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PROPELLER NEAR-FIELD AND NOISE RADIATION TO THE FAR-FIELD

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INTRODUCTION

Because of the necessity to reduce the fuel consumption, propeller aeroplanes are of rising interest. Such aeroplanes radiate sound from propeller and engine and thus annoy people especially in the neighbourhood of airports. However there is also a need to reduce the interior noise. International and national noise regulations are one way, development of new less noisy propellers and engines are another [1,2]. Research on propeller pressure signals [3,4], on ground reflection effects during overflight [5] is just as important as the development of special propeller noise measurement techniques [6]. The primary scope of this paper is to describe the propeller near-field and the radiation into the far-field.

EXPERIMENTS

Experimental investigations on propeller noise were conducted in the DFVLR Research Center/Braunschweig at widely varying conditions. Measurements on model propellers at different tip-Mach-numbers (up to one) and flow velocities were carried out in an Aeroacoustic Windtunnel [7]. Directivity pattern of airplane noise on stationary test stands were obtained. Propeller generated noise has also been recorded using a sailplane as microphone carrier in flyby positions thus avoiding wind effects and ground reflections. Finally microphones have been placed at different heights above ground to study the effects of ground reflections on level and spectra.

When conducting propeller noise experiments, in addition to the usual microphone measurement techniques, optical pulses were used - one pulse for every revolution of the shaft - in order to obtain a time reference for the acoustical propeller signals. Both signals and a time code are stored on a multichannel tape recorder. A digital FFT Analyser can be started by a time code trigger pulse precisely at a predictable time producing two channel time-histories and correlations as well as frequency spectra. Density gradients in the near-field of the propeller are detected by high speed schlieren movies.

DISTURBANCE PROPAGATION

Properties of the propagation of pressure disturbances can be investigated under the assumption of the mode of action and controlling it by experimental results: Pressure disturbances are generated continuously at the blade tip and propagate by velocity of sound as spherical waves superimposing in space. Following this principle resulting front waves can be constructed at every blade position. For better understanding and simplification graphic constructions are done in the plane of rotation and in a perpendicular one: Fig. 1 shows the reference frame. As a result of this procedure Fig. 2 shows the location of the resulting wave front due to the fixed blade position as shown. The spirally curved wave front originates from spherical waves which left the tip positions 1, 2, 4, and 6,e.g. This spiral is recreated at any blade location and has the identical curvature and position to the blade when tip speed is constant. Thus, the wave front traverses every point at blade passing frequency. The shape of the wave front and its position relative to the blade chord depends on tip Mach number (Ma_{tip}) (Fig. 3). Fig. 4a-4c shows the resulting fronts in the plane perpendicular to the plane of rotation and these wave fronts were detected in schlieren movies because of high density gradients. Two or more wave fronts are produced at $Ma_{tip} \geqslant 1$, when there are two or more pressure disturbances [8] at the blade tip, Fig. 5; these disturbances may originate from the leading and trailing edge or from the tip vortex region. The influence of axial airflow is shown in Fig. 6. A consequence of the formation of the wave front is that radial signal velocity can be greater than sound velocity as shown in Table 1. At two radial distances in the near-field ($r/R < 3$) the acoustical signal may arrive at the same time giving the idea of a blade coupled pressure field what indeed was measured but turns out to be only the effect of the front curvature. This is only a near-field effect, vanishing in the far-field because the spirals become circular after several revolutions. A quantitative picture of the type of experimental results obtained from two different model propeller is given in Fig. 7, where a system of graphs of pressure amplitude decay are plotted as a function of radius in the plane of propeller rotation. It can be seen that the amplitude decay cannot be described by a single power-function. In the neighbourhood of the tip ($r/R = 1{,}2$) the pressure drops rapidly at low tip Mach numbers and is proportional to r^{-8} up to r^{-4}, whereas at a Mach number of 1 the decay is of the order of r^{-3} up to r^{-2}. All curves tend to a power function of r^{-2} to r^{-1} at distances of about $r/R = 2$, indicating that the far-field decay ($p \propto r^{-1}$) is not yet reached. Standby tests of a Real Propeller demonstrate that even at a distance $r/R = 10$ the pressure decay is still higher than the condition, which is reached at about $r/R = 20$. Flyby experiments, practicable in distances $20 \leq r/R \leq 200$, yield a good fitting of the far-field decay.

The near-field results can be applied to the interior noise reduction, choosing a greater distance between the cabin and propeller-axis for instance at two-engined aircraft.

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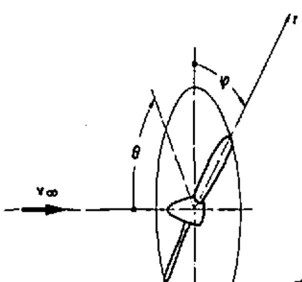

Fig.1 Coordinate System at the Propeller

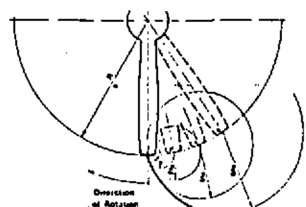

Fig.2 Pressure Front in the Plane of Rotation Formed by Disturbances

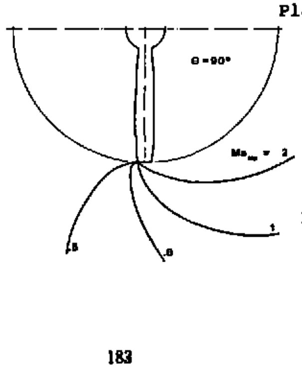

Fig.3 Pressure Fronts at several Tip-Mach-Numbers

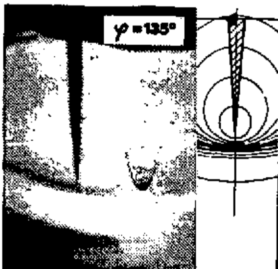

Fig.4a

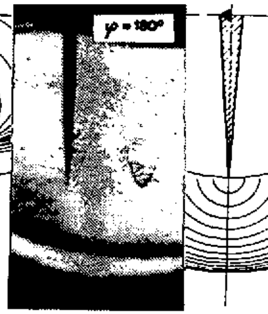

Fig.4b

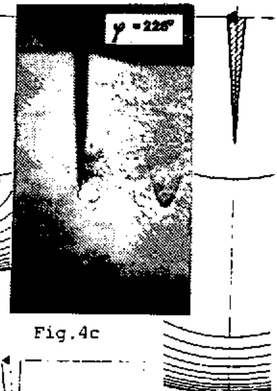

Fig.4c

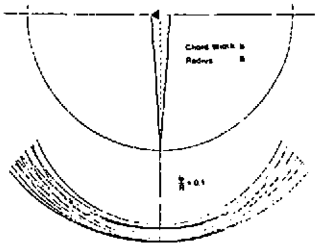

Fig.5 Two Wave Fronts Arising from Leading and Trailing Edge

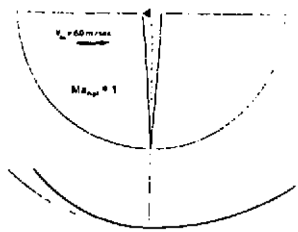

Fig.6 Influence of Forward Speed on the Wave Front

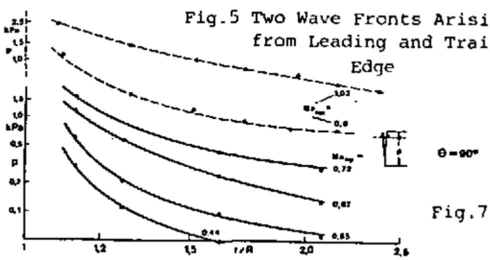

Fig.7 Pressure Decay in the Near-Field

$\bar{r}/R$	$Ma_{hel} = 0.8$ $\frac{V_{\bar{r}}}{a_o}$(gr.)	$\frac{V_{\bar{r}}}{a_o}$(ex.)	$Ma_{hel} = 1$ $\frac{V_{\bar{r}}}{a_o}$(gr.)	$\frac{V_{\bar{r}}}{a_o}$(ex.)
1.2	–	–	1.8	2.5
1.4	3.5	2.4	1.5	1.8
1.6	2.2	1.8	1.3	1.3
1.8	1.7	1.9	1.2	2.0
2.0	1.5	1.8	1.15	1.35
2.2	1.2	-	1.1	1.2

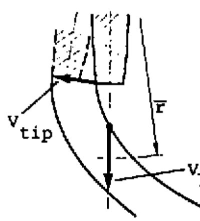

Table 1