NASA Technical Memorandum 104134

P16

Helicopter Main-Rotor Speed Effects–
A Comparison of Predicted Ranges of Detection
From the Aural Detection Program ICHIN and the
Electronic Detection Program ARCAS

Arnold W. Mueller and Charles D. Smith

September 1991

ABSTRACT

NASA LaRC personnel have conducted a study of the predicted acoustic detection ranges associated with reduced helicopter main-rotor speeds. This was accomplished by providing identical input information to both the aural detection program ICHIN 6, ("I Can Hear It Now," version 6) and the electronic acoustic detection program ARCAS ("Assessment of Rotorcraft Detection by Acoustics Sensing"). In this study, it was concluded that reducing the main-rotor speed of the helicopter by 27% reduced both the predicted aural and electronic detection ranges by approximately 50%. Additionally, ARCAS was observed to better function with narrowband spectral input than with one-third octave band spectral inputs and the predicted electronic range of acoustic detection is greater than the predicted aural detection range.

INTRODUCTION

The design of a helicopter is based on an understanding of many variables and their interactions. It has been noted that in the design stage of a helicopter, the weight, engine, and rotor speed must be considered along with the rotor geometry when considering helicopter operations (ref. 1). However, the relationship between the noise radiated from the helicopter and these parameters is not well understood, and only a limited set of model and full-scale field test data were available for study. In general, the previously available data showed that reduced rotor speeds resulted in reduced far-field noise levels; however, no systematic flight tests had been reported where field recorded data were available for study. Additionally, the relationship of the effects of reducing the rotor speed of a helicopter on its acoustic detection characteristics had not been studied.

The helicopter noise research project reviewed in reference 1 discussed experimental flight data collected to study helicopter rotor speed effects on far-field acoustic levels. Reference 1 presented the results of tests conducted with a

McDonnell Douglas Helicopter Company model MD-500E helicopter operating with the rotor speed as the control variable over the range of 103% of the main-rotor speed (NR) to 75% NR. The forward speed was maintained at a constant value of 80 knots for the tests. Reference 1 showed that as the main-rotor speed was reduced, a significant sound pressure level reduction occurred in the one-third octave bands containing the main and tail rotor fundamental acoustic frequencies. Furthermore, the largest reduction in sound pressure level occurred at the first reduction of the main-rotor speed. These reduced sound pressure levels generated an interest in determining the magnitudes of the acoustic detection ranges associated with them.

To investigate the relationship of detection range reductions for the reduced sound pressure levels, two different computer programs were used to predict detection ranges. The first program used was the aural detection program ICHIN ("I Can Hear It Now," refs. 2-3). These references present a discussion of the development of the ICHIN computer program along with a discussion of the changes made in it. They note that four modules (named "input," "aural detectability," "propagation" and "output") comprise the program. Required inputs are either one-third octave band or narrowband spectra, aircraft speed and position at the time of an input spectrum, weather data, and ambient noise data.

The second acoustic detection computer program to be used to predict acoustic detection ranges was the program ARCAS ("Assessment of Rotorcraft Detection by Acoustics Sensing," refs. 4-5). ARCAS has been referred to as an electronic "ICHIN," because the probability of acoustic detection is based on electronic measurements without any relationship to human hearing. Briefly, ARCAS determines the probability of acoustic detection based on an operator chosen probability of false alarm, the probability distribution function of the measured ambient noise, the probability distribution function of the measured helicopter signal plus the ambient noise, and an operator chosen level for the

2

probability of detection of the helicopter acoustic signature. Noise source spectra, helicopter speed and altitude, and weather conditions, along with ambient noise data, are ARCAS input requirements. Within the ARCAS program, acoustic signals are operated on in a propagation module typical of that in ICHIN except that the attenuation of the sound signal due to the presence of the ground is considered using the results of current "state-of-the-art" analytical expressions in lieu of empirical results as used in ICHIN. This results in ARCAS having the capability to evaluate the attenuation of an acoustic signal as if it has propagated over an acoustically "hard" or "soft" surface, a capability not contained in ICHIN.

RESEARCH OBJECTIVES

The objective of this report is to present the results of a study of the acoustic detectability of measured helicopter flight noise data as a function of main-rotor speed. Comparisons are made of the predicted detection ranges obtained from the two acoustic detection computer programs ICHIN and ARCAS.

To meet the objective of this report, measured acoustic spectra obtained from the McDonnell Douglas MD-500E helicopter operating at four different main-rotor speeds were used as input to each of the computer programs. A complete description of the MD-500E flight test is given in reference 1.

TEST HELICOPTER

For review purposes, figure 1 presents a photograph of the light-weight (approximately 3100 kg) McDonnell Douglas MD-500E helicopter. The aircraft may carry a pilot and five passengers at a nominal cruising speed of 125 knots at sea level. It has a five-bladed main-rotor and a two-bladed tail rotor each of which operates at nominally standard rotor tip speeds of approximately 213.4 m/s at 103% NR.

3

TEST DATA

Although a linear array of ground-board microphones was used to obtain acoustics data (ref. 1), only data reduced from a single microphone are reported in this study. The acoustics data used as input to ICHIN and ARCAS were measured for the helicopter flying at a constant 75 meter altitude and 80 knot forward speed. Initial take-off gross weight was 4994 kilograms. Test variables were rotor speeds of 492 rpm (typical for standard operations), 430 rpm, 392 rpm, and 358 rpm.

DATA REDUCTION AND RESULTS

Weather Measurements

Both acoustic detection computer programs require weather data as input. Table 1 lists measured values of wind speed and direction, temperature, and relative humidity at ground level at the test site during times of acoustic data acquisition. These values were used as input to both ICHIN and ARCAS.

One-Third Octave Band Spectra

Figure 2 presents the one-third octave spectral analysis of the noise obtained when the helicopter was at a range of 1 kilometer from the microphone and at an elevation angle of 4 degrees. These spectra, which represent in-plane thickness noise of the main-rotor, tail-rotor and their harmonics, were used as input to ICHIN and ARCAS. The top curve in each part of figure 2 is the spectrum measured for the different rotor speeds. For comparison, the ambient noise spectrum measured before the flight is shown at the bottom. Table 2 presents measured overall and one-third octave band sound pressure levels in frequency bands containing the Doppler-shifted main and tail rotor fundamental tones. Figure 2 and table 2 show that as the rotor speed is reduced, the noise levels and the acoustic frequencies of both the main and tail rotor are reduced, except for the 75% NR condition. At 75% NR, both the overall and the tail-rotor sound pressure level increased by 2 to 3 dB from the 82% NR run. This change is

4

due to a change in ambient noise. It was noted earlier in reference 1 that the location where data were measured was about 1.6 kilometers from an interstate highway.

Relative one-third octave band sound pressure levels of the received Doppler-shifted main rotor fundamental frequency (from table 2) are presented in figure 3. These relative sound pressure levels are presented as a bar chart with the advancing blade tip Mach number and percent of NR of the main-rotor speed listed on the abscissa. Amplitudes of the sound pressure levels are relative to the measured sound pressure level at 103% NR. The data show that reducing the main-rotor speed from 103% to 90% (12.6% reduction) NR resulted in a 6.1 dB reduction of the far-field noise level. The succeeding rotor speed decreases provided 2.7 and 2.2 dB further noise reductions. Thus by reducing the main-rotor speeds from 103% to 75% of NR (a 27% reduction in rotor speed), the measured main-rotor in-plane thickness noise was reduced by approximately 11 dB.

Figure 4 presents a comparison of the relative predicted detection range results of ARCAS and ICHIN using the spectra of figure 2 and the weather data from table 1 as input. The results are relative to the maximum range of predicted detection resulting from ICHIN operating on the 103% NR one-third octave band spectrum. Operator chosen parameters used in ARCAS were a probability of false alarm of 0.1% at a probability of detection of 50% for an acoustically "hard" surface over which the signals were propagated. The figure shows that as the rotor speed is reduced from 103% to 75% NR (a difference of 27%), the predicted detection ranges tend to be reduced by approximately 50%. The figure also indicates that both ICHIN and ARCAS predicts the expected general trend of reduced acoustic detection distances as the rotor speed is reduced.

Figure 4 also shows that at 103% NR, ARCAS predicts an acoustic detection range approximately 60% greater than ICHIN. This significant difference is not seen at the other rotor speeds. This was believed to be the result of two factors. First the signal-to-noise (S/N) ratios for the tones in the 103% NR data are much larger than for those at the other rotor speeds. The second factor is the analysis bandwidth which increases for the constant percentage one-third octave analysis. This produces smaller S/N ratios at the higher tones because more "noise" is measured in the one-third octave band containing a tone than the "noise" measured by the constant narrowband bandwidth. Since both ICHIN and ARCAS may use either one-third octave or narrowband spectra input, it was of interest to determine if using constant bandwidth narrowband spectra produced similar results between ICHIN and ARCAS as did the one-third octave band spectra. The narrowband spectra (bandwidth of 2.5 Hz) of the data in figure 2 were used as input to both ICHIN and ARCAS for this consideration with no other changes in input conditions to either program.

Figure 5 presents the results of using narrowband spectra as input to both ICHIN and ARCAS. The data presented are the relative predicted ranges of detection as referenced to the maximum detection range of ICHIN as discussed for figure 4. Figure 5 shows that for the narrowband ARCAS results, predicted ranges are indeed greater than ICHIN predictions by almost 2 to 1 at all engine operating conditions. The figure also indicates that the ICHIN results for the narrowband spectra produce predicted ranges slightly larger than for the one-third octave band spectra results of figure 4. These detection differences between the one-third octave band and narrowband results are due to the changes in the signal-to-noise (S/N) ratios which occur for the two types of analysis bandwidths. As the bandwidth continually increases for the one-third octave analysis, the S/N ratios of the tones of the helicopter contained within the bandwidths experience a larger decrease than for the tones contained within the constant

6

narrowband bandwidth analysis. Thus, this brief study showed that use of one-third octave band noise inputs to ARCAS could produce biased results unless the input S/N ratios were comparable to those for the one-third octave data at 103% NR.

CONCLUSIONS

Results from data in this report show that the reduction of the main-rotor speed of a light-weight commercial helicopter by 27% produced a corresponding far-field noise reduction of 11 dB in the one-third octave band containing the main-rotor fundamental frequency. More than half of this decrease, 6.1 dB, occurred when the normal operating speed of the rotor was reduced from 103% NR to 90% NR. When the one-third octave band noise levels resulting from the different rotor speeds were used in the computer program ARCAS, predicted ranges of detection were lower for all reduced rotor speeds than that for 103% NR. The aural detection computer program ICHIN showed lower detection ranges for only the first two reduced rotor speeds, with seemingly little changes after the second rotor speed reduction. When one-third octave band flight noise data were used as input to the ARCAS and ICHIN programs, ARCAS produced a significant difference in the predicted range of detection compared to ICHIN for the 103% NR spectra but produced comparable detection ranges for spectra at the slower rotor speeds. When narrowband spectra were used in lieu of one-third octave band spectra as input into ARCAS and ICHIN, the ARCAS predicted ranges of detection were generally twice as large as for the ICHIN predicted detection ranges.

REFERENCES

1. Mueller, Arnold W.; Childress, Otis S.; and Hardesty, Mark: Helicopter Main-Rotor Speed Effects on Far-Field Acoustic Levels. NASA Technical Memorandum 100512, October 1987.

2. Abrahamson, A.: Correlation of Actual and Analytical Helicopter Aural detection Criteria. USAAMRDL Technical Report 74-102A, Vol. 1, January 1975.

3. Mueller, Arnold W.; Smith, Charles D; Shepherd, Kevin P.; and Sullivan, Brenda M.: A New Version Of The Helicopter Aural Detection Program— ICHIN. NASA Technical Memorandum 87745, July 1986.

4. Garber, Donald P.; Preisser, John S.; and Willshire, William L., Jr.: A Method for Assessment of Rotorcraft Detection by Acoustic Sensing. NASA Technical Memorandum SX-89103, July 1988.

5. Willshire, William L., Jr; Smith, Charles D.; and Garber, Donald P.: A Computer Program for Assessment of Rotorcraft by Acoustic Sensing. NASA Technical Memorandum SX-89162, October 1988.

Table 1. Measured Weather Data Used as Input to ICHIN and ARCAS

Engine RPM	Wind		Temperature	Relative Humidity
% NR	Speed Knots	Direction Deg True N	Deg °C	Percent
103	4.5	014	24.1	89
90	4.5	014	25.1	78.2
82	4.5	014	25.8	78.2
75	4.5	014	23.7	82.4

Table 2. Measured Sound Pressure Levels for Slowed Rotor Noise Tests Using the MDHC Model 500E Helicopter

Nominal Values:

Airspeed, 80 Kts
Altitude, 76 Meters
Slant Range 1 Kilometer

Acoustic Fundamental Frequency at 103% NR
Main Rotor 41 Hz
Tail Rotor 98 Hz

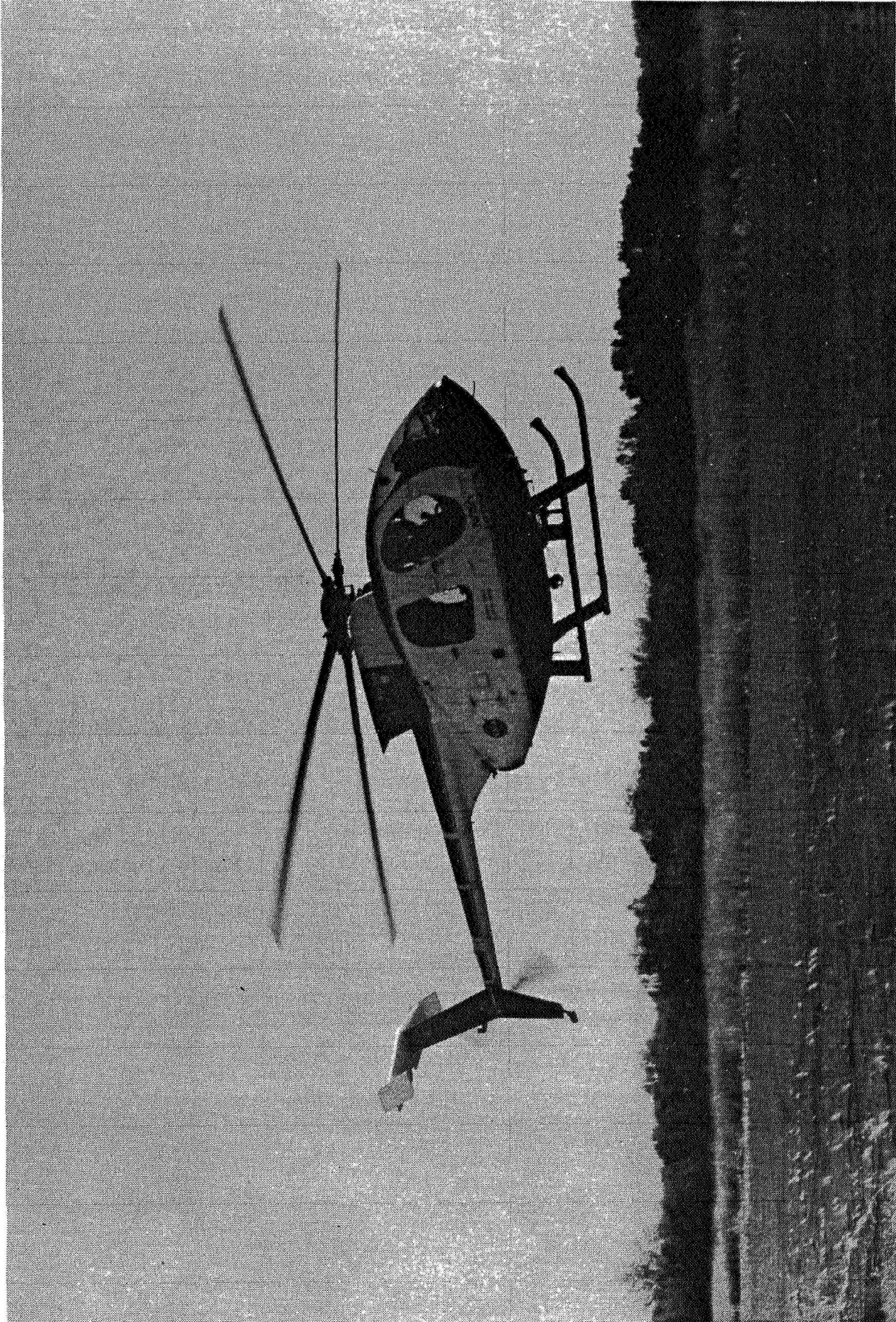| Engine RPM % NR	Overall Sound Pressure Level, dB	Doppler Shifted Frequency, Hz		One-Third Octave Band Sound Pressure Level, dB	
		Main Rotor	Tail Rotor	Main Rotor	Tail Rotor
103%	69.7	46.5	110.9	63.6	63.5
90%	63.8	41.8	99.8	57.5	57.3
82%	63.1	38.1	90.9	54.8	56.8
75%	65.1	34.9	82.2	52.6	59.6

9

Figure 1.- Photograph showing the McDonnell Douglas helicopter company model 500E helicopter.
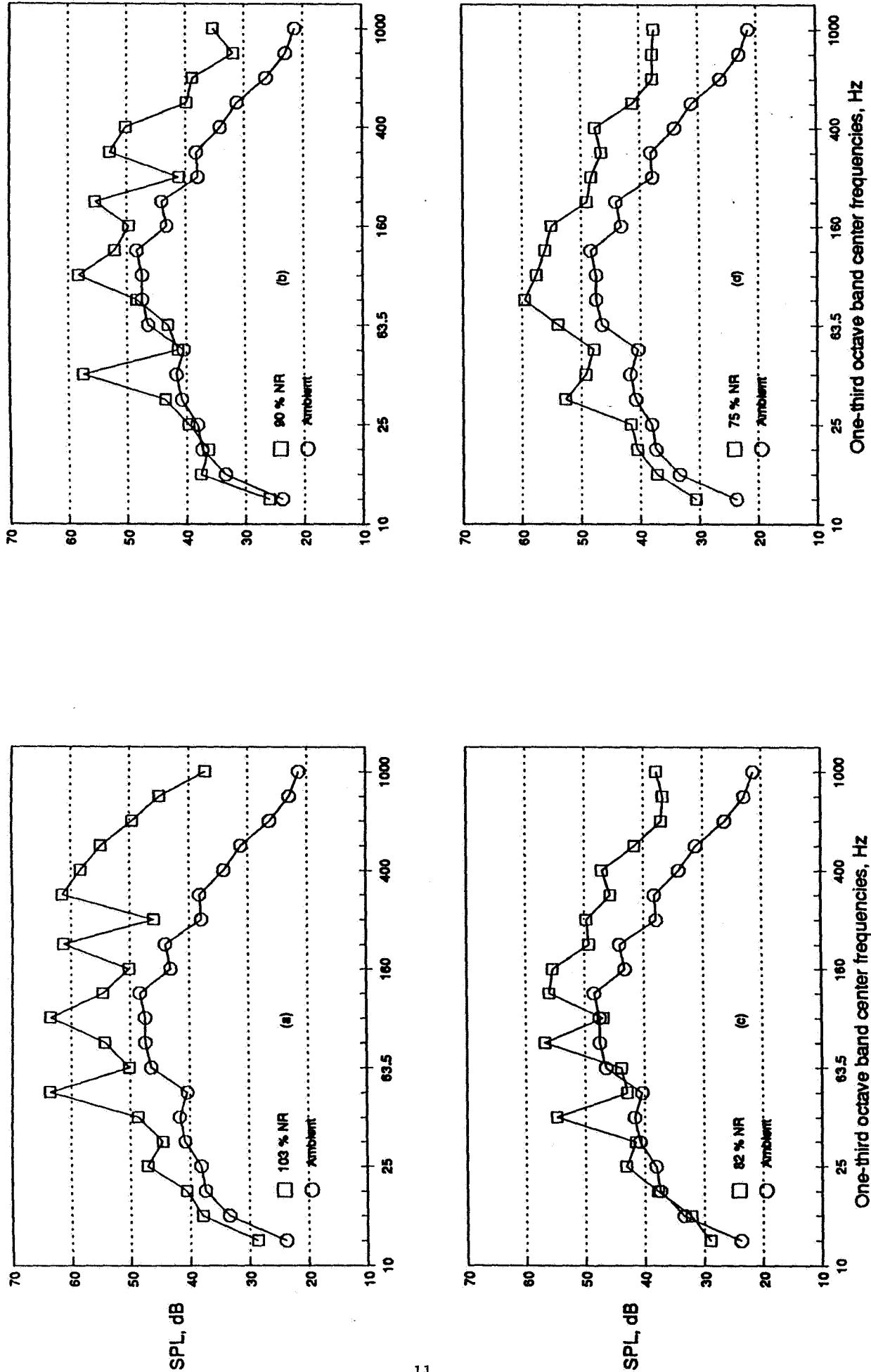
Fig 2: One third octave band spectra for ambient noise and different rotor speeds for the MD 500E helicopter
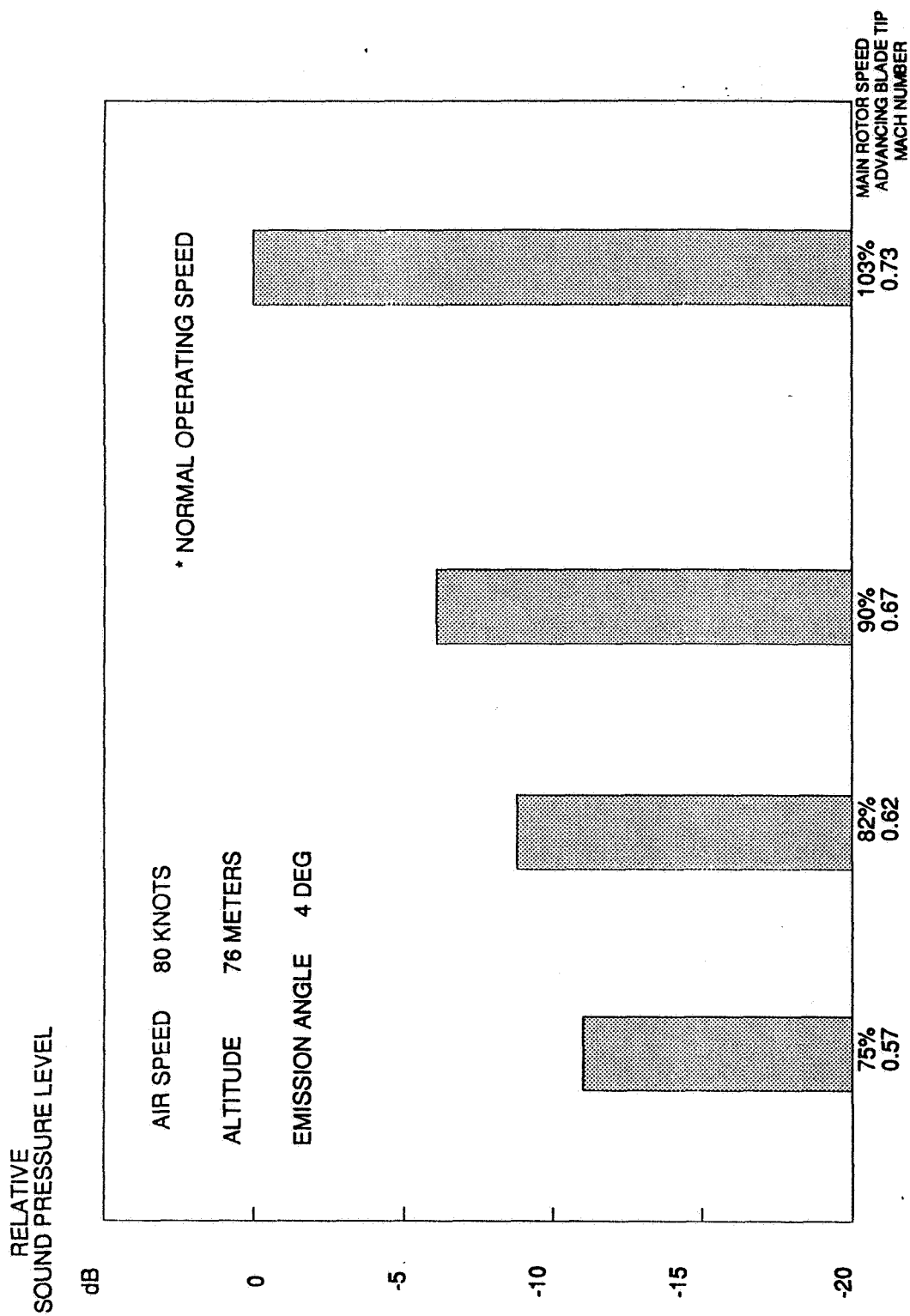
11

FIG 3. A COMPARISON OF 1/3 OCTAVE BAND SOUND PRESSURE LEVELS
OF THE MAIN ROTOR FUNDAMENTAL FREQUENCY AT FOUR
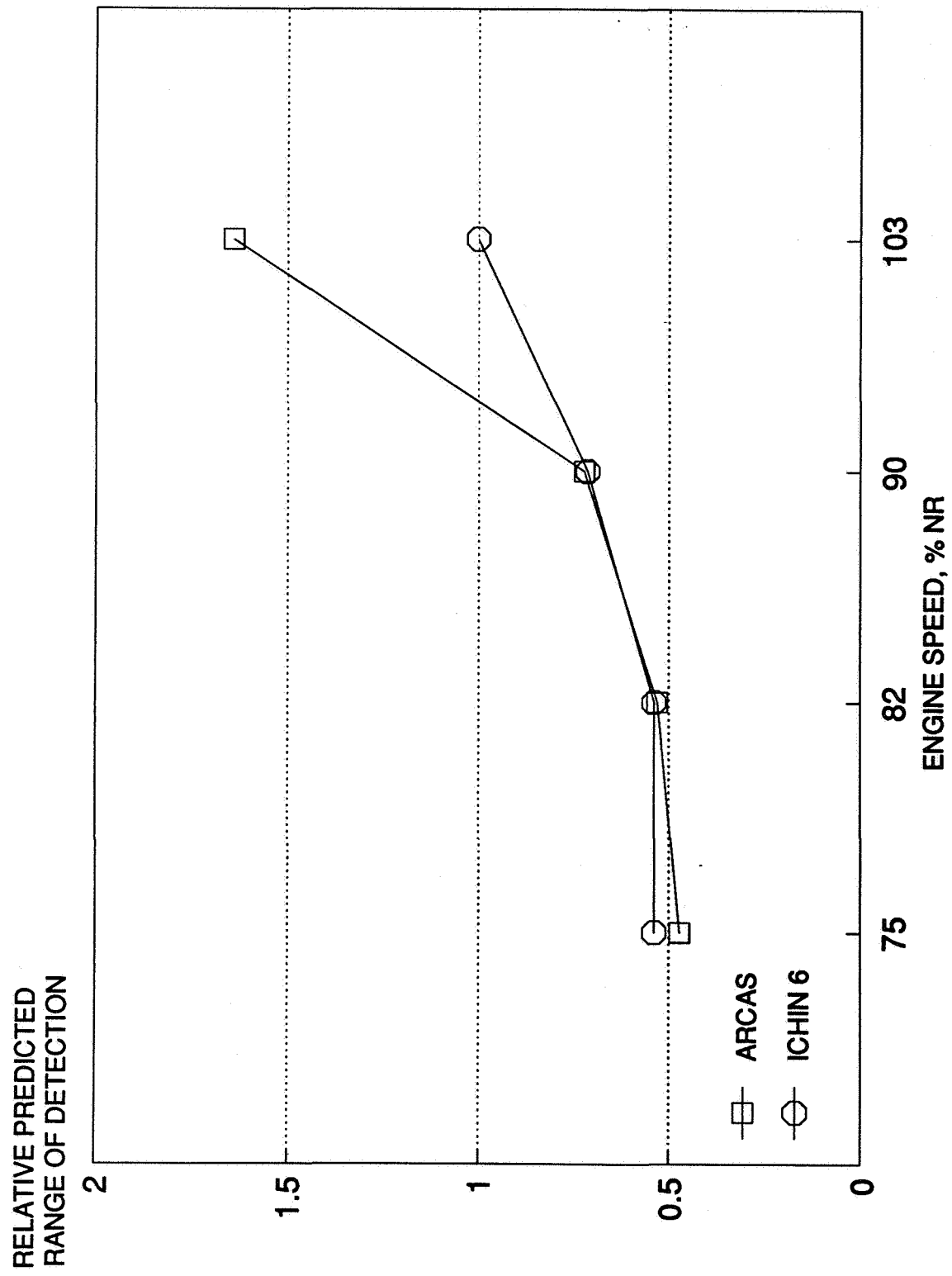DIFFERENT ROTOR SPEEDS OF THE MD 500E HELICOPTER

RELATIVE PREDICTED
RANGE OF DETECTION

FIG.4. COMPARISON OF RELATIVE PREDICTED DETECTION RANGES
FOR ICHIN AND ARCAS USING MD 500E 1/3 OCTAVE BAND SPECTRA
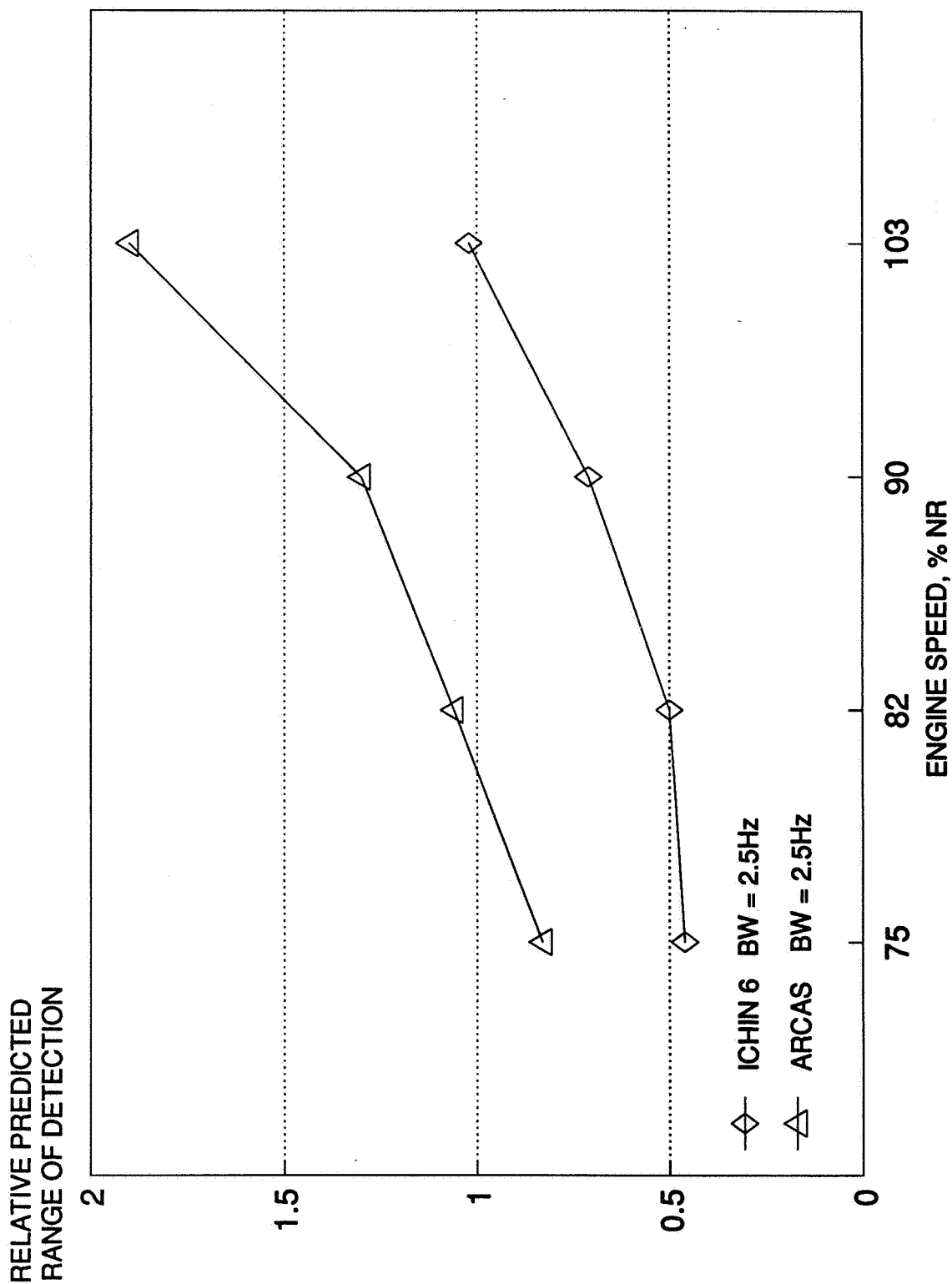
RELATIVE PREDICTED
RANGE OF DETECTION

FIG 5. COMPARISON OF RELATIVE PREDICTED DETECTION RANGES
FOR ICHIN AND ARCAS USING MD 500E NARROW BAND SPECTRA

REPORT DOCUMENTATION PAGE

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1991	Technical Memorandum

4. TITLE AND SUBTITLE
Helicopter Main-Rotor Speed Effects - A Comparison of Predicted Ranges of Detection from the Aural Detection Program ICHIN and the Electronic Detection Program ARCAS

5. FUNDING NUMBERS
WU 532-06-36-02

6. AUTHOR(S)
Arnold W. Mueller and Charles D. Smith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA   23665-5225

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC   20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-104134

11. SUPPLEMENTARY NOTES
Mueller: Langley Research Center, Hampton, VA; Smith: Lockheed Engineering & Sciences Co., Hampton, VA.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified-Unlimited

Subject Category 71

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
NASA Langley Research Center personnel have conducted a study of the predicted acoustic detection ranges associated with reduced helicopter main-rotor speeds. This was accomplished by providing identical input information to both the aural detection program ICHIN 6 ("I Can Hear It Now," version 6) and the electronic acoustic detection program ARCAS ("Assessment of Rotorcraft Detection by Acoustic Sensing"). In this study, it was concluded that reducing the main-rotor speed of the helicopter by 27% reduced both the predicted aural and electronic detection ranges by approximately 50%. Additionally, ARCAS was observed to better function with narrowband spectral input than with one-third octave band spectral inputs, and the predicted electronic range of acoustic detection is greater than the predicted aural detection range.

14. SUBJECT TERMS
helicopter acoustics; far-field noise; reduced rotor speeds

15. NUMBER OF PAGES
15

16. PRICE CODE
A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

NSN 7540-01-280-5500