4. Summary

All natural laws are derived empirically. Experimental techniques in transport processes are classified into flow visualization and measurement. This paper has presented the role of flow visualization in the derivation of natural laws and important phenomena in heat and fluid flow since the Renaissance era. In the second half of the 20th century, the advent of high-speed computing machines brought a revolutionary change in the role of flow visualization to include the quantization of information in flow fields being observed through experimental means or numerical computations. Both computer graphics and image processing aid in display and in quality enhancement.

Flow visualization has been instrumental in the advancement of medical vision for diagnostics and treatments, space exploration, and high-tech industries. It will continue to serve as the vanguard for the exploration of new flow phenomena and as a vital instrument in the study of complex phenomena such as three-dimensional flow, turbulence, combustion, medical imaging, and more.

5. References

[1] Yang, Wen-Jei (ed.), Handbook of Flow Visualization, Hemisphere, Washington, D.C. (1989).
[2] Yang, Wen-Jei, Computer Aided Flow Visualization, Second Generation Techniques, CRC Press Boca Raton, Florida (1994).
[3] Cheng, K.C., "Internal Flows", Chapter 27 in Handbook of Flow Visualization (Wen-Jei Yang, editor), Hemisphere, Washington, D.C. (1989).
[4] Merzkirch, W, Flow Visualization, Academic Press, New York (1974).
[5] Rouse, H. and Ince, S., History of Hydraulics, Dover, New York (1957).
[6] Mach, E. and Salchar, P., Sitzungsber, Wien Akad. Wiss. II '95, pp.764-780 (1887).
[7] Schmidt, E., " Schlieren aufnahmen des Temperturfeldes in der Nahe Warmeabgebender Koper", Forsch.Geb. Ingenieurwes., Vol.3, pp. 81-89 (1932).
[8] Eckert, E.R.G. and Drake, R.M.,Jr., Introduction to the Transfer of Heat and Mass, McGraw-Hill, New York (1950).
[9] Merzkirch, W., Techniques of Flow Visualization, AGARDograph No.302, NATO, Germany (1987).
[10] Trolinger, J.D., Laser Applications in Flow Diagnostics, AGARDograph No. 296, NATO, Belgium (1988).
[11] Asanuma, T., Flow Visualization I, Hemisphere, Washington, D.C.(1978).
[12] Merzkirch, W. Flow Visualization II, Hemisphere, Washington D.C.(1982).
[13] Yang, Wen-Jei, Flow Visualization III, Hemisphere, Washington, D.C. (1985).
[14] Veret, C., 1987, Flow Visualization IV, Hemisphere, Washington, D.C.(1987).
[15] Reznicek, R., Flow Visualization V, Hemisphere, Washington D.C.(1990).
[16] Tanida, Y. and Miyashiro, H., Flow Visualization VI, Springer Verlag, Berlin-Heidelberg (1992).

THE SIXTH ASIAN CONGRESS OF FLUID MECHANICS
May 22–26, 1995, Singapore

THE ROLE OF FLUID MECHANICS IN ENHANCING COASTAL ENVIROMENTAL QUALITIES

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The physical and geophysical processes taking place in coastal waters involving fluid mechanics of transport of mass, momentum and energy in various forms are very complex in manifest. Of these phenomena spanning over a wide scope, this paper selects three specific classes of problems to illustrate the roles that fluid mechanics can play in helping improve our knowledge and technology for maintaining and enhancing our coastal environmental qualities. These problems are:
(1) interaction between long gravity waves on coastal waters and beach;
(2) terminal effects of internal waves in coastal waters; and
(3) interaction between bidirectional nonlinear dispersive waves.

For these problems, an appropriate theoretical model is the generalized Boussinesq (gB-) model (Wu, Ref [1]) which is known to be reliable in predicting generation, propagation and evolution of long gravity waves in coastal water of depth slowly varying in both longshore and seaward directions. It is based on the premise that both the nonlinear and dispersive effects are weak but nevertheless on a par with the net linear effects. For the above three problems, solutions will be presented using various degrees of modification of the gB model.

1. Long waves on straight beach of variable slope; longshore currents

To gain insight into coastal dynamics in nature, we first consider the three-dimensional run-up of long waves on a straight beach of variable downward slope which is connected to an open ocean of uniform depth. A linear long-wave theory, which is the linearized version of the gB model, is applied to obtain the fundamental solution for a uniform train of sinusoidal waves obliquely incident upon the beach, without wave breaking. The solution, obtained in terms of a series of rapid convergence (Zhang & Wu, Ref [2]), is characterized by two parameters, one being the incidence angle (β, the angle subtended by the incoming wave vecter and the landward axis) and the wave number (κ) scaled by the beach width. For waves at normal incidence ($\beta = 0$) on a sloping plane beach, the runup given by the linear theory is equal to that by nonlinear theory. At oblique incidences, the run-up is found to increase with increasing incidence angle up to about $\beta = 45°$. For waves at nearly grazing incidences, $85° < \beta < 90°$, run-up is significant only for the waves in a set of eigenmodes being trapped within the beach at resonance with the exterior ocean waves (see figure 1). The impact of this trapped grazing waves upon coastal environmental quality is not yet in focus, but its effects should be of interest on coastal

ocean circulation and long-term interactions between ocean and land.

This new solution also affords a critical comparison with the ray theory. It is shown that while the classical ray theory predicts the evolution of only the incident wave, leaving the reflected wave unknown, the asymptotic expansion of the present theory for large κ yields results for both the incident and reflected waves and their phase shifts. In the range with $\kappa > 2$ and with the incidence angles $\beta < 60°$, the ray theory and the asymototic expansion are in complete agreement. But both become poorer, compared with the present linear theory without expansion, for smaller κ and larger β. This discrepancy is primarily due to the singular behavior of the trapped grazing modes of waves at resonance. These are the new conspicuous features that now qualify the ray theory.

An interesting result is about the wave-induced longshore current which is given by the Stokes drift of the water particles carried by the momentum of the waves obliquely incident upon a sloping beach. Currents of increasingly significant velocities are produced by waves (of given wave number κ) of increasing obliquity, reaching a maximum at about $\beta = 45°$, and within this range of β, the current speed increases with κ like κ^3. In the range of $45° < \beta < 90°$, the outstanding feature is that the longshore current is strongly dominated by the eigenmodes of the trapped waves.

In short, these featuristic results cast new light on coastal dynamics of interest that remains to be further modified as the physical effects of nolinearity, dispersion and dissipation due to wave breaking and bottom friction are to be taken into account.

2. Terminal effects of oceanic internal waves on sloping seabed

In constrast with the natural forces occuring along ocean coast that may arise to hazardous strength like hurricanes and tsunamis, which are relatively rare, interior oceanic forcing by internal gravity waves (IW) propagating along pycnoclines in the ocean and terminating on coasts seems ubiquitous globally in different parts of the oceans. Such potential hazards to coastal regions, called the *undersea tsunamis* by Wu (Ref [3]), emerged in the Chesapeake Bay incident in early 1970's when an abrupt anoxic condition surfaced with a marked decline in marine production from its previous rich level. It took the 5-year, 3-State U.S. Congress *Chesapeake Bay Program* to ascertain the IWs incident from the ocean to be primarily responsible for causing a strong biochemical degradation of the bay water. This therefore opens the case for further investigation related to our environmental quality.

For this class of problems an internal-wave run-up model has been developed by Wu & Lin [Ref.3] for nonlinear and nondispersive long waves propagating along the interface of a two-layer inviscid fluid, incident upon a sloping plane seabed. Explicit solutions of the nonlinear equations are obtained for several classes of wave forms, which are matched, whenever necessary for achieving uniformly valid results, with the outer solution based on linear theory for the outer region in which the lower layer is no longer shallow compared to the top one. Under certain criteria, these waves can keep progressing without breaking. The new results obtained in this first stage, as

illustrated in figure 2, can be useful for more general studies.

3. Interation between bidirectional nonlinear dispersive waves

Giant oceanic internal waves have been measured, e.g. in the Andaman Sea to the scale of 10 km in wavelength, extending laterally to a span of 150 km, to a total downward height of 200 m, progressing in packets of five to ten soliton-like waves along the pycnocline shallowly submerged under the ocean surface. They are known to be hazardous to exploring ships and offshore infrastructures. Satelite photographs have shown oblique packets interacting with each other and this raises the question if the interacting IW's can be more hazardous to our environment in a broad sense.

Studies along this line have led Wu (Ref [4]) to develop a *bidirectional nonlinear long-wave model* to evaluate interactions between multiple solitary waves progressing in both directions in a straight channel with gradually varying breath and water depth, which is a further development of the basic gB model. The salient features of wave-wave and wave-wall interactions recently determined by Wu & Yih (Ref [5]) will be presented for binary head-on or overtaking collisions between these solitons.

References

[1] Wu, T.Y. 1981 *J. Engng. Mech. Div. ASCE* **107**, 501-522.
[2] Zhang, J. E. & Wu, T. Y. 1995 Oblique run-up of long waves on straight beach of variable slope and induced longshore current (submitted for publication).
[3] Wu, T. Y. & Lin, D. M. 1994 *Physica D* **77**, 97-107.
[4] Wu, T.Y. 1994 *Meth. Appl. Anal.* **1**(1), 108-117.
[5] Wu, T. Y. & Yih, C. S. 1995 Bidirectional soliton street (submitted for publication).

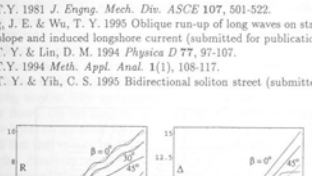
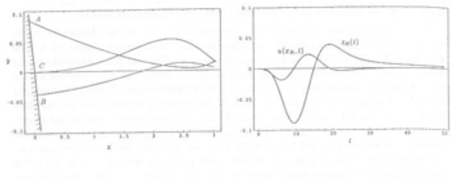


Figure 1: Variations of the run-up function $R(\kappa, \beta)$ and the phase lag function $\Delta(\kappa, \beta)$, —— for a list of β indicated; - - - - asymptotic expansion.



(a) (b)

Figure 2: (a) Illustrative wave profiles evolved from an initial internal water elevation; — C, initial profile at time $t = 0$, — A, Maximum run-up, — B, minimum run-down; (b) An illustrative plot of time history of the run-up position $x = x_R(t)$, and fluid velocity, $u(x_R, t)$.

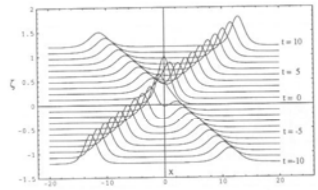


Figure 3: Head-on collision of two solitons with amplitudes $a_+ = 0.6$ and $a_- = 0.3$, for time $-10 < t < 10$.

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REVIEW OF TURBULENCE RESEARCH IN CHINA

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ABSTRACT Turbulence research has been emphasized in China since 1980's on both fundamental and applied areas. In this paper the author will present the major contributions of turbulence research made by Chinese scientists in last decade and prospect its furher development.

1. Introduction

Turbulence is one of the extremely difficult topics in fluid mechanics. It attracts a large number of scientists to make long lasting efforts for exploring its nature. Considerable progress has been achieved in last few decades, but there is still a long way to fully understand, precisely predict and effectively control turbulent flows. On the fundamental side the discovery of coherent structures shed new lights on the nature of turbulent shear flows forty years ago, and people expected that they would break through the unpredictable barrier of turbulence. Indeed the discovery of coherent structures is the significant progress in turbulence research such that the coherent structures dominate the generation of turbulence in various shear flows and there are a number of devices for turbulence control based on the management of the coherent structures. However the dynamics of the coherent structures is not well understood for their complexity. One can not completely succeed in control of turbulent flows when they do not fully understand the flow nature. And also it is not so clear how to predict the turbulent flows by use of the knowledge of coherent structures. On the theoretical side the chaos in nonlinear dynamics and fractal geometry in topological analysis of the flows give rise to the some new ideas on the turbulence, however they are conceptual but not constructive. The rapid development of modern computer in last two decades has provided a powerful tool for turbulence study and it is a great hope for the deep understanding and accurate prediction of turbulent flows by means of modern computers. There are a number of available data banks of direct numerical simulation of simple turbulent flows for detailed studies of the structures and properties of those flows, for instance the examination of the turbulence models and investigation of the