

**LEVEL**

13

# A COMPREHENSIVE BIBLIOGRAPHY OF LITERATURE ON HELICOPTER NOISE TECHNOLOGY.

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16. Abstract <p>The basic purposes of this report are to provide a comprehensive BIBLIOGRAPHY of Helicopter Noise Technology literature covering the period 1975 through calendar 1980, to present this bibliography arranged by helicopter NOISE TECHNOLOGY AREAS, and to provide ABSTRACTS on literature that appear to make a significant contribution to the field of helicopter noise technology.</p> <p>The helicopter is recognized as a complex noise generator, with significant contributions from the rotors, the engine and the gearbox. Much progress continues to be made in the noise areas of: (a) Formulations, Math Models and Analytical Procedures; (b) Noise Prediction Methodology; (c) Noise Reduction Techniques; and (d) Subjective Response to helicopter noise. The body of information, data and knowledge has use in many applications, including the reduction of helicopter noise in a cost effective manner and in minimizing annoyance to the civil populace.</p> <p>This report has been arranged with the objective of being most useful to those having an interest in the individual areas of helicopter noise technology, as well as those having an overall interest in the field. It is intended that this report will be of particular use to those persons involved in: (a) the Formulation, Math Modeling and Analysis related to helicopter noise technology; (b) Prediction Methodology associated with helicopter noise; (c) Helicopter Noise Reduction Techniques; and (d) the Subjective Response to helicopter noise, both from a helicopter certification and community reaction standpoint.</p>					
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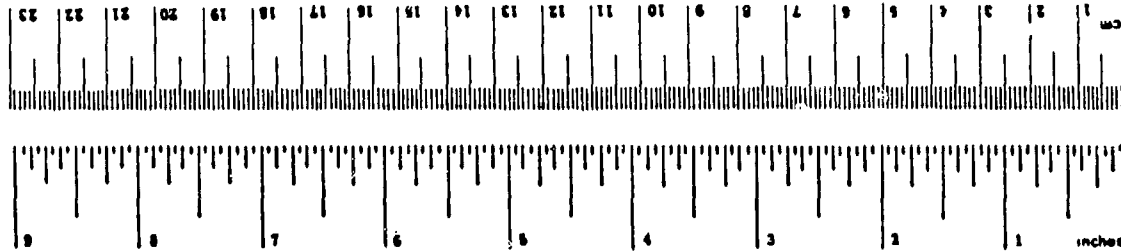
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
sq in	square inches	6.5	square centimeters	cm <sup>2</sup>
sq ft	square feet	0.09	square meters	m <sup>2</sup>
sq yd	square yards	0.8	square meters	m <sup>2</sup>
sq mi	square miles	2.6	square kilometers	km <sup>2</sup>
acres	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
teaspoon	teaspoons	5	milliliters	ml
tablespoon	tablespoons	15	milliliters	ml
fluid ounce	fluid ounces	30	milliliters	ml
cup	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.96	liters	l
gal	gallons	3.8	liters	l
cu ft	cubic feet	0.03	cubic meters	m <sup>3</sup>
cu yd	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
km	kilometers	1.1	yards	yd
		0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	sq in
m <sup>2</sup>	square meters	1.2	square yards	sq yd
km <sup>2</sup>	square kilometers	0.4	square miles	sq mi
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	acres
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	short tons
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	cu ft
m <sup>3</sup>	cubic meters	1.3	cubic yards	cu yd
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



\* 1 in = 2.54 (exactly). For other exact conversions and more data see tables, see NBS Spec. Publ. 250, Units of Length and Measures, Price \$2.25, SD Catalog No. C13.10.236.

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## SECTION II

### SUMMARY

The basic purpose of this report is to provide a comprehensive BIBLIOGRAPHY of Helicopter Noise Technology reports and literature covering the period 1975 through calendar 1980, to present this bibliography arranged by Helicopter NOISE TECHNOLOGY AREAS, and to provide ABSTRACTS on literature that appear to make a significant contribution to the field of helicopter noise technology.

The helicopter is recognized as a complex noise generator, with significant contributions from the rotors, the engine and the gearbox. Much progress continues to be made in the noise areas of:

- a. Formulations, Math Models and Analytical Procedures;
- b. Noise Prediction Methodology;
- c. Noise Reduction Techniques; and
- d. Subjective Response to Helicopter Noise.

The body of information, data, and knowledge has use in many applications, including the reduction of helicopter noise in a cost effective manner and in minimizing annoyance to the civil populace.

The report has been arranged with the objective of being most useful to those having an interest in the individual areas of helicopter noise technology, as well as those having an overall interest in the field.

Section III contains ABSTRACTS of those reports in the bibliography that appear to be the most significant in analyzing and/or advancing the state-of-the-art in helicopter noise technology.

Section IV contains the reports listed in the bibliography rearranged or GROUPED BY NOISE AREAS. It is expected that this section will be of particular use to one interested in a specific noise area, such as "Subjective Response."

Section V contains a comprehensive BIBLIOGRAPHY of helicopter noise technology literature. It is basically arranged alphabetically by author. An added feature is the inclusion of NOISE AREA CODES (NAC's) by which each report is coded to the NOISE AREAS to which it relates. The definitions of these codes are on page 18.

It is intended that this report will be of particular use to those persons involved in:

- a. The Formulation, Math Modeling and Analysis related to helicopter noise technology;
- b. Prediction Methodology associated with helicopter noise;
- c. Helicopter Noise Reduction Techniques; and
- d. The Subjective Response to helicopter noise, both from a helicopter certification and community reaction standpoint.

## SECTION III

### ABSTRACTS

#### Helicopter Noise Technology Reports

Bowes, M.A.

"Anticipated Benefits and Costs of Applying Current Helicopter Noise Reduction Technology"

1978; 6 pp.

Inter-Noise 78: Designing for Noise Control: Proceedings of the International Conference, San Francisco, California, May 8-10, 1978

Kaman Aerospace Corporation, Bloomfield, Connecticut

NAC: R, FH (See page 18 for Noise Area Code - NAC definitions)

An analytical study was carried out to determine the possible impact of applying current noise reduction technology to future helicopter designs. The noise and cost characteristics of several existing helicopters were calculated as a baseline reference. Vehicle design parameters were then used to calculate basic performance capabilities in terms of range, out-of-ground effect hover ceiling and main rotor stall margin at maximum payload. The effects of specific changes in selected vehicle design parameters were assessed, where the changes were chosen to reflect currently available helicopter noise reduction methodology. The results indicate that small though meaningful reductions in helicopter noise can be obtained by treating the turbine engine exhaust duct, and that these reductions do not result in excessive life cycle cost penalties. However, the currently available main rotor noise reduction methodology is inadequate and excessively costly.

Bowes, M.A.

"Helicopter Noise Reduction Design Trade-off Study"

January, 1977; 252 pp.

Report No.: R-1493; Contract: DOT-FA76WA-3791

Kaman Aerospace Corporation, Bloomfield, Connecticut

NAC: R FH, P.

A study was performed to determine the noise reduction benefits and economic costs associated with applying state-of-the-art noise reduction methods to future design of civil helicopters. As part of this study, a survey of the make-up of the Civil fleet was performed, and this fleet make-up was projected to the 1980 time frame. Analytical methods were developed and/or adopted for calculating helicopter component noise, and these methods were incorporated into a unified total vehicle noise calculation model. Analytical methods were also developed for calculating the effects of noise reduction methodology on helicopter design, performance and cost. The analytical methods were used to calculate baseline noise and cost characteristics of several existing civil helicopters. These methods were also used to calculate changes in noise, design, performance and cost due to the incorporation of engine and main rotor noise reduction methods. All noise reduction techniques were evaluated in the context of an established mission performance criterion which included consideration of hover ceiling, forward flight range/speed/payload and rotor stall margin.

Charles, B.D.

"Acoustic Effects of Rotor-Wake Interaction During Low Power Descent"

March, 1975

Report No.: None

Bell Helicopter Company, Fort Worth, Texas

NAC: FO, FOI, FOR

Helicopter blade-vortex interaction noise has been measured in partial-power descent using a microphone array mounted external to the vehicle. The array was designed to permit spatial location of dominant slap noise sources while mapping intensity levels with forward speed and descent rate. Vortex interactions were predicted using a free-wake aerodynamic analysis, and show good trend correlation with noise intensity variations with descent rate. However, the predicted intersection azimuth positions yield only fair agreement with position data. Vortex interaction aerodynamics are modeled simply by two-dimensional, quasi-static theory and indicate that shock formation and stall may be responsible for intense slap noise.

Clevenson, S.A.; Shepherd, W.T.

"Time-of-Day Corrections to Aircraft Noise Metrics"

March, 11-12, 1980

Report No.: FAA-EE-80-3; NASA Conference Publication 2135

NASA Scientific and Technical Information Office

NAC: S, P

The objective of the Workshop was to develop information on noise metrics needed to guide government policy and rulemaking decisions. Time-of-day corrections to cumulative metrics were the primary concern. The participants were asked to focus on two areas: background/applications and research. In the first area, discussion topics included the technical bases for time-of-day corrections, needs and criteria, current practice and experience, government policy and regulation, and economic, social, and other impacts of using corrections. Research discussions dealt with past research, statements of current problems, needed research areas, and specific research approaches.

Edwards, R.G.; Broderson, A.B.; Barbour, R.W.; McCoy, D.F.; Johnson, C.W.

"Assessment of the Environmental Compatibility of Differing Helicopter Noise Certification Standards"

June, 1979

Report No.: FAA-AEE-79-13; Contract: DOT-FA78WA-4194

Federal Aviation Administration, Washington, D.C.

NAC: S

Areas having the heaviest helicopter activity in the U.S. were visited and environmental noise measurements made in order to evaluate the impact of possible relaxed noise emission standards for helicopters restricted to remote regions. Measurement results showed that an average of 10 flyovers per hour produced a one-hour energy-averaged sound level (Leq) of 54.5 dBA, a level 2.5 dBA above ambient. An average of 34 events per hour adjacent to heliports produced a one-hour Leq of 63.1 dBA, which was 13.3 dBA above ambient. If emission levels were increased by 10 dBA, projected Leq values of 57.0 and 71.2 dBA resulted for the flyover and heliport conditions respectively. Sixty-four percent of those responding to a questionnaire stated that they had not experienced a problem from helicopter noise. The degree to which the remaining respondents were bothered ranged from "slightly" to "very annoyed" with no significant preference for either category.

Edwards, R.G.; Broderson, A.B.; Johnson, C.W.

"Helicopter Noise Impact"

March, 1980

Watkins and Associates, Inc., Box 951, Lexington, Kentucky 40501/Sound and Vibration Magazine

NAC: FH, S

To evaluate the environmental noise impact of civil helicopters, areas along the Gulf Coast of Louisiana and Texas, identified as those in the U.S. characterized by the "heaviest of helicopter activity," were visited and environmental noise measurements taken. Results showed an average of 10 flyovers per hour produced a one-hour energy-averaged sound level Leq of 54.5 dBA, a level 2.5 dBA above ambient. An average of 34 events per hour adjacent to heliports produced a one-hour Leq of 63.1 dBA, which was 13.3 dBA above ambient. Based on these results it appears that both source noise reduction and operational control of helicopters could best be applied to areas nearby heliports, and that dispersed over-flights minimally impact man.

Farassat, F.; Brown, T.J.

"A New Capability for Predicting Helicopter Rotor and Propeller Noise Including the Effect of Forward Motion"

June, 1977; 25 pp.

Report No.: NASA-TM-X-74037

National Aeronautics and Space Administration, Langley Research Center, Langley Station, VA

NAC: FO, P, S, R

The governing equation and computing technique for the prediction of helicopter rotor and propeller noise are described. The method which gives both the acoustic pressure time history and spectrum of the noise includes the thickness and the loading noise. It was adapted to computers resulting in a new capability in noise prediction by removing many of the restrictions and limitations of previous theories. The capability results from the fact that the theory is developed entirely in the time domain. The formulation and the technique used are not limited to compact sources, steady level flight or to the far-field. In addition, the inputs to the computer program are normally available or are amenable to experimental measurements. This program can be used to study rotor and propeller noise with the aim of minimizing the radiated noise to reduce annoyance to the public. Several examples demonstrating the features and capability of the computer program are presented.

Federal Aviation Administration

"Noise Standards for Helicopters in the Normal, Transport, and Restricted Categories"

July 19, 1979

Vol. 44, No. 140; 14 CFR Parts 21 & 36; Docket No. 13410; Notice No. 79-13

Federal Register, Federal Aviation Administration

NAC: S, R, P, FH

This notice proposes regulations growing out of FAA's review of preliminary proposals for regulating noise of civil "short-haul," including rotary wing, aircraft contained in an advance notice of proposed rule making and is based on review of recent tests and studies of helicopter noise characteristics. These proposals apply to civil helicopters certificated in the normal, transport, and restricted categories. For purposes of this notice, "helicopters" include other aircraft for which lift is furnished, in whole or part, by an engine-driven rotor during takeoff, hover, or landing. The proposals provide

noise levels and test procedures for the issuance of new type certificates and of original standard airworthiness certificates and restricted category airworthiness certificates for newly produced helicopters of older design types. They also include a prohibition of certain changes in the type design of helicopters that might increase their noise levels beyond prescribed limits. The FAA believes that the rules are necessary to provide current and future relief and protection to the public health and welfare from the noise of the affected helicopters, but that it should not propose rule making at this time for the other aircraft covered by the advance notice.

Federal Interagency Committee on Urban Noise  
"Guidelines for Considering Noise in Land Use Planning and Control"  
June, 1980  
Report No.: None  
EPA, HUD, DOT, DOD; Virginia  
NAC: S

In recent years noise has become a recognized factor in the community planning process: Some significant advancements are being made in the reduction of noise at its source; however, noise cannot be eliminated completely. Local, state, and federal agencies, in recognition of this fact, have developed guidelines and procedures to deal with noise in the community land use planning process. The purpose of this document is to put the various federal agency policy and guidance packages into perspective. Although this document does not replace the individual federal agency material, it can serve as the departure point for dealing with each Agency's programs and facilitate the consideration of noise in all land use planning and interagency/intergovernmental coordination processes. Section 1 presents consolidated federal agency land use compatibility guidelines. Section 2 overviews techniques by which the guidelines can be implemented. Section 3 briefly overviews the major federal agency noise control policies and programs. The Appendices contain brief descriptions of environmental noise descriptors and annotated bibliographies of selected federal documents.

Galloway, W.J.  
"Helicopter Noise Level Functions for Use in Community Noise Analyses"  
January, 1979; 47 pp.  
Report No.: BBN-3713; Contract: F33615-76-C-0528  
Bolt, Beranek and Newman, Inc., Canoga Park, California/USAF Aerospace Medical Research Laboratory, Dayton, Ohio  
NAC: S, FH

Acoustical data obtained from helicopters in level flight and during 6 degree approaches are used to obtain the variation of A-weighted sound exposure level and effective perceived noise level with distance. These functions are normalized to a reference airspeed which differs for individual helicopter types. Sound level functions at airspeeds different from the reference airspeed, either higher or lower, are obtained by adding a decibel increment to the reference functions. This increment is obtained by multiplying a constant, different for each helicopter, times the square of the difference between the airspeed of interest and the reference airspeed. These data are provided for the following aircraft: CH-3C, CH-47C, CH-54B, HH-53B/C, OH-6A, TH-55A, UH-1N, UH-13. Maximum A-weighted sound levels and perceived noise levels at a distance of 76 meters (250 feet) are also provided as a function of angle around the aircraft during stationary hover conditions.

George, A.R.

"Helicopter Noise-State of the Art"

October 3-5, 1977

Grant: DAHC04-75-6-0120; AIAA Fourth Aeroacoustics Conference

American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas,  
New York, New York 10019

NAC: FO, FOR, P, R, S

Helicopter external noise is reviewed with particular emphasis on the noise due to helicopter main and tail rotors. The bases for annoyance and audibility are discussed. It is found that a variety of different helicopter noise mechanisms can be important to annoyance or audibility depending upon flight conditions and observer location. The full range of mechanisms which can contribute to rotor noise through blade volume, force, and Lighthill stresses (quadrupoles) is reviewed. Some of the more important mechanisms are understood in general but not sufficiently to be used for prediction and design. Other potentially important mechanisms such as drag forces, Lighthill stresses due to flow gradients, and unsteady shock waves are only beginning to be understood. Noise prediction and reduction are discussed in the light of our understanding of noise mechanisms.

George, A.R.; Kim, Y.N.

"High Frequency Broadband Rotor Noise"

April, 1977; pp. 538-545

AIAA Journal, Vol. 15, No. 4

NAC: FOB, FOR

A method has been developed to find the absolute spectral level of high frequency far field sound of a rotor in terms of random load fluctuations on the rotor blades. The analysis deals with frequencies where the radiated sound spectrum is smooth, i.e., above 300 to 400 Hz for a typical helicopter. This is in contrast to the low frequency regions where the spectrum is continuous but peaked near bladed passing harmonics. We first show that the smooth, broadband part of the spectrum corresponds to load fluctuations which are uncorrelated between blade passages. Then the spectral intensities from the individual blades are additive. A point load approximation with spanwise loading corrections is used and the blade loading spectrum is specifically derived for upwash fluctuations due to inflow turbulence. Analytic approximations are made to simplify the evaluation of certain integrals and series. The method is compared to the more general method of Homiez and George, where practical, and to published experimental data. The agreement between the two theories is excellent. The comparison to the experiments is good although it is not clear how to estimate the increase in intensity of atmospheric turbulence as it is distorted while being drawn into the rotor. The results indicate that atmospheric turbulence is perhaps the major contribution to broadband noise in hover. The approach is also applicable to other load fluctuation mechanisms.

Goff, R.J.; Novak, F.W.

"Environmental Noise Impact Analysis for Army Military Activities: User Manual"

November, 1977; 120 pp.

Report No.: CERL-TR-N-30

Construction Engineering Research Lab (Army) Champaign, Illinois

NAC: S, P

This manual presents the most current techniques for evaluating the environmental impact of noise emissions from proposed and ongoing Army activities. It is designed for use in conjunction with the CERL-developed computer systems to produce an integrated approach to environmental impact assessment. The manual provides the methodology for determining and documenting environmental noise levels, procedures for interpreting these levels in terms of impact on the human environment, methods by which these impacts might be mitigated, and finally procedures to prepare comprehensive environmental noise impact assessments or statements in accordance with the Council on Environmental Quality (CEQ) Guidelines and AR 200-1.

Homans, B.; Little, L.; Schomer, D.

"Rotary-Wing Aircraft Operational Noise Data"

February, 1978; 70 pp.

Report No.: CERL-TR-N-38

Construction Engineering Research Lab (Army), Champaign, Illinois

NAC: S, P, F, H

This report presents Sound Exposure Level (SEL) vs. distance curves for eight models of Army rotary-wing aircraft (OH-58, AH-1G, UH-1M, UH-1H, UH-1B, CH-47B, CH-54, and TH-55) performing dynamic operations, and Equivalent Sound Level contours for the same aircraft in static operations. The dynamic operations consisted of level flyovers, ascents, descents, turns, takeoffs, and landings; static operations included in-ground and out-of-ground effect hovers. Results are grouped according to model and type of operation and are suitable for use in manual or computerized programs for predicting noise impact from rotary-wing aircraft.

Kim, Y.N.; George A.R.

"Trailing Edge Noise from Hovering Rotors"

May, 1980

36th Annual Forum of the American Helicopter Society, Preprint No. 80-60

American Helicopter Society, 1325 - 18th Street, N.W., Washington, D.C. 20036

NAC: P, FOB

A method has been developed to predict the high frequency broadband noise due to the trailing edges of a hovering rotor. The trailing edge noise from each blade was modeled as point dipole noise with spanwise loading corrections. This point dipole approximation was checked by applying the concept to a stationary airfoil in a moving medium with excellent results. In order to estimate the strength of the point dipole, the trailing edge noise theory of Amiet was used. The method was applied specifically to blade boundary layer turbulence and compared to incident atmospheric turbulence noise. The results indicate that the relative importance of these two mechanisms is related to the magnitudes of the intensity and of the length scales of the inflow and boundary layer turbulence. The results tend to fall below some available experimental data indicating that in those experiments other broadband noise sources were stronger than boundary layer-trailing edge noise. The approach which was developed is also applicable to blade-turbulence interaction mechanisms such as local stall and tip noise.

King, R.; Gupta, B.  
"Effective Perceived Noise Level for Future Civil Helicopters"  
June, 1980  
Contract: DOTFA01-80-C-10017  
Hughes Helicopters, Culver City, California  
NAC: R, P, FH, S

The objective of this program is to present the detailed acoustic results of the future helicopter noise trends developed under the Reference 1 contract which assessed future civil aircraft noise reduction alternatives. That study dealt with air carrier and general aviation aircraft as well as helicopters. As a consequence of the large scope of that study, results were limited to a summary format and noise details were not presented. Additionally, acoustic results for the helicopter case were presented in terms of "A" weighted Sound Pressure Level (SPLA). This unit provides a valid basis for comparison of external noise generation and allows evaluation of acoustic changes. However, it does not allow direct comparison with the regulatory data base which is normally presented in EPNL units. This study, therefore, expands the detail of the reference study acoustic data by adding 1/3 octave band noise levels as a function of time for each helicopter configuration and microphone location, presents time-history data also in terms of Perceived Noise Level (PNL) and Tone-Corrected Perceived Noise Level (PNLT), presents integrated EPNL data, shows correlation between predicted and measured Hughes Helicopters 500C noise levels in PNdB and EPNdB units, and indicates trends for noise and the cost of noise control.

Lawton, B.W.  
"Subjective Assessment of Simulated Helicopter Blade-Slap Noise"  
December, 1976; 55 pp.  
Report No.: NASA-TN-D-8359; L-11137  
National Aeronautics and Space Administration, Langley Research Center, Langley Station, VA  
NAC: S, FOI

The effects of several characteristics of helicopter blade slap upon human annoyance are examined. Blade slap noise was simulated by using continuous and impulsive noises characterized by five parameters: the number of sine waves in a single impulse; the frequency of the sine waves; the impulse repetition frequency; the sound pressure level (SPL) of the continuous noise; and the idealized crest factor of the impulses. Ten second samples of noise were synthesized with each of the five parameters at representative levels. The annoyance of each noise was judged by 40 human subjects. Analysis of the subjective data indicated that each of the five parameters had a statistically significant effect upon the annoyance judgments. The impulse crest factor and SPL of the continuous noise had very strong positive relationships with annoyance. The other parameters had smaller, but still significant, effects upon the annoyance judgments. Psychacoustic annoyance rating for impulsive noise characteristics variables include number of sine waves, frequency of sine waves, impulse frequency, sound pressure level, and impulse peak ratios. Forty-eight figures and seven tables are included.

Lynn, R.R.; Cox, C.R.

"Helicopter Noise Standards - Another Point of View, A Rational Approach to Rotorcraft Noise Regulation"

September, 1978

Fourth European Rotorcraft and Powered Lift Aircraft Forum, Paper No. 55

Associazione Italiana di Aeronautica ed Astronautica Associazione Industrie Aero-spaziali, Stresa, Italy

NAC: FO, FH, S, R, P

This paper discusses and assesses the impact of proposed noise standards for rotorcraft and presents an alternate approach. The pattern followed in developing transport aircraft noise standards is reviewed. It is noted that a much shorter time is being proposed for rotorcraft noise standards development, even though helicopter technology is not as advanced. It is pointed out that this lack of regard for or understanding of the state of technology can have serious adverse consequences.

Contrasts between subsonic CTOL and rotorcraft regarding operational characteristics, economic base, and state of technology are then highlighted. These differences suggest that experience gained during the past decade in CTOL noise control cannot be transferred to rotorcraft.

Noise requirements being considered for helicopters within the United States and the International Civil Aviation Organization are summarized. The economic and safety consequences of these requirements are then discussed for new and derivative designs. It is shown that the economic penalty for noise reduction is significant for new aircraft and not economically reasonable for derivative machines.

A noise index is defined and used to compare the relative impact of noise produced by various transportation systems. This comparison shows that for high-density scheduled carrier use a helicopter produces no more annoyance than a bus. An alternate approach to noise regulation is suggested that makes use of a maximum noise index and the use of flight path and operational controls to achieve it.

Magliozzi, B.

"V/STOL Rotary Propulsion Systems Noise Prediction and Reduction. Volume I. Identification of Sources, Noise Generating Mechanisms, Noise Reduction Mechanisms, and Prediction Methodology"

May, 1976; 145 pp.

Contract: DOT-FA74WA-3477

United Technologies Corporation, Windsor Locks, Connecticut, Hamilton Standard Division/Federal Aviation Administration, Washington, D.C., Systems Research and Development Service

NAC: P, FH, FO, FE, FG, R

The propulsion systems of current and future V/STOL vehicles can be defined as combinations of free-air propellers, shrouded propellers, variable pitch fans, fixed pitch fans, tilt rotors, helicopter rotors, lift fans, gearboxes, and drive engines. In this report, noise sources for each of these propulsors, gearboxes, and drive engines are identified and rank ordered. The noise generating mechanisms for each of the propulsor noise sources identified are defined and systematically catalogued. Three approaches to reduction of propulsor noise are discussed: changes in physical geometry, changes in design operating conditions, and the use of acoustic treatments. Computerized and graphical procedures based on methodology from the open literature and at United Technologies Corporation, are presented for predicting

aerodynamic performance of and noise from the V/STOL propulsors identified in this study. The developed methodology allows the user to estimate the achieved noise reduction as well as the incurred performance penalties of noise reduction design features and noise attenuation devices such as partly sonic inlets and acoustic treatment. It is shown that much of the noise generating mechanism substantiation data and prediction methodology are based on static operation. Forward flight effects have recently been recognized as having a significant effect on the noise sources. Therefore, forward flight effect corrections are included in the methodology, but these have not been fully substantiated due to lack of data.

Magliozzi, B.

"V/STOL Rotary Propulsion Systems Noise Prediction and Reduction. Volume II. Graphical Prediction Methods"

May, 1976; 299 pp.

Contract: DOT-FA74WA-3477

United Technologies Corporation, Windsor Locks, Connecticut, Hamilton Standard Division/Federal Aviation Administration, Washington, D.C., Systems Research and Development Service

NAC: P, R, FH, FO, FE, FG

Graphical procedures for estimating noise and performance of free-air propellers, variable pitch fans with inlet guide vanes, variable pitch fans with outlet guide vanes, fixed pitch fans, helicopter rotors, tilt rotors, and lift fans are presented. Noise prediction methods for drive engines, gearboxes, jets with and without bypass flow, as well as noise reduction and performance losses for partly sonic inlets and duct linings are also presented. These graphical methods are parallel to those developed for the computer program discussed in Volume 3 of this report to the extent possible without their becoming too involved and tedious to use. The procedures are extensive and applicable to a wide variety of V/STOL propulsor systems, including present and future V/STOL vehicles. The methods have been validated with available data wherever possible. However, high quality data for isolated propulsors which is free from contamination by other sources and ground reflections is somewhat limited, particularly for forward flight conditions.

Magliozzi, B.

"V/STOL Rotary Propulsion Systems - Noise Prediction and Reduction. Volume III. Computer Program User's Manual"

May, 1976; 300 pp.

Contract: DOT-FA74WA-3477

United Technologies Corporation, Windsor Locks, Connecticut, Hamilton Standard Division

NAC: P, FE, FR, FH, FG

A computer program is presented which allows a user to make performance and far-field acoustic noise predictions for free-air propellers, variable pitch fans with inlet guide vanes, variable pitch fans with outlet guide vanes, fixed pitch fans, helicopter rotors, tilt rotors, fixed pitch lift vanes with remote, integral, and tip-turbine drives, and variable pitch lift fans with remote and integral drives. Noise prediction methodology for drive engines, single stream and coaxial jets, and gearboxes are also included, as well as noise reduction and performance losses of partly sonic inlets and duct acoustic treatment. A description of the program, detailed instructions for its use, required inputs, and sample cases are presented. Related documents include Volume 1 - Identification of Sources, Noise Generating Mechanisms, Noise Reduction Mechanisms, and Prediction Methodology and Volume 2 - Graphical Prediction Methods.

Magliozzi, B.; Metzger, F.B.; Bausch, W.; King, R.J.

"A Comprehensive Review of Helicopter Noise Literature"

June, 1975; 188 pp.

Contract: DOT-FA74WA-3477

United Technologies Corporation, Windsor Locks, Connecticut, Hamilton Standard Division/Federal Aviation Administration, Washington, D.C., Systems Research and Development Service

NAC: F, P, R, S

This report summarizes the state-of-the-art in helicopter noise. It includes a bibliography of reports on all components of helicopter noise including main rotor, tail rotor, engine and gearbox. Literature on helicopter noise reduction and subjective evaluation of helicopter noise were also included. Capsule summaries of important reports are included which describe the purpose of the report, summarizes the important results, compares the report with others on the same subject, and provides a critical evaluation of the work presented. It is concluded that the available prediction methodology provides a means for estimating helicopter sources on a gross basis. However, the mechanisms of noise generation are still not fully understood, although the experimental and theoretical tools are now available to conduct the definitive experiments and establish the mathematical models needed for accurate definition of helicopter noise generation mechanisms. Spectrum analyses of helicopter noise show that main rotor, tail rotor, and engine sources contribute significantly to annoyance. In cases where these sources have been heavily suppressed, gearbox noise will also appear as a significant contributor to annoyance. Therefore, quieter helicopters must include suppression of all of these components.

National Aeronautics and Space Administration

"Helicopter Acoustics: Proceedings of an International Specialists Symposium"

1978; 402 pp.

Conference Publication 2052

National Aeronautics and Space Administration, Scientific and Technical Information Office, Springfield, Virginia

NAC: F, FH, P, R

Part I of this book of proceedings contains four overview papers and fifteen technical papers related to rotor noise. The overview papers are very interesting and by themselves justify a reading of the book. The initial paper outlines the FAA views with regard to external noise certification and gives an insight into the background used in preparation of the recently issued NPRM. Specific reference is made to the potential gains from the application of new technological innovations, and it is stated that this will lead to reduced noise and lower fuel consumption. This statement is not justified, and none of the other papers give this encouraging view. The proposed certification concepts are outlined. The second paper, giving an industrial perspective, puts forth a pessimistic view, highlighting the complexities of noise reduction and the fact that although the FAA approach is based on "fixed wing" concepts, there are significant differences between the two forms of transport. The primitive state-of-the-art in noise prediction is mentioned. The paper also discussed the implication of applying the certification standards to remote area operations. The next paper, the military (U.S. Army) point of view is given; it is interesting to note that in essence it states that external noise of military helicopters should be comparable to that of civil helicopters, providing there are no performance penalties--impossible in a practical sense. Reference is also made to internal noise, and it is clear that communications are being impaired by high noise levels, but there is no reference to trading off weight/performance for a better environment. The

final paper in this set discusses the impact of helicopter operations on an urban environment, and implies that very quiet helicopters will have to be developed if the potential growth of this market is not to be inhibited. This paper appears to give undue weight to community reactions and pressure groups, without any consideration to "acceptable criteria."

Newman, J. S.

"Correlations of Helicopter Noise Levels with Physical and Performance Characteristics"

September, 1980

Report No.: DOT-FAA-EE-80-42

Federal Aviation Administration/National Technical Information Services, Springfield, VA

NAC: S, P, FH

This report investigates the correlation between physical and performance characteristics of helicopters and the noise levels which they generate in various operational modes. The analysis is generally empirical although several theoretical functions described in the literature have been examined. The EPNL is the acoustical metric employed in this study. One, two, and three-step multiple regression analyses are conducted for takeoff, approach, and level flyover operations. Plots are provided for the three best single variable regression models for each mode of flight.

Newman, J. S.; Rickley, E.J.

"Noise Levels and Flight Profiles of Eight Helicopters Using Proposed International Certification Procedures"

March, 1979; 298 pp.

Report No.: FAA-AEE-79-03

Federal Aviation Administration, Washington, D.C., Office of Environment and Energy

NAC: S, P

This document reports the findings of helicopter noise tests conducted at the FAA National Aviation Facility Experimental Center (NAFEC), located in Atlantic City, New Jersey. The tests were conducted with the following objectives: first, determine the feasibility of a takeoff procedure for helicopter noise certification; second, establish a data base of helicopter noise levels to be used in defining noise standards; and, third, acquire helicopter acoustical spectral data for a variety of acoustical angles for use in the FAA Integrated Noise Model. This report addresses the first two objectives.

Schomer, P.D.; Homans, B.L.

"Technical Background: Interim Criteria for Planning Rotary-Wing Aircraft Traffic Patterns, and Siting Noise-Sensitive Land Uses"

September, 1976; 17 pp.

Report No.: CERL-IR-N-9

Construction Engineering Research Lab (Army) Champaign, Illinois

NAC: S

This report presents interim criteria for locating rotary-wing aircraft traffic patterns and ingress and egress corridors into an airfield/heliport to avoid conflict with noise-sensitive land uses, and provides criteria for planners to site noise-sensitive land uses

with respect to the established airfield/heliport and established flight corridors. These interim criteria are required because the exact Air Force technique for predicting fixed-wing aircraft noise cannot currently be used due to the unpredictability of helicopter flight patterns; these criteria are the basis for interim procedures established in a companion report, User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses (Construction Engineering Research Laboratory Interim Report N-10,1976)

Schomer, P.D.; Homans, B.L.

"User Manual: Interim Procedure for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses"

September, 1976; 40 pp.

Report No.: CERL-IR-N-10

Construction Engineering Research Lab (Army) Champaign, Illinois

NAC: S

This report presents (1) interim procedures for determining the location of rotary-wing aircraft traffic patterns and ingress and egress corridors into an airfield/heliport area to avoid conflict with noise-sensitive land uses, and (2) criteria for siting noise-sensitive land uses with respect to established airfield or heliport plans. The procedures are based on interim criteria established in a companion report, Technical Background: Interim Criteria for Planning Rotary-Wing Aircraft Traffic Patterns and Siting Noise-Sensitive Land Uses (Construction Engineering Research Laboratory Interim Report N-9 1976) impact measures, a background of the development of noise contours, and tables for finding the noise impact. A complete descriptive example of the use of the procedures is presented as an aid to the reader.

Sciarra, J.J.; Howells, R.W.; Lenski, J.W., Jr.; Drago, R.J.; Schaeffer, E.G.

"Helicopter Transmission Vibration and Noise Reduction Program. Volume I. Technical Report"

March, 1978; 307 pp.

Report No.: D210-11236-1; Contract: DAAJ02-74-C-0040

Boeing Vertol Company, Philadelphia, Pennsylvania

NAC: FG, P, R

The objective of the Helicopter Transmission Vibration/Noise Reduction Program was to generate analytical tools for the prediction and reduction of helicopter transmission vibration/noise that provide the capability to perform trade studies during the design stage of a program. Application of this optimization capability yields drive train components that are dynamically quiet with reduced vibration/noise levels and inherently longer life.

Sciarra, J.J.; Howells, R.W.; Lenski, J.W., Jr.; Drago, R.J.

"Helicopter Transmission Vibration and Noise Reduction Program. Volume II. User's Manual"

March, 1978; 431 pp.

Report No.: D210-11236-2; Contract: DAAJ02-74-C-0040

Boeing Vertol Company, Philadelphia, Pennsylvania

NAC: FG, P, R

The objective of the Helicopter Transmission Vibration/Noise Reduction Program was to generate analytical tools for the prediction and reduction of helicopter transmission vibration/noise that provide the capability to perform trade studies during the design stage of a program. Application of this optimization capability

yields drive train components that are dynamically quiet with reduced vibration/noise levels and inherently longer life. The work conducted under this program is highly computer-oriented and makes extensive use of several computer programs as indicated in the technical report (Volume I). This User's Manual describes these computer programs, presents rationale for their use, and discusses their application.

Spencer, R.H.; Sternfeld, H., Jr.

"Study of Cost/Benefit Tradeoffs Available in Helicopter Noise Technology Applications"

January, 1980; 128 pp.

Contract: DOT-FA78WA-4161

Boeing Vertol Company, Philadelphia, Pennsylvania/Federal Aviation Administration, Washington, D.C.

NAC: R, F, H, FO, P

This study investigated cost/benefit tradeoffs using the case histories of four helicopters for which design and development were complete, and in three cases, have undergone substantial flight testing. The approach to quieting each helicopter was an incremental reduction of each source as required to obtain reductions in flyover noise with modifications to other secondary systems only as necessary. The methodology used to predict the effects of the design modifications on acquisition, maintenance, and operating costs were typical of those employed by rotorcraft manufacturers. The reduction of helicopter flyover noise generally was achieved through reductions in rotor tip speed. Performance characteristics were maintained to specified minimums for each aircraft in the study.

Sternfeld, H.

"Helicopter Rotor Noise Control"

December 16, 1974

Report No.: None

Boeing Vertol Company, P.O.B. 16858, Philadelphia, Pennsylvania 19142

NAC: FO, FOI, FOR, P, R, S

This article reviews the sources of helicopter noise and describes several design changes which produced a low noise helicopter. It is hopeful that even quieter helicopters can be designed in the future. In addition, the noise criteria which should be used to certify new helicopters as well as those criteria which should assure acceptance in the community are discussed.

Sternfeld, H.

"Recent Developments in Helicopter Noise Reduction"

September, 1978

Paper A4-04/Proceedings of the XI Congress of the International Council of the Aeronautical Sciences/Republished in the Aeronautical Journal of the Royal Aeronautical Society August, 1979

NAC: R, FO

This paper reports on research activities directed at understanding and reducing interior and exterior noise of modern helicopters. Impending regulatory criteria for external noise are discussed, along with some of the newer understandings of the sources of rotor noise. The effect of rotor design on generated noise and methods for reducing the noise are presented. The paper also explains the application of finite element analytical techniques to optimizing the dynamic response of helicopter transmissions in order to minimize interior noise.

Sternfeld, H.; Doyle, L.

"The Effects of Engine Noise and Rotor Broadband Noise on Civil Helicopter Operations"

June, 1978

Report No.: NASA CR145085

Boeing Vertol Company, P.O.B. 16858, Philadelphia, Pennsylvania 19142

NAC: R, S, FE, FEC

The purpose of this program was to identify the noise reduction research which is required to permit continued growth of civil helicopter operations while observing community noise constraints such as those forecast by a previous study. Since active programs have already been established for some time in the area of harmonic rotor noise (particularly the impulsive types), this study considered only broadband rotor noise, engine noise and dynamic component noise.

A measurement program was conducted to evaluate the levels associated with a representative group of current helicopters; the Bell Model 204B, Sikorsky SH-3A and S-65, Boeing Vertol CH-47B and a ground test rig of a large rotor and drive system designed for the Boeing Vertol Heavy Lift Helicopter. The results indicate that additional noise reduction of future models will be required to maintain Effective Perceived Noise Levels below 95 EPNdB at heliport boundaries.

Broadband rotor noise was found to be the major contributor when compared with broadband noise from the engine inlet of combustor. Pure tones from the engine compressors on the larger helicopters, however, were found to be significant.

Sternfeld, H., Jr.; Wiedersum, C.W.

"Study of Design Constraints on Helicopter Noise"

July, 1979; 91 pp.

Report No.: NASA-CR-159118

Contract: NAS1-15226

Boeing Vertol Company, Philadelphia, Pennsylvania

NAC: FO, P, S

A means of estimating the noise generated by a helicopter main rotor using information which is generally available during the preliminary design phase of aircraft development is presented. The method utilizes design charts and tables which do not require an understanding of acoustical theory or computational procedures in order to predict the perceived noise level, a weighted sound pressure level, or C-weighted sound pressure level of a single hovering rotor. A method for estimating the effective perceived noise level in forward flight is also included. In order to give the designer an assessment of the relative rotor performance, which may be traded off against noise, an additional chart for estimating the percent of available rotor thrust which must be expended in lifting the rotor and drive system, is included as well as approach for comparing the subjective acceptability of various rotors once the absolute sound pressure levels are predicted.

Tangler, J.L.

"Schlieren and Noise Studies of Rotors in Forward Flight"

May, 1977

Preprint No. 77.33-05, Presented at 33rd Annual National Forum of the American Helicopter Society

American Helicopter Society, Washington, D.C.

NAC: FO, FOI, R

A wind-tunnel investigation of model rotors operating at full-scale Mach numbers in simulated partial power descent and high-speed flight is described. Schlieren flow visualization aided by full-scale blade pressure measurements helped identify seven blade/vortex intersections that occur during partial power descent. Two of the 1st-quadrant intersections have the potential of inducing bow shocks. Observation of the high-speed crescent-shaped shock which results from transonic flow over the advancing blade has provided new insight into its structure and directivity. Correlation of the flow visualization results with acoustic measurements gives clarification of the relationship between aerodynamic events that occur on the blade and the various components of the slap signature. Comparisons of rotors having different twist, airfoil profile, and thickness show qualitative differences that suggest means of alleviating this noise.

True, H.C.; Rickley, E.J.

"Noise Characteristics of Eight Helicopters"

July, 1977; 167 pp.

Report No.: FAA-RD-77-94

Federal Aviation Administration, Washington, D.C., Systems Research and Development Service

NAC: S, P

This report describes the noise characteristics of eight helicopters during level flyovers, simulated approaches, and hover. The data were obtained during an FAA/DOT Helicopter Noise Program to acquire a data base for possible helicopter noise regulatory action. The helicopter models tested were the Bell 47G, 206L, and 212 (UH1N), the Hughes 300C and 500C, the Sikorsky S-61 (SH-3B) and S-64 (CH-54B) and the Vertol CH-47C. The acoustic data is presented as Effective Perceived Noise Level, A-weighted sound pressure level and 1/3 octave band sound pressure level with a slow meter characteristic per FAR Part 36. Selected waveforms and narrow band spectra are also shown. Proposed methods to quantify impulsive noise ("blade slap") are evaluated for a level flyover for each of the helicopters. The tested helicopters can be grouped into classes depending upon where the maximum noise occurs during a level flyover. Helicopters with the higher main rotor tip speeds propagate highly impulsive noise ahead of the helicopter. The maximum noise for most of the helicopters occurs near the overhead position and appears to originate from the tail rotor. Unmuffled reciprocating engine helicopters appear to have significant engine noise behind the helicopter. Noise levels, when compared as a function of gross weight and flown at airspeeds to minimize "Compressibility slap" from a band 7 EPNdB wide with a slope directly proportional to gross weight. The quieter helicopters have multibladed rotors and tipspeeds below 700 fps.

## SECTION IV

### HELICOPTER NOISE TECHNOLOGY REPORTS GROUPED BY NOISE AREAS

#### Introduction

This section contains the reports listed in Section V - Bibliography grouped in the appropriate noise areas identified below:

<u>Noise Areas</u>	<u>(NAC's) Noise Area Codes</u>
A. Formulations, Math Models, Analytical Procedures	F
1. Rotors	FO
a. Rotational	FOR
b. Broadband	FOB
c. Impulsive	FOI
2. Engine	FE
a. Combustion	FEC
b. Turbine	FET
c. Jet	FEJ
d. Compressor	FER
3. Gearbox	FG
4. Complete Helicopter	FH
B. Helicopter Noise Prediction Methodology	P
C. Helicopter Noise Reduction Techniques	R
D. Subjective Response to Helicopter Noise	S

In the noise area coding, the primary area of involvement is noted first, with secondary areas following. Where a report content is associated with more than one noise area, the report is listed in this section in the primary area of involvement.

**Formulations, Math Models, Analytical Procedures**

**NAC: F**

Jones, D.S., F.R.S.

"The Scattering of Sound by a Simple Shear Layer"

February 18, 1977; pp. 287-315

Philosophical Transactions Series A Vol. 284 Part 1323

Department of Mathematics, The University, Dundee, London

NAC: F

Magliozzi, B.; Metzger, F.B.; Bausch, W.; King, R.J.

"A Comprehensive Review of Helicopter Noise Literature"

June, 1975; 188 pp.

Contract: DOT-FA74WA-3477

United Technologies Corporation, Windsor Locks, Connecticut, Hamilton Standard Division/Federal Aviation Administration, Washington, D.C., Systems Research and Development Service

NAC: F, P, R, S

Melnikov, B.N.

"Experimental Investigation of Helicopter Flight Modes on Helicopter Generated Noise"

June, 1979; pp. 450-453

Akusticheskii Zhurnal, Vol. 25, May-June, 1979. In Russian.

Gosudarstvennyi Nauchno-Issledovatel'skii Institut Grazhdanskoi, Aviatsii, Moscow, USSR

NAC: F, P

National Aeronautics and Space Administration

"Helicopter Acoustics: Proceedings of an International Specialists Symposium"

1978; 402 pp.

Conference Publication 2052

National Aeronautics and Space Administration, Scientific and Technical Information Office, Springfield, VA

NAC: F, FH, P, R

## Rotor Noise

NAC: FO

Amiet, R.K.

"Noise Due to Rotor-Turbulence Interaction"

1978; pp. 109-126

NASA Conference Publication 2052

United Technologies Research Center, East Hartford, Connecticut, 06108

NAC: FO, P

Amiet, R.K.

"Noise Produced by Turbulent Flow into a Propeller or Helicopter Rotor"

1976

AIAA Paper No. 76-560/AIAA Journal, Vol. 15, No. 3, March 1977, pp. 307-308

United Technologies Research Center, East Hartford, Connecticut 06108

NAC: FO, P

Aravamudan, K.S.; Harris, W.L.

"Experimental and Theoretical Studies on Model Helicopter Rotor Noise"

January, 1978; 158 pp.

Report No.: 78-1; 83852-1; Contract: DAAG29-76-C-0027

Massachusetts Institute of Technology, Cambridge, Fluid Dynamics Research  
Lab/Army Research Office, Research Triangle Park, North Carolina

NAC: FO, FOR, FOB, P

Charles, B.D.

"Acoustic Effects of Rotor-Wake Interaction During Low Power Descent"

March, 1975

Report No.: None

Bell Helicopter Company, Fort Worth, Texas

NAC: FO, FOI, FOR

Cox, C.R.

"Helicopter Rotor Aerodynamic and Aeroacoustic Environments"

October, 1977

Preprint 77.1338

Presented at the Fourth Aeroacoustic Conference of the American Institute of  
Aeronautics and Astronautics, Atlanta, Georgia

Bell Helicopter Textron, Fort Worth, Texas

NAC: FO, FOR, FOB, FOI, P

Dahan, C.; Gratioux, E.

"Helicopter Rotor Thickness Noise"

June 4-6, 1980; 11 pp.

Report No.: AIAA Paper 80-1012/ONERA TP No. 1980-45

American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 6th,  
Hartford, CT

NAC: FO

Damongeot, A.  
"Helicopter Tail Rotor Noise Generated by Aerodynamic Interactions"  
1978; 13 pp.  
European Rotorcraft and Powered Lift Aircraft Forum, 4th, Stresa, Italy, September  
13-15, 1978, Proceedings Volume 2  
Societe Nationale Industrielle Aerospatiale, Division Helicopteres, Marignane,  
Bouches-du-Rhone, France  
NAC: FO, P

Engineering Sciences Data Unit Limited  
"Estimation of the Maximum Discrete Frequency Noise from Isolated Rotors and  
Propellers"  
September, 1976; 12 pp.  
Report No.: ISBN-0-85679-157-1  
Engineering Sciences Data Unit Limited, London, England  
NAC: FO, P

Farassat, F.  
"A Bound on Thickness of Rotating Blades"  
1977  
Published in the Proceedings of 14th Annual Meeting of the Society of Engineering  
Science, Inc.  
The George Washington University/Joint Institute for Advancement of Flight  
Sciences, Washington, D.C.  
NAC: FO

Farassat, F.  
"The Derivation of a Thickness Noise Formula for the Far-Field by Isom"  
1979; pp. 159-160  
Published letter to the Editor, Journal of Sound and Vibration (1979)64(1)  
The George Washington University/Joint Institute for Advancement of Flight  
Sciences, Hampton, VA  
NAC: FO

Farassat, F.  
"Theory of Noise Generation from Moving Bodies with an Application to Helicopter  
Rotors"  
December, 1975; 61 pp.  
Report No.: NASA-TR-R-451; L-10379  
National Aeronautics and Space Administration, Langley Research Center, Langley  
Station, VA  
NAC: FO, P

Farassat, F.; Brown, T.J.  
"A New Capability for Predicting Helicopter Rotor and Propeller Noise Including the  
Effect of Forward Motion"  
June, 1977; 25 pp.  
Report No.: NASA-TM-X-74037  
National Aeronautics and Space Administration, Langley Research Center, Langley  
Station, VA  
NAC: FO, P, S, R

Farassat, F.; Brown, T.J.

"A New Formula for the Determination of the Acoustic Pressure Signature of Helicopter Rotors"

October 7-8, 1975

Presented Review of Research Theme "Helicopter and V/STOL Aircraft Research," Moffett Field, CA

The George Washington University/Joint Institute for Advancement of Flight Sciences, Hampton, VA

NAC: FO

Farassat, F.; Brown, T.J.

"Development of a Noncompact Source Theory with Applications to Helicopter Rotors"

July, 1976

AIAA Paper 76-563/ Presented at AIAA Third Aeroacoustics Conference, Palo Alto, CA

The George Washington University/Joint Institute for Advancement of Flight Sciences, Hampton, VA

NAC: FO

Farassat, F.; Morris, C.E.K., Jr.; Nystrom, P.A.

"A Comparison of Linear Acoustic Theory with Experimental Noise Data for a Small-Scale Hovering Rotor"

March 12-14, 1979

AIAA Paper No. 79-1608/ Presented at AIAA Fifth Aeroacoustics Conference, Seattle, WA

The George Washington University/Joint Institute for Advancement of Flight Sciences, Hampton, VA

NAC: FO

Farassat, F.; Pegg, R.J.; Hilton, D.A.

"Thickness Noise of Helicopter Rotors at High Tip Speeds"

March, 1975

Paper No. AIAA 75-453/ Presented at AIAA Second Aeroacoustics Conference

The George Washington University/Joint Institute for Advancement of Flight Sciences, Hampton, VA

NAC: FO

Gangwani, S.T.

"The Effect of Helicopter Main Rotor Blade Phasing and Spacing on Performance, Blade Loads and Acoustics"

September, 1976; 100 pp.

Report No.: NASA-CR-2737; SRL-3169-0014; Contract: NAS1-13705

Systems Research Labs, Inc., Newport News, Virginia

NAC: FO

George, A.R.

"Helicopter Noise--State of the Art"

October 3-5, 1977

Grant: DAHC04-75-6-0120; AIAA Fourth Aeroacoustics Conference

American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas, New York, N.Y.

NAC: FO, FOR, P, R, S

George, A.R.

"Research on Helicopter Rotor Noise"

February 10, 1975; 17 pp.

Contract: DAHC04-74-C-0001

Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca,  
New York/Army Research Office, Durham, North Carolina

NAC: FO, P

George, A.R.; Najjar, F.E.; Kim, Y.N.

"Noise Due to Tip Vortex Formation on Lifting Rotors"

June 4-6, 1980

Report No.: AIAA-80-1010/AIAA Sixth Aeroacoustics Conference, Hartford, CT  
American Institute of Aeronautics and Astronautics, 1290 Avenue of the Americas,  
New York, N.Y.

NAC: FO, FOR, FOB, P

Gottlier, J.J.

"Simulation of a Travelling Sonic Boom in a Pyramidal Horn"

July, 1974

Report No.: None

University of Toronto, Institute of Aerospace Studies, Toronto, Canada

NAC: FO

Greene, G.C.

"An Overview of NASA's Propeller and Rotor Noise Research"

June, 1980; 7 pp.

Report No.: AIAA Paper 80-0992

NASA Langley Research Center, Hampton, Virginia/American Institute of Aeronautics and Astronautics Aeroacoustics Conference, 6th, Hartford, Connecticut

NAC: FO

Hartman, W.F.

"Potential Applications of Acoustic Emission Technology as a Nondestructive Evaluation Method for Naval Aviation Ground Support"

July 5, 1978; 19 pp.

Contract: N68335-77-M-5735

Hartman (William F.), Knoxville, Tennessee

NAC: FO, P

Hoad, D.R.

"Evaluation of Helicopter Noise Due to Blade-Vortex Interaction for Five Tip Configuration"

December, 1979; 80 pp.

Report No.: NASA-TP-1608; AVRADCOM-TR-80-B1; Contract: DA PROJ. 1L2-62209-AH-76

National Aeronautics and Space Administration, Langley Station, Virginia, Langley Research Center

NAC: FO, FOI, R

Isom, M.P.

"Some Nonlinear Problems in Transonic Helicopter Acoustics"

May, 1979; 64 pp.

Report No.: POLY-M/AE-79-19

Polytechnic Institute of New York, Brooklyn Department of Mechanical and Aerospace Engineering/Army Research Office, Research Triangle Park, North Carolina

NAC: FO, P

Kasper, P.K.

"Determination of Rotor Harmonic Blade Loads from Acoustic Measurements"

October, 1975; 66 pp.

Report No.: NASA-CR-2580; Contract: NAS1-12390

Wyle Labs, Inc., Hampton, Virginia

NAC: FO, P

Lee, A.

"An Acoustical Study of Circulation Control Rotor"

January, 1979

NASA-CR-152209/NAS2-9865

Beam Engineering, Inc., Sunnyvale, California

NAC: FO

Leverton, J.W.; Southwood, B.J.; Pike, A.C.; Woodward, M.A.

"A Reevaluation of Helicopter Main Rotor Noise"

September, 1976; 10 pp.

Report No.: None

Westland Helicopters, Ltd., Yeovil, Somerset, England

NAC: FO

Liebowitz, H.; Farassat, F.

"Research on Helicopter Rotor Noise"

October, 1979; 13 pp.

Grant: DAAG29-78-G-0152; DAAG29-76-G-0259

George Washington University, Washington, D.C., School of Engineering and Applied Science/Army Research Office, Research Triangle Park, North Carolina

NAC: FO, P

Lynn, R.R.; Cox, C.R.

"Helicopter Noise Standards - Another Point of View, A Rational Approach to Rotorcraft Noise Regulation"

September, 1978

Fourth European Rotorcraft and Powered Lift Aircraft Forum, Paper No. 55

Associazione Italiana di Aeronautica ed Astronautica Associazione Industrie Aero-spaziali, Stresa, Italy

NAC: FO, FH, S, R, P

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## SECTION V

### BIBLIOGRAPHY

#### Introduction

This section contains a comprehensive listing of reports, literature, books and articles concerning helicopter noise technology. The listing is alphabetically by author, and includes the source and/or publisher, report identification numbers, contract or grant number, and date of the report. To increase the usability of this bibliography, the following standard format has been followed:

- a. Author
- b. Title of report, book, article, paper, etc.
- c. Date of report, and number of pages
- d. Report identification numbers, contract number, etc.
- e. Name of source or publishers, and geographical location or address
- f. Noise Area Codes for the report

The Noise Area Codes are defined and discussed in Section IV. It should be noted that each report in the Bibliography is listed in Section IV under the first Noise Area Code listed for each report in this Section. This first Noise Area Code is considered the primary area of involvement of the report.

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