AEROACOUSTIC RESEARCH — AN ARMY PERSPECTIVE

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SUMMARY

A short perspective of the Army aeroacoustic research program is presented that emphasizes rotary-wing, aerodynamically generated noise. Exciting new breakthroughs in experimental techniques and facilities are reviewed which are helping build a detailed understanding of helicopter external noise. Army and joint Army/NASA supported research programs in acoustics are leading to a rapidly developing technology which promises to reduce the noise of future helicopters without severe performance penalties.

INTRODUCTION

The Reforger 76 NATO exercises reinforced the Army's concept of aviation's role in the combined arms team. The Army has considerably expanded its use of the helicopter to include the traditional functions of land combat mobility including intelligence, firepower, combat service support, command control, and communications. The use of the helicopter by ground forces has added another battlefield dimension by enhancing the ability to conduct land combat functions.

The unique maneuvering capability which has made the helicopter so valuable has also brought with it unique acoustic problems (fig. 1). High tip speed rotors are one source of aeroacoustic near- and far-field noise which is unique to rotary-wing vehicles, and this noise has a very distinctive character. It is responsible for large detection distances, severe community annoyance, and can significantly influence internal noise levels. High-speed and power transmissions, shafts, and engines also contribute significantly to both internal and external noise levels. Although the helicopter has become an integral part of the Army airmobile concept, its usefulness and acceptance can be enhanced if detectability, annoyance, and internal noise levels can be reduced with minimal loss of its desirable performance capabilities.

In response to these problems, the Army has focused its acoustic research program on those noise sources unique to rotary wing. Initially, the program attempted to apply existing technology to alleviate the high noise levels. After determining that the technology was inadequate, the emphasis of the program shifted. Today, the Army program emphasizes a more fundamental approach — to isolate the most offending sources, to analytically describe their dependence, and then to control helicopter noise with a new, more accurate technology in a cost-effective manner. This research is being performed in-house, in joint participation with NASA and through contracts with industry and universities.

AEROACOUSTIC RESEARCH

For purposes of this paper, it is convenient to separate the noise sources into two broad categories: first, noise of aerodynamic origin from main or tail rotors which will be referred to as rotary-wing aerodynamically generated noise; and second, the helicopter noise that originates from the generation and distribution of power or mechanical vibrations which we can call power- and mechanically generated noise. The Army research programs involve all noise sources, but the main emphasis of this paper is on the first category.

Some indication of the extent of Army-supported research is indicated in table 1. Of particular significance are the joint Army/NASA programs which make available special facilities and/or joint resources to provide a sound rotary-wing acoustic technology base of mutual benefit to commercial and military helicopter development. The Army rotary-wing acoustic technology program is highly dependent on the special skills and capabilities provided by the universities and industry, largely through the Army Research Office (ARO).

ROTARY-WING AERODYNAMICALLY GENERATED NOISE

Rotary-wing aerodynamically generated noise can be further broken down into conventional categories of high-speed impulsive, blade vortex interaction, broadband, and inflow turbulence noise sources. There have been several excellent technical summaries over the years which have described what was known about each source of noise (refs. 1-6). By reading them in the listed order, one can gain a feeling for the rapid progress being made in the field of rotary-wing acoustics. Of these sources, one of the most objectionable is the high-speed impulsive noise source. When rotor tip speeds are high, whether due to high rotational tip speeds or combinations of rotational and translational velocities, large pressure waves are propagated out from the rotor disk plane.

Due to the complexity of the problem, it has been very difficult, if not impossible, to isolate and identify the contribution of the separate sources to the total helicopter-generated noise. Isolated tests of rotors in wind tunnels or fly-by measurements are plagued with additional complications associated with reverberation, the peculiar rotor noise directivity, and other complicating factors. A technique was sought which would allow direct measurement of a helicopter far-field noise radiation pattern without inducing complications associated with reverberated pressure waves and other conventional constraints. These objectives required noise measurements of a helicopter when operating in its own environment.

An in-flight noise measurement technique was developed that allows the elicopter to operate under desired conditions in free space while the microhones and recording equipment are supported on a quiet fixed-wing aircraft hat is capable of maintaining the microphone at the desired position fixed elative to the rotor (fig. 2). (Symbols used in the figures are defined in he appendix.)

The in-flight helicopter noise source calibration experiment was first onducted utilizing an OV-1C as the microphone support and recording station nd a UH-1H helicopter as the test aircraft (ref. 7). The aircraft were flown n close formation with the UH-1H helicopter, maintaining position and disance behind the OV-1C aircraft. The free turbine engines allowed the OV-1C ropeller speeds to be selected to minimize interference with the rotor fundaental and harmonic frequencies. From this first experimental in-flight elicopter noise measurement test, the first true picture of the high-speed mpulsive noise and blade vortex interaction noise radiation patterns was ecorded. Some unexpected results were obtained and previous techniques used or UH-1H noise abatement operations had to be abandoned as ineffective.

In addition, the details of the recorded time history of the pressure aves raised questions as to the validity of theoretical predictive techniques nd provided a strong emphasis for better data with lower background noise evels. An idealized pressure time history or wave form (fig. 3) shows the arge negative pressure wave associated with high-speed impulsive noise. This eak negative pressure increases as the tip Mach number increases. Also shown re several positive pressure pulses which occur just prior to the negative pike: the positive spikes are caused by blade vortex interactions. Recorded n-plane pressure signals of the UH-1H (fig. 4) show how the peak negative ressure increases with forward speed: the negative peak pressure increase ith forward velocity from 80 to 100 and to 115 knots is similar in level light, 122 m/min (400 ft/min) and 244 m/min (800 ft/min) rates of descent.

Note, however, that the positive pressure spikes attributed to blade ortex interaction increase from the top left to bottom right. Intuitively, ne would expect blade vortex interaction noise to be maximum at a consistent orward velocity to descent rate ratio which results in the tip vortex emaining in the rotor disk plane where intersections occur with following lades. As would be expected, this noise level also increases as the blade elocity or Mach number increases. The success of the in-flight test echnique in producing interference-free time-pressure histories and irectivity patterns of different rotor noise sources proved the concept and increased the desire to find an improved microphone platform.

Fortunately, an almost ideal quiet flying platform had been developed in very limited quantities by the U.S. Army for surveillance and target acquisition. The aircraft, designated the YO-3A (fig. 5), was an extensively modified Schweitzer 2-32 sailplane that saw only limited service during the last Asian conflict. They were surplused to other government agencies, and the F.B.I. acquired two of the few remaining "YO-3A quiet aircraft." The Aeromechanics Laboratory borrowed one of the F.B.I. aircraft and instrumented it for acoustic testing (ref. 8) in a similar manner to the OV-1C (fig. 6). In addition to a tail-mounted microphone, wing-tip microphones were used to gather data for noise source identification. The background noise of the YO-3A is about 15 dB below that of the OV-1C, thus assuring excellent signal-to-noise levels.

A sample of the quality of data obtainable by in-flight measurements with the YO-3A is shown in figure 7 for the UH-1H helicopter. At 80 knots forward speed and 122 m/min (400 ft/min) descent rate, even though the tail rotor is about 13 tail rotor diameters from the microphone, the impulsive pressure wave is discernible. Main rotor positive pressure spikes from blade vortex intersection and the high-speed impulsive negative pressure pulse can also be clearly seen. Note the symmetry of the high-speed pressure pulse at 80 knots in comparison to the very rapid pressure recovery at 115 knots. The obvious advantages of the in-flight technique utilizing the YO-3A aircraft for acoustic calibration or rotorcraft led to measurements for the Army SSEB during evaluation of both the UTTAS (fig. 8) and the AAH helicopters (fig. 9). Unfortunately, the recorded data cannot be released because of security classification; however, all four of these helicopters exhibited the same characteristic high-speed impulsive noise and the blade vortex interaction noise. The magnitude and degree of presence of these characteristic sources differed between the aircraft but were present and detectable in each.

The data collected by in-flight measurement are serving another important purpose. It has demonstrated the validity of using scaled model rotors to experimentally measure, in acoustically treated wind tunnels, high-speed impulsive noise (ref. 9). As shown in figure 10, the wave forms are nearly identical although there is a difference in geometric scale of 7 to 1. Figures 10 and 11 show that the shape of the peak pressure variation with tip Mach number and the peak pressures are also in good agreement. Small-scale wind-tunnel tests provide the opportunity to utilize laser velocimeters, flow visualization techniques, and other specialized instrumentation to investigate this noise source.

The steepening of the high-speed impulsive negative pressure recovery at high forward speeds leads one to speculate as to the cause of this unexpected change. If the same noise source could be studied in the simplest of all rotor operating conditions (hover), additional insight could be obtained. The hovering rotor also affords opportunities to utilize specialized instrumentation.

The U.S. Army, in cooperation with NASA, has developed a very specialized facility capable of testing model rotors (fig. 12). The facility is acoustically treated to eliminate acoustic reverberations down to 110 Hz. The flow enters from the roof and passes through acoustically treated passages that attenuate external ambient noise; the flow then passes at very low velocity into the room. The rotor wake is the driving force as the wake passes into the ejector, under the lower floor, and out the end doors; fresh air is drawn in through the top of the building. Both aerodynamic performance and acoustic measurements can be made. Model rotors up to 2.4 m in diameter can be tested on the metric drive system which is capable of providing up to 89.52 kW (120 hp) and over 3000 rpm (fig. 13). This facility as been used to obtain high-speed impulsive wave forms of the same 1/7-scale H-1H rotor used in previous wind tunnel tests.

A sample is shown in figure 14 (from ref. 10). Note the very rapid ressure recovery which is not predicted by theory. The shapes of the experiental and theoretical curves are totally different and the peak pressure is nderpredicted by a factor of 2. The experimental wave form is essentially dentical in shape to those obtained at M = 0.9 in both the wind tunnel and on he full-scale UH-1H in flight, free from interference. It must be concluded hat the theoretical model is inadequate.

Figure 15 shows that the peak negative pressure is also not predictable or is the variation of the peak pressure with Mach number. A great deal of rogress has been made. Although the theory has been shown to be inadequate, technique to measure full-scale interference-free helicopter-radiated noise as been developed, and it has been shown that small-scale rotors can be used n hover and wind tunnels to simulate the full-scale, high-speed impulsive otary-wing noise source.

The wind tunnel also holds promise of providing the necessary tool for xperimental investigations of blade vortex interaction noise (fig. 16). The uestion of how Reynolds number affects this noise source has not yet been dequately answered. Larger scale models or boundary layer transition strips ay be required to simulate the full-scale blade vortex interaction effects.

Recent experimental investigations in both model-scale and full-scale flight have shown that rotor blade tip shapes can, in fact, alter the power required and radiated noise of helicopter rotors. These results are in agreement with what many helicopter enthusiasts have believed possible for a long time but had not been proved until recently. The Ogee tip shape flown on a UH-1H helicopter has both increased the aerodynamic efficiency and reduced the total radiated noise (ref. 11).

Further refinements and improvements are sure to follow once the effects of the Ogee tip are fully understood. A great deal of theoretical effort combined with well-conceived experimental programs is required to provide a basic technology from which improved blade geometry will result in reduced blade vortex interaction noise. The detailed problem of vortex formation must be examined and the rotor flow field defined with sufficient accuracy such that the vortex size, strength, and spacial location can be determined.

BROADBAND NOISE

Although on sounder footing, broadband noise is probably a more complex problem because of its sensitivity to both turbulence levels and the rotor wake (ref. 5). Obtaining high quality experimental data is more difficult in that the background noise must be lower, the frequency of broadband noise is higher, and Reynolds number is likely to be a very important parameter. The acoustic rotor hover facility and small-scale rotor tests in wind tunnels may be beneficial in defining the sensitivity of the broadband noise to the scaling parameters. However, in-flight noise measurements will be required to assess the magnitude of the errors induced by scaling effects, background noise, or wall effects. The theoretical treatment of broadband noise has not yet really withstood the baptism of fire. The low-frequency impulsive noise and blade-vortex interaction noise both induce very rapid time variations in pressure which contribute to the amplitude of the higher harmonic frequencies. It is therefore essential that these contributions be predictable before an adequate assessment of broadband noise theoretical calculations can be obtained.

INTERIOR NOISE

As techniques for alleviation of impulsive, blade-vortex interaction, and broadband noise are implemented, the effects of the aerodynamically generated rotor noise on the cabin interior noise levels will be reduced. The main sources of interior noise are noise transmission from the power generation and drive system and noise generated by sympathetic vibrations of fuselage structures. Techniques must be devised for noise isolation. Insulation of cabin interiors can considerably reduce the internal noise, but only by relatively large infringements on the payload capability.

Noise deadening and noise isolation appear to hold the most promise for reducing cabin interior noise levels with a minimum reduction in payload capability. Considerable effort in both materials and applications is required. Better theoretical models for sound transmission will have to be developed. Refinements are required to accurately calculate the blade passage unsteady pressure environment of the fuselage structure. The Army Aeromedical Research Laboratory is developing improved equipment for better communications in the noisy environment of current helicopter interiors. However, in the longer term, both interior and exterior noise reduction techniques are required that will not severely affect the unique performance capabilities of the helicopter.

CONCLUDING REMARKS

Rotary-wing acoustics is emerging from a complex, confusing, and often contradictory era into a well-founded scientific discipline. We are fortunate to be involved in this exciting emergence of a rapidly evolving technology. We believe that this change is primarily due to recent advancements in experimental techniques and philosophy which are resulting in a wealth of new information that is pressing our theoreticians to face current theoretical limitations and to push forward the frontiers of the theoretical treatment. The experimentalists must coordinate their efforts to avoid unnecessary duplication and to maintain a flexibility to provide verification data for emerging theoretical refinements. The Aeromechanics Laboratory, in cooperation with Ames Research Center, intends to continue refinement of the full-scale, in-flight noise measurement techniques utilizing the YO-3A aircraft and to further develop the anechoic hover testing facility. The Ames YO-3A aircraft will be maintained as an in-flight acoustic platform facility for future problems in low-speed V/STOL noise research. The Army will continue to utilize its technical expertise to improve the rotary-wing acoustic technology by a systematic approach of reviewing and improving theoretical techniques while utilizing specially developed experimental equipment and facilities made available through the joint agreement with NASA.

APPENDIX

SYMBOLS

A/S	airspeed
C_T	rotor thrust coefficient
D	diameter of rotor
M_{AT}	Mach number of advancing blade tip
M_T	tip Mach number in hover
R/S	rate of descent
r	distance from microphone to rotor center line
V	flight velocity
α	angle of tip path plane relative to a line between the tail microphone and the rotor hub
α_{TPP}	tip path plane angle
γ	rate-of-descent angle
μ	advance ratio
σ	rotor solidity

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TABLE 1.- HELICOPTER NOISE RESEARCH EFFORTS

Army in-house	AARL	
	ECOM	
	R&T Labs	
Joint programs	Army/NASA	
Universities	Cornell	ARO
	M.I.T.	
	George Washington U.	
	Poly. U. of New York	
	U. of Mississippi	
	Stanford U.	
Industry	Bell Helicopters	
	Boeing VERTOL	ARO
	UTRL	
	RASA	

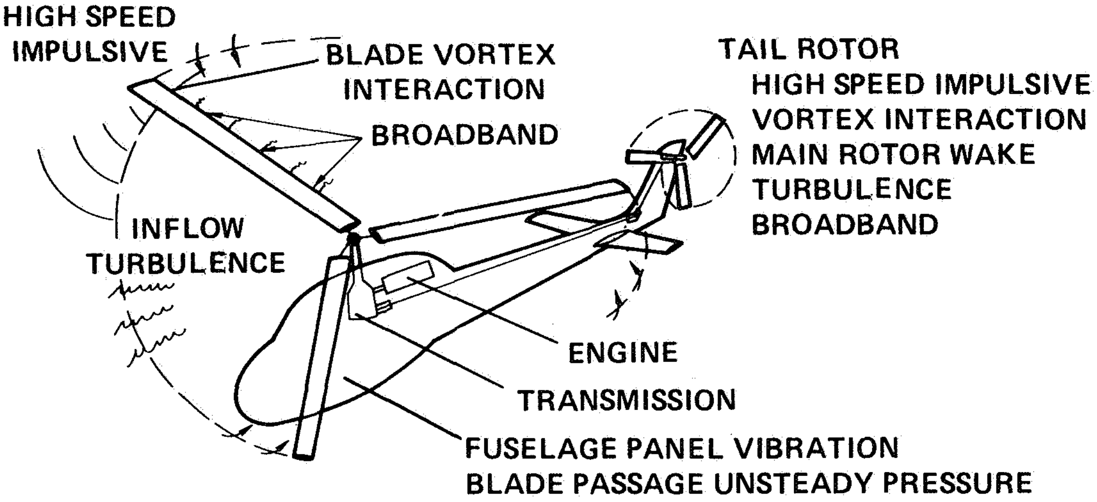

Figure 1.- Helicopter noise sources.

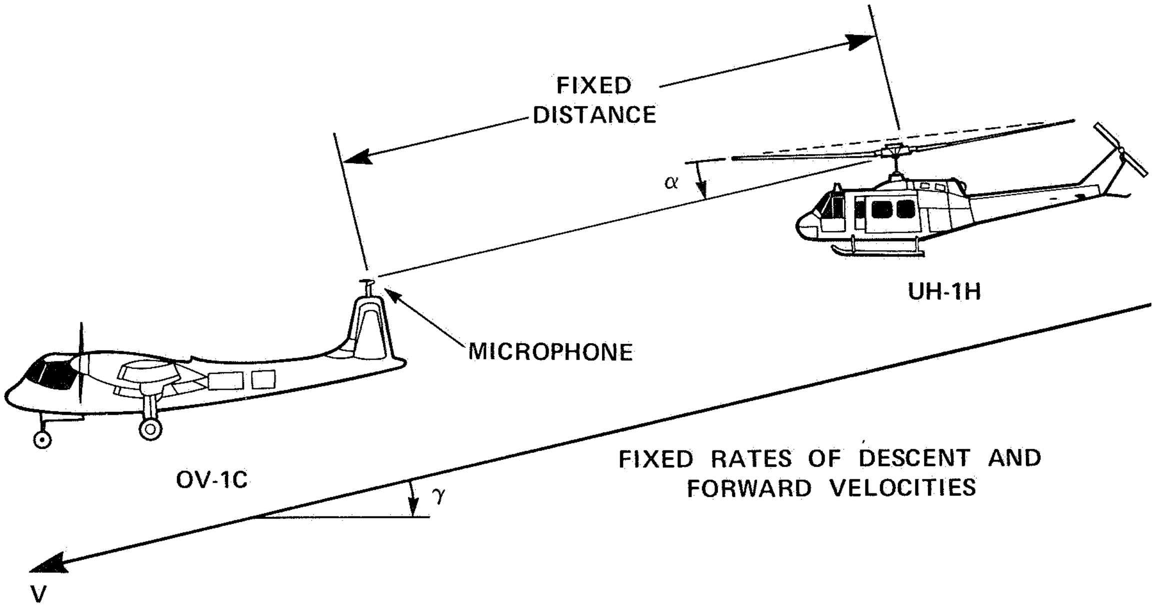

Figure 2.- Schematic of in-flight far-field measurement technique.

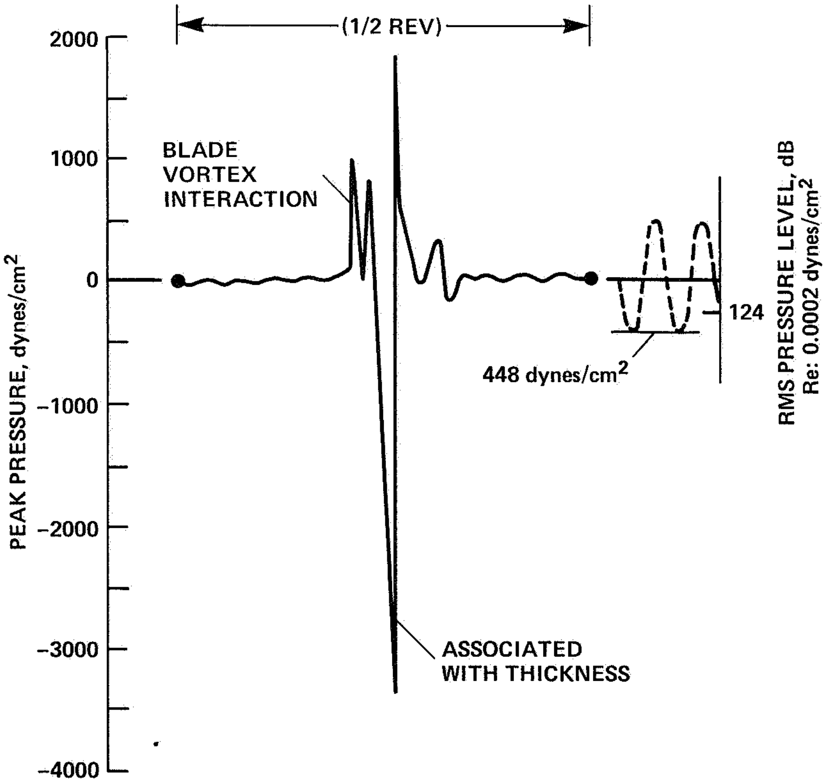

Figure 3.- Composite illustration showing dominant UH-1H acoustic waveform features.

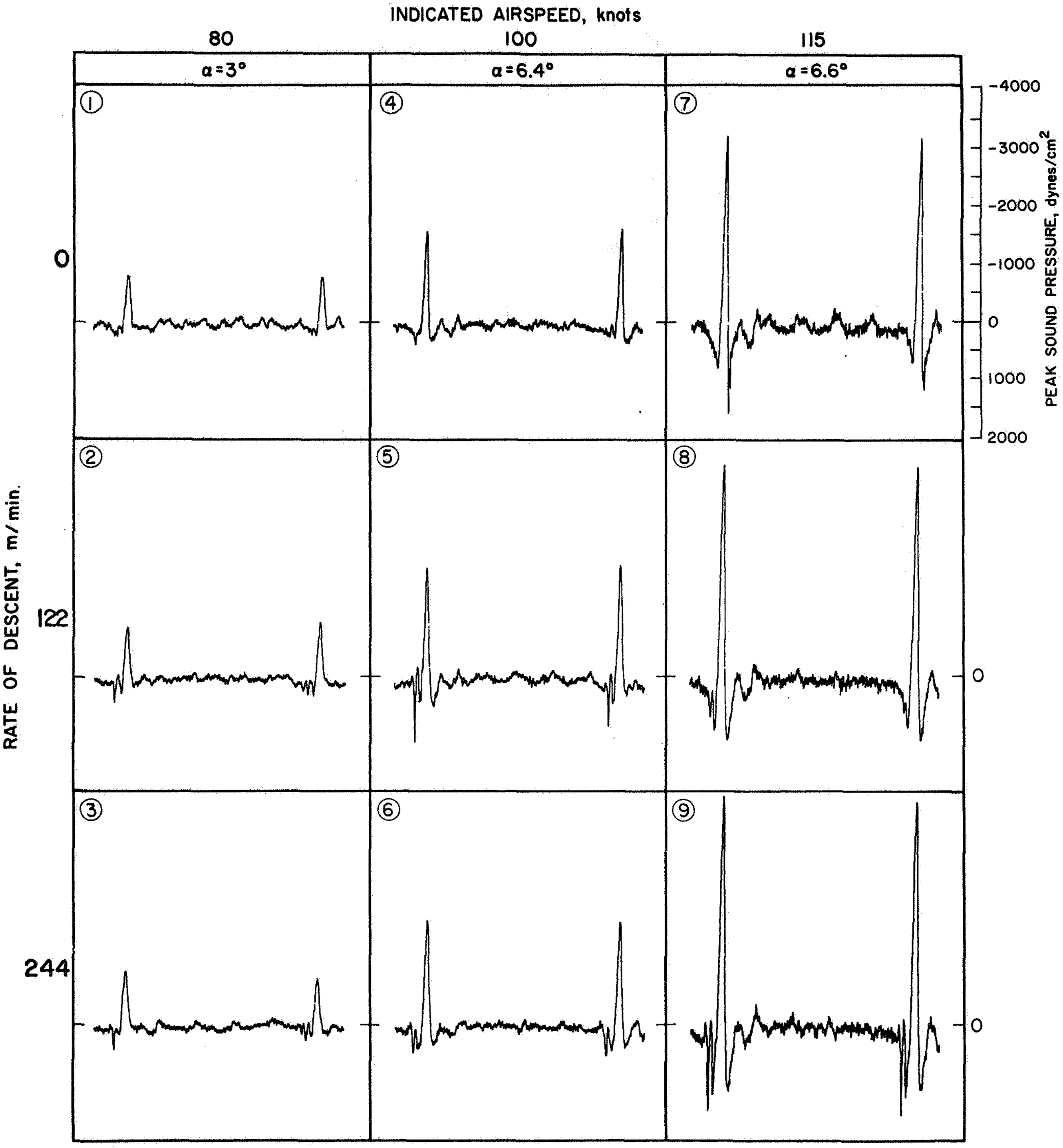

Figure 4.- UH-1H impulsive noise.

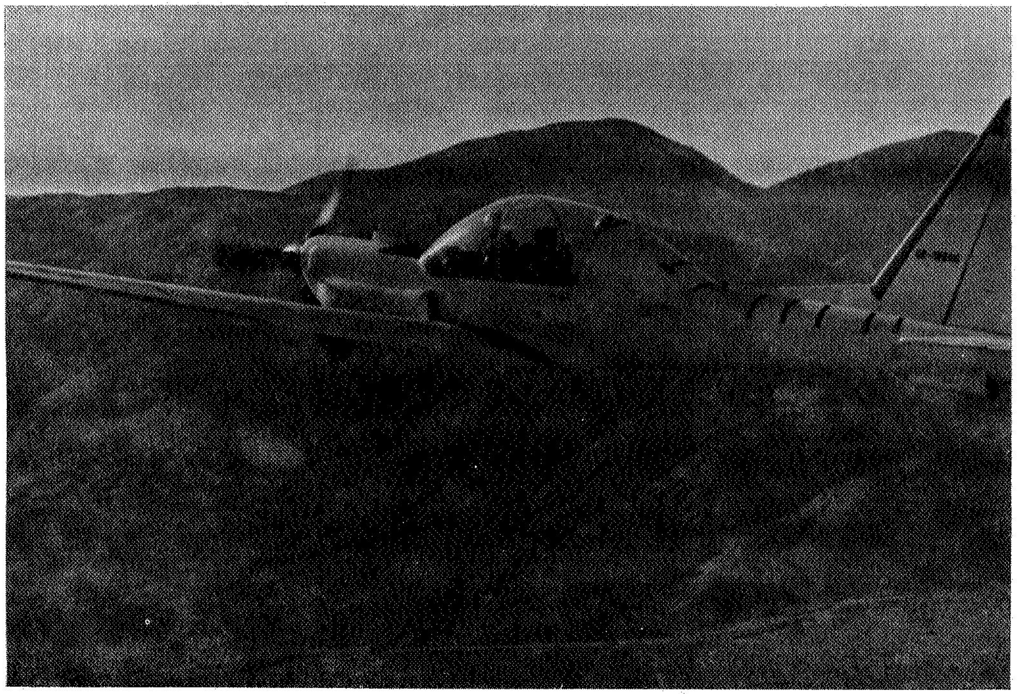

Figure 5.- YO-3A "quiet aircraft."

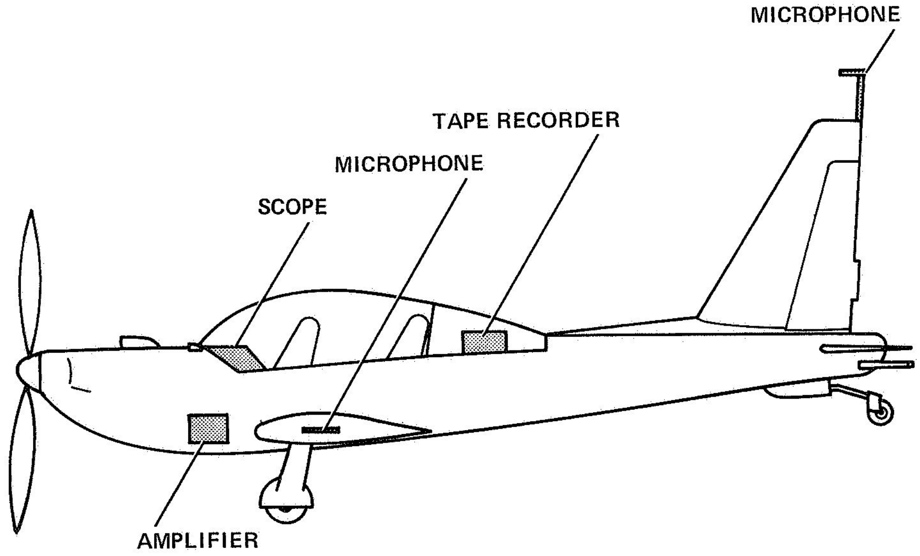

Figure 6.- Instrumentation on YO-3A.

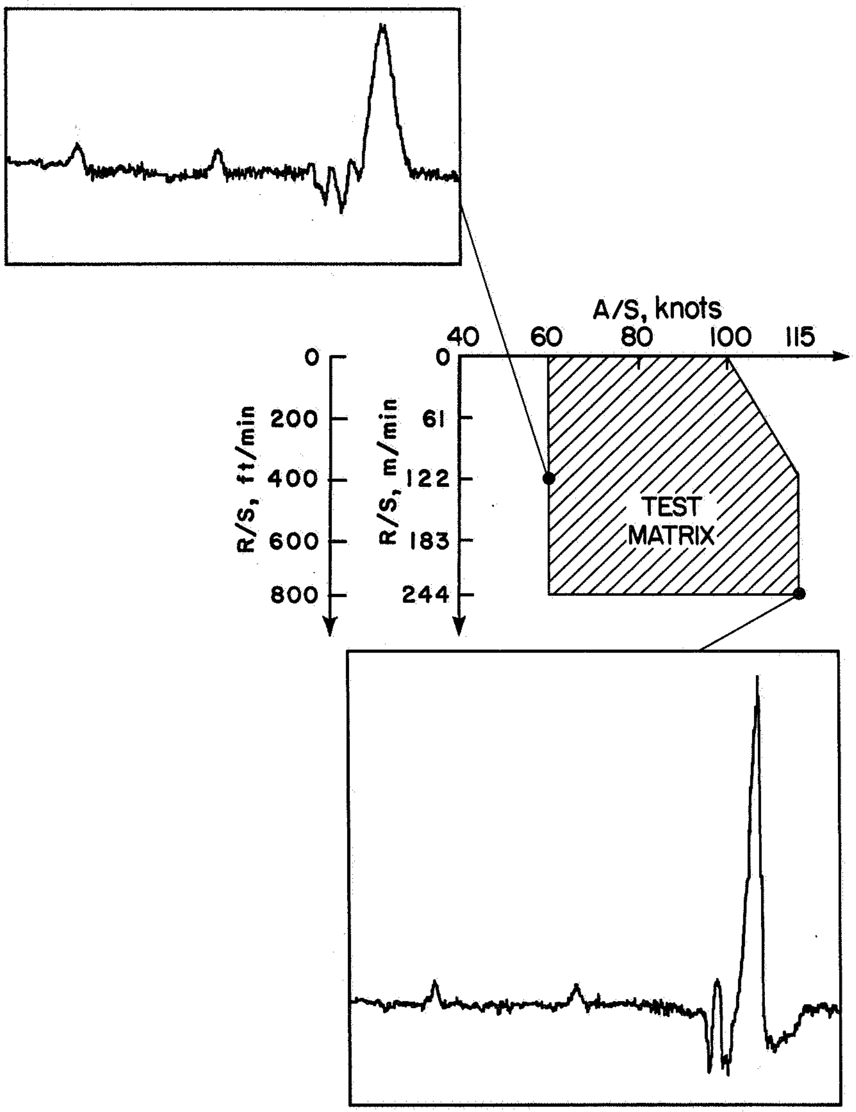

Figure 7.- Waveform shapes from YO-3A flight program — preliminary data.

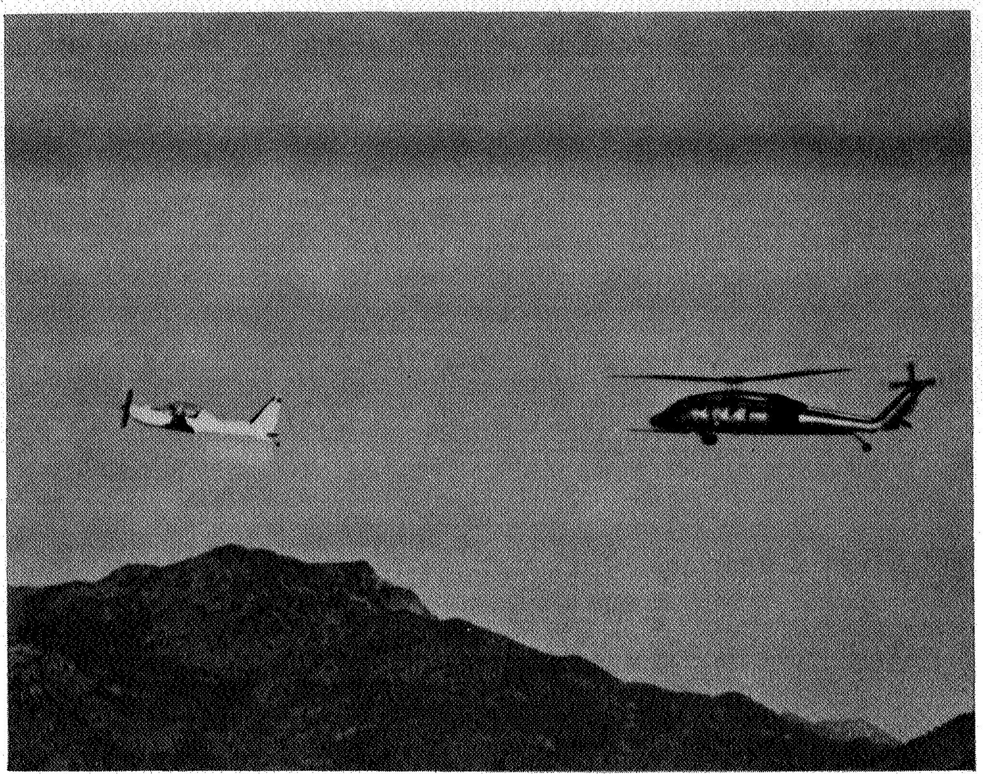

Figure 8.- YO-3A gathering acoustic data on Sikorsky UTTAS.

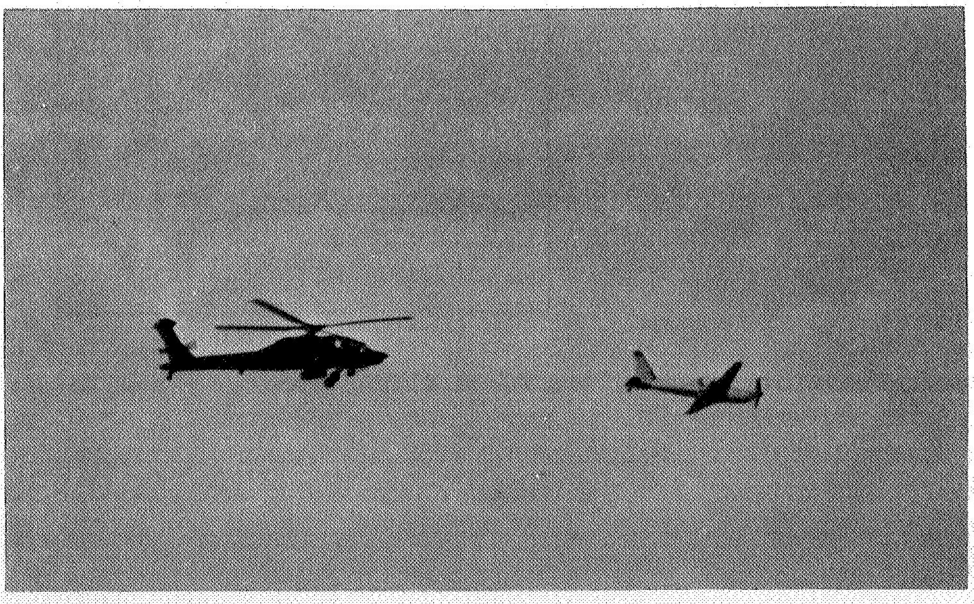

Figure 9.- YO-3A gathering acoustic data on Hughes AAH.

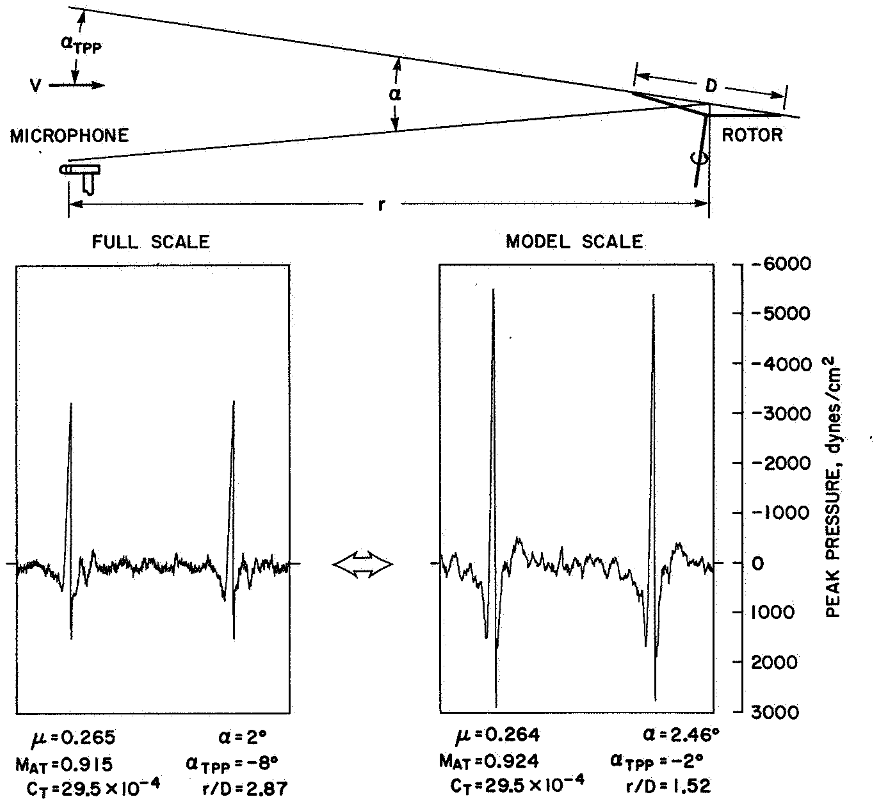

Figure 10.- Waveform comparison — full-scale and model-scale high speed data.

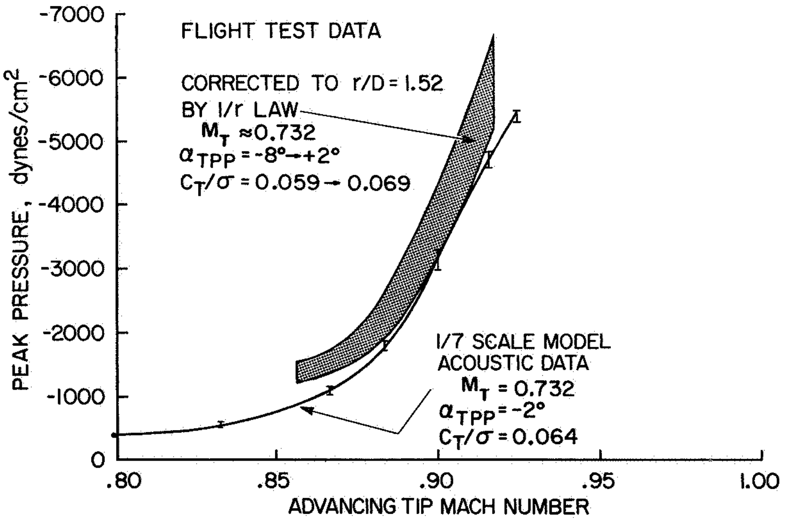

Figure 11.- Peak negative amplitude comparison — full-scale and model-scale high speed data.

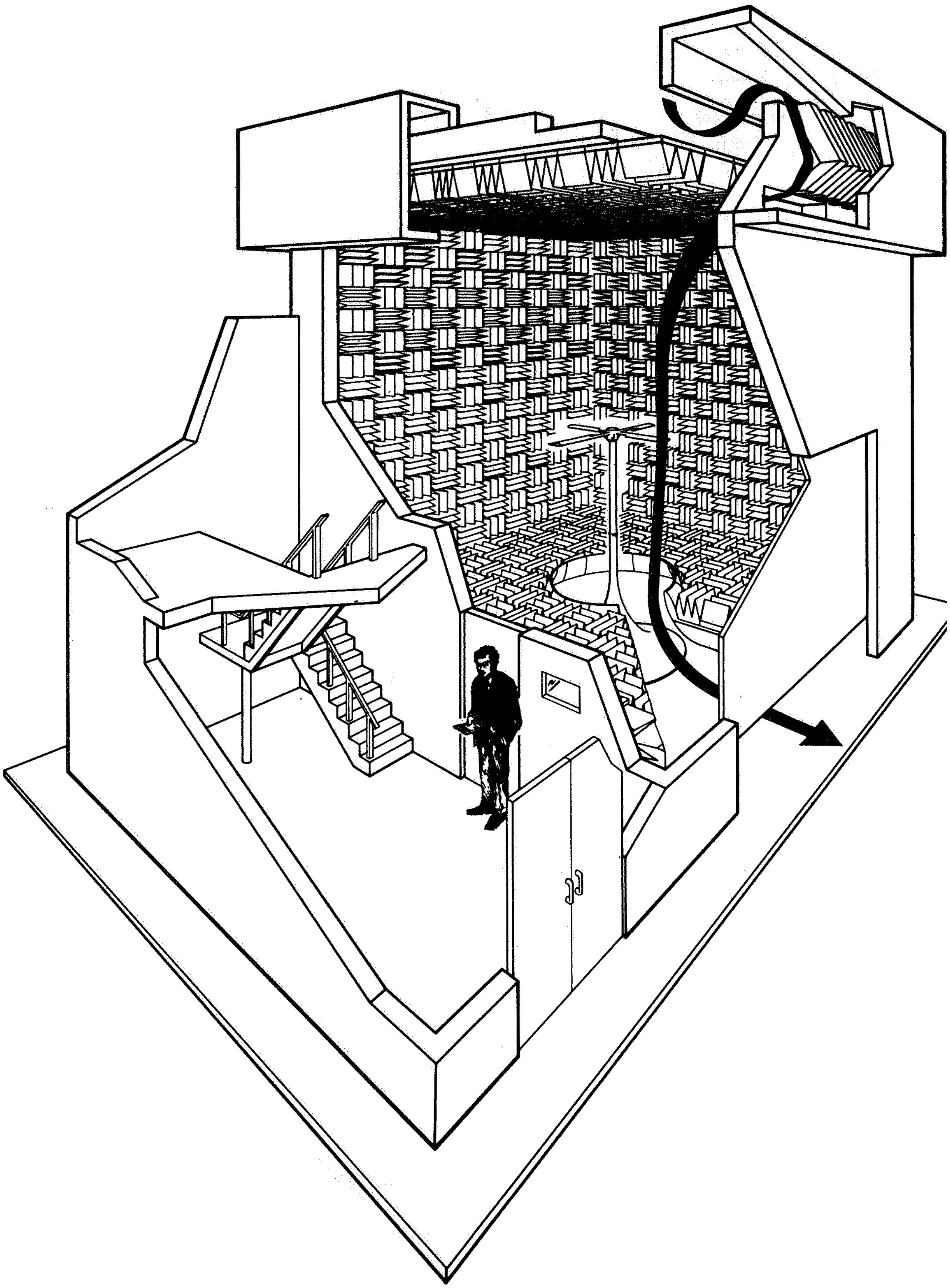

Figure 12.- Schematic of the anechoic rotor hover testing facility.

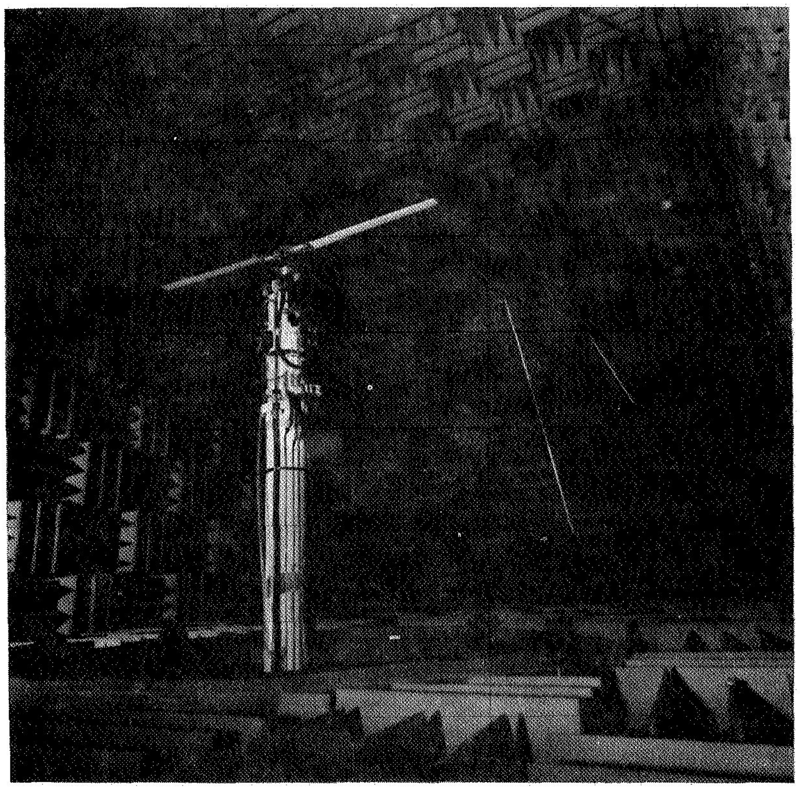

Figure 13.- 1/7-scale UH-1H model rotor in the anechoic rotor hover testing facility.

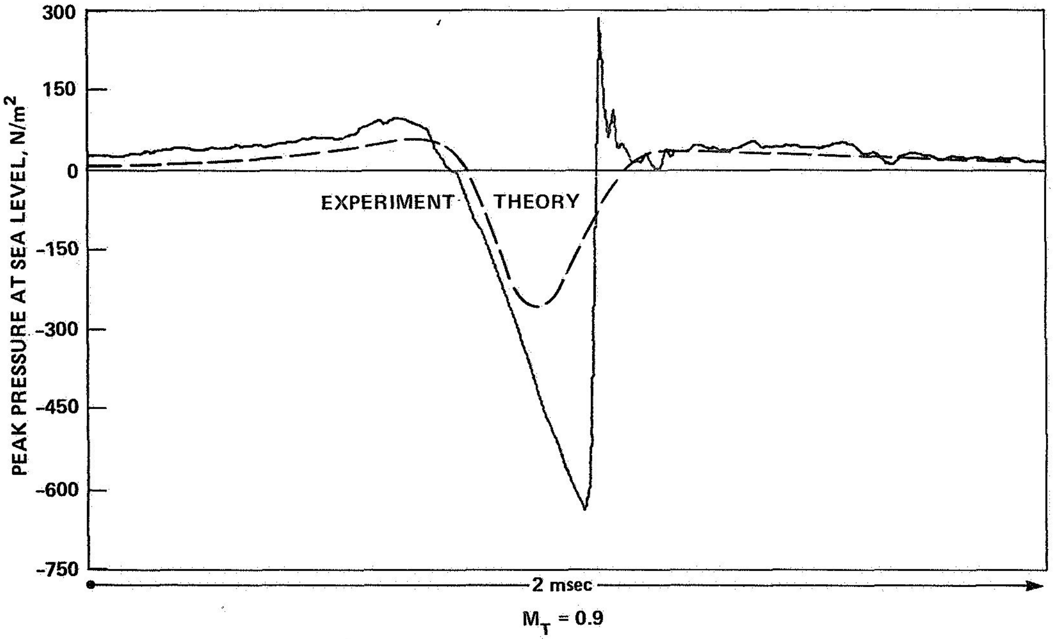

Figure 14.- Hovering model rotor comparison of theory and experimental pressure-time history in-plane.

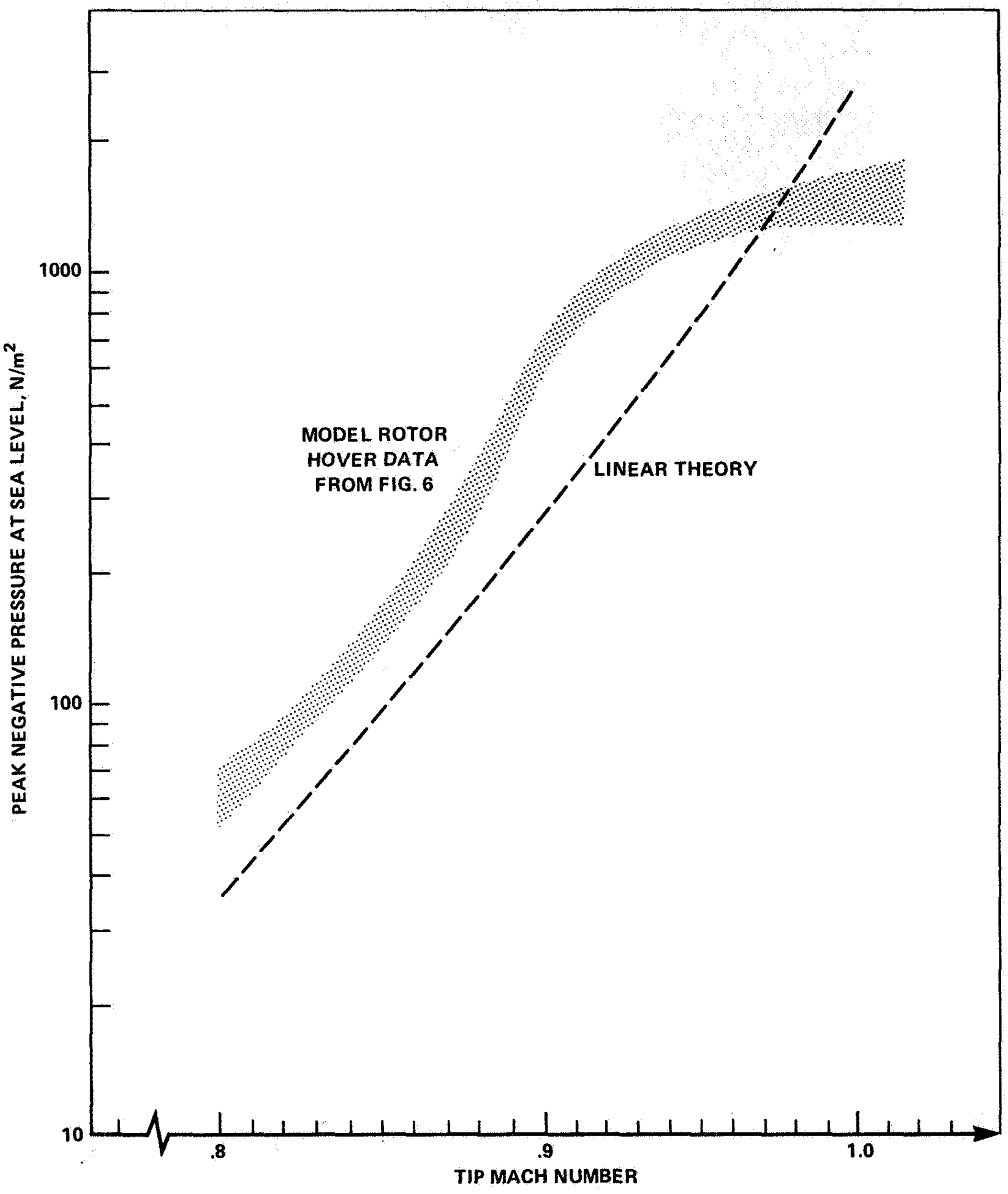

Figure 15.- Hovering model rotor comparison of peak negative pressure — theory and experiment.

Figure 16.- Model UH-1H rotor interacting with previous tip vortices.