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RESULTS OF THE 1986 NASA/FAA/DFVLR MAIN ROTOR TEST ENTRY IN THE GERMAN-DUTCH WIND TUNNEL (DNW)

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ABSTRACT

An acoustics test of a 40 percent scale MBB BO-105 helicopter main rotor was conducted in the Deutsch-Niederlandischer Windkanal (DNW). The research effort, directed by NASA Langley Research Center, concentrated on the generation and radiation of broadband noise and impulsive blade-vortex interaction (BVI) noise over ranges of pertinent rotor operational envelopes. Both the broadband and BVI experimental phases are reviewed herein, along with highlights of major technical results. For the broadband portion, a significant advancement is the demonstration of the accuracy of prediction methods being developed for broadband self noise, due to boundary layer turbulence. Another key result is the discovery of rotor blade-wake interaction (BWI) as an important contributor to mid frequency noise. Also the DNW data is used to determine for "full scale" helicopters the relative importance of the different discrete and broadband noise sources. For the BVI test portion, a unique and comprehensive data base documents the BVI impulsive noise character and directionality as functions of rotor flight conditions. The detailed directional mapping of BVI noise emitted from the advancing side as well as the retreating side of the rotor constitutes a major advancement in the understanding of this dominant discrete mechanism.

INTRODUCTION

The Acoustics Division at the NASA Langley Research Center has an active ongoing program in helicopter system noise research. The program is directed at providing the technology base for quiet helicopter design in order to meet the present and future community noise concerns and to guide the development of noise certification criteria. Program results are employed in Langley's helicopter noise predictions software (ROTONET) development and contribute to the "design for noise" technology of the joint NASA/American Helicopter Society National Rotorcraft Noise Reduction Program.

The present project grew from needs identified in the early 1980's to acquire a benchmark high-quality aeroacoustic database from a large scale model of a current helicopter main rotor. The research topics of specific interest were the generation and radiation of rotor broadband noise and rotor blade-vortex interaction noise (BVI) over the operational envelopes where these sources are dominant. The benchmark database was intended to satisfy at least three major program needs: provide verification of existing analytical prediction capabilities, guide the development of new prediction methods, and define the various rotor noise sources in spatial and spectral domains as a function of rotor operating conditions. These three program needs directly support improved noise certification criteria for rotary wing aircraft.

Planning for the project began in early 1984 during exchanges of technical information and visits of research personnel between Langley and the DFVLR. Because of common research interests, the DFVLR Technical Acoustics Division became a partner in the BVI noise research effort, as established by a NASA/DFVLR Letter of Agreement. The DFVLR Rotary Wing Department was enlisted to provide a 40 percent scaled model of the MBB BO-105 rotor and model test stand through a contractual arrangement with NASA. Substantial financial support for the project was provided by the noise certification group of the Federal Aviation Administration since the test objectives were naturally complimentary to the FAA's development of noise certification regulations. Additional professional support was provided by the Army

Rotorcraft Aerodynamics Office located at NASA Langley. The excellent collaboration and support from the FAA, DFVLR and Army research groups permitted pre-test preparations to start in mid 1985.

This joint NASA/FAA/DFVLR rotor experiment was completed in the DNW in May 1986. A high quality, comprehensive database of both broadband and BVI noise data was acquired. Broadband noise prediction capabilities have already been validated with the present database in reference 1, and unique results on BVI noise directivity have been reported in reference 2. Key results of great relevance to the noise certification work of the FAA include the identification of a previously unrecognized rotor noise source, named blade-wake interaction (BWI) noise, and the documentation of primary BVI radiation lobes and their strong dependence on rotor flight conditions. Data were acquired which support the DFVLR's current program investigating the BVI interaction physics, and will be reported in reference 3.

This report will highlight some of the major technical results of the experimental program. The two phases of the experiment aimed at broadband and blade-vortex interaction noise are reviewed separately; each is presented with a discussion of the background, test philosophy and approach, key results, and current analysis efforts.

BROADBAND NOISE TEST

Background

In the absence of impulsive noise, random or broadband noise due to the rotor blade's interaction with turbulent air can be the primary source of rotor noise. While this is generally considered true, there has been debate as to when and to what extent this dominance occurs. As reviewed in reference 4, research at NASA Langley and other places have tremendously increased our fundamental understanding of broadband noise from aerodynamic surfaces in general. However, there has been a serious lack of suitable experimental rotor broadband noise data. Such data is required for development of new rotor broadband prediction methods, as well as the verification and refinement of methods already developed for particular rotor sources from the fundamental studies. The DNW test entry represents the first time that broadband noise from a large dynamically scaled rotor model has been measured systematically under various flight conditions in a well-controlled environment. Many of the acoustic measurements have already been reported in reference 1. The DNW results can provide the means to address a number of rotor noise issues including the community noise problem for the present and future commercial helicopter fleet.

Test Philosophy and Approach

An overview of the test set up in the DNW is shown in figure 1. The open anechoic tunnel configuration has an 8-m wide by 6-m high nozzle providing a free jet with a low turbulence potential core. The rotor is positioned in the flow between the nozzle on the right and the collector on the left. The model is a large (40 percent scale) dynamically and Mach number scaled MBB BO-105 main rotor. The out-of-flow acoustic instrumentation included a NASA-developed directional array containing 12 out-of-flow microphones placed above the rotor and 9 microphones placed about the ceiling, wall, and floor. Four floor microphones are shown in Figure 1.

Testing was conducted over a large operating range from hover to moderately high flight speeds for various climb and descent rates at different thrust settings. Diagnostic tests including rotor speed and blade geometry changes were made to better isolate and study the rotor noise sources. In parallel to and in support of this test program, an analytical effort was undertaken to develop a rotor self noise prediction capability. Self noise is broadband noise due to rotor blade boundary layer flow effects. The prediction method, which is by far the most sophisticated and complete to date, utilizes Langley developed scaling laws for self noise and the NASA ROTONET program[5] to define rotor performance and to sum noise contributions.

Key Results

An important result of the test is the distinction that was made possible between the noise contributions of the different main rotor noise sources--harmonic as well as broadband. This was accomplished by studying the characteristics and parametric dependence of acoustic pressure time histories and spectra, along with the broadband self noise prediction comparisons. A newly identified and important broadband noise source due to blade-wake interaction (BWI) was demonstrated.

The present understanding of how the different sources contribute to the total signal is illustrated in Figure 2, which shows the narrowband sound pressure spectra from an overhead microphone for three rotor flight conditions. A dual-frequency presentation is shown of that measured for the model and that corresponding to an equivalent "full scale" rotor. Indicated at the top are the spectral regions dominated by four noise source types. At the lowest frequency range is harmonic blade loading noise. Next is blade-vortex interaction (BVI) noise which is harmonic noise of impulsive character which occurs during helicopter descent when the rotor blades encounter the tip vortices of other blades. An illustration is given in Figure 3 of the flow field, including the tip vortices, about the rotor blades which are associated with noise production. The spectra show that in going from mild descent to mild climb, BVI disappears while the other sources generally maintain their levels. The frequency range which was dominated by BVI is now dominated by the higher harmonics of the loading (HHL) noise but at reduced levels compared to BVI noise. At slightly higher frequencies, the previously mentioned broadband BWI noise, due to blade interaction with turbulence in and about the wakes and tip vortices, controls the spectrum. The BWI source emerges in this study as the most important of broadband sources because of its mid frequency character and its persistance over a large range of operating conditions. Broadband self noise dominates the spectra at high frequencies. The self noise prediction curve shown for the climb case includes noise from turbulent boundary layers, vortex shedding from laminar boundary layers, and blade tip flow. These blade boundary layer flows are illustrated in Figure 3.

The self noise prediction comparisons with data, such as that shown in Figure 2, greatly aid our understanding of rotor spectra in general, as well as satisfying the more specific needs of prediction development and verification. The predictions use scaling laws developed from previous low speed non-rotating blade tests[6-9] conducted at Langley. The scaling laws were applied to the helicopter rotor by employing a performance program and a quasisteady assumption for boundary layer aerodynamics. The DNW rotor test matrix was particularly designed to validate these prediction codes. Figure 4 shows spectra for four rotor tip-path-plane angle, α_{TPP}, cases for the design rotor speed of 1050 rpm and half speed of 525 rpm. The rotor thrust coefficient C_T and advance ratio (ratio of tunnel speed to rotor tip speed) μ were maintained constant. This means the flow field and local blade orientations remained about the same for the two speed cases but all velocity magnitudes (and Reynolds numbers) were reduced by a factor of two. Note that all α_{TPP} cases shown correspond to climb cases (large negative angles for steepest climb) so the BVI mechanism does not contribute to the spectra. The BWI mechanism is seen to be important especially for the small negative rotor α_{TPP} angles. In the same figure, the self noise predictions are presented in a format useful for diagnostics. The predicted total noise, the total without the trailing edge bluntness noise contribution, and the combined contributions of the turbulent boundary layer noise and tip noise are shown. The difference between the latter two represents the predicted contribution from laminar boundary layer-vortex shedding noise.

The comparisons of Figure 4 show that self noise is well predicted in many respects. For the full speed case of Figure 4(a) the agreement is very good, except for some overprediction in the mid frequency range and in the high frequencies for the trailing edge bluntness source. When the rotor speed is reduced by half, as in Figure 4(b), the frequency ranges of the active mechanisms are squeezed to lower frequencies. With this lower speed, noise from vortex shedding due to blade laminar boundary layers is seen to increase substantially with respect to the other mechanisms. Note the predictions follow this behavior well and the noise due to bluntness appears well predicted at this lowered speed. A key general conclusion here is that as helicopter rotor speed is lowered, broadband noise increases in importance relative to discrete harmonic noise.

Figure 5 shows the effect of blade modifications, used to diagnose the individual self noise sources, for a particular climb condition for the rotor at half speed. The self noise predictions are now shown with the individual contributions as well as the total. Figure 5(a) shows results for the standard blade. Figure 5(b) is the result when the standard trailing edge geometry (which has a step and blunt edge) is smoothed and bluntness rounded. The data show increased vortex shedding noise with the modified trailing edge to bring the data into closer agreement with prediction. Such might be expected since the smooth flow condition is what was modelled in the predictions. The data-prediction comparison also shows good agreement for the changes in bluntness noise--the trailing edge modification produced a rounder and larger bluntness. Figures 5(c) and 5(d) are for the standard and modified trailing edge, as above, but the blades' boundary layers were forced to be turbulent, thus eliminating the vortex shedding noise. For both these cases the comparisons appear reasonable.

Scaling and Annoyance Calculations

In addition to the study of the mechanisms and their predictions, analysis has been underway to determine the importance of the individual sources to community impact as a function of helicopter operating conditions. What follows is a summary of this scaling analysis and a result.

The data from several of the floor microphones shown in Figure 1 has been processed to scale the data to equivalent "full scale" flyover cases. During the tunnel testing a run condition was specified in terms of rotor angle α_{TPP}, thrust coefficient C_T, and the advance ratio μ. Spectra were measured for each microphone. The scaling process employs a wind tunnel correction analysis to determine effective free-field rotor angles α_{TPP} and a flight condition analysis to find the equivalent full-scale descent rates for the corresponding tunnel cases. An acoustic scaling analysis is performed to determine frequency shifts required due to model-to-full scale rotor size ratios and that due to the Doppler effect for the flyover cases. Spectral amplitude changes are made to correct tunnel shear-layer refraction effects and to account for the differences in observer distances for the tunnel and flyover cases. The equivalent flyover spectra are then determined from that measured by employing those amplitude and frequency scale adjustments (note the example frequency scale in Figure 2).

A key result is given in Figure 6 showing the A-weighted overall sound pressure levels (dBA) as a function of equivalent "full scale" flyover descent angle θ and rotor advance ratio μ. This is for a main rotor of a MBB BO 105 with a gross weight of 2000 kg ($C_T \approx 0.0044$). The observer position with respect to the rotor flight path is illustrated by the inset of Figure 6 for two example descent angles of +10° and -10°. The flight path geometry chosen takes the rotor 150m directly above the observer for all angles. For all data shown, this effective observer position is at a directivity angle ϕ_e of about 65° and a distance r_e of about 163 m from the rotor source emission location along the flight paths. The cross marks in the figure are the tunnel test points and the number to the left are the corresponding dBA values. The contour lines illustrate the apparent trends in dBA. Regions of operating conditions are shaded indicating where particular noise source contributions dominated in the calculations dBA levels.

Figure 6 shows that BVI and higher harmonic loading (HHL) noise dominate dBA for the descent cases. In going to level flight and mild climb the broad-band source BWI becomes the major contributor due to the demise of BVI. At higher climb angles BWI is reduced and self noise becomes the most important. Calculations have been performed for Perceived Noise Levels (PNL) for the cases of Figure 6 and these show very similar trends as that of the dBA values. In addition, a different microphone location giving overflight angle ϕ_e values of about 94° has been found to give similar results but with a slight increase in importance of broadband BWI and self noise sources in the descent cases.

BLADE-VORTEX INTERACTION NOISE TEST

Background

Helicopter blade-vortex interaction noise (BVI) has in recent years become a problem of great interest in the helicopter acoustic research community. The impulsive noise resulting from blade-vortex interactions is the result of the aerodynamic interaction of a rotor blade with the trailing vortex system generated by preceding blades, and is predominantly generated during descent or low-speed manuevers. Since the interactions are highly dependent on the wake characteristics, the intensity and direction of propagation of this phenomenon is extremely sensitive to the rotor design and helicopter operating conditions. When BVI does occur, it dominates the acoustic signal and is in the frequency range considered the most important to human subjective response. The BVI noise source is a major problem for community noise in areas surrounding airports and heliports. The strong dependence of this noise source, and its directionality, on flight operations makes it a difficult source to accurately quantify in noise certification methods.

Results from previous flight tests[10,11] and wind tunnel experiments[12-17] have been reported on the directivity patterns of the BVI signal, with considerable conflict with regard to the primary radiation directions. The issue of impulsive noise created on the retreating side of the rotor has also been a controversial one. To date, a well-designed experiment aimed at documenting BVI directivity or the existence of retreating side BVI had not been performed. For these reasons, the primary objectives of the BVI phase of this program were to acquire a comprehensive data base to improve the present knowledge of the directivity patterns of rotor BVI impulsive noise; the locations on the rotor disk where BVI occurs; and to identify retreating side BVI noise. Acoustic results have already been reported in reference 2 and further results on the locations of the vortex interactions will be presented in reference 3.

Test Philosophy and Approach

Figure 7 presents a photograph looking downstream of the test set up in the DNW. The BVI directivity was investigated through the use of a large microphone array traversing in a plane under and upstream of the rotor. This large range of measurement locations and the facility's excellent acoustic qualities resulted in a high quality data base, useful for defining the BVI source locations using acoustic triangulation techniques[3]. The measurement of BVI acoustic signals from the retreating side of the rotor was pursued by positioning the microphone array under and downstream of the rotor, in the previously reported optimum measurement positions[16,17].

A nominal test plan was developed which concentrated on two thrust coefficients, C_T=.0044 and .0030, the forward speed range of 20 to 40 m/sec (advance ratio μ = .09 to .18), for a range of tip-path-plane angles. The traversing microphone array enabled measurements from 3 rotor radii upstream of the rotor, to 0.5 radius downstream, in a horizontal plane 1 radius below the rotor. To determine the optimum test conditions for strong BVI noise generation and the best measurement locations for the traversing microphone array, an initial exploratory approach was used, with data acquired on-line to guide test matrix design. During this initial exploratory testing, a high-pass filter was employed to remove the low frequency rotor loading noise harmonics, to obtain a better measure of only the mid-frequency BVI impulsive content of the signal. An average peak-to-peak acoustic pressure for forty "blade passages" was calculated to provide a noise metric of the mid-frequency BVI impulsive content of the signal. A more extensive test matrix was subsequently recorded on analog tape for more sophisticated post processing. Only data from the on-line analyses will be presented here.

Key Results

BVI Directivity.-Several high BVI test conditions in the low speed range of μ = .09 to .18 were defined by the initial exploratory test matrix, and the directivity of the BVI signal then documented by the traversing array measurements. The directivity results are presented as color contours of the averaged, filtered blade-passage peak-to-peak acoustic amplitudes of 72 independent measurements in the measurement plane. The acoustic data have been normalized for spherical spreading to an assumed nominal BVI source location on the advancing side. The discussion of the validity of the far field assumption and the use of this assumed source location is presented in reference 2. The circle on these contours represent the projection of the rotor disk on the horizontal measurement plane.

Figure 8(a) shows the radiation directivity pattern at μ = .075, α_{TPP} = 4.4 deg. The normalized peak-to-peak amplitudes do not show much variation in the upstream region, although there are three maximum regions of about 30 Pa normalized pressure ahead and upstream of the retreating side. This indicates that the impulsive content at this condition is not highly directional and has moderate strength. The real-time signals are indeed impulsive over the entire measurement plane, except in the region under the retreating side shielded by the fuselage. In general, two to three impulses are seen per blade, and these multiple blade-vortex interactions have roughly the same magnitude.

The directivity contours for higher μ values exhibit increased acoustic amplitudes and clearly show a maximum acoustic level region under the advancing side. At μ=.090 and particularly at μ=.116, the impulsive content tends to one strong, sharp, positive pressure impulse[2]. At μ = .138, shown in Figure 8(b), the highest amplitudes (about 60 Pa normalized pressure) were measured, and the maximum location appears to have moved off the measurement plane to the right. The real-time signals for this case typically exhibit only one very strong impulse; or if more than one impulse is present, one is generally much stronger than the others. Some indication of impulsive content is seen at the microphones upstream of the retreating side, but the impulses are less distinct and have lower amplitudes than those in the strong advancing side radiation lobe.

A clearly defined maximum region is still observed in the directivity contours for μ = .146, but the highest amplitude has decreased to about 40 Pa normalized pressure. A further decrease in amplitude is seen at μ = .170, shown in Figure 8(c), with a maximum region of about 25 Pa normalized pressure. The maximum region seems to move back upstream of the retreating side as μ increases from .138 to .170. At μ = .170, the interactions are less distinct, the radiation pattern is less focussed, and some BVI is seen under the retreating side.

Retreating Side BVI.-Impulsive content was observed at several test conditions in the data measured directly under the aft retreating quadrant of the rotor. The source of this impulsive activity is not immediately obvious. Most of the aft retreating quadrant is blocked by the fuselage from receiving signals from the aft advancing side of the rotor. Acoustic triangulation was applied using the arrival times of these impulses measured by the four microphones under the retreated side, and established that this impulsive signal was generated on the retreating side.

Retreating side BVI was not measured at μ = .075, and only very low levels were measured at μ = .090. Measurements under the retreating side at μ = .116 and .138 show increasing amplitudes for the retreating side BVI acoustic signal. Figure 9(a) presents the acoustic data measured under the retreating side for μ = .138. The advancing side BVI impulses are enclosed with boxes; the retreating side BVI with circles. Both advancing and retreating side impulses can be seen in the data from directly under the model (microphone 5). At μ = .146, the retreating side BVI amplitudes begin to decrease. At μ = .170, shown in Figure 9(b), the retreating side BVI's have almost the same amplitudes as the advancing side interactions, although lower than the BVI levels at μ = .116 or .138. Further data exhibiting retreating side interactions were also found at the lower C_T (.0030), with the highest amplitudes at μ = .184.

Although at some locations the retreating side signals appear to have equivalent strength as the advancing side signals, the available data cannot conclusively define the direction of strongest acoustic radiation. Since advancing side BVI noise is known to propagate forward of the blade leading edge, i.e., upstream of the advancing side, it is reasonable to assume that the retreating side BVI propagates downstream of the retreating side in an analogous manner. Thus the data measured in the present experiment, due to the practical constraints, are probably not in the region of strongest retreating side BVI radiation, but only on the outer edge of the primary radiation lobe.

Discussion

The above results show clearly that the impulsiveness, the sharpness of directionality, and the direction of strongest radiation for BVI noise are strong functions of the rotor flight condition. The temporal characteristics of the high BVI noise conditions show that: the lower speed cases exhibit multiple BVI while the higher speed typically have single BVI; the lowest and highest speed cases show a relatively omnidirectional radiation, while the moderate speed cases (μ = .138 and .146) exhibit more focussed radiation patterns. The movement of the primary radiation lobe indicates movement of the interaction location or changes in the interaction geometry, primarily due to changes in wake patterns.

These results have important implications regarding the operational regulations and noise certification of helicopters. The strong dependence of BVI noise on flight condition shows that there is clearly an optimum, minimum noise approach path for a specific helicopter. The occurrence of highly directional acoustic radiation patterns at certain operating conditions indicates that a limited and fixed set of measurement positions may be not adequate for accurate quantifying a wide range of flight conditions. The occurrence of retreating side BVI, which appears to have moderate acoustic levels which propagates downstream and behind the aircraft, is shown to be a non-negligible noise source which is not presently considered in noise certification procedures.

CONCLUDING REMARKS

The rotor broadband noise results obtained are by far the most creditable data available and will be a primary basis for broadband rotor noise research for years. It is shown that by scaling the DNW data to "full scale" conditions that broadband noise can be the dominant noise for a current design helicopter in level flight and climb. The data also reveal that as helicopter rotor speed is lowered, broadband noise increases in relative importance to discrete harmonic noise. These facts makes the consideration of broadband noise sources essential to a prudent and well-balanced design effort for future helicoters. The discovery of rotor blade-wake interaction (BWI) noise as an important contribution in the mid frequencies provides a key research focus for the broadband noise prediction problem. For the broadband self noise problem, accurate predictions appear nearly at hand. Self noise prediction methods are to be refined as based on the DNW data comparisons, and will be documented and installed on the ROTONET prediction system.

A unique and comprehensive data base has been acquired for rotor blade-vortex interaction (BVI) noise which documents this discrete noise sources' temporal characteristics and directionality as functions of rotor flight conditions. The strong dependence of impulsive amplitude, primary radiation lobe and the occurrence of multiple acoustic interactions on advance ratio and tip-path-plane is shown. Blade-vortex interactions created on the retreating side have been identified, although an accurate assessment of this source's directionality and importance relative to advancing side BVI would require more extensive spatial measurements. Analysis of the remainder of the data base is underway to more precisely define the parametric dependence of both the advancing and retreating side BVI signals, and the locations of the acoustic interactions on the rotor disk.

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Figure 1 - Broadband noise test setup in DNW.

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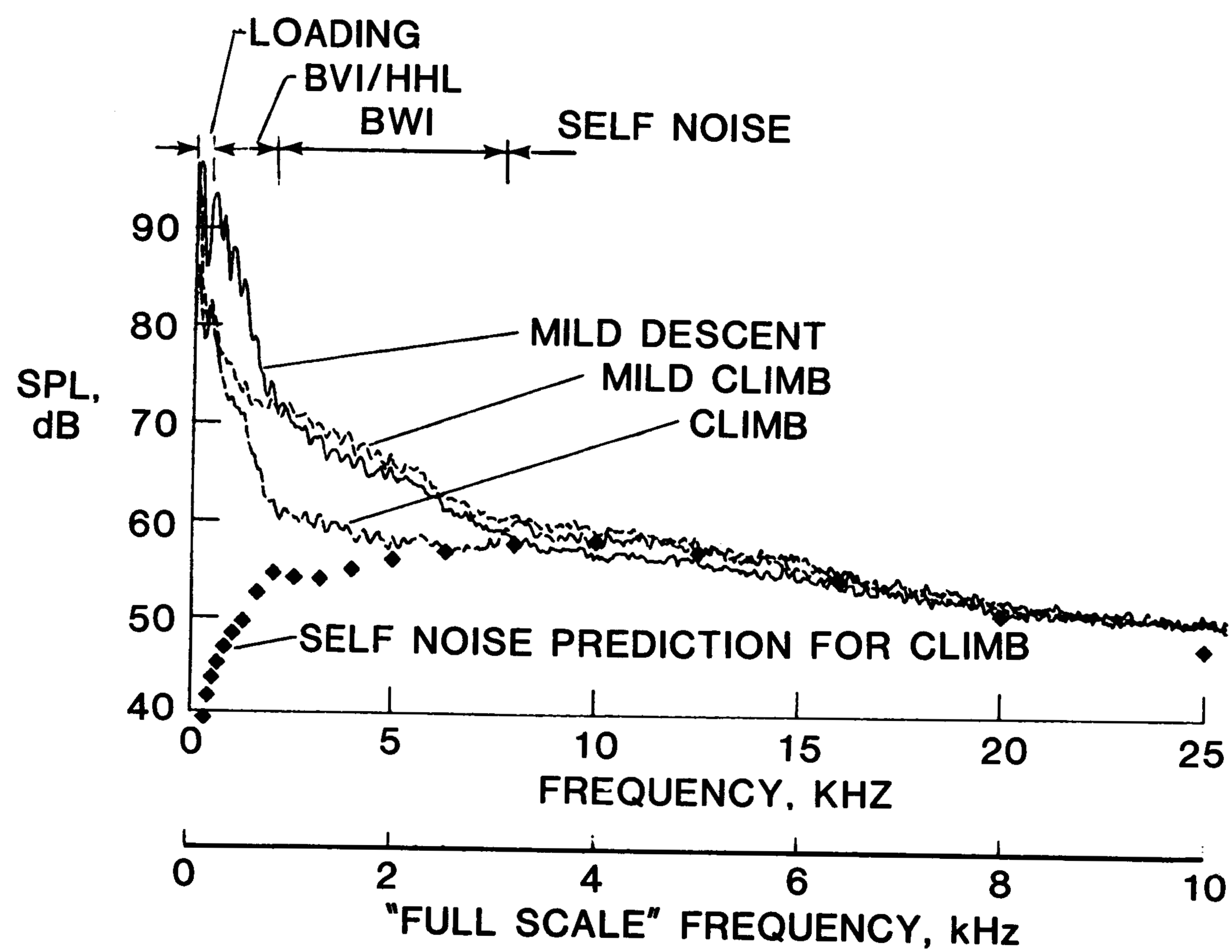

Figure 2 - Overhead noise spectra showing effects of descent angle change for constant thrust C_T=0.0044 and advance ratio μ=0.173 (v=74 knots). Blade passage frequency is 70 Hz. Bandwidth is 50 Hz.

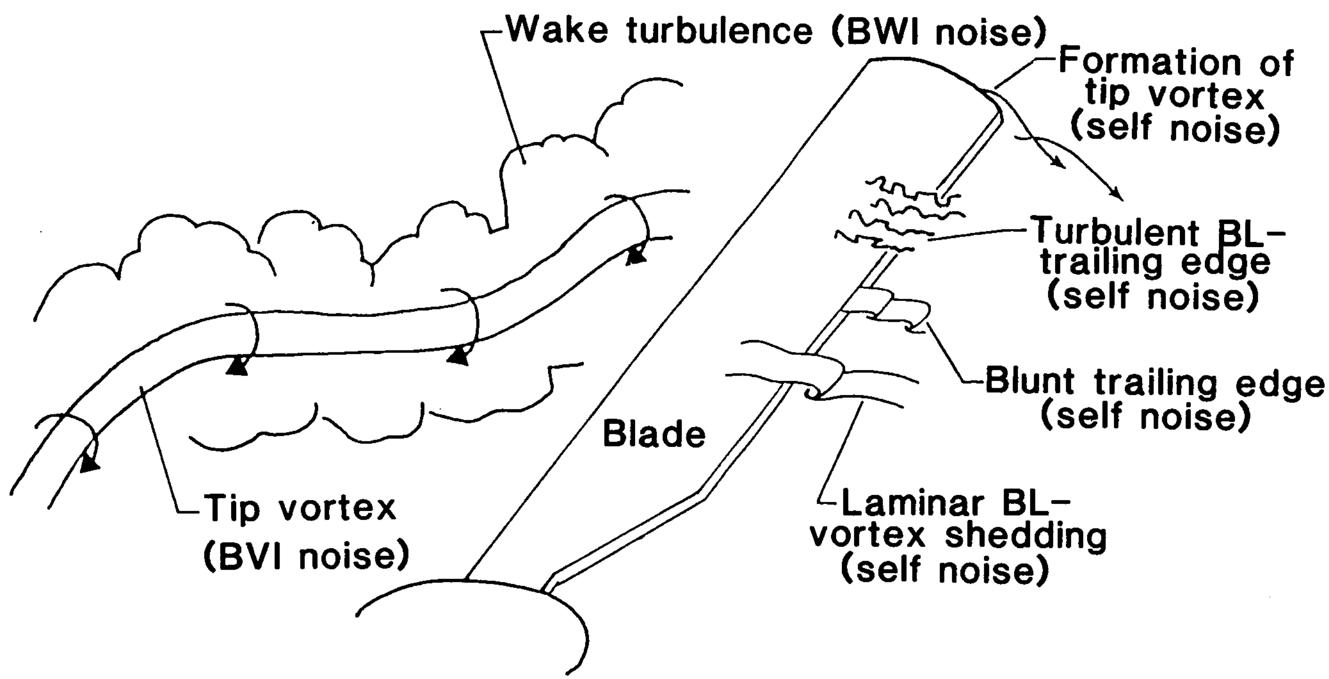

Figure 3 - Illustration of flow field encountered by and generated by rotor blades.

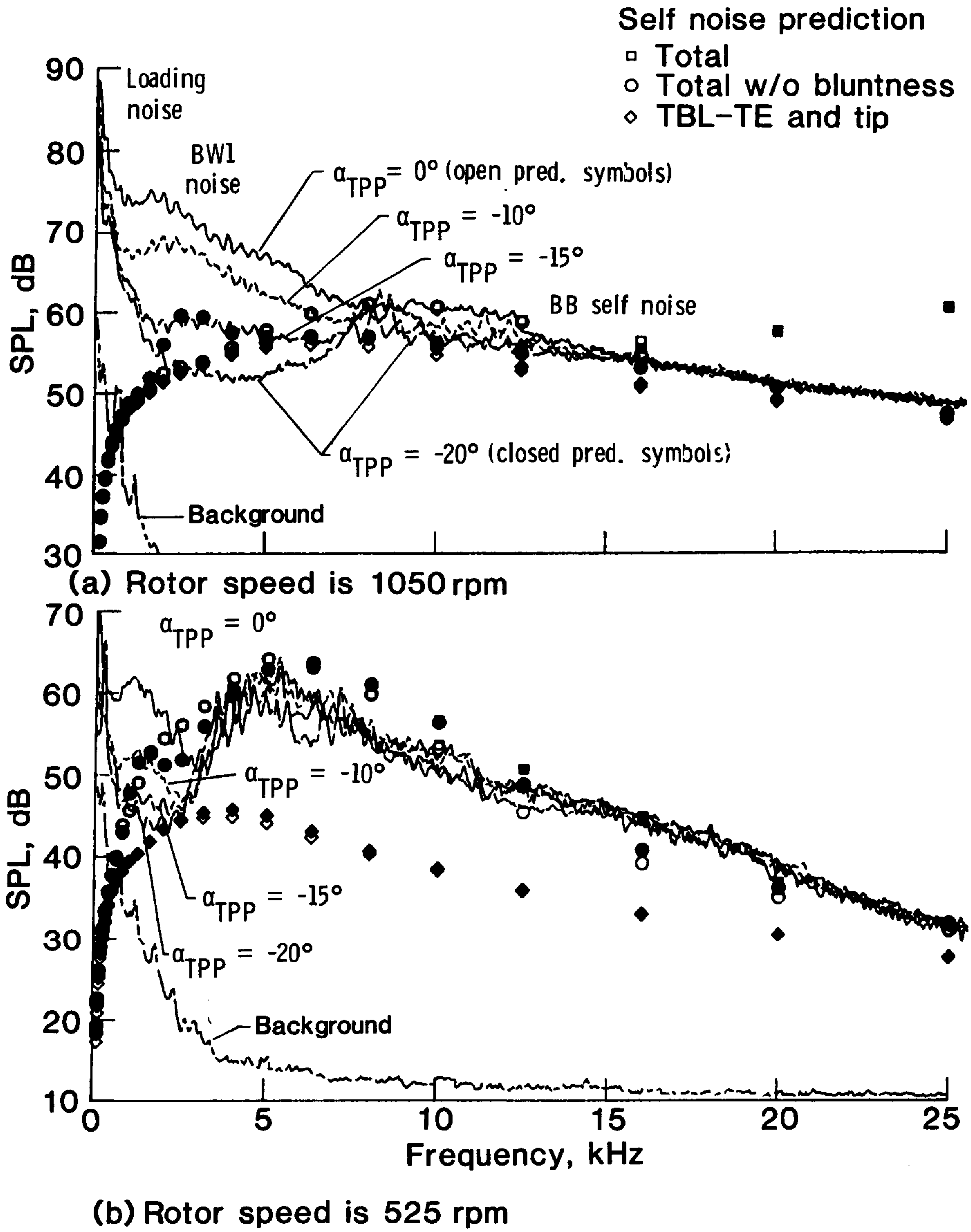

Figure 4 - Effect of rotor angle α_{TPP} for constant C_T=0.0044 and μ=0.086 for full and half rotor speeds.

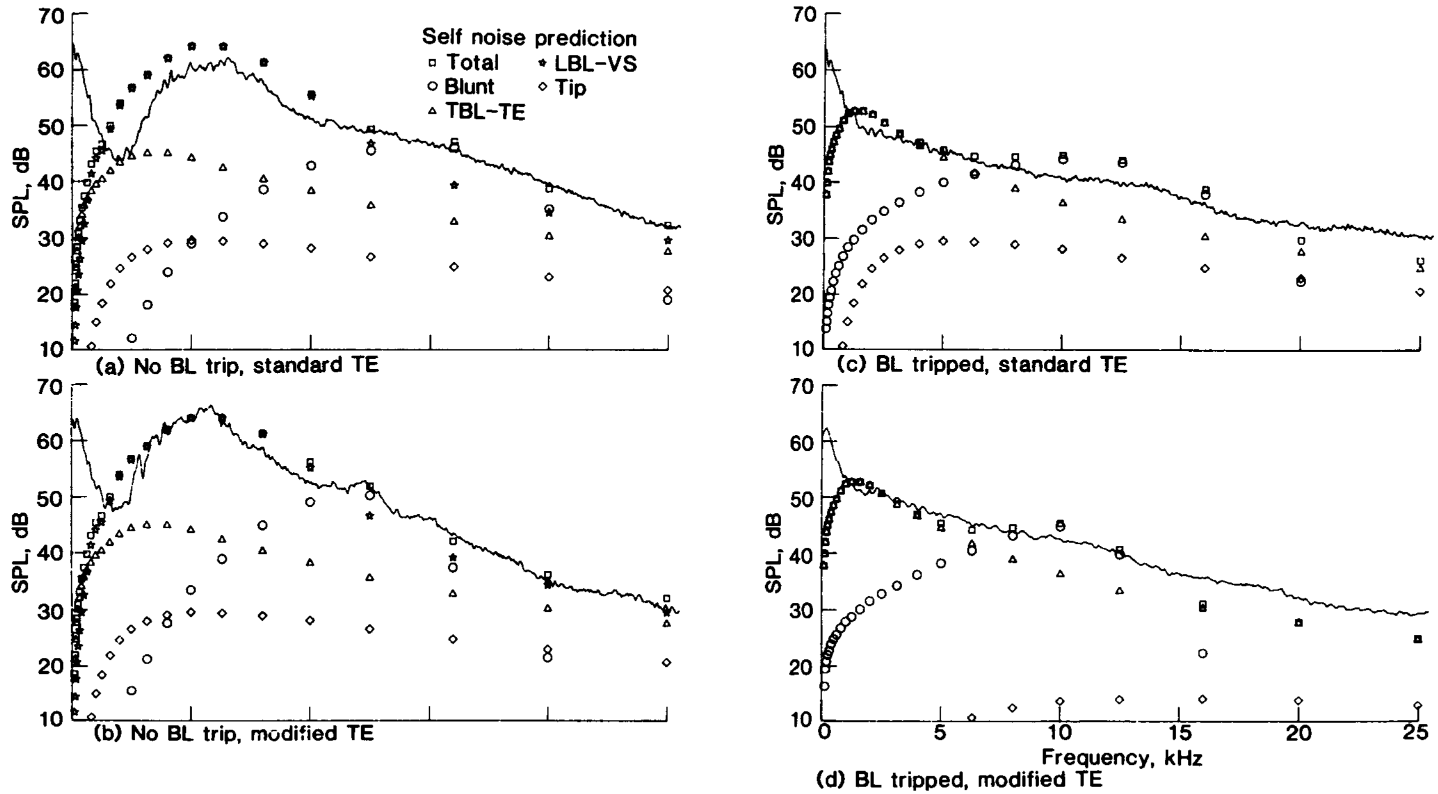

Figure 5 - Effect of blade modification with tripped and untripped boundary layers; rotor rpm=525, α_{TPP}=-10°, C_T=0.0044, and μ=0.173.

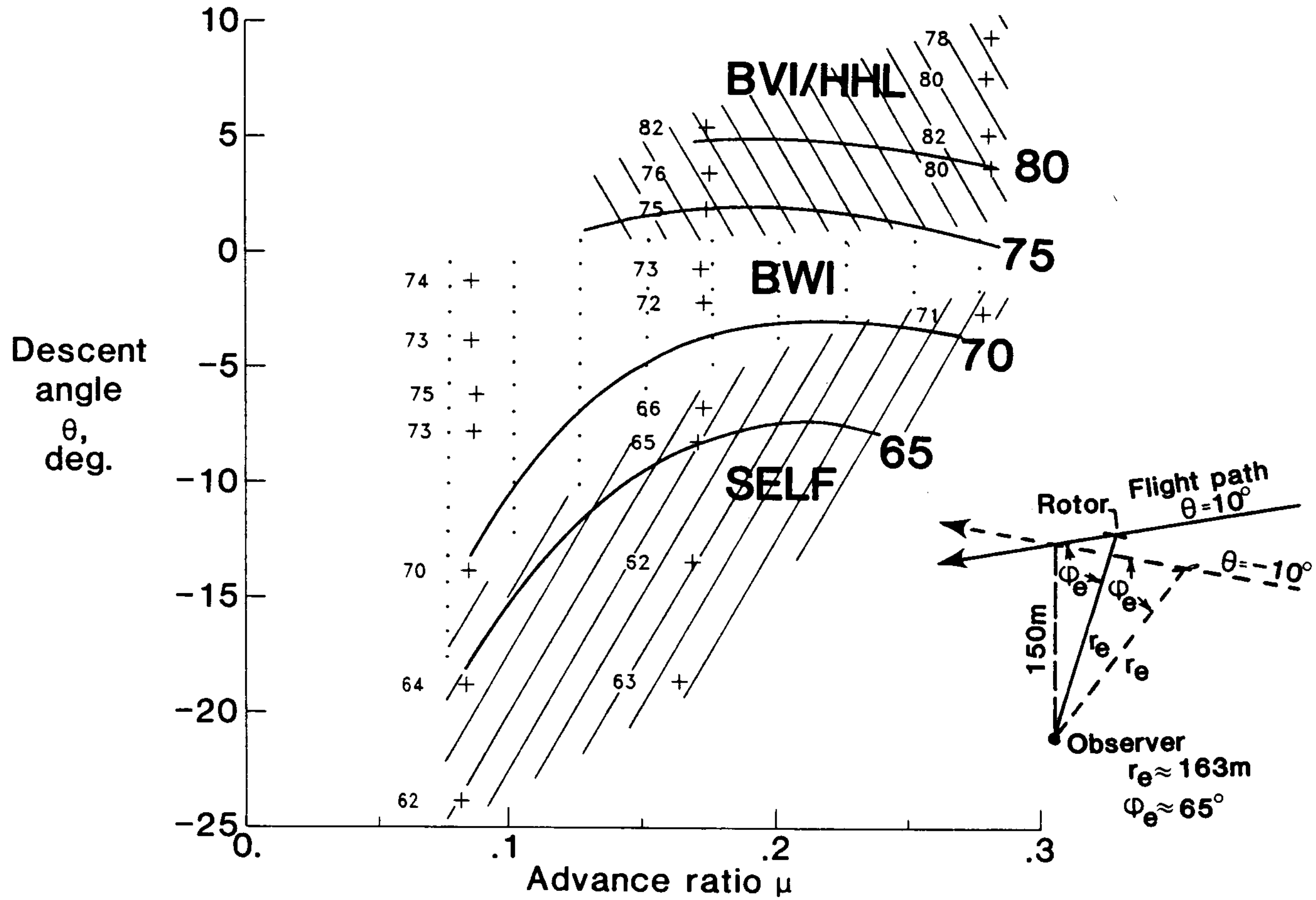

Figure 6 - dBA and dominant regions of main rotor noise source types versus descent angles and speeds for "full scale" BO-105 as scaled from DNW model. Inset sketch shows observer geometry.

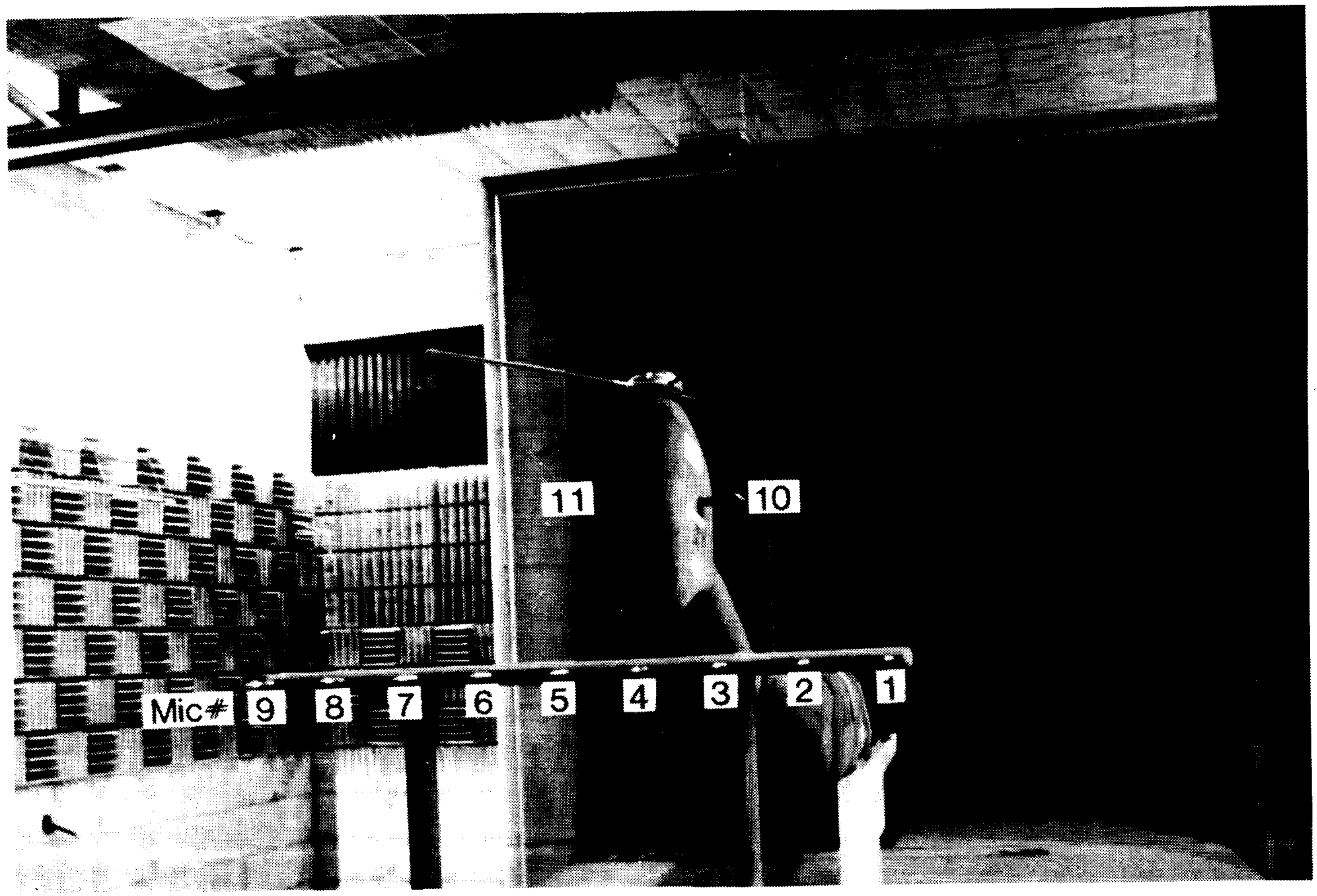

Figure 7 - Blade-vortex interaction noise test setup.
Photograph (looking downstream) shows traversing microphone array.

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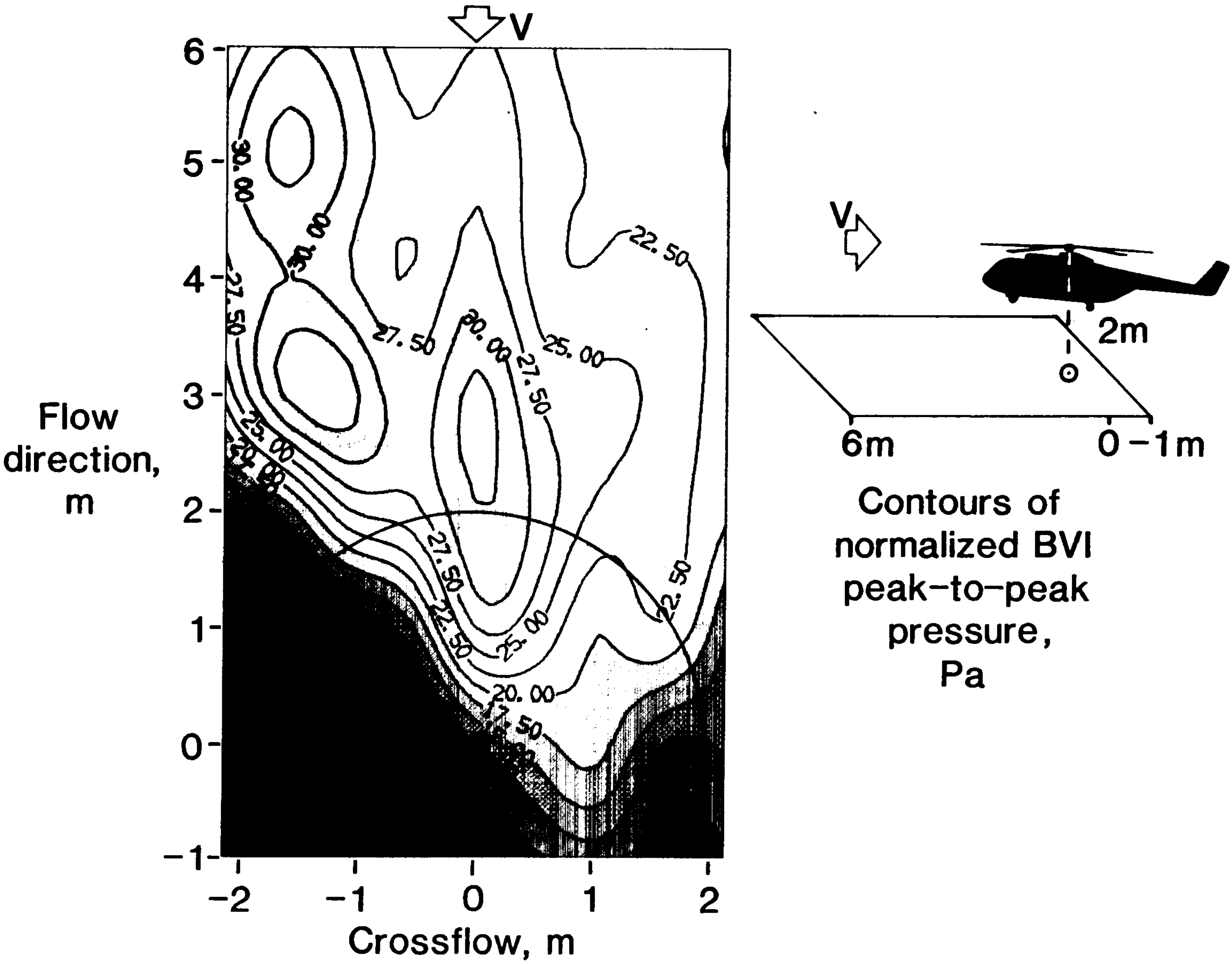
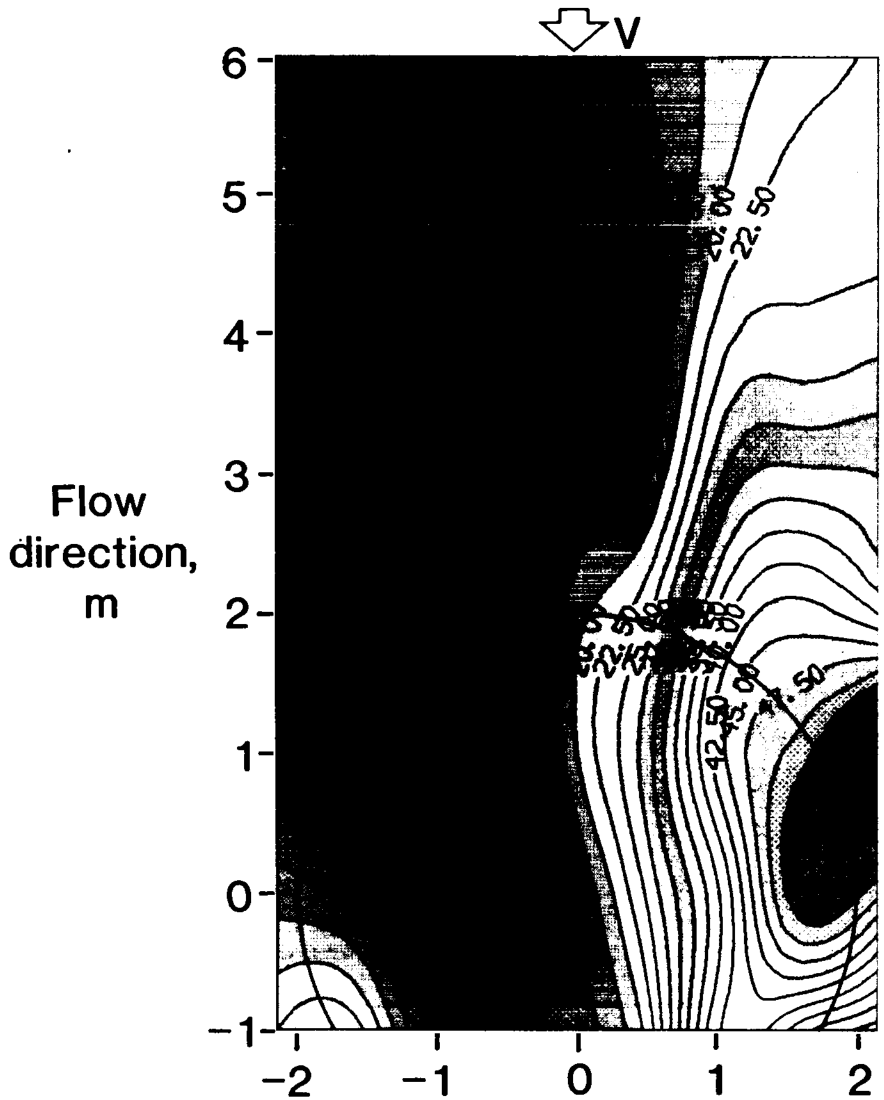
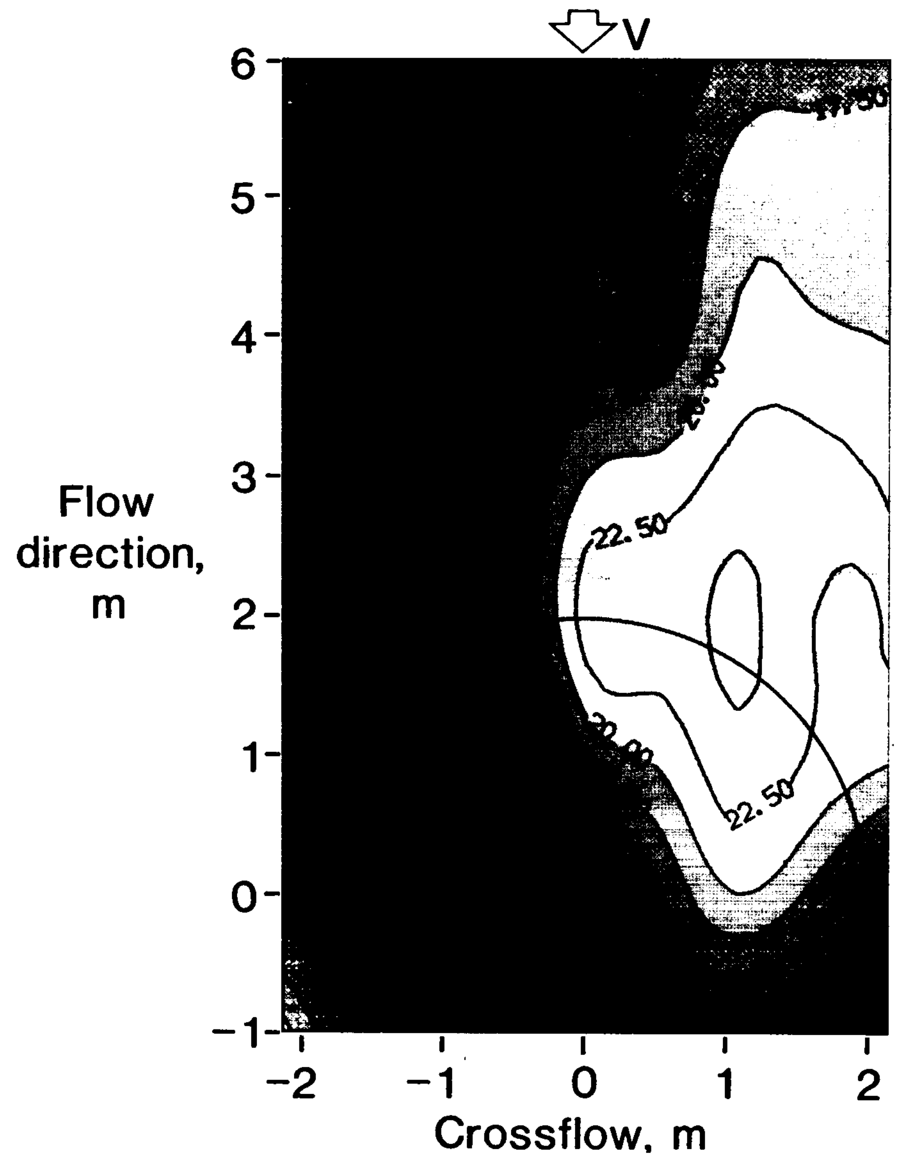


(a) μ=0.075, α_{TPP}=4.4°

Figure 8 - Contours of BVI peak-to-peak acoustic pressure (in units of Pa) normalized to a 4 m reference distance and nominal BVI source location.



(b) μ=0.138, α_{TPP}=2.3°.



(c) μ=0.170, α_{TPP}=−1.1°.

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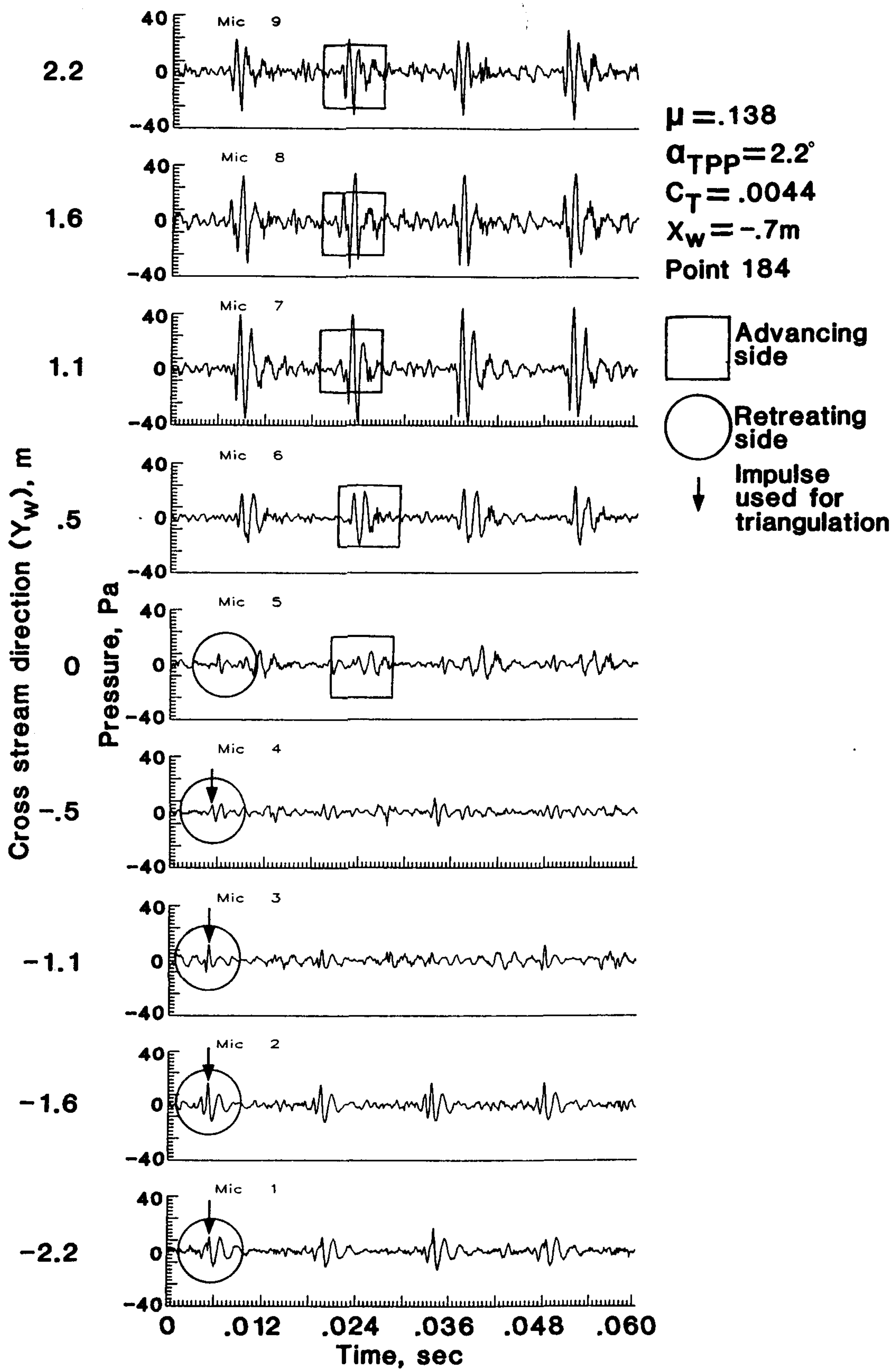
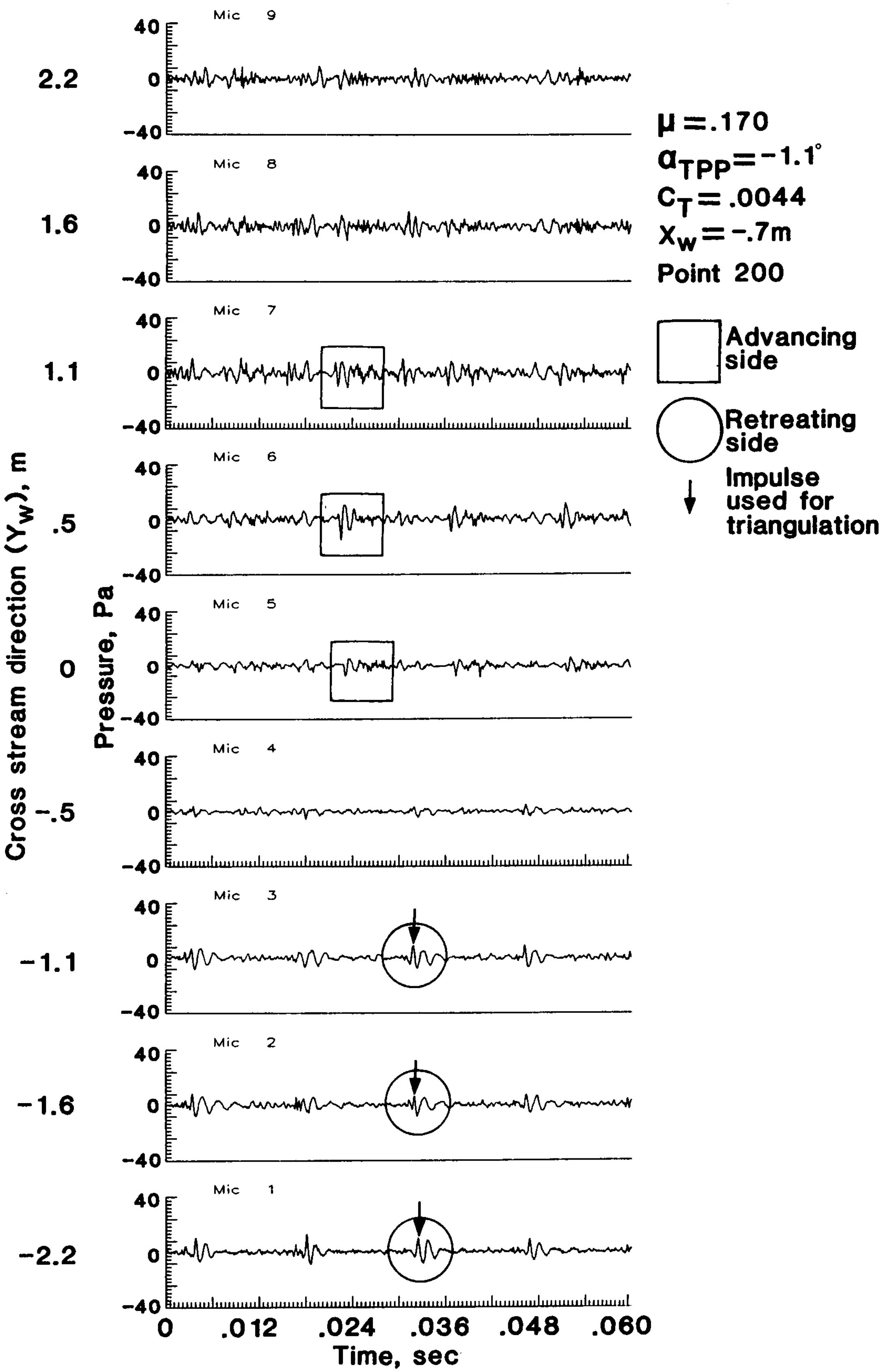
Figure 8 - (Concluded)



(a) μ=0.138, α_{TPP}=2.2°

Figure 9 - Acoustic data exhibiting BVI from advancing and retreating side of rotor disk.



(b) μ=0.170, α_{TPP}=-1.1°.

Figure 9 - (Concluded)

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16. Abstract

An acoustics test of a 40 percent scale MBB BO-105 helicopter main rotor was conducted in the Deutsch-Niederlandischer Windkanal (DNW). The research effort, directed by NASA Langley Research Center, concentrated on the generation and radiation of broadband noise and impulsive blade-vortex interaction (BVI) noise over ranges of pertinent rotor operational envelopes. Both the broadband and BVI experimental phases are reviewed herein, along with highlights of major technical results. For the broadband portion, significant advancement is the demonstration of the accuracy of prediction methods being developed for broadband self noise, due to boundary layer turbulence. Another key result is the discovery of rotor blade-wake interaction (BWI) as an important contributor to mid frequency noise. Also the DNW data is used to determine for "full scale" helicopters the relative importance of the different discrete and broadband noise sources. For the BVI test portion, a unique and comprehensive data base documents the BVI impulsive noise character and directionality as functions of rotor flight conditions. The detailed directional mapping of BVI noise emitted from the advancing side as well as the retreating side of the rotor constitutes a major advancement in the understanding of this dominant discrete mechanism.

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