MACH WAVE NOISE OF A SUPERSONIC JET

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ABSTRACT: Supersonic jets emit noise to the outside in form of Mach waves which are long, straight and have about equal angles. Many experimental and theoretical studies in the past did not allow a complete understanding of the phenomenon. Experiments by Oertel et al. [1] revealed that such Mach waves exist also inside the jet. The Mach waves inside and outside are visualized by single frame pictures (Fig. 1), by immobilization images (Fig. 2) and by streak records (Fig. 3). Differential interferometry (DI) is used for visualizing density differences by light intensity variations. Measuring the Mach wave angles in more than 300

Fig. 1 Jet differential interferogram

shock tube experiments revealed the existence of three wave families. They move with speeds w, w' and w'' which depend only on the jet Mach number M_i and the ratio a_a/a_i of the sound speeds outside (a) and inside (i) of the jet [1]:

$$\frac{w}{a_a} = \frac{M_i}{1+a_a/a_i} \quad (1), \quad \frac{w'}{a_a} = \frac{M_i + w/a_a}{1+a_a/a_i} \quad (2), \quad \frac{w'}{a_a} = \frac{M_i - w/a_a}{1+a_a/a_i} \quad (3) \; .$$

A theory has been proposed which explains the three equations. Its central point is the production of Mach waves by pairs of vortices. The front vortex creates the w'-Mach waves outside the jet and the rear vortex is accompanied by the w''-Mach waves inside. The w-Mach waves accompany the notch in-between both and are finally also formed when a front vortex combines with an overtaking preceding rear vortex. This process is suggested by immobilizations like those shown in Fig. 2 and the streak records in Fig. 3. In both cases the flow is observed through a slit on a rotating drum camera. Immobilizations are taken with a wide opened slit on the camera turning with the speed of the Mach waves to be observed. The streak records with a narrow adjusted slit show clearly the Mach wave traces.

This theory and the visualization techniques are discussed in context with recent scientific results, e. g. [2, 3] which are also based on the vortex pair assumption supporting the theory of Oertel et al. [1] which describes the vortex pair and Mach wave speeds w, w' and w'' by the formulae (1)-(3). The visualizations of Oertel et al. suggest that significant noise is only generated at the beginning of the free jet. More downstream by vortex pairing just the w-Mach waves are dominant and visible.

Fig. 2 Immobilization images
y-slit orientation

Fig. 3 Streak records:
upper x- and lower y-
slit orientation

References

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3. S. K. Lele, S. Mendez, J. Ryu, J. Nichols, M. Shoeybi and P.Moin. *Sources of high-speed jet noise: analysis of LES data and modeling*. Procedia IUTAM 1 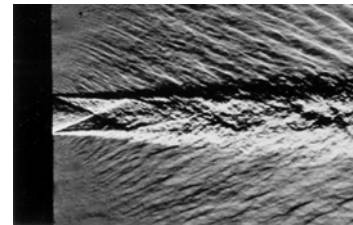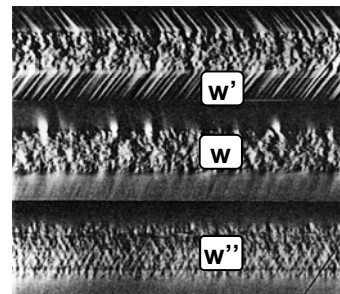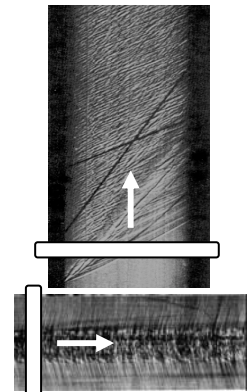2010 84–93, ELSEVIER Publication, 2010