especially with regard to remote sensing of the sea surface, ocean structural loading, and ship performance.

## **OBJECTIVES**

The objectives of this effort are to understand and simulate:

1. The role of wind, currents, and wave breaking on the long-term evolution of wave systems, including discretization, wave group formation, downshifting, direction distribution of energy, and the generation of extreme waves.
2. The morphology of deformed and breaking waves in connection with impulsive hydroelastic loading.
  - a. Anomalous radar scattering (sea spikes).
  - b. Splashing bow waves at the bow of combatant ships.
3. Impulsive loading and hydroelastic response of ocean structures due to breaking wave impact.
  - a. Breaking wave impact on ship bows due to slamming.
  - b. Extension of existing loading prediction methods.

## **APPROACH**

*(Numbers refer to Objectives)*

*Objective 1.* Wave evolution experiments in the large Ocean Engineering Laboratory tank, including wind. Radar observations of wind waves in the OEL tank. Numerical simulations utilizing a range of evolution models (fully non-linear, spectral, NLS). Theoretical development utilizing the Lagrangian (variational) method. Close comparisons with ocean data.

*Objectives 2, 2a, 2b.* Synchronized wave tank observations with other measurements (structural response, radar backscatter). High-resolution (2d&t) numerical simulations (ship waves).

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*Objectives 3, 3a, 3b.* Observations and tank measurements on hydroelastic models; numerical simulation and comparison with experiment (slamming); theoretical analysis (loading on curved structures).

## **WORK COMPLETED**

*Objective 1.* Extensive tank experiments on the evolution of heavily breaking (initially) two wave systems were completed, including wind effects; wind waves were observed with radar, showing discretization of the wave system and wave group formation. A forerunner paper on previous three wave (unstable Benjamin-Feir) systems was extended and modified and has now been accepted for publication by the *Journal of Fluid Mechanics*. A new summary paper on ocean wave evolution was prepared and presented (Keynote Lecture) at the 3rd International Symposium on Hydrodynamics (Seoul). New analyses of wave response to gusts were made based on our previous measurements, and a paper submitted to the *Journal of Geophysical Research*. A paper on “The stability and nonlinear dynamics of ocean-like wave systems with energy continuously distributed in direction” was accepted for publication in the *Journal of Engineering Mathematics*. A short paper on the long time evolution of gravity wave systems comparing fully non-linear, spectral, and NLS based computation was presented at the 13th International Workshop on Water Waves and Floating Bodies (IWWW) and appears in the Proceedings. A report was written on an experimental investigation of single moored buoys in modulated waves in wave groups. A new and denser wave wire range was installed in the tank; two methods for the measurement of particle velocities on the water surface of modulating and breaking waves were developed and put into use (one ptv and one radar tracing). An extensive computer simulation and studies have been carried out on the evolution of wind waves under conditions of wind unsteadiness, using the “line squall” as an atmospheric model.

*Objective 2.* Correlations between wave shape and loading were carried out and are presented in the papers described under *Objective 3* below.

*Objective 2a.* Correlations between radar scattering and breaking wave shapes have been completed and described in a Technical Report.

*Objective 2b.* A summary paper has been prepared of high resolution 2d&t numerical simulations of splashing bow waves at the bow of combatant ships and presented at a NATO Vehicles Symposium in Amsterdam.

*Objective 3.* Extensive measurements were completed of the hydroelastic response of an elastic vertical cylinder mounted in the OEL wind-wave tank, and subject to loading by monochromatic waves and wave groups, both breaking and non-breaking. Three papers on the foregoing measurements were prepared; (i) ISOPE '98 Proceedings, (ii) ISOPE Journal submission, (iii) 13th IWWW. Two presentations were made at International Meetings: ISOPE-Montreal, IWWW-Delft.

*Objective 3a.* A paper has been prepared on ship slamming including hydroelastic effects and presented at PRADS '98 in Amsterdam.

*Question 3b.* The general theory of the hydrodynamic loading of curved structures has been completed and a manuscript submitted to the *Journal of Fluid Mechanics*.

## RESULTS

*Wave Evolution & Breaking.* We have shown in 1997, through experiments in the OEL wind-wave tank with waves 1m and larger that the consequence of Benjamin-Feir wave instability is discretization of the spectrum, wave modulation (group formation), strong breaking for waves of steepness ( $ak$ ) greater than 0.1, and downshifting (in press, *JFM*). However, even with the fetch available in the big tank (length=175'), the experiments did not provide more than one cycle of evolution (instability, sideband growth, modulation, breaking, and downshifting). A very significant finding in 1997 was that the end state of the cycle was the division of the bulk of the wave energy between two closely spaced waves.

We have in 1998, therefore, studied experimentally the further rapid evolution of this system beginning with two waves at the wavemaker. We have covered a larger range of wave steepness and wave spacing, and have had great success in producing successive evolution cycles, reaching as many as seven discrete downshifting in a single experiment (compared to one, in all earlier experiments). The role of breaking was again shown to be very marked and indeed crucial for downshifting. These experiments and their analysis, including comparison with our own evolution models are providing further validation of these models, which emphasize the role of breaking. In this year we have also extended the validity of earlier evolution theory (in press, *JFM*), and in work still ongoing we have developed a rigorous evolution theory utilizing the averaged Lagrangian approach, which puts a firm basis under earlier heuristic models and provides for their extension. Simultaneous numerical simulation studies of existing conservative evolution models have shown the serious shortcomings in nonlinear Schrodinger models in comparison to spectral (Krasitskii) and fully nonlinear calculations (which provided a benchmark).

*Ringling.* We have shown in 1997 as the result of our wave loading experiments on a surface piercing flexible cylinder that impulsive loading (ringing) occurs when the cylinder is impacted by a deformed wave in the process of breaking; in our experiments the breaking occurred in wave groups.

In 1998 we have shown (submitted to *ISOPE Journal*) that the rigid body loading during impact by a breaking wave correlates very well with the local slope of the wave at the cylinder. This finding provides a basis for the extension of the Morison formula to deal with forces on surface piercing elements in very steep and breaking waves. At the same time we found that the high frequency response of the cylinder shell was correlated with breaking jet impact on the cylinder, which requires its own analysis.

## IMPACT/APPLICATIONS

The hydroelastic impact (ringing) experimental results allow the estimation of loading transients on surface piercing ocean structures in the design phase. Our results also allow for an estimation of high frequency fatigue loading due to steep and breaking waves.

Our models of wind-wave evolution permit the detailed and high-resolution prediction of ocean response to wind and current perturbations. Two examples of applications that we are now making are

(i) to the generation of extreme waves due to line squalls, and (ii) to the prediction of remote sensing effects due to weak currents.

In earlier years under other ONR support, we have developed the 2d&t numerical method for the simulation of nonlinear interaction between waves and ships as well as the simulation of bow splash on fine ships and the propagation of divergent waves. In 1998 we have continued with some impact applications under this contract and have also prepared a summary of the method and its applications including its historical development and mathematical justifications (NATO Amsterdam Conference). We mention this now because the value of this simulation method to provide relevant high-resolution simulations of highly energetic wave formations (bow splash, water on deck) is beginning to be appreciated and applied in other countries.

## **TRANSITIONS**

None beyond those already mentioned in 1997.

## **PUBLICATIONS**

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