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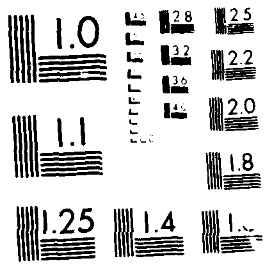

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Noise Generation and Boundary Layer Effects
in Vortex-Airfoil Interaction and Methods
of Digital Hologram Analysis for these Flow Fields

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The mechanism of sound generation and the kind of viscid interaction of vortices with airfoils in an airflow is investigated. Experiments have been performed in regular, quasi-stationary flow with vortices of a Karman vortex street. Depending on the dimensions of vortices and airfoils, their distance, and the flow Machnumbers, different kinds of upstream propagating sound waves occur.

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Noise Generation and Boundary Layer Effects in Vortex-Airfoil Interaction and Methods of Digital Hologram Analysis for these Flow Fields

Abstract

The mechanism of sound generation and the kind of viscid interaction of vortices with airfoils in an airflow is investigated. Experiments have been performed in regular, quasi-stationary flow with vortices of a Karman vortex street. Depending on the dimensions of vortices and airfoils, their distance, and the flow Machnumbers, different kinds of upstream propagating sound waves occur.

1. Introduction

Initial experiments with vortex airfoil interaction have been performed since 1983 at this institute (PART B of Contract DAJA 37-81-C-o251, 1981 - 1984 [1]). We still investigate a 2-dimensional flow in the present experiments. Also the theoretical considerations and calculations are based on this geometry.

A possible application of our results is found in the field of helicopter rotor noise. A vortex - the tip vortex of an advancing rotor blade - interacts with the following rotor blade. Blade-vortex-interaction is the main reason for helicopter rotor noise as shown in many papers, experimentally and theoretically [2].

2. Wind tunnel experiments

The duct is vacuum operated. An undisturbed flow period up to 20 seconds, depending on the flow Machnumber, can be achieved. In the test section the inlet walls are parallel with a distance of 100 mm. The maximum height is 600 mm and the length of the test section can be chosen as 600 mm or 1200 mm. In the side walls are windows of 230 mm diameter with interferometric quality for observation purposes. The vortex generator is a rectangular cylinder.

The first tests with the wake downstream of a bluff body of quadratic (40 mm * 40 mm) cross-section and the interaction with an NACA 0012 airfoil gave no obvious results according to sound generation but showed a lot of effects due to viscosity (PART B of Contract DAJA 37-81-C-o251, 1981 - 1984, previous results [1]). As it was cleared from shock tube experiments, where to find the important region of sound generation [1] wind tunnel experiments are now repeated with changed parameters. The cylinder has a cross-section of 14 mm * 20 mm and is placed in such a position, that only one row of vortices interacts with the airfoil. Now the conditions are similar to those in the shock tube, where the vortices are rotating towards the leading edge.

Various parameters are tested. At first the Mach number is varied from 0.6 to 0.9. Additionally we use different horizontal distances between the airfoil and the vortex row. Experiments are performed with three different airfoil shapes with chord length of 120 mm as well as with a large plate of 220 mm length.

Some preliminary results are shown in Fig.1. Three interferogams with density plots are evaluated by image processing. In the first picture the clockwise rotating vortex of the upper row of the vortex street is moving below the leading edge of the airfoil, while the stagnation point has moved upward. Here, at this instant of time, the pressure has a maximum as it is seen in the evaluated plots of the density. In the second picture the position of the stagnation point has changed and is back again in the state of the undisturbed flow. The vortex itself generates a supersonic flow regime at the lower side of the airfoil which ends with a shock. First hints for the resulting sound wave can be seen here. Upstream of the leading edge a density maximum in the flow is visible. In the 3D-plot even the decreasing density at the stagnation point can be seen. The density maximum ahead of the airfoil becomes stronger, what can be seen in picture 3, and moves upstream with the velocity of sound. In the upper part of the flow the steepening of the wave becomes obvious. This is a compressibility effect, some kind of a moving bow shock. Therefore we call this a compressibility wave.

The observed process is so fast, that only the region very close to the stagnation point can contribute to the sound wave. For theoretical consideration it follows from this experiment, that the interaction of the vortex with the leading edge area is essential for the peaky sound wave generation only. This leads to a model for the upstream sound generation, where only a half plate is needed.

3. Theoretical considerations

At first the incoming vortex changes the angle of attack, so that a downward force is acting on the airfoil. When the vortex has passed the leading edge, the angle of attack changes again and an upward force acts. With respect to the force term in the Ffowcs-Williams-Hawkings equation there is to take the time derivative of the forces for the pressure pulse in the far field. Thus the quick change of the forces on the airfoil is leading to a positive pressure pulse. But it should be expected that this had to be a symmetric peak. In contrary the experimental result shows a steep anterior side and a weak posterior side.

By comparing the shock tube and the wind tunnel experiments it is to argue whether the obtained sound waves are based on the same mechanism. It is easy to see that in the shock tube an N-wave appears, which is thinner than the wind tunnel wave. Furthermore the vortices in the shock tube have to pass very near by the profile to create a sincere wave. It seems to be that the region of sound generation here is more concentrated.

By this observation it is likely to suppose that a wave in the shock tube with the smaller vortices is established more locally in the nose area of the airfoil. This assumption is proved by last experiments with the wind tunnel, where both kinds of sound waves are observed. In the wind tunnel, however, these "shocks", which are merely monitored in strong interaction at the stagnation point, are rather seldom. Probably the size of the vortex core is an important parameter here. Until we get more experimental evidence for a common mechanism, we call these upstream moving shocks the N-wave type of vortex sound.

To establish a theory which satisfactory discribes these mechanisms, the following results should be regarded:

- the flow is transsonic
- the source distribution is not compact
- the volume effect of sound generation is not further neglectable
- a vortex model has to assure a good approximation of the vortex core

For more detailed information, further optimated measurements are neccessary.

4. Personnel:

With respect to personnel we have won for contract work Dipl.-Phys. H.-M. Lent and Dipl.-Phys. K.F. Löhr for the main experimental work. The evaluation of interferometric flow recordings is done by Dipl.-Phys. R. Wenskus and Dipl.-Phys. G. Shi. Some additional consulting is done by Professor P.A. Thompson and Dr. B. Stasicki.

5. References

[1] Meier, G.E.A.: Vortex-Airfoil Interaction and Application of Methods for Digital Fringe Analysis. Final Technical Report Contract Number DAJA 37-81-C-o251. MPI f. Strömungsforschung (1986).

[2] Schmitz, F.H. and Y.H. Yu: Helicopter Impulsive Noise: Theoretical and Experimental Status. IN: Aerodynamics and Aeroacoustics Standford University (1983).

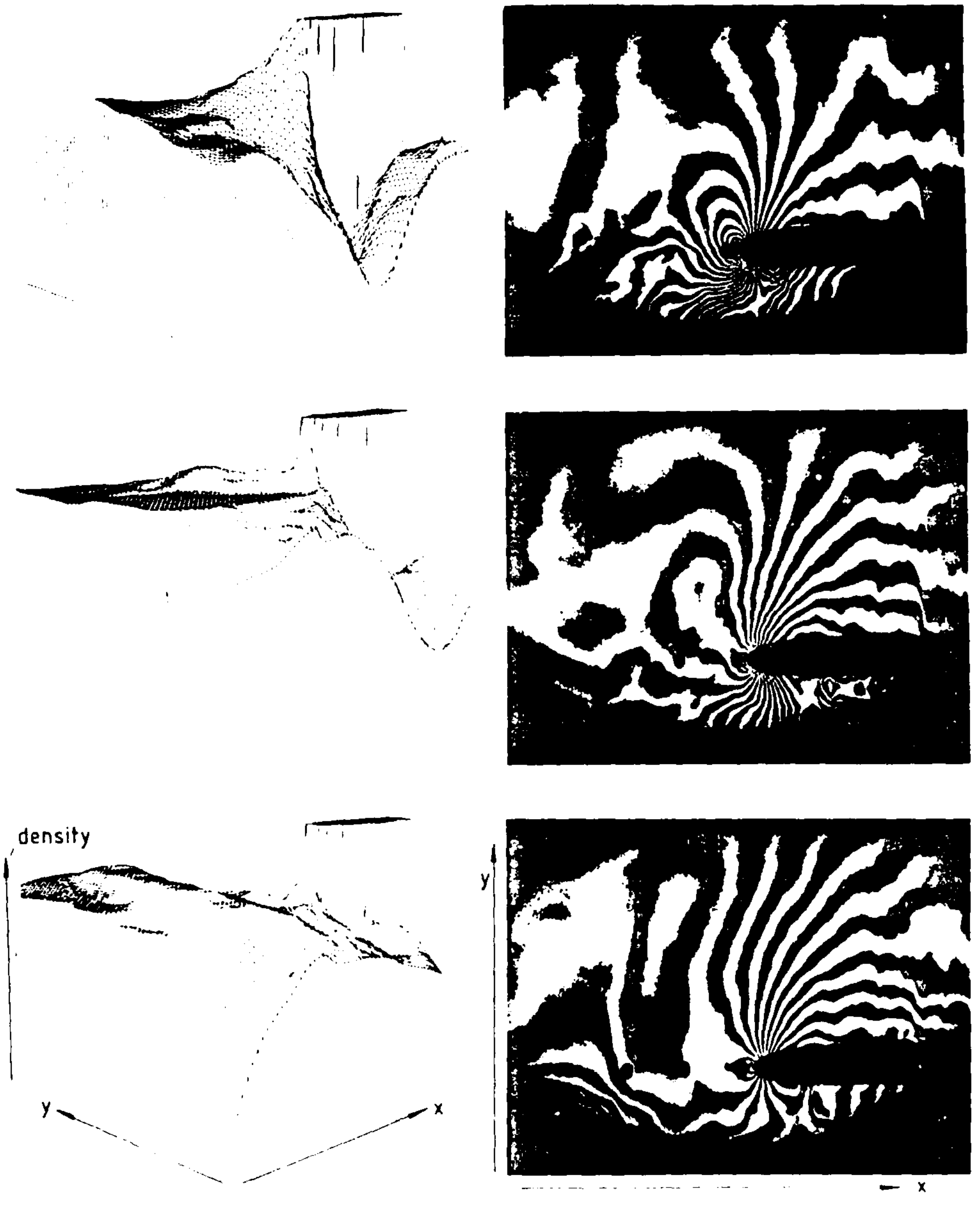

Figure 1: Generation of an upstream propagating sound wave by a clockwise rotating vortex after interaction with an airfoil (Airfoil SC 1095, Ma = 0.66, Δt = 0.13 msec.) Interferometric observations and their density calculations

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