行政院國家科學委員會補助專題研究計畫成果報告

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計畫編號：NSC 90－2611－M－009－001

執行期間：九十年八月一日至九十一年七月三十一日

計畫主持人：蔡武廷

共同主持人：

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執行單位：國立交通大學土木工程學系

中　華　民　國　九 十 一年　七 月　三 十 一 日

行政院國家科學委員會專題研究計畫成果報告

大氣-海洋微尺度耦合紊流場之研究（I）流場安定性分析

A study on the microscale atmosphere-ocean coupled flow (1) Stability analysis

計畫編號：NSC 09-2611-M-009-001

執行期限：90 年 8 月 1 日至 91 年 7 月 31 日

主持人：蔡武廷　國立交通大學土木工程學系

中文摘要

本研究完成氣-水耦合剪流場中之二維擾動波的安定性分析，以瞭解微尺度大氣-海洋耦合剪紊流場中產生組織性結構之可能機制，以為將來進行三維氣-水耦合剪紊流場數值模擬之準備。針對此安定性分析，我們發展一能同時求解不穩定擾流之特徵值（發展率）與特徵函數之數值方法，並進一步探討流場物理參數對不安定波生成與發展之影響。

關鍵詞：邊界層紊流、大氣-海洋交互作用、安定性分析

Abstract

The linear stability of a two-dimensional perturbed wave in a coupled air-water turbulent shear flow is considered to study the generation and growth of initial wavelets by the wind. A robust numerical method is developed to solve the eigenvalue problem. Calculations of the growth rates and phase speeds of unstable wavelets compare well the early theoretical results as well as laboratory measurement. Dependence of the instability on the flow parameters is then studied systematically.

Keywords: Turbulent boundary layer, Atmosphere-ocean interaction, Stability analysis

Introduction

To have a better understanding of the possible structures embedded in an air-water coupled turbulent shear flow (Komori *et al.* 1993; Veron & Melville 2002) before proceeding towards the fully three-dimensional numerical computations (cf. water flow simulations in Tsai 2001), we completed in this study a linear stability analysis of a two-dimensional coupled mean shear flow. A robust numerical method has been developed to solve the discretized Orr-Sommerfeld equations and the coupled interfacial boundary conditions for the eigenvalue (growth rate) and the eigenfunctions (velocity streamfunctions) of the perturbed waves.

Validation of the model

To validate the present numerical procedures we compare our computed growth rates of unstable perturbed initial wavelets with other numerical and theoretical results as shown in Figure 1. For low wind speeds (air friction velocity u_{*a} = 13 and 17 cm s^{-1}), the growth rates show good agreement between the present results and those of van Gastel (1985) and Kawai (1979). Differences in the three results increase for the cases of high wind speeds (u_{*a} = 21.4, and 24.8 cm s^{-1}). The present computed growth rates are slightly lower than the numerical values of Kawai but higher than theoretical predictions of van Gastel (1985).

The results shown on Figure 1 also reveal the influences of the air friction velocity u_{*a} on the growth rate $\hat{a}$. The corresponding variations in the phase velocity c are plotted in Figure 2. For an unstable perturbed wavelet with a particular wavenumber k, the growth rate $\hat{a}$ increases monotonically with u_{*a}. This, however, is not the case for the phase velocity c. For any air friction velocity, there exist a wavenumber with a maximum growth rate and also a wavenumber with a minimum phase velocity. The two wavenumbers, nevertheless, do not coincide, and the difference between them increases with u_{*a}.

Maximum Growth rate

The unstable mode with the maximum growth rate $\hat{a}_{\max}$ is usually the first visible wavelet under a constant wind condition as has been observed in the experiments of Kawai (1979). Kawai further showed numerically that the maximum growth rate $\hat{a}_{\max}$ is linearly proportional to $u_{*a}^{3.5}$. The analyses of van Gastel *et al.* (1985) however reveal that $\hat{a}_{\max}$ u_{*a}^{3} for the range of friction velocities 5 cm s^{-1} u_{*a} 40 cm s^{-1}. The variation of $\hat{a}_{\max}$ with u_{*a} from the present analysis is shown in Figure 3 in logarithmic-scale coordinates. Power fitting of the data is also plotted. The result indicates that there indeed exists a simple functional relation between $\hat{a}_{\max}$ and u_{*a}, and the relation is the same as what obtained by Kawai, $\hat{a}_{\max}$ $u_{*a}^{3.5}$. Note that the mean velocity profile used in reaching the functional is the same as that used by van Gastel *et al.* (1985).

Concluding Remarks

We have also studied the impacts of other flow parameters on the initial generation and growth of the perturbed wavelets by wind. Specifically, the parameters we have explored include surface tension of water ó, viscosities of air $í_a$ and water $í_w$, and the surface drift velocity of water U_0. A full manuscript, reporting the results outlined above, is under preparation and will be submitted for publication. Two Ph.D. students were involved in this study and they are currently participating in developing the three-dimensional air-water coupled numerical model.

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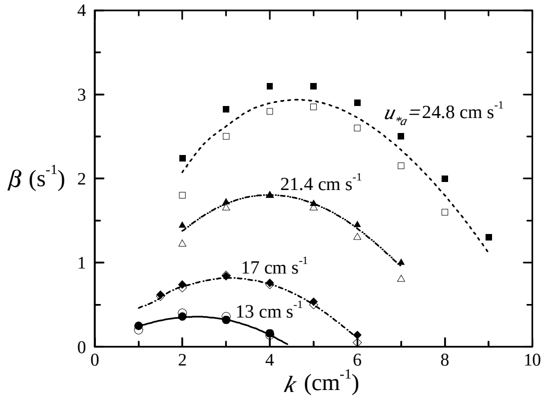

Figure 1. Comparisons of our computed growth rate of energy $\hat{a}$ with the asymptotic solutions of van Gastel (1985) (open symbols) and the numerical solutions of Kawai (1979) (solid symbols) for varied wavenumbers k and four air friction velocity u_{*a} = 13, 17, 21.4 and 24.8 cm s^{-1}.

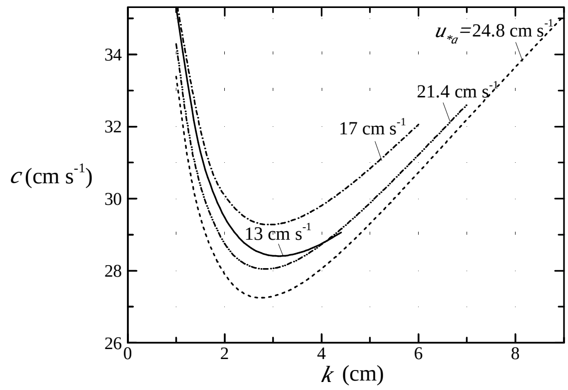

Figure 2. The corresponding phase velocity c of the unstable wavelets shown in Figure 1 for varied wave number k and air friction velocity u_{*a}.

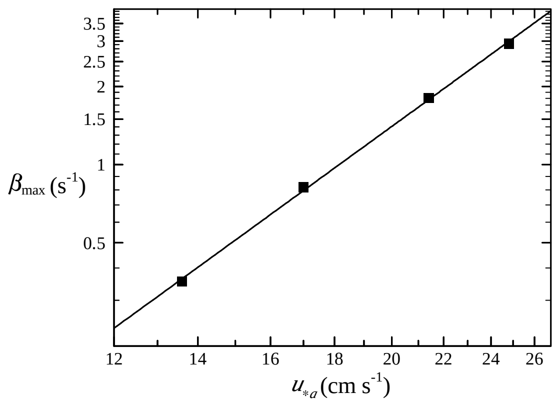

Figure 3. The dependence of the maximum growth rate $\hat{a}_{\max}$ on the air friction velocity u_{*a}. The symbols are the present numerical results. The straight line is the least-square fitting of the numerical data.