VORTEX STUDIES RELATING TO BOUNDARY LAYER TURBULENCE AND NOISE

J. L. Adelman
George Washington University
Joint Institute for Advancement of Flight Sciences
Hampton, Virginia 23665

and

J. C. Hardin
NASA Langley Research Center
Hampton, Virginia 23665

ABSTRACT

Knowledge of vortex dynamics is crucial to the understanding of boundary layer flow and its noise production, as well as structural fatigue caused by interactions between turbulent flows and various surfaces. The growing use of high-performance aircraft, rotorcraft, and other high-speed transportation systems in recent years has emphasized the need to understand such dynamics, since laminar flow control, interior noise reduction, and structural fatigue characteristics may be critical to the success of such vehicles.

Turbulent boundary layers are comprised of vorticity whose characteristics are defined by the flow direction and surface geometry. As a simple model of a boundary layer, the present study considers the two-dimensional case of an array of N rectilinear, like-sign vortices above an infinite flat boundary. The method of images can be employed with this configuration to reduce the problem to that of 2N vortices in free space, constrained by 2N symmetry relations. This system is Hamiltonian and therefore certain invariants of the motion are known. Further, from the Hamiltonian constant, the equations of motion are readily derived and may be integrated numerically to determine the vortex trajectories. This knowledge of the time-dependent vortex motion then allows the resulting noise radiation to be computed by standard aeroacoustic techniques.

(NASA-TM-87475) VORTEX STUDIES RELATING TO BOUNDARY LAYER TURBULENCE AND NOISE (NASA) 5 p HC A02/MF A01 CSCL 20D

N85-27139

Unclas

G3/34 23378

The model has been examined extensively for many different initial vortex configurations, including both trajectory and noise calculations. Several analytical and numerical characteristics of the interactions are observed. For example, for N=2, a criterion,

$$Y_1^{\gamma} Y_2^{1/\gamma} (X^2 + Y_o^2) > \bar{Y}^{\gamma+1/\gamma} (X^2 + Y^2),$$

where Y_1 and Y_2 are the initial heights of the two vortices above the plane, X and Y are their initial separations in the respective coordinate directions, Y_o is twice the average height of the vortices above the boundary, γ is the ratio of the circulations, and $\bar{Y}$ is the centroid of vorticity, for oscillating motion of the vortices can be derived. Such motion is periodic and therefore produces sound spectra containing only harmonically related discrete frequency components. Figure 1a is an example of the vortex trajectories in this case while Figure 1b is the resulting noise radiation to a fixed observer. The apparent modulation of the noise signal is due to the directivity of the noise source as it moves with respect to the fixed observer. When this criterion is not satisfied, the vortex motion is non-oscillating in nature and therefore produces very little noise. Figure 2a is an example of the trajectories in this type of motion while Figure 2b displays the resulting noise. In this case, the influence of the image of the vortex closest to the boundary causes it to convect rapidly away from the other vortex resulting in negligible interaction. The differences between these two cases are similar to those between laminar and turbulent boundary layers.

The analysis is extended for N>2. In this case, the phenomena of non-integrability and non-deterministic "chaotic" solutions occur. Examples of this type of motion are included.

The results of the study indicate that the separation of vortices is an important factor in the noise production of boundary layer flow. Thus, the possibility of control of this separation has implications to the development of turbulence within the boundary layer and its noise radiation and may offer a potential for drag reduction. However, it may prove difficult to obtain even a small degree of control over vortex spacing within a boundary layer. The possibility of doing this must be the subject of future experimental and analytical work.

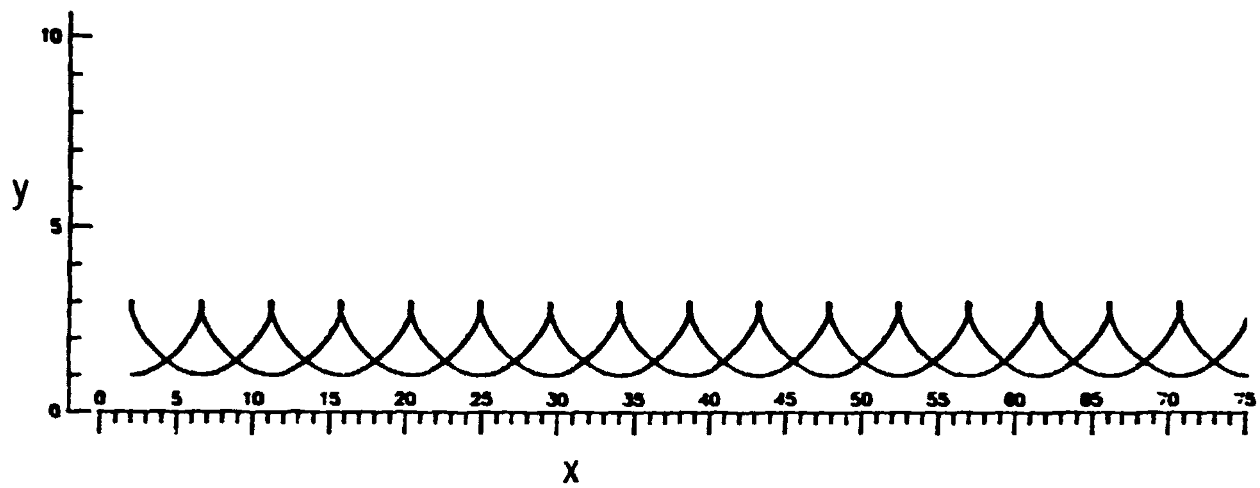

Figure 1a: Vortex Trajectories in Oscillating Case

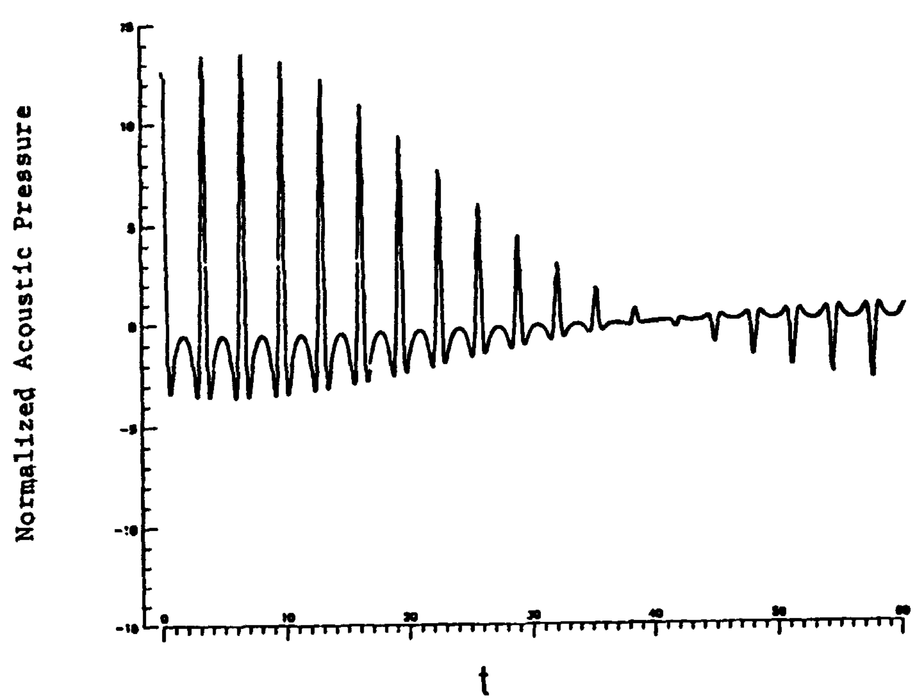

Figure 1b: Acoustic Time History in Oscillating Case

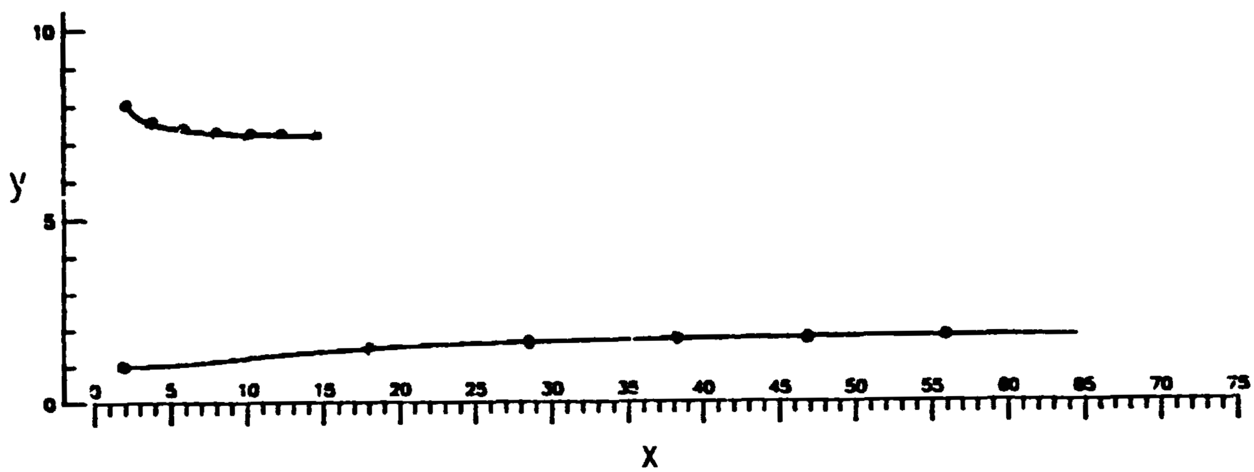

Figure 2a: Vortex Trajectories in Nonoscillating Case

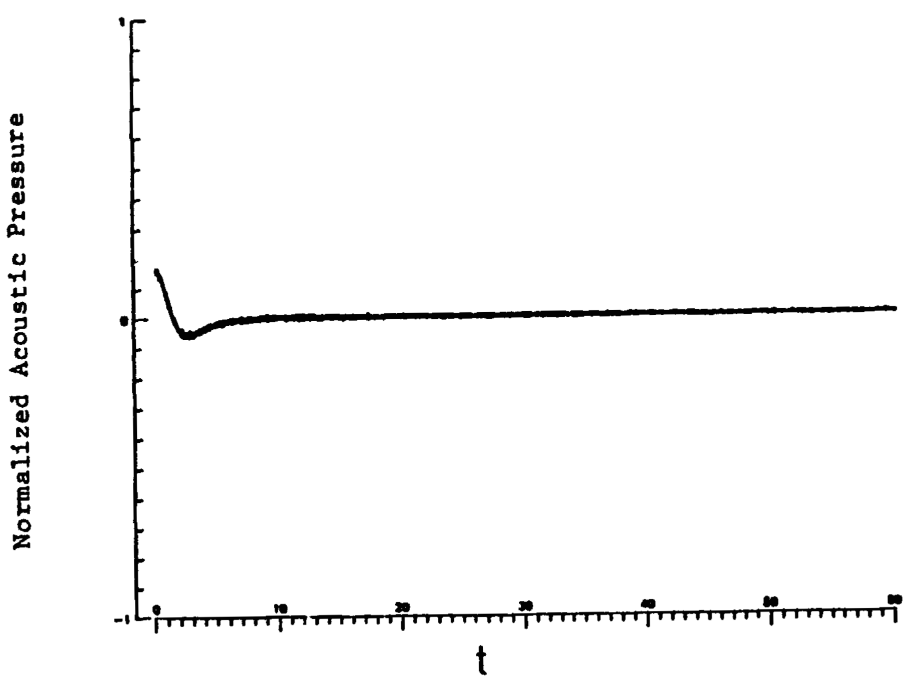

Figure 2b: Acoustic Time History in Nonoscillating Case