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INSIGHTS INTO THE NATURE AND CONTROL OF ROTOR NOISE

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SUMMARY

This paper summarizes the present understanding of four important far-field rotating blade noise sources and highlights techniques for noise reduction. These four noise areas include the role of unsteady blade surface loads on rotational noise, the effect of turbulent inflow on the radiated broadband noise of an airfoil, the influence of the trailing vortex on impulsive noise and tail rotor noise, and the effect of blade geometry on high-speed impulsive noise. These noise mechanisms occur to varying degrees on both helicopter rotors and propellers.

Considerable theoretical work has been done in the area of high-speed impulsive noise resulting from the geometry of the rotating blade system. Both model and full-scale experimental correlation of helicopter and propeller high-speed noise are presented. The effect of blade number and airfoil thickness distribution in reducing the high-speed noise is shown. The ideas presented in this paper should be of special interest in light of the proposed federal helicopter noise certification rulings.

INTRODUCTION

In the V/STOL and short-haul aircraft market of the future, the helicopter and propeller-driven aircraft will comprise a significant part of the overall population. Noise requirements such as those currently being proposed for helicopters, which are dictated by operations into densely populated or quiet surburban areas, require that the designer have a better understanding of the complex noise-generating mechanisms.

Rotating blade noise is the primary noise component for these aircraft. For general aviation propeller-driven aircraft, engine exhaust noise could also become a dominant noise source. This paper, however, will deal with the noise problems associated with helicopters. This type of aircraft can have several significant noise sources. These sources are shown in figure 1. Even though the operating conditions vary widely for the various types of rotating blade propulsion systems, a generalized noise spectrum represents the radiated noise. This generalized spectrum is shown schematically and indicates in figure 2 the primary sources of interest. The first source is associated with steady blade loads which do not vary as a function of time or azimuth position. These loads are related to the torque, thrust, coning, and blade thickness. The second source is that due to the incoherent loads on a blade moving through the air and is referred to by Wright (ref. 1) as "self-noise." These latter nonperiodic noises are related to the viscosity effects of the air and arise from such phenomena as inflow turbulence, boundary layer, separated flows, and vortex shedding. The noise generated by the steady loads and the self-noise are components which are considered to be unavoidable with the operation of conventional rotating blades and thus constitute the minimum noise of the system (ref. 1). A third component of noise is termed "excess noise" and results from unsteady loading due to interaction with natural atmospheric turbulence, interaction with shed vortices, or blade operation in the transonic speed regime. These latter noises generally occur at a blade passage frequency in a range which is critical to detection and community annoyance.

Numerous investigations have established the effect and relationships of steady loads (ref. 2 to 4) and incoherent loads (self-noise) (refs. 5 and 6) on the radiated noise. The purpose of this paper is to identify the mechanisms and possible noise control approaches associated with the noise resulting from unsteady loading on helicopter rotor blades.

UNSTEADY NOISE

Role of Fluctuation Pressure

Fluctuating blade loads can be categorized broadly as both periodic and nonperiodic. These loads may arise from such phenomena as blade vibrations, cyclic blade input, localized shock effects, and potential field interactions. By using current rotational noise prediction techniques, improved agreement between predicted and measured noise requires a knowledge of these high-frequency fluctuating aerodynamic blade loads. Figure 3 shows highlights of tests conducted on the Langley helicopter rotor test facility (ref. 7). These tests included simultaneous measurements of high-frequency fluctuating surface pressures and far-field radiated noise made on a full-scale nontranslating rotor system. Spectral characteristics of measured blade surface pressures were then applied to the existing compact rotational noise theory and compared with measured far-field noise. A comparison of the calculated and measured rotational noise showed that good agreement was obtained by using a 40-percent chordwise integration of the measured fluctuating blade loads acting at a single point on the blade. Reliable information concerning the variation of these fluctuating loads with flight condition is still not available.

Vortex Interaction

Main rotor.- The effect of free air turbulence on the discrete noise from rotating blade devices having skewed inflow is apparently small. Skewed-inflow rotating blade devices (helicopter rotors and tilt rotors), however, are affected by the rapid pressure fluctuations caused by a shed vortex passing close to a lifting surface. One of the largest contributions to helicopter noise, when it occurs, results from the interaction of the shed blade tip vortex and the following blade. This "slapping" noise can be very significant from an annoyance and detectability standpoint. In figure 4, vapor condensation shows the shed vortices for a hovering commercial helicopter. In forward flight and at certain rates of descent these vortices go through the rotor disk and interact with the rotor blades and result in rapid pressure fluctuations and impulsive noise. Figure 5 presents schematically the regions of helicopter impulsive noise due to vortex interaction and high-speed effects. High-speed effects are treated in a later section. This figure is a means of mapping the flight regions (rate of descent and airspeed) where impulsive noise becomes a problem. The blade slap boundary map has been used to determine flight path management techniques to reduce terminal area noise levels (ref. 8).

The lack of adequate experimental acoustic data, which can be used to identify the basic noise mechanisms and the radiation patterns of helicopter impulsive noise, can be traced to a variety of measurement difficulties; this lack of data forced past investigators to utilize qualitative observations and limited measurements to judge the extent of the blade slap problem. The most common method of measuring impulsive noise is to station a microphone at a fixed position on or above the ground and fly the helicopter along nominal trajectories at selected forward-flight conditions. Under ideal conditions, a quantitative assessment of the character of the noise is possible. However, when one tries to compare, in detail, the noise produced by the same aircraft under different flight conditions, or to develop directivity patterns of the radiated noise holding all other pertinent variables constant, such as distance to the microphone, azimuth angle, and ambient wind effects, the technical problems and statistical uncertainties combine to make the data-gathering task very difficult.

Several inflight techniques for obtaining impulsive noise measurements have been developed. The inflight acoustic measurement system (IFAMS) is a research tool designed to study these phenomena. Typical pressure time histories measured with IFAMS are shown in figure 6. By providing a microphone array close to the acoustic source, source location, near-field spectral characteristics, and pressure signatures can be obtained. The data on the left of figure 6 show a pressure time history and spectrum from the advancing side microphone, and data on the right are from the retreating side. The flight conditions are 36 m/sec (70 knots) airspeed and 183 m/min (600 ft/min) rate of descent. The advancing side pressure time history shows discrete amplitude spikes attributable to main-rotor blade and vortex interaction at main-rotor blade passage frequency. The retreating side pressure time history shows no distinguishing pressure peaks and is about 20 dB below the noise level of the advancing side.

Another inflight measurement technique utilizes a quiet, fixed-wing aircraft, instrumented with a microphone, and flown to maintain a fixed relative position with the test helicopter. Results of flight tests using this method are reported in reference 9. This technique can be used to obtain far-field noise measurements without Doppler shift.

Various attempts to modify the tip vortex and thereby reduce the vortex-induced excess noise have been tried. These attempts have been both passive (blade tips) and active (air mass injection). The results of an investigation with a linear air mass injection system on a 2.1-m diameter (7 ft) wind-tunnel model are shown in figure 7. The objective of this investigation was to determine whether the accelerated vortex aging by the air injection would reduce the noise. The left-hand pressure time history and spectrum come from the rotor in a descent condition that results in the maximum interaction impulsive noise. The interaction peaks in the pressure time history are clearly visible. When air is introduced at the blade tips into the vortex core, the resulting pressure time history is obtained as shown on the right-hand side. The interaction peaks on the pressure time history have been substantially reduced, and the overall sound pressure level has been reduced approximately 5 dB(A).

Tail rotor.- In addition to the effect of the vortex of a following main-rotor blade, the effect of the vortex plays an important part in the noise generated by the tail rotor. A research model was constructed, and a wind-tunnel investigation was conducted to determine the effect that the shed vortex from the main rotor had on the noise generated by the tail rotor. Figure 8 shows a picture of the model and some initial test results. The model has the capability of independent rotor speed control, variable thrust on both rotors, variation of the direction of tail-rotor rotation, and placement of tail rotor relative to the main rotor.

The spectra shown in figure 8 indicate the effect of main-rotor wake on the tail-rotor noise at increasing airspeeds. The predominant discrete harmonics are those due to the tail rotor. It can be seen that the general overall noise level increases with increasing airspeed. As airspeed is increased, tail rotor and vortex interactions occur at different positions on the tail-rotor disk and thus affect different harmonics. In addition, it was ascertained that tail-rotor noise was sensitive to the location of the vortex interaction on the tail-rotor disk, the direction of tail-rotor rotation, the lateral fin-rotor spacing, and the thrust direction of the tail rotor. Tail-rotor noise was found to be insensitive to the main-rotor thrust coefficient, longitudinal spacing of tail rotors, and the tail-rotor ratios of rotational speed to main-rotor rotational speed. The results of this study offer several approaches to reduce the noise of the tail rotor.

High-Speed Flow

Impulsive noise from helicopters can also originate from compressibility phenomena. Figure 5 schematically indicates that part of the flight regime where this type of noise becomes an increasing problem. Certain techniques can be used to push this boundary to higher speeds, but will never eliminate it. If the operational emphasis is on high-speed flight, then this source of noise will be important in determining en route flight limitations.

The two main sources for high-speed noise are the periodic pressure distributions due to unsteady shock formations on the advancing side and the monopole noise due to blade thickness and planform.

A recent theoretical prediction technique (ref. 10) based on a noncompact acoustic source model is directly applicable to high-speed propellers and rotors. Figure 9 shows a comparison of measured and calculated pressure time histories of a helicopter flying at 165 knots over a microphone. The advancing tip Mach number is 0.89. The two time histories agree very closely; the calculated pressure signature is based only on thickness noise. The effect of the tail rotor can also be seen in the measured pressure time history. By using this theory for high-speed rotating blade noise, an analytical tool exists for developing means of reducing high-speed rotor noise. An example of the use of the theory for noise reduction is highlighted in figure 10. Pressure signatures were calculated for three nonlifting rectangular planform blades with different airfoil sections. The airfoil sections are a biconvex parabolic arc, a NACA four-digit symmetrical airfoil, and a supercritical airfoil, all with a 9.3-percent thickness ratio. The flight conditions were held constant for all three airfoil cases. From this figure, it is obvious that reduced noise levels have been achieved with the biconvex airfoil section. Camber shape does not enter into the analysis of thickness noise, but does govern airfoil lift characteristics; therefore, one can theoretically obtain suitable aerodynamic characteristics and lower high-speed impulsive noise by controlling the airfoil thickness distribution.

NOISE CONTROL TECHNIQUES

There are several basic approaches for the control of the unsteady load noise sources. These techniques can be categorized into three major areas: those involving detailed design changes such as rotor blade tip design, those involving overall configuration changes such as an increase in the number of blades, and those pertaining to changes in operation procedures. Table 1 outlines these noise control approaches for the four primary noise sources.

CONCLUDING REMARKS

It has been pointed out that the general noise spectra for a number of free, rotating blade systems are the same and that the excess noise is the primary contribution to annoyance and detectability. The excess noise is made up of various sources of unsteady loads such as the ingestion of natural atmospheric turbulence, vortex and lifting surface interaction, and transonic flow phenomena.

The effect of shed vortex modification (reduced strength, etc.) has a significant effect on reducing the impulsive noise associated with helicopters operating in the terminal area. Lastly, it was shown that by careful attention to blade airfoil and planform, the high-speed impulsive noise boundary can be pushed to higher flight speeds; thus the helicopter could cruise more economically.

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TABLE 1.- NOISE CONTROL SUMMARY

NOISE SOURCE	NOISE CONTROL APPROACH		
	DETAIL DESIGN	OVERALL CONFIGURATION	OPERATIONAL PROCERURES
NONUNIFORM INFLOW		✓	
MR VORTEX INTERACTION	✓		✓
MR/TR VORTEX INTERACTION	✓	✓	
HIGH-SPEED THICKNESS	✓		✓

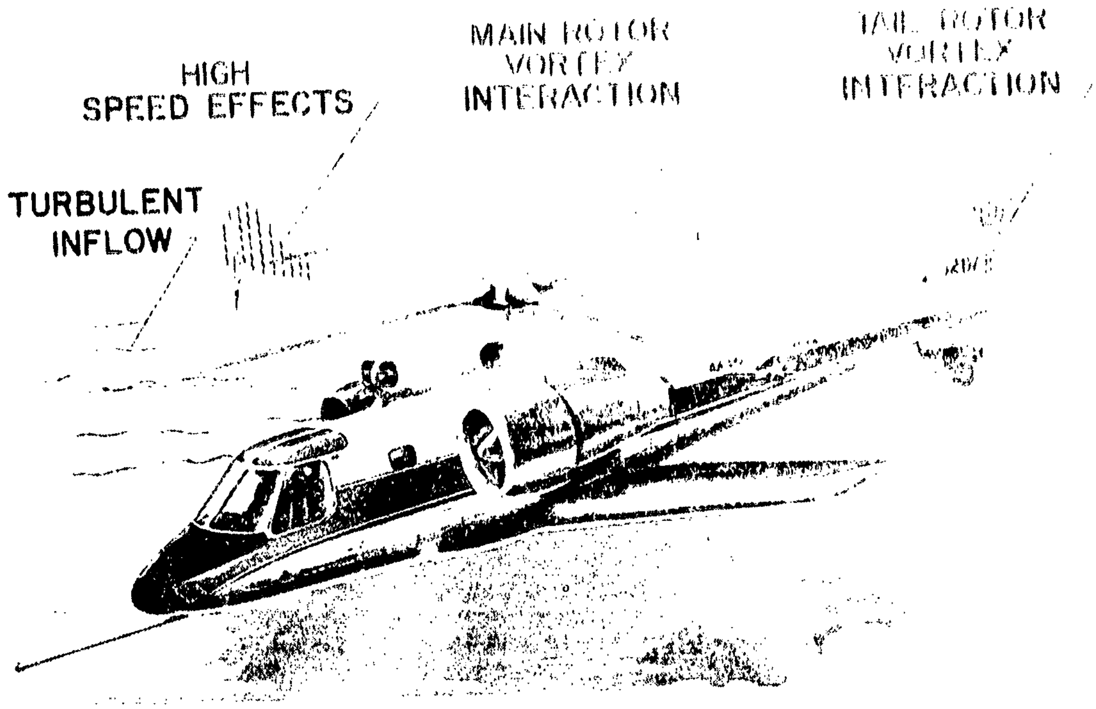

Figure 1.- Pictorial representation of rotor noise sources.

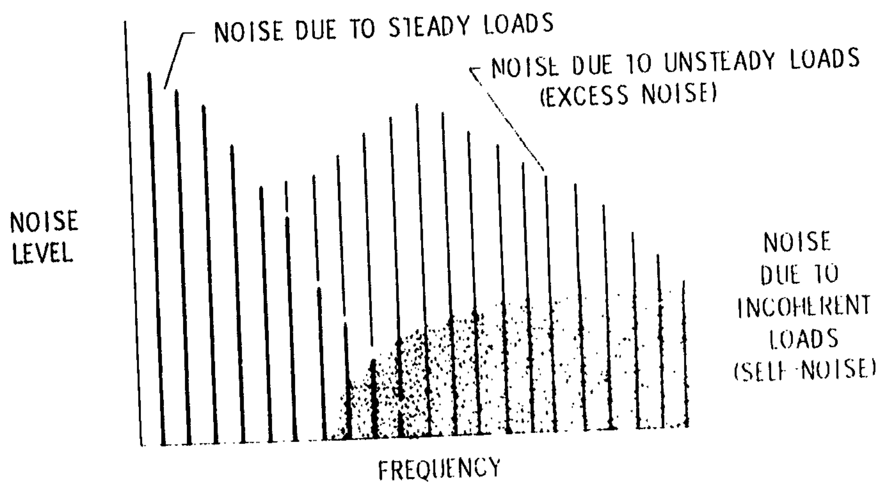

Figure 2.- Generalized acoustic spectrum for rotors.

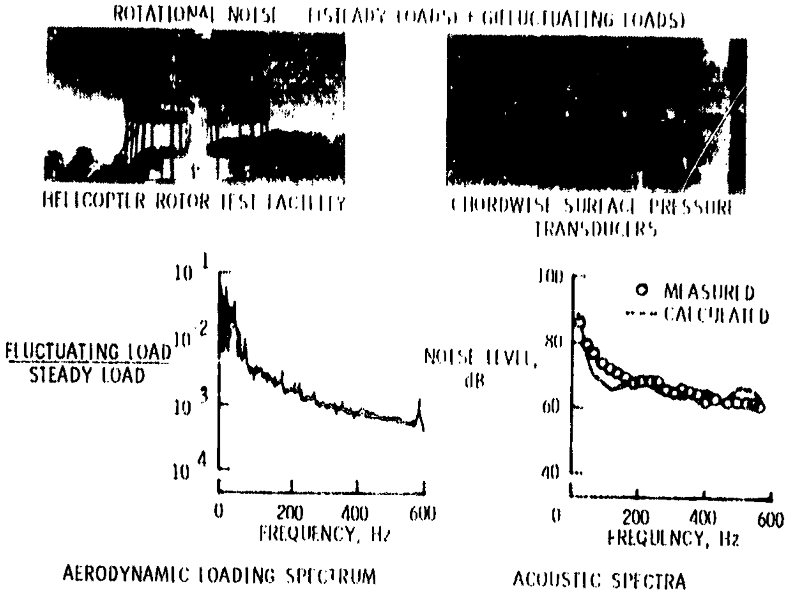

Figure 3.- Comparison of measured and calculated noise spectra using high-frequency fluctuating airloads.

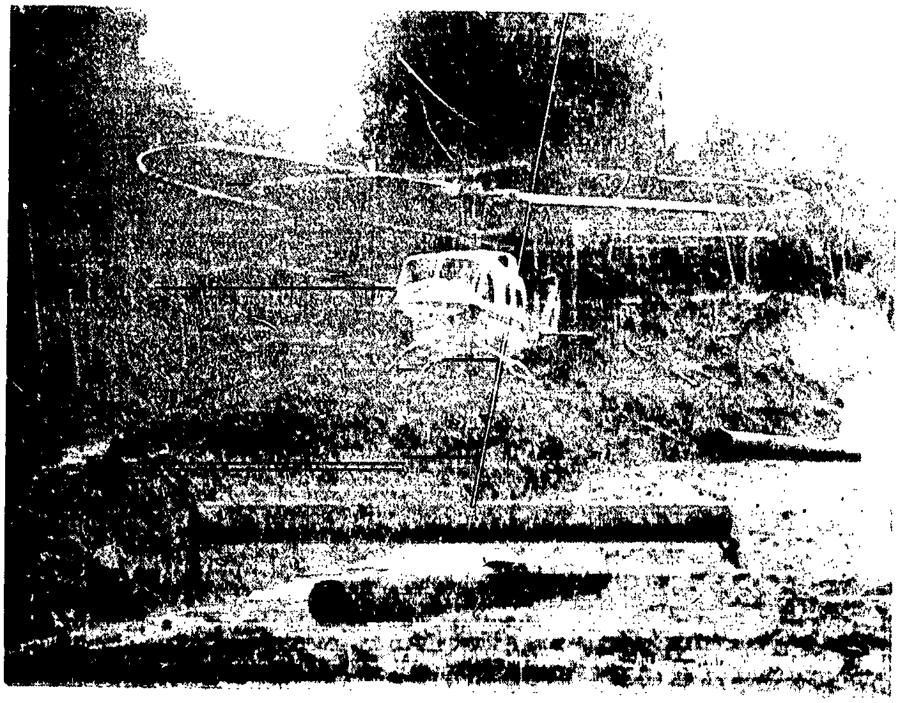

Figure 4.- Main-rotor vortex flow visualization for a hovering helicopter.

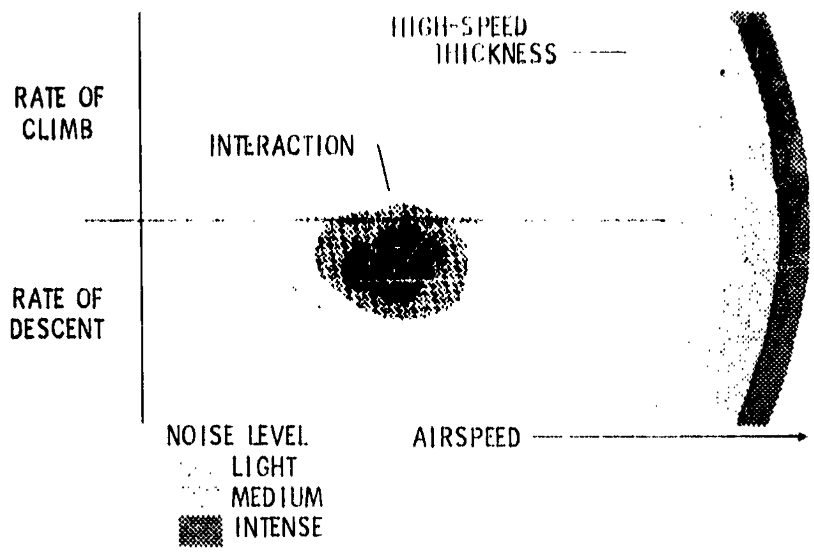

Figure 5.- Regi ~s of flight where helicopter impulsive oise can be expected.

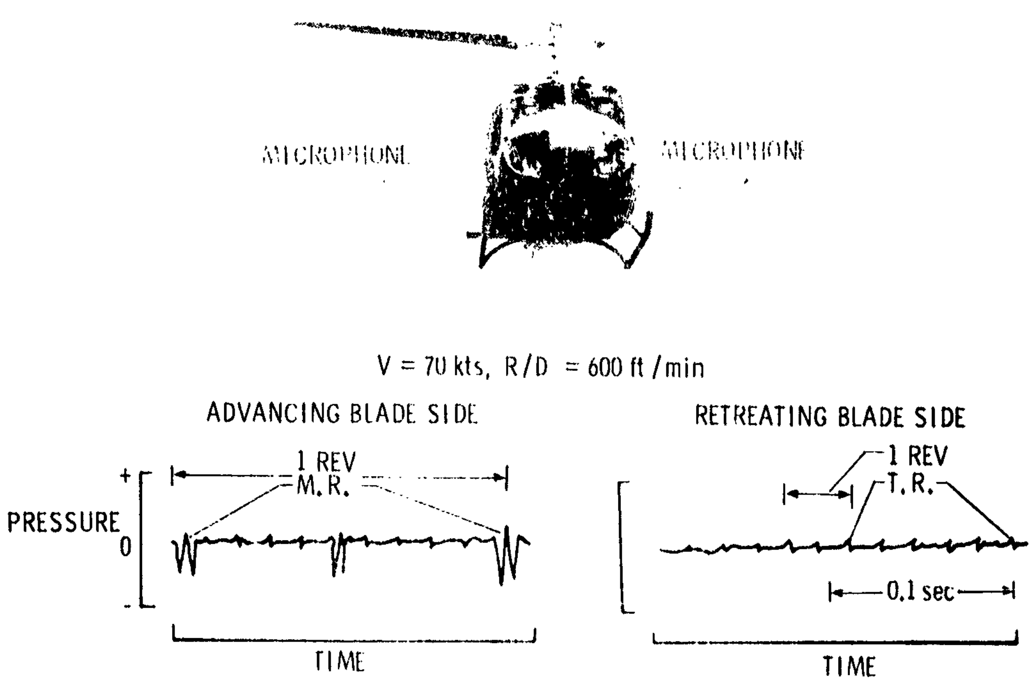

Figure 6.- Near-field measured acoustic pressure waveforms on the advancing and retreating side of a helicopter in descending flight.

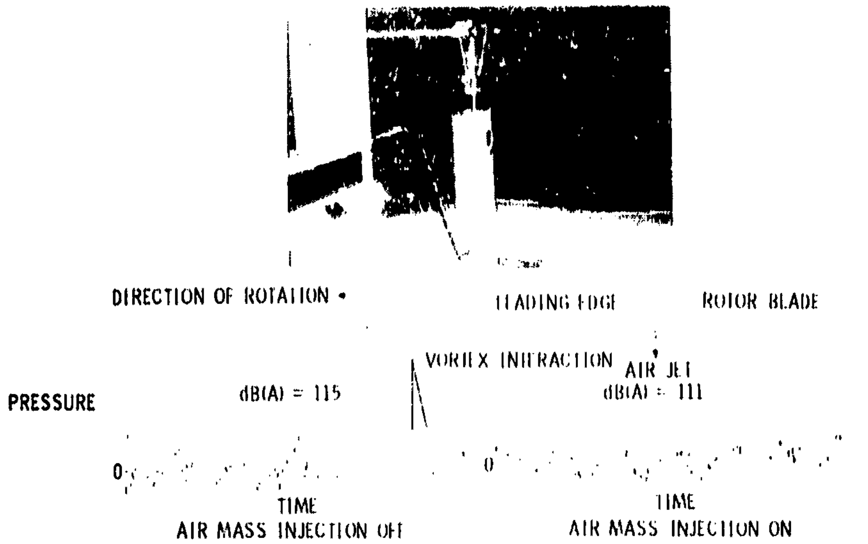

Figure 7.- Wind-tunnel verification of the effect of vortex modification on rotor impulsive noise.

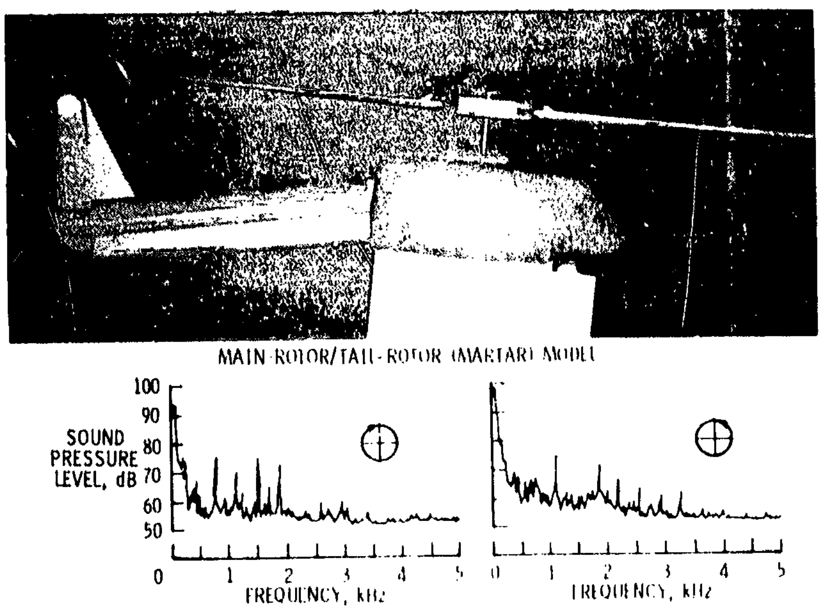

Figure 8.- A preliminary result obtained from the main-rotor/tail-rotor model showing the effect of tail rotor rotation and wake interaction on tail-rotor noise.

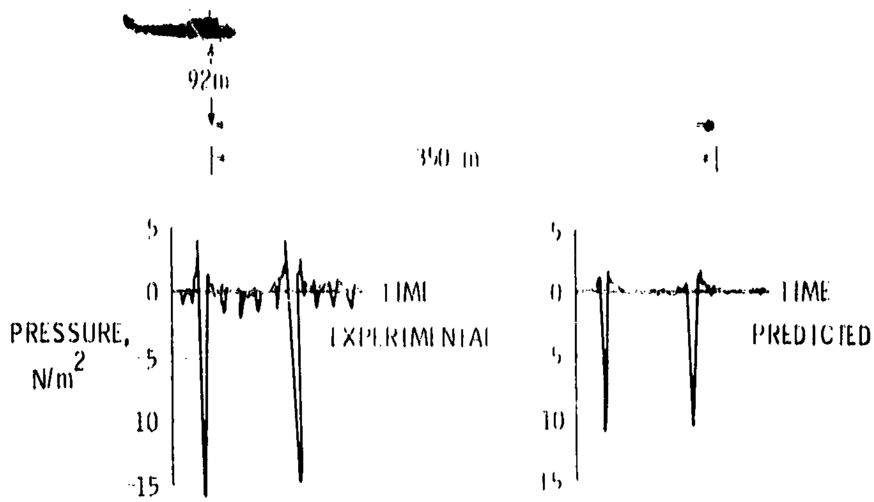

Figure 9.- Comparison of measured and calculated sound pressure signatures for high-speed helicopter rotors.

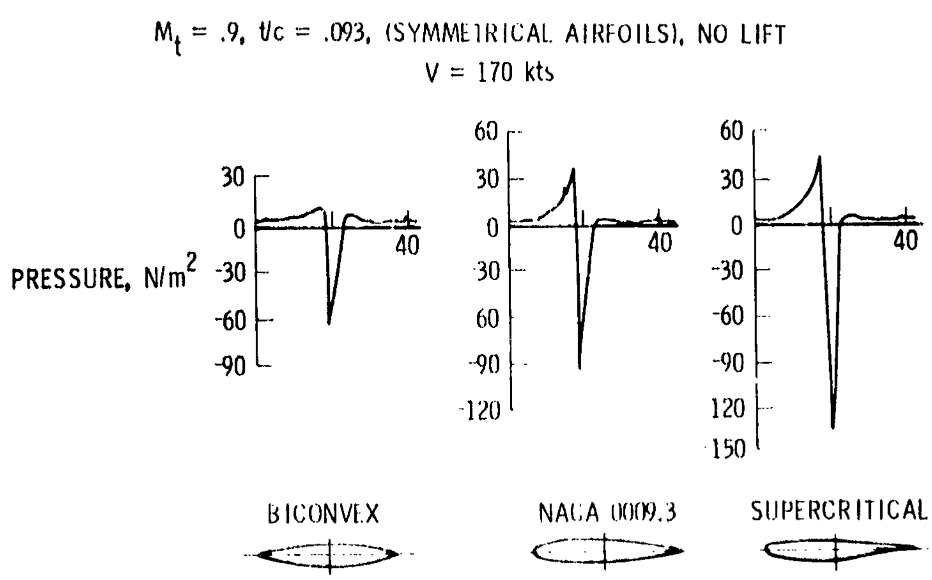

Figure 10.- Calculated sound pressure signatures of a rotor showing the effects of three different airfoil thickness distributions.