IN-FLIGHT FAR-FIELD MEASUREMENT OF HELICOPTER IMPULSIVE NOISE

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INTRODUCTION

Impulsive noise, sometimes called "blade slap," is one of the most annoying and easily detectable sounds a helicopter can generate. Characterized by an intense low frequency and often harsh sounding succession of impulses which radiate efficiently in the direction of forward flight, it has been the subject of much theoretical research (1–7). Unfortunately, the lack of good experimental helicopter impulsive noise data has hindered the verification of existing theories and has probably slowed the development of a clear understanding of the physical events leading to the generation of the noise.

Although impulsive noise can occur in near-hovering flight on some single-rotor helicopters, it usually occurs at high forward velocities and during partial-power descents. Combinations of high advancing-tip Mach numbers, high blade loadings, and blade-wake interaction are prime suspects of its generation. Many researchers believe that two basic and independent mechanisms are responsible for the one phenomenon labeled "impulsive noise." The first is thought to be a direct result of rapid changes in aerodynamic forces on the blade due to blade-tip vortex interaction which is known to exist on many single-rotor helicopters in partial-power descents (8–10) and on tandem helicopters as a function of rotor spacing and trim conditions. The second mechanism, which has been attributed to compressibility effects on the advancing blade of a helicopter in high-speed flight, is often called "high speed" impulsive noise. Although there is presently some controversy about the major sources of this noise (2–5), it is known to occur on helicopters whose advancing-tip Mach numbers approach or exceed 1.

The lack of far-field 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, forcing past investigators to utilize qualitative observations and limited measurements to attempt 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 to fly the helicopter along nominal trajectories at selected forward flight conditions. Under ideal circumstances, a quantitative assessment of the character of the noise is possible (11,12). 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, such as distance to the microphone, azimuth angle, and ambient wind effects, constant, the technical problems and statistical uncertainties combine to make the data-gathering task quite difficult. In fact, the quantification of just one flight condition from ground acoustical measurements can be difficult due to statistical uncertainties in the acoustic transmission path and ground reflection effects.

Wind tunnels have also been used to gather impulsive noise data. For example, several programs have been run in the NASA-Ames 40 X 80-Ft Wind Tunnel on full-scale helicopters. From the noise measurements that were taken, it was often possible to evaluate the relative acoustic merits of competing blade slap configurations or operational conditions, or both. However, the reverberation characteristics of the tunnel, together with its high ambient operational noise levels, make a quantitative evaluation of the blade slap signal difficult.

Another approach currently being used to obtain impulsive noise data due to blade-vortex interaction utilizes microphones mounted on the inside of the helicopter cabin and along chosen exterior surfaces.(8- 10) Acoustic signatures taken by this measurement technique have been used to develop subjective "blade slap boundaries" as a function of operating conditions and to attempt to locate, through triangulation methods, the point(s) in space where the noise originates. The blade slap boundary map of references 8 and 9, which was developed utilizing this technique, is reproduced in figure 1 for the UH 1 series helicopters. One interesting aspect of this figure is that the impulsive noise measured in the cabin was at a maximum level within an enclosed area centered at a rate of descent of 300 ft/min and a forward speed of 75 knots. As airspeed increased, blade slap decreased until it was no longer recorded on the cabin microphone. If this map is indicative of the actual far-field noise radiated by the helicopter, one must then deduce that at some moderately high forward velocities no significant blade-wake interaction exists. It would then be possible to devise high-speed descent profiles to avoid the blade-vortex interaction acoustic radiation – a technique developed in reference 8. However, it will be shown that this is not the case for the UH–1H helicopter. Impulsive noise radiation due to blade-wake interaction, which is apparently not discernible on the cabin microphone, does exist at moderately high forward speeds and moderate rates of descent.

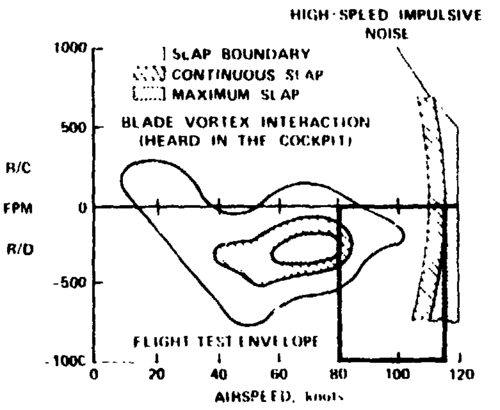

Figure 1. - Impulsive Noise Boundaries for UH 1 Series Helicopters (from ref. 9)

This in-cabin or near-fuselage method of measuring impulsive noise has several limitations. Because either cabin- or fuselage-mounted microphones are in the helicopter's low- to mid-frequency acoustic near field (depending upon their proximity to the rotor disc), it can be difficult to quantitatively evaluate how much of the aerodynamically generated noise actually radiates to the far field. Also, it is not presently feasible to attempt measurements of in-plane acoustic data by this technique. As fuselage-mounted microphones approach the rotor disc, near-field pressures dominate the impulsive acoustic signature. Other factors, such as masking by adjacent noise sources (engine, gearbox, etc.) and reflection and generation of acoustic signals by vibrating fuselage surfaces, can disguise and distort the waveform.

To surmount the difficulties of ground, wind tunnel, and near-field in-flight measurement attempts, an in-flight far-field acoustic measurement technique was developed. This measurement technique utilized a quiet fixed-wing aircraft, instrumented with a microphone, and flown to maintain fixed relative positions with a helicopter. Because impulsive noise was thought to have its maximum intensity radiation patterns in the general direction of forward flight, the microphone was installed on the tail of a monitoring fixed-wing aircraft and flown in front of the helicopter as illustrated in figure 2. Calculated values of microphone wind noise and monitoring aircraft noise levels indicated that with a proper choice

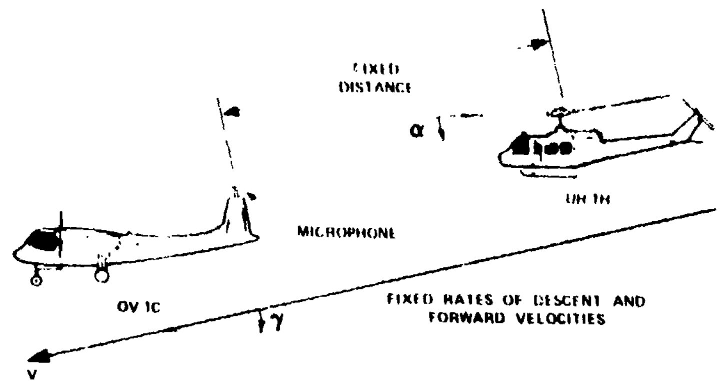

Figure 2. Schematic of In-Flight Far-Field Measurement Technique

of fixed-wing aircraft, the periodic phenomenon of helicopter blade slap could be measured above or extracted from the potential masking sounds of the testing procedure. By using this testing procedure, quantitative acoustic far-field impulsive noise radiation patterns were easily obtained under a wide range of steady operating conditions.

EXPERIMENTAL METHOD

A UH–1H helicopter ("Huey") was chosen as the subject aircraft for the acoustic measurement program because of its known ability to generate blade slap throughout a range of flight conditions and because of its widespread use throughout the U.S. Army. The Huey's general and operational characteristics that are of interest acoustically are given in the appendix.

Many factors entered into the decision to choose the OV–1C ("Mohawk") as the monitoring or lead aircraft for this initial test program. The acoustical characteristics of the Mohawk are of prime importance. Its twin turboprop engines employ a governor system that allows the pilot to specify the rotation rate of both three-bladed propellers. A fixed rotation rate of 1200 rpm, resulting in a propeller tip speed of 628 ft/sec, was predetermined to be the most compatible with the governor system and at the same time served to minimize the amplitude and to position the harmonics of propeller rotational noise to avoid those generated by the main and tail rotor of the UH–1H helicopter.

Relatively good slow-speed flight capability at low rpm settings was another factor in choosing the Mohawk as the monitoring aircraft. Zero to 1000 ft/min rates of descent could be held at 1200 rpm at airspeeds down to 80 knots. These performance limitations are indicated on the forward velocity-rate of descent map for the UH–1H (fig. 1) by the left border of the boxed flight test envelope. As shown in this figure, previously reported regions of intense slap resulting from blade-vortex interaction as well as conditions of high-speed impulsive noise could be investigated with the OV–1C.

A Brüel and Kjaer 1/2-inch condenser microphone, fastened to the center vertical stabilizer of the OV–1C aircraft by a 15-inch aerodynamically shaped strut, was used to record all acoustic data. To minimize wind noise and avoid unnecessary complexity, the microphone was outfitted with a Brüel and Kjaer "nose cone" and oriented to a fixed nominal direction facing the relative wind; the direction was chosen so that the microphone centerline was nearly aligned with the relative wind under all test conditions. (Microphone angles of attack of less than 10° were predicted for trimmed flight throughout the measurement envelope.)

For the test program, normal copilot functions were superseded by acoustic monitoring and recording tasks. This capability was provided for by locating, in the cockpit area, a Brüel and Kjaer microphone preamplifier-power supply unit, a small two-channel oscilloscope, and tape recorder remote controls. Preamplifier gains (±20 dB range) were determined in-flight to maximize signal-to-noise ratios and to avoid peak pressure saturation prior to recording the blade slap signal received from the microphone. This optimized signal was monitored on one oscilloscope channel and recorded on a Honeywell (5600) 14-channel FM tape recorder (DC to 5000-Hz frequency response) that was shock-mounted in the OV-1C instrumentation bay. The recorded signal was then monitored on the second oscilloscope channel for immediate in-flight data confirmation. A one/rev signal, generated by a contactor on the helicopter shaft, was transmitted over a radio channel and served as external trigger input for the oscilloscope display of the acoustic signal. Audio comments of both pilots and the one/rev signal were tape recorded simultaneously with the data. Field calibration signals were provided by a Bruel and Kjaer portable pistonphone.

Spatial orientation of the UH-1H helicopter with respect to the OV-1C aircraft was achieved through visual flight reference. Once the pilot of the Mohawk established a specified flight condition, the UH-1H helicopter pilot utilized predetermined visual cues to fly behind the OV-1C at fixed separation distances, and at relative angular displacements from the direct-in-trail position. Calibrated canopy markings were used by the UH-1H pilot to establish desired separation distances. These canopy markings were established on the ground with the helicopter directly behind the OV-1C. For each measured separation distance, one pair of vertical lines was drawn on the canopy of the UH-1H, spaced so that, to the helicopter pilot, they appeared to intersect the wing tips of the OV-1C aircraft. By simply recreating this same visual image in formation flight, the helicopter pilot maintained fixed separation distances (within an estimated accuracy of ±5 ft).

Longitudinal angular directivity (α) of microphone position with respect to the helicopter's tip-path (fig. 2) was determined solely by sighting known markings on the OV-1C aircraft. The pilot flew the helicopter so as to position the Mohawk's center vertical stabilizer light in line of sight with preestablished fuselage markings. This determined a fixed angular relationship between the visual sighting line and the Mohawk's reference line. Knowing (by inclinometer measurement) the angle between the Mohawk's reference line and the horizontal, and calculating the UH-1H's tip-path plane angle and hub center position for each flight condition, the longitudinal angular directivity (α) of the microphone position could be calculated (within an estimated error of ±2°).

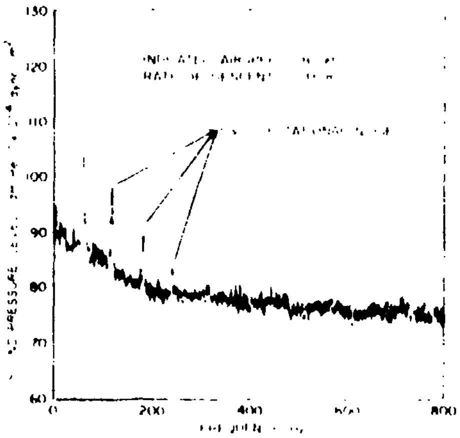

Figure 3. In-Flight Measurement of Background Noise

Lateral angular directivity (β) of microphone position with respect to the forward flight direction of the helicopter was determined in a similar manner. Distinguishable vertical tail features of the Mohawk were placed in line of sight with fuselage and wing markings and noted during flight. Lateral microphone angles (β) were calculated by constructing these sight lines on scaled drawings of the OV-1C aircraft (within an estimated error of ±1°).

Before taking acoustic data in formation flight with the UH-1H helicopter, the OV-1C was flown by itself at airspeeds from 80 to 115 knots at rates of descent from 0 to 1000 ft/min in quiescent air. During these initial runs to check out ease of control of the Mohawk during descending flight, background noise levels were recorded. Figure 3 shows a frequency spectrum of the measured background acoustic signature during level flight at an indicated airspeed of 80 knots. The spectrum was obtained with 1-Hz wide bandwidth resolution and is representative, in character and level, of background noise over the entire flight test envelope. The rotational noise of the OV-1C predominated at higher power settings in the low-frequency range, but fell off rapidly as frequency was increased. Factors contributing to the remainder of the background noise were turboprop engine noise, wind noise over the microphone, and scrubbing noise. Fortunately, the background noise levels were low enough to insure good signal-to-noise ratios when recording the UH-1H impulsive noise.

EXPERIMENTAL FINDINGS†

Forward-flight impulsive noise data were gathered with this in-flight far-field measurement technique with relative ease. By utilizing highly qualified pilots, the entire flight test matrix of about 50 test points was completed in two half days of flying. Acoustic data were recorded over variations in indicated airspeed (IAS) from 80 to 115 knots and rates of descent (R/D) of −200 ft/min to 1000 ft/min. Longitudinal and lateral directivity data were taken at two conditions; 80 knots IAS, 400 ft/min R/D and 115 knots IAS, 0 ft/min R/D. In all cases, signal-to-noise ratios of at least 10 dB, and more commonly 20 dB, were recorded.

It was generally observed from the measured data that the far-field acoustic waveform radiated by each blade was multipulse in nature. Up to three distinct pressure disturbances could be repetitively identified in the acoustic waveform. For identification of this waveform structure and familiarity with data presented in the following sections, an idealized composite drawing of the acoustic waveform showing this multipulse character is presented in figure 4. In this figure, peak pressure amplitude of the acoustic signature is illustrated vs. one-half revolution (one blade passage) in time, with time increasing from left to right. The convention established by early high-tip-speed propeller researchers (14) is adhered to: a pressure decrease (negative pressure) is indicated upward and a pressure increase (positive pressure) downward. The peak pressure amplitude scale used here and throughout the paper is an absolute scale measured in dynes/cm². On this scale a sinusoidal-shaped waveform with a peak pressure amplitude of 448 dynes/cm² would exhibit a root mean square (RMS) sound pressure level of 124 dB (Re: 0.0002 dyne/cm² RMS).

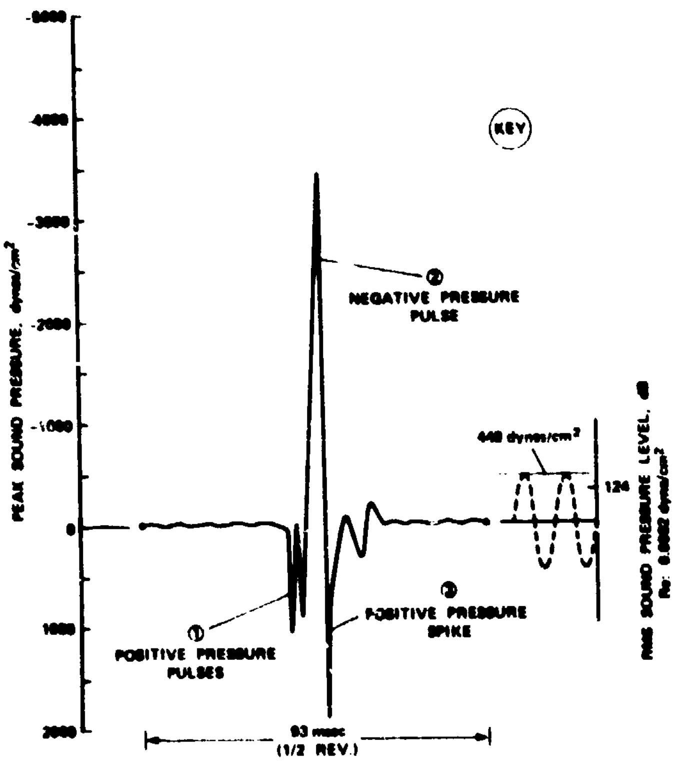

Figure 4. Composite Illustration Showing Dominant UH-1H Acoustic Waveform Features

†See reference 13 for averaged acoustic waveforms and impulsive noise power spectra.

The composite waveform model illustrates three predominant pressure disturbances observed in the data. They are shown in the same relative sequence and approximate pulse width that were characteristic of the measured data. Typically, the sequence began with one or two successive increases in positive pressure of "triangular" pulse shape (fig. 4, no. 1). These positive pressure peaks are followed by a negative pressure rise (fig. 4, no. 2), usually increasing in amplitude slightly slower than its subsequent rapid decrease and represented more by a sawtooth or half-triangular pulse shape. Finally, when it was observed to occur, an extremely narrow positive pressure spike (fig. 4, no. 3) followed immediately after the decrease in negative pressure.

Although it is not the intent of this paper to relate in detail the potential design causes of the radiated noise to the acoustic time history, some discussion and general observations are in order. It is the authors' hypotheses that the initial series of positive pulses (fig. 4, no. 1) is a direct result of blade-tip vortex interaction and that the remainder of the impulsive noise waveform features are associated with high advancing-tip Mach numbers. The large rise in negative pressure (fig. 4, no. 2) is thought to be attributable to "thickness" effects, while the following sharp increase in pressure (fig. 4, no. 3) is related to a radiated shock wave being shed after the position of maximum advancing-tip Mach number. No attempt at theoretical justification of these hypotheses is attempted in this work; the primary intent is to furnish a consistent set of acoustic impulsive noise data. For completeness, each data point is cross-referenced in the appendix, where the acoustically important nondimensional variables are tabulated for each flight condition. The circled number in each of the following figures is the key to this appendix. In the following paragraphs, this composite waveform is shown to be highly dependent on helicopter performance and directivity measurements.

Figure 5 presents a performance matrix of measured acoustic data at flight conditions between 80 and 115 knots IAS and 0 to 800 ft/min R/D. (Reference the boxed flight test envelope in fig. 1.) These unaveraged acoustic waveforms, corresponding to two consecutive blade passages, were recorded at a nominal hub-to-microphone separation distance of 75 ft with the microphone positioned directly ahead of the helicopter ($\beta = 0$) and nearly within the plane of the rotor tips ($\alpha \cong 0$). Each of the acoustic time histories has the same amplitude scale shown, for example, with the upper right waveform in the performance matrix.

Two striking features of the pressure-time histories are present. The first is the multipulse nature that was previously discussed. The second is the presence of a blade-to-blade acoustic variability. This variability was in most cases repetitive, indicating that each blade has a distinct signature – a phenomenon observed by other acoustic researchers. Blade-to-blade variability was most prominent for the positive pressure pulses, tending to indicate a more detailed dependence of these pulses upon the local aerodynamic environment of each main rotor blade.

Several data trends are evident. Peak amplitude of the large negative pressure pulse is strongly dependent on forward speed. Although the width of the negative pulse appears to decrease slightly with increasing speed, no consistent trends in amplitude or pulse width could be deduced with changes in descent rate. It is interesting to note that under level-flight conditions at all airspeeds, no impulsive noise was heard in the cabin, indicating that for all flight conditions tested, the pilot was audibly unaware that the helicopter was radiating that part of the impulsive noise waveform associated with the negative pressure peak.

At the high forward speed conditions of 115 knots, the large negative pressure peak, when measured nearly inplane, was followed by a positive pressure spike which exhibited some variability from blade to blade. These extremely sharp pressure pulses documented here were so intense as to be heard directly in the cockpit of the Mohawk, over and above the aircraft's own internal noise levels. However, no apparent slapping was heard in the cabin of the helicopter at any speed above 100 knots IAS regardless of rate of descent. To the pilot of the helicopter, a moderate increase in vibration level was the only noticeable effect, even though the UH–1H was radiating tremendous amounts of acoustic energy.

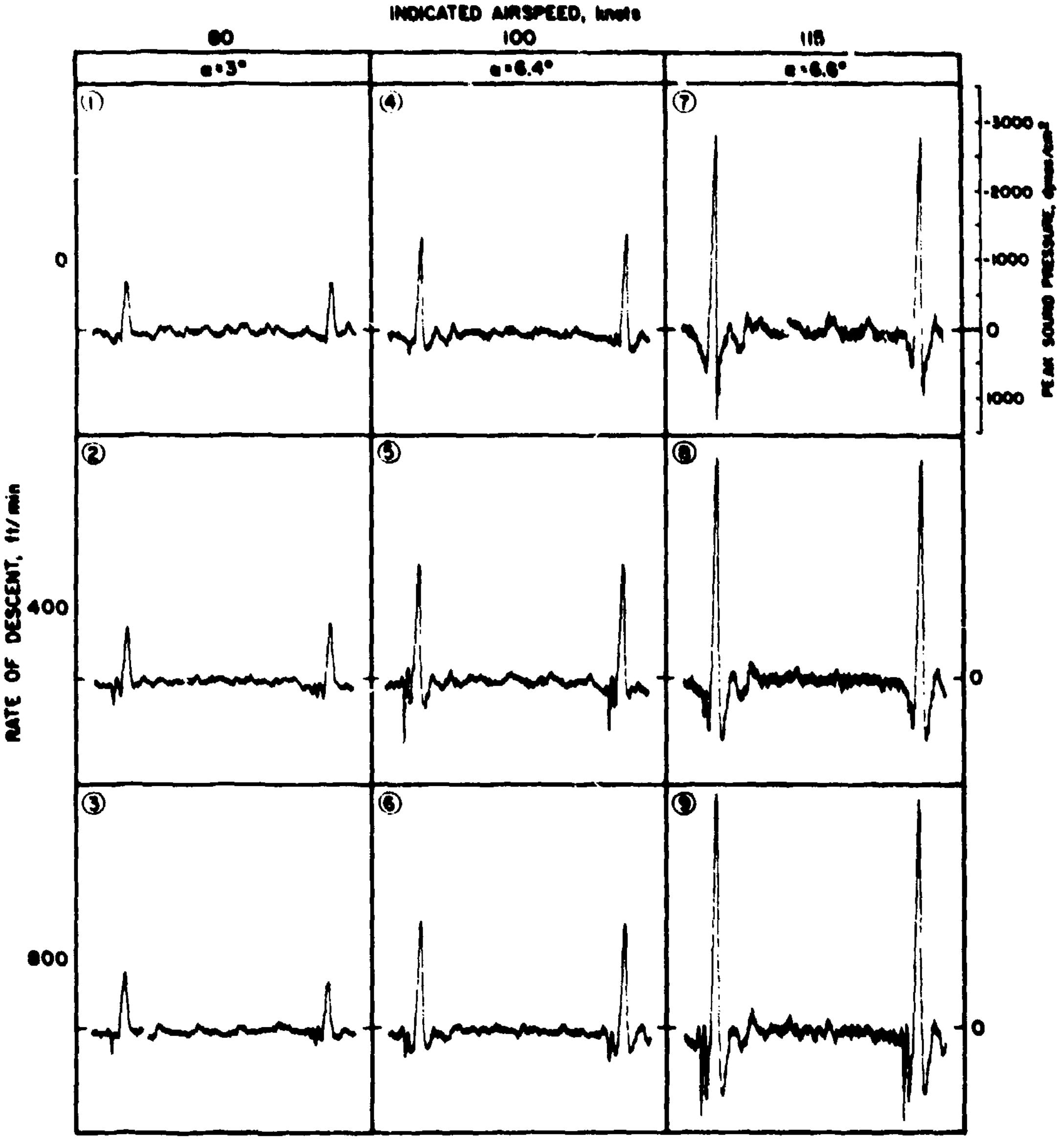

Figure 5. Unaveraged Acoustic Signature of UH -1H Impulsive Noise Versus Forward Airspeed and Rate of Descent

Blade slap was heard in the cabin under partial-power descents below forward speeds of 100 knots. Similar to the findings of reference 8 (fig. 1), blade slap appeared to be most intense within th: helicopter at about 80 knots IAS at a rate of descent of 400 ft/min. The occurrence of this cabin noise correlates with the positive i.npulsive pressures which precede the large negative pressure pulse on the acoustic waveforms (fig. 5). Because the occurrence of these positive pressure pulses appears to be very sensitive to rates of descent and resulting rotor wake geometry, it is thought that these pulses are a direct result of blade-tip vortex interaction. However, contrary to the findings of references 8–10, this blade-vortex interaction noise does not disappear at higher forward velocities. At a given indicated airspeed, the positive pressures were found to increase, maximize, and then decrease again with increasing rate of descent. The point of maximum positive peak pressure occurred at higher descent rates as forward velocity was increased, following a somewhat diagonal path from 80 knots/400 ft/min to 115 knots/800 ft/min conditions.

It is apparent from these findings that the regions of radiated blade slap noise reported in references 8–10 are larger than previously thought. Only the impulsive noise heard in the cabin forms a closed region (fig. 1) when plotted versus forward velocity and rate of descent. The external radiated acoustic signature is quite different and fairly independent of the normal internal noise environment of the UH–1H helicopter at airspeeds above 80 knots. Unfortunately, there appears to be no quiet corridor (8) through which to fly when decelerating for an approach to landing from high forward speeds. The helicopter pilot must descend through regions of measured "severe" blade slap to reach the previously reported less intense regions of blade-vortex interaction at lower forward velocities and high rates of descent.

Directivity profiles of the UH-1H impulsive noise were measured throughout a sweep of angular microphone positions for two operating conditions: 80 knots IAS, 400 ft/min R/D and 115 knots, 0 ft/min R/D. The longitudinal and lateral angles, α and β, respectively were measured from a line in space drawn between the rotor hub and microphone to the rotor tip-path plane for longitudinal directivity and to the forward velocity vector for lateral directivity. The directivity data were recorded using two different but complementary flying procedures, the primary one being a continuous slow sweep by the helicopter pilot around the Mohawk at a nominal separation distance of 75 ft. The resulting figures present "two-blade passage" snapshots of the continuously changing acoustic waveform at specified angular orientations. The second method of measuring directivity data utilized the stationkeeping procedures outlined in the "experimental method" section. Data gathered by this latter technique are indicated on the directivity figures by an asterisk.

Figures 6 and 7 present the longitudinal and lateral directivity profiles of the UH–1H helicopter in an 80 knot IAS, 400 ft/min rate of descent. As discussed previously, this operating condition produced blade slap noise that was audible to the helicopter pilot.

The longitudinal directivity signatures (fig. 6) contain both positive and negative pressure pulses, the former exhibiting considerable variability from blade to blade. These positive pressure pulses, which are associated with blade-tip vortex interaction, become large for longitudinal angles (α) between 10° and 52°. Even at the nearly in-plane or overhead position, some blade-tip vortex interaction radiation is evident, indicating that a wide angular distribution of acoustic energy is radiated to the far field in the longitudinal plane. However, the negative pressure peak exhibits quite different radiation characteristics. It reaches its maximum level near the in-plane positions of the rotor disc but decreases rapidly to half amplitude by the 23° position and continues to decrease uniformly with increasing angle until it is hardly discernible above background noise levels at the 52° angular position.

Lateral directivity, shown in figure 7, for the same operating conditions depicts a rapid decrease in the impulsive nature of the positive pressure pulse for measurements to the advancing blade side of the rotor and a gradual disappearance into background noise by the 54° point. Again, variability between blade signatures is present. The negative pressure pulse is shown to decay less rapidly in-plane than out-of-plane as the directivity angle is increased. It is approximately half amplitude at 73° and still discernible to the side of the helicopter ($\beta = 94°$). Although the helicopter pilot cannot hear any slapping noise associated with the negative pressure pulse, it is clear that near the tip-path plane of the helicopter, large angular distributions of acoustic energy are being radiated.

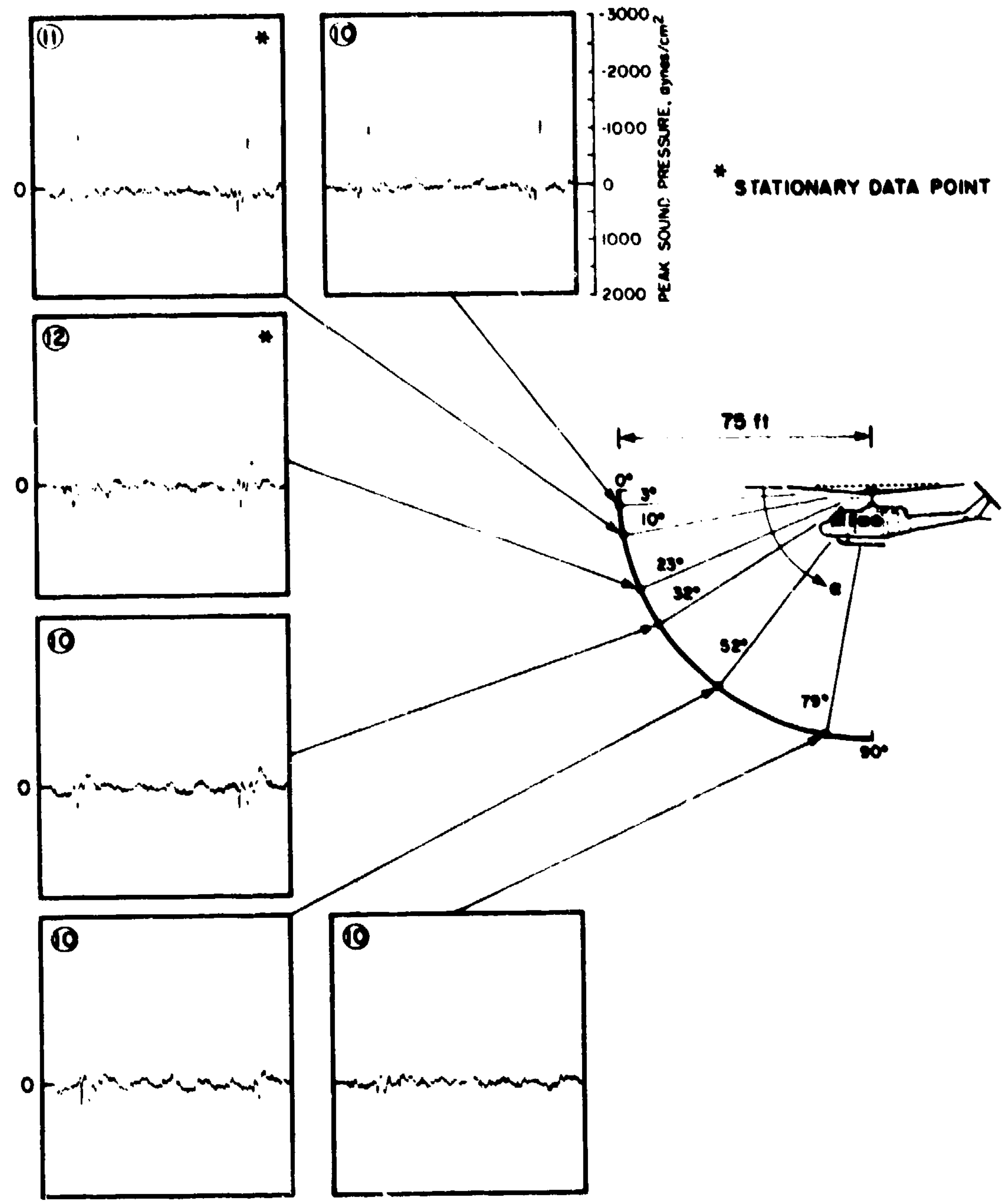

Figure 6. UH-1H Longitudinal Acoustic Directivity at 80 Knots IAS and 400 Ft/Min R/D ($\beta = 0^\circ$)

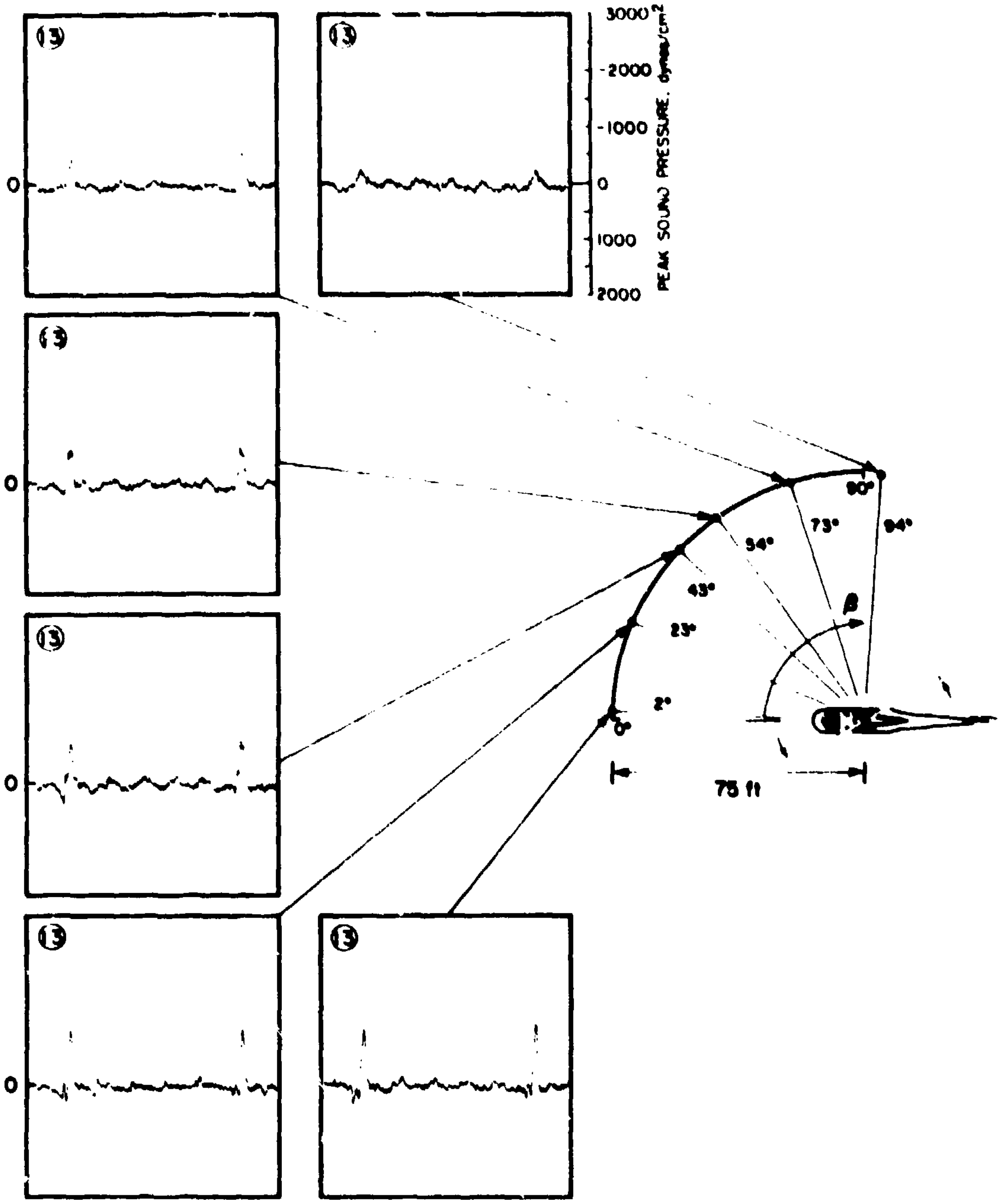

Figure 7. – UH- 1H Lateral Acoustic Directivity at 80 Knots IAS and 400 Ft/Min R/D ($\alpha = 3°$)

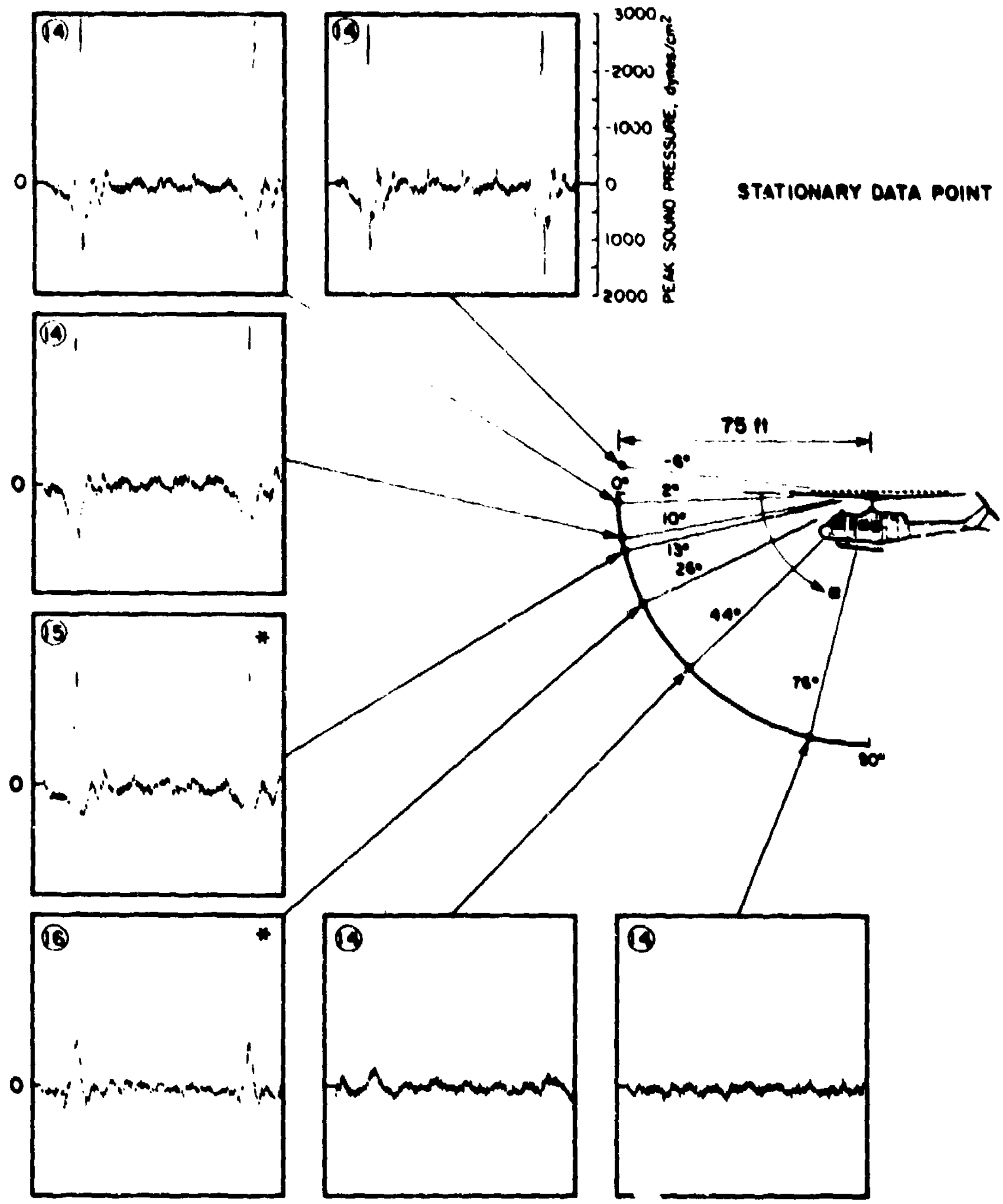

Figure 8. UH 1H Longitudinal Acoustic Directivity, Level Flight, 115 Knots IAS ($\beta = 0°$)

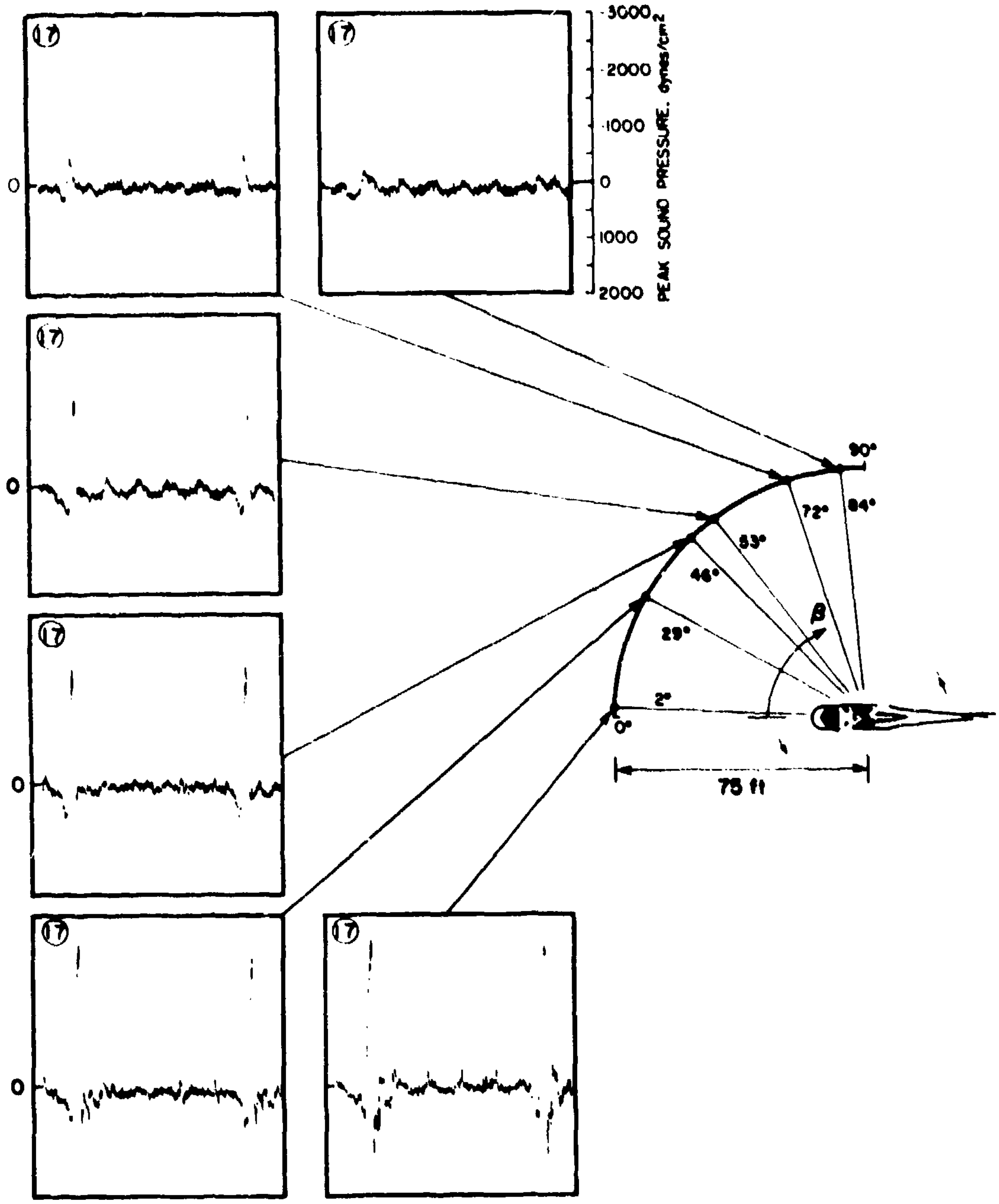

Figure 9. - UH - 1H Lateral Acoustic Directivity, Level Flight, 115 Knots IAS ($\alpha = 7^\circ$)

The longitudinal and lateral directivity profiles for high-speed level flight are shown in figures 8 and 9. Although the positive pressure pulses associated with blade-tip vortex interaction impulsive noise are noticeably absent for this flight condition, large-amplitude negative and positive pressure pulses do exist.

The negative pressure peak, although much larger in amplitude for this high-speed condition, varies in longitudinal and lateral directivity in much the same fashion as in the low speed case. It is at a maximum near the tip-path plane of the rotor (fig. 8) and falls off uniformly with increasing lateral directivity angles (fig. 9), where, at $\beta = 84^\circ$, it is barely noticeable. As indicated previously, the pilot cannot identify this large angular distribution of radiated impulsive noise from inside the helicopter.

The extremely sharp positive pressure rise shown to exist in a narrow angular region near and above the rotor's tip-path plane (fig. 8) and in the direction of forward flight (fig. 9) resulted in very intense radiated noise levels. However, similar to the negative pressure pulse, no impulsive noise radiation could be detected by the helicopter pilot.

CONCLUSIONS

An in-flight technique for measuring UH-1H helicopter impulsive noise by stationkeeping with a quiet instrumented lead aircraft was found to be highly successful. Far-field quantitative acoustic waveforms and radiation patterns were easily obtained over a wide, continuous range of UH–1H flight conditions, including several areas known to produce annoying acoustic radiation. The data collected using this technique were not (to any significant degree) contaminated by background noise, doppler effects, ground reflections, and other transmission path distortions that have hindered many measurement efforts in the past. Care was exercised, however, in choosing a compatible, quiet fixed-wing aircraft and in accurately recording impulsive noise data. Feasibility of extending this technique for noise measurements of other helicopters appears to be quite promising.

There were two major findings as a result of this initial measurement program:

(1) Judging the occurrence and severity of a helicopter's radiated impulsive noise signature from cabin-based noise measurements can be misleading. For the UH–1H helicopter, a reduction in cabin audible impulsive noise levels may constitute a necessary but certainly not a sufficient indication that far-field impulsive noise radiation has been reduced.

(2) Three distinct types of impulsive noise are radiated by the UH–1H helicopter while flying between 80 and 115 knots at descent rates from zero to 1000 ft/min.

The first is a series of positive pressure pulses believed to be related to blade-tip vortex interaction. These pulses are responsible for the crisp popping sound of the radiated noise. During blade-vortex interaction, acoustic energy is radiated with relatively large angular directivity in the longitudinal plane, reaching a maximum about 40° below the helicopter's tip-path plane in the direction of forward flight.

The second type of impulsive noise is a negative pressure disturbance that rapidly increases in amplitude with forward velocity, becoming quite intense and sawtoothed in shape at 115 knots IAS. Subjectively, it sounds like a loud thumping and radiates not only near the tip-path plane of the rotor, but over wide azimuthal angles in the general direction of forward flight.

The third is a narrow positive pressure spike that closely follows the sawtooth-shaped negative pressure pulse at high airspeeds (115 knots). The resulting intense impulsive sound dominates all other noises generated by the helicopter and radiates within narrow azimuthal angles in the direction of forward flight near the tip-path plane of the rotor.

ACKNOWLEDGMENTS

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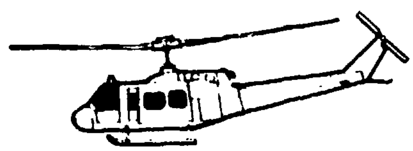
APPENDIX

UH-1H OPERATIONAL CHARACTERISTICS



HOTOR SYSTEM DESIGN VARIABLES	MAIN ROTOR	TAIL ROTOR
NUMBER OF BLADES	2	2
ROTOR DIAMETER	48 ft	8.5 ft
ROTOR SOLIDITY	0.0464	0.105
BLADE CHORD	21 in	8.41 in
BLADE AIRFOIL	NACA 0012	NACA 0015
BLADE TWIST (ROOT TO TIP)	-10.9 deg	0

AIRCRAFT OPERATIONAL LIMITS	MAXIMUM	MINIMUM
MAIN ROTOR TIP SPEEDS (ft/sec)	813.8	740.0
TAIL ROTOR TIP SPEEDS (ft/sec)	736.1	669.0
FORWARD FLIGHT AIRSPEEDS (kn)	115	0
GROSS WEIGHT (lb)	9500	6600

INDEX OF FLIGHT CONDITIONS

INDEX KEY	C_T/σ	ADVANCE RATIO	ADVANCING-TIP MACH No.
1	0.066	0.179	0.857
2	0.062	0.174	0.857
3	0.060	0.172	0.859
4	0.063	0.230	0.893
5	0.059	0.224	0.890
6	0.066	0.219	0.888
7	0.069	0.265	0.918
8	0.066	0.260	0.916
9	0.063	0.255	0.915
10	0.061	0.177	0.862
11	0.064	0.176	0.863
12	0.062	0.174	0.861
13	0.059	0.175	0.860
14	0.063	0.265	0.915
15	0.068	0.266	0.919
16	0.067	0.265	0.920
17	0.063	0.264	0.917

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