INTERFACE WAVES ON A COMPLIANT COATING BOUNDED BY A FLUID FLOW, AND THEIR EXCITATION BY ACOUSTIC RESONANCE

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INTERFACE WAVES ON A COMPLIANT COATING BOUNDED BY A FLUID FLOW, AND THEIR EXCITATION BY ACOUSTIC RESONANCE

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Résumé - La stabilité des ondes que se propagent à l'interface d'une couche souple, attaché à un fond rigide et soumis à un écoulement laminar ou turbulent, a été l'objet de plusieurs études théoriques, et d'investigations expérimentales déterminant le début et l'accroissement des ondes d'instabilité. Nous avons obtenu des solutions de l'équation caractéristique du problème, fournissant des courbes de dispersion, et de l'information sur la stabilité des ondes d'interface; nous avons supposé que le fluide soit compressible afin que la limite statique peut etre atteint. Nous avons montré que l'excitation de ces ondes d'interface peut se faire d'une façon résonnante. Usant cette méthode, on peut déterminer expérimentalement d'une façon précise les courbes de dispersion, le début d'instabilité, et les propriétés d'accroissement des ondes d'interface.

Abstract - The stability of interface waves on a compliant coating, attached to a rigid substrate and exposed to a laminar or turbulent fluid flow, has been the subject of several theoretical studies, and of experimental investigations in which the onset and growth of instability waves was determined. We have obtained solutions of the characteristic equation of the problem, which furnish dispersion curves and stability information for the interface waves, assuming a compressible fluid in order to attain the correct static limit. We have shown that the excitation of these interface waves can occur in a resonant fashion; using this approach, an accurate experimental determination of the dispersion curves, of the onset of instability, and of the growth properties of interface waves will be possible.

1 - INTRODUCTION

Waves in compliant media with boundaries subject to a fluid flow have been investigated for various purposes. Liamshev /1/ studied acoustic reflection and transmission of a layer bounded by a fluid flow; resonances are here caused by sound interaction with boundary waves. Madigosky /2/ measured *in vivo* waves on compliant Dolphin skins, for the purpose of understanding drag reduction effected by the suppression of interface wave instabilities. We have carried out a study of such interface waves on layers, obtaining the dispersion curves and attenuations of a variety of the allowed modes, both stable and exhibiting instabilities. The diagnostics of these waves using acoustic resonance experiments is discussed. Our theory approaches the correct static limit as the flow velocity tends to zero, which was not the case in several previous investigations.

2 - THEORY

Interface wave instabilities have first been studied by Kramer /3/ who performed experiments trying to reduce boundary layer flow instabilities by distributed damping in a compliant layer attached to a rigid substrate and subject to a fluid flow. His results were positive but only marginally so. Soon thereafter, extensive theories of flow instabilities on compliant layers subject to a fluid flow were presented by Benjamin /4/and by Landahl /5/, and later on by Carpenter and Garrad /6/. Recent experiments on the subject are due to Gaster /7/, and to Gad-el-Hak /8/.

An early theory of the properties of surface waves on an elastic layer with rigid backing,

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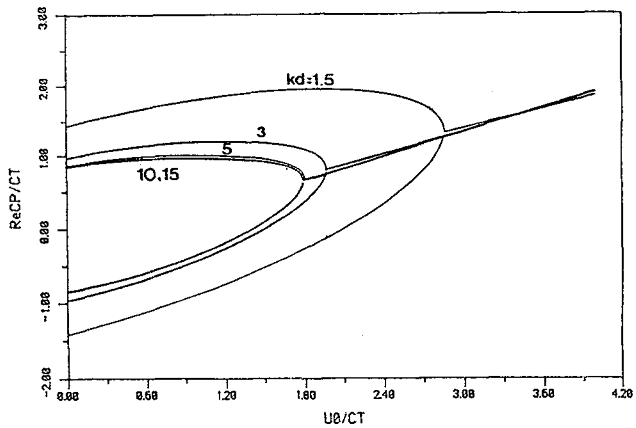

Fig. 1 - Phase velocity of interface waves on a rubber layer with rigid backing, vs. flow velocity of bounding fluid.

bounded by an inviscid fluid flow, was given by Pierucci /9/ in 1977; later investigations /10,11/treated the layer as viscoelastic but considered the fluid (of flow velocity U_o at infinity) as incompressible, so that the static limit ($U_o \to 0$) is no longer attainable in these theories. We here use Pierucci's approach.

In this method, the elastic layer equations, coupled to the Navier-Stokes equations for the fluid by the boundary conditions, lead to an eigenvalue problem for the complex surface wave speed on the layer, while the wave number k is assumed real. More elaborate treatments solving the Orr-Sommerfeld equation for the fluid modes in the boundary layer lead to essentially similar results /12,13/. For the case of a rubber layer with c_L = 1,030 m/s, c_T = 3.65 m/s, and ρ = 1g/cm^3 bounded by water with c_o = 1,482.5 m/s, ρ_o =1g/cm^3, Fig. 1 shows the real part of the lowest-mode surface wave phase velocity c_p plotted vs. the flow velocity U_o, both normalized by c_T. (A second mode, with larger c_p nearly independent of U_o, is shown e.g. in Fig. 4 of Ref. /11/. For increasing U_o, the negative-c_p lower branch becomes positive, and the two branches merge at U_o/c_T = 1.80 whereupon a "class B" or CIFI instability /13/ develops. The figure shows the dependence of c_p on the value of kd, d being the layer thickness. For kd > 5 the curves have reached an asymptotic value.

3 - RESONANT EXCITATION

We have considered the resonant excitation of these interface waves by an inhomogeneous sound wave such as given by Eq. (15b) of Ref. /14/; Pierucci's theory /9/ was extended for such a purpose. For the case kd = 10, Fig. 2 shows the resulting normal component of the surface wave displacement velocity plotted vs. the normalized propagation speed c_p/c_T of the surface wave, at the flow velocity values (as indicated) of U_o/c_T = 0, 1.7, 1.79 and 1.8; this corresponds to the appropriate intersections of the kd = 10 curves of Fig. 1 with the vertical. Resonant excitation takes place a these intersections; for U_o/c_T = 0 only the upper branch of the first mode is excited as well as the second mode (not shown in Fig. 1). At 1.7 (note change in scale!) the lower branch is excited in addition; at 1.79 the two branches are about to merge, and at 1.8 they have merged to generate the onset of instability.

These results indicate the possibility of exploring the phase velocity and instability structures of interface waves on compliant layers subject to a fluid flow by using incident sound waves as an excitation agent (and diagnostic tool), rather than mechanical shakers employed so far /7/. This may serve as a useful approach for developing instability delay and drag reduction methods.

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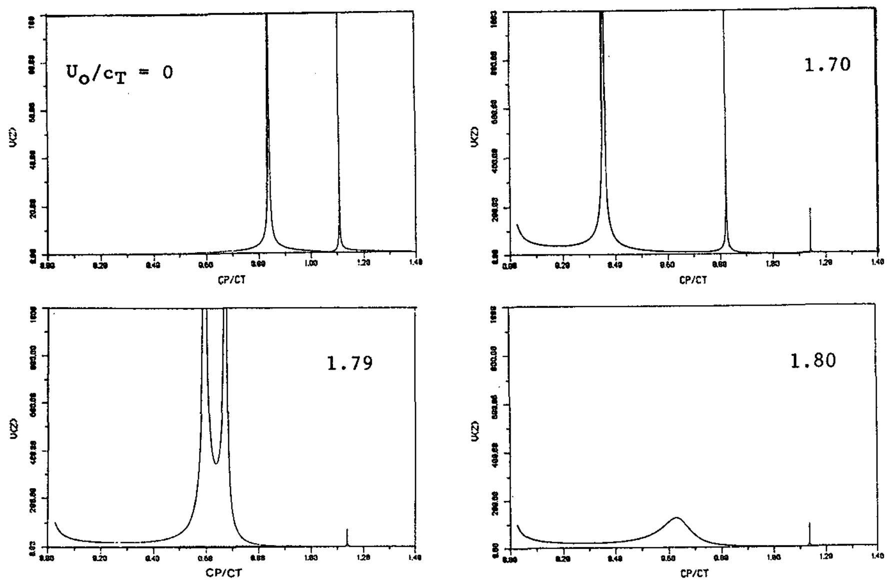

Fig. 2 - Resonant excitation of interface waves at U_o/c_T = 0, 1.7, 1.79 and 1.8, respectively.

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