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Theoretical Studies of the Kinematics, Dynamics, Stability and Control of
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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
1) Several unsteady vortical flows have been computed with success. A free vortex might be trapped by an oscillating airfoil for lift augmentation. 2) Numerical simulations of streaklines have shown some pitfalls that might be encountered when interpreting photographs of unsteady vortical flows. 3) Traveling acoustic waves are found to have the effect of either re-orienting a cluster of vortices or destabilizing the otherwise stable Karman vortex street. 4) The onset of instability of boundary layers along semi-infinite circular cylinders is analyzed, including the effects of transverse curvature and spin motion of the cylinders. Some important mechanisms that are responsible for vorticity generation and flow separation on bodies in unsteady motion have been identified.

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Theoretical Studies of the Kinematics, Dynamics, Stability and Control of Unsteady/Vortical Flows

Final Report for the period August 1, 1988–December 31, 1990

I.   Objectives of the Research Effort

To gain further understanding of the basic physics of unsteady vortical flows, the following four topics were proposed for a research period of two years and four months:

1)   Numerical simulation of vortical flows about airfoil in unsteady motions.
2)   Numerical simulation of streakline patterns in unsteady flows.
3)   Acoustic control of vortical structures.
4)   Boundary layer transition on spinning and nonspinning circular cylinders.

II.   Status of the Research Effort

Accomplishments during the period of support are described separately as follows, in the same order as shown in Part I.

1)   The method of discrete vortices is used in combination with the conformal mapping technique to stimulate unsteady vortical flows around a symmetric airfoil in an inviscid and incompressible fluid.   Numerical results indicate that a free vortex, while passing an airfoil oscillating in pitch, may temporarily increase the lift of the airfoil; and under a suitable arrangement such a vortex may become trapped above the oscillating airfoil to cause lift augmentation for a much longer period.   In the simulation of accelerating flows past a flat-plate airfoil at high angles of attack, the computed vortex patterns agree well with those photographed in the laboratory.

Similar computational techniques have also been employed to study both the vortical flow behind a normal plate whose height varies with time and that caused by an oscillating spoiler mounted on an airfoil.   Good agreements are again found between computed and observed vortex patterns in cases where smoke pictures are available.

2)   Numerical simulations of streakline patterns have been made for several unsteady flows.   According to the computation, streaklines trace out a core region around a moving vortex near a wall, and the size of that region varies significantly with the velocity of the vortex as well as with its distance from the wall.   Thus a wrong conclusion might be obtained to determine the strength of such a vortex by measuring only the core size from a smoke picture without knowing the motion of the vortex.   Results for a uniform potential flow past a rotating or oscillating elliptic cylinder show that a vortex-like coherent structure in the streakline pattern may appear in the wake, even if there is no vorticity in the flow at all.   Based on the results of numerical simulations, it is concluded that special care must be taken in the interpretation of streakline photographs if the flow is unsteady.

3)   In studying acoustic control of vortices, two problems concerning different vortical structures have been tackled.   The structure in the first problem has the configuration of two, three, or four discrete vortices situated at equal

distances on a circle. After the passage of a traveling acoustic wave, computations show that the amplitude of vortex displacement away from the mean path may become substantial at certain acoustic frequencies, indicating that the application of a sound wave may play an important role in re-orienting vortices. Examined in the second problem is the effect of a traveling acoustic wave on the stability of Karman's infinitely long double row of vortices. Computed results suggest that acoustic waves of specific wavelengths can be used to destabilize the Karman vortex street manifested in nature, so as to scatter its vortices in an effort to weaken its impact on the surrounding.

4) The accurate prediction of boundary layer transition on cylindrical bodies, such as missile, bullet, torpedo, and the fuselage of an airplane, is important in the design and performance determination of these bodies. Linear stability analyses have been carried out to predict the onset of instability in boundary layers along a semi-infinite circular cylinder with and without a curved nose, as influenced by the transverse curvature and a spinning motion of the cylinder. Results show that the transverse curvature has a stabilizing effect but the spin motion destabilizes the flow by shifting the transition point upstream.

III. Professional Personnel Associated with the Research

C. Y. Chow, professor and principal investigator.

K. Chawla, research assistant, August 1–22, 1988, continued from a previous Air Force Office of Scientific Research support.

K. H. Kao, research assistant, August 23, 1988–July 31, 1990.

K. C. McColl, research assistant, January 1–May 31, 1989.

S. Chen, research assistant, January 1, 1989–July 31, 1990.

P. G. Aaronson, research assistant, June 1–August 31, 1990.

Advanced degrees awarded:

Ph.D., August 1988, awarded to K. Chawla. Thesis title: Computation of Dynamics and Control of Unsteady Vortical Flows.

M.S., May 1989, awarded to K. C. McColl.

M.S., May 1990, awarded to S. Chen.

Ph.D., May 1990, awarded to K. H. Kao. Thesis title: Numerical Study of Boundary Layer Transition of Flow Over Axisymmetric Cylinder.

IV. Publications in Technical Journals

K. H. Kao and C. Y. Chow, "Stability of the Boundary Layer on a Spinning Semi-Infinite Circular Cylinder," to appear in *Journal of Spacecraft and Rockets*, 1991.

K. H. Kao and C. Y Chow, "Stability of the Boundary Layer on a Spinning Blunt-Nosed Cylinder," to appear in *Journal of Spacecraft and Rockets*, 1991.

C. Y. Chow and K. H. Kao, "Movement of the Dividing Streamline in Unsteady Stagnation-Point Flows," to appear in *Computer Physics Communication*, 1991.

V. Papers Presented at Meetings and Conferences

K. Chawla and C. Y. Chow, "Vortical Flows Past Normal Plate and Spoiler of Time Dependent Height," AIAA Paper 89-0291, presented at AIAA 27th Aerospace Sciences Meeting, Reno, NV, January 1989.

C. Y. Chow, R. Leben and L. M. Gea, "Numerical Simulation of Streaklines in Unsteady Flows," AIAA Paper 89-0292, presented at AIAA 27th Aerospace Sciences Meeting, Reno, NV, January 1989.

K. Chawla and C. Y. Chow, "Acoustical Control of Vortices," AIAA Paper 89-1042, presented at AIAA 12th Aeroacoustic Conference, San Antonio, TX, April 1989.

K. Chawla and C. Y. Chow, "Stability of Karman Street Under the Influence of Acoustic Waves," AIAA Paper 89-1113, presented at AIAA 12th Aeroacoustic Conference, San Antonio, TX, April 1989.

K. H. Kao and C. Y. Chow, "Stability Analyses of Boundary Layer on a Semi-Infinite Circular Cylinder With and Without Spin," AIAA Paper 90-0116, presented at AIAA 28th Aerospace Sciences Meeting, Reno, NV, January 1990.

K. H. Kao and C. Y. Chow, "Stability of Boundary Layer on a Blunt-Nosed Cylinder With and Without Spin," AIAA Paper 90-0117, presented at AIAA 28th Aerospace Sciences Meeting, Reno, NV, January 1990.

C. Y. Chow and K. H. Kao, "Investigation of Mechanisms for Vorticity Generation and Flow Separation on Bodies in Unsteady Motion," presented at the Workshop on Forced Unsteady Separation, cosponsored by NASA, AFOSR and ARO, NASA Ames Research Center, April 1990.

C. Y. Chow and K. H. Kao, "Unsteady Stagnation-Point Flows," presented at the IMACS 1st International Conference on Computational Physics, Boulder, CO, June 1990.

K. H. Kao and C. Y. Chow, "Axisymmetric Boundary-Layer Instabilities," presented at the IMACS 1st International Conference on Computational Physics, Boulder, CO, June 1990.

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