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AIRCRAFT NOISE EFFECTS ON CULTURAL RESOURCES: RECOMMENDATION AND RATIONALE FOR FURTHER RESEARCH

Carl E. Hanson, Kenneth W. King, Mary Ellen Eagan and Richard D. Horonjeff

Prepared for:

National Park Service, U.S. Department of the Interior
NPS-DSC Contract No. CX-2000-0-0025
Work Order No. 4

HARRIS MILLER MILLER & HANSON INC.
Consultants in Noise and Vibration Control

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FOREWORD

This report is the second of three products prepared under Work Order No. 4, Contract No. CX-2000-0-0025, dated July 16, 1990. The scope of work required a review, critique and analysis of the scientific literature to assess the nature and probable magnitude of the potential effects of aircraft overflights on historical and cultural resources in the National Park System. Excluded under this work order are such items as historical or cultural context or setting.

Separate from this report are two other products:

1. A review of the available literature on aircraft noise-induced vibrations of structures, with a focus on damage to historical and cultural resources.

2. An annotated bibliography of the literature reviewed.

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AIRCRAFT NOISE EFFECTS ON CULTURAL RESOURCES: RECOMMENDATIONS AND RATIONAL FOR FURTHER RESEARCH

EXECUTIVE SUMMARY

This report is the second prepared by Harris Miller Miller & Hanson Inc. (HMMH) under Work Order #4. Its purpose is to identify the need for further research in specific areas necessary to assess the effects of aircraft overflights on historical and cultural resources and to develop mitigation measures for the most important adverse effects. The first report is a literature survey on aircraft noise-induced vibrations of structures. The most significant finding from the first report is the potential damage risk from helicopter noise, especially from helicopters hovering at the same level as a prehistoric cliff dwelling. In order to determine the probability of damage to sensitive structures, a measurement program is proposed for selected buildings at Mesa Verde. Results of the measurements should be useful to define a set of procedures for helicopters to avoid damage to prehistoric structures.

1. SUMMARY OF FINDINGS FROM LITERATURE REVIEW

In the first report of Work Order #4, HMMH summarized the available literature on aircraft noise-induced vibrations of structures, with a focus on damage to historical and cultural resources (Hanson et al, 1991). HMMH found that most of the available literature stems from research on the effects of sonic booms conducted by the U.S. Air Force, the National Aeronautics and Space Administration and the Federal Aviation Administration. These studies conclude that sonic booms present very substantial risks to structures within the area of their influence. Methods of estimating probabilities of damage to historical and cultural resources have been developed. Research is being continued by the Air Force.

In contrast, very limited information was found relating to the response of structures to subsonic aircraft and helicopters. Measurement programs have been conducted which conclude there is normally a minimal risk of damage to structures from low altitude overflights of subsonic jet aircraft and small helicopters. Moreover, a recently-developed prediction method indicated a distinct possibility of noise-induced damage to prehistoric structures and other cultural resources from low overflights of multi-engine bombers and heavy helicopters (greater than 20,000 lbs). Among the structures most susceptible to damage are parts of wood-frame historic houses and prehistoric buildings with intact roofs.

Perhaps the most significant finding from the literature review is the potential damage risk from helicopter noise. The noise characteristics of helicopters are such that they tend to excite nearby structural elements at their resonance frequency, causing low frequency vibrations, rattle, and in some cases, damage. Since receivers are generally below a helicopter, most research effort has gone toward quantifying sound radiated in the downward direction. However, the sound pressure from a helicopter is greatest in the plane of the main rotor; the risk of damage is greater to the side than below. Under these conditions small helicopters hovering beside fragile structures such as cliff dwellings could result in damage. This subject is worthy of further investigation.

HMMH reviewed four representative cultural resources administered by the National Park Service according to published models for probability of damage from either subsonic or supersonic aircraft. Each of the four experienced some risk of damage from overflights, including:

- Fort Jefferson National Monument: Fragile mortar may be susceptible to damage from sonic booms.

- White Sands National Monument: Flat roof with viga construction is susceptible to damage from helicopter noise.

- San Antonio Mission National Historic Park: Masonry buildings with intact roofs are in the very high risk category for sonic booms, low-flying subsonic multi-engine bombers, and heavy helicopters.

- Chaco Culture National Historic Park: Rubble-core adobe walls are somewhat susceptible to damage from helicopter noise.

Mitigation measures for aircraft noise-induced vibration effects found in the literature are based on maintaining a "clear zone" between the vibration-sensitive receivers and aircraft operations that may cause damage. Definition of what distance constitutes a clear zone is not clearly delineated in the literature; one study identified 50 feet to avoid damage from helicopter noise to a fragile structure at Mesa Verde, while another identified 500 feet as a minimum to avoid "rattle" in wood frame houses from helicopter noise. Further development of a clearly defined distance to minimize the probability of damage is needed.

2. TOPICS FOR FURTHER RESEARCH

As the literature review indicates, much of the research on aircraft noise-induced vibration has been driven by the need of the military to evaluate the effects of its operations on the public. For example, sonic boom research was conducted by the U.S. Air Force in order to determine whether the effects are severe enough to force a curtailment of supersonic air operations over populated areas (Haber and Nakaki, 1989). Similarly, the research on vibrations induced by low altitude subsonic military air operations was prompted by the need to define areas where training missions could be exercised without adverse effects (Sutherland, 1990).

The motivation for the foregoing studies has been an interest on the part of the aircraft operator to evaluate its effects so as to minimize restrictions on operations in the future. The aircraft operator, in this case the military, had reason to do so because its operations are often carried out by special aircraft capable of generating sonic booms or high noise levels at the ground from low altitude terrain-following combat maneuvers. There is general agreement that damage can occur from some of these unusual causes. Commercial aircraft operations, on the other hand, have not been considered to have the potential for causing damaging effects from noise-induced vibration except possibly for locations very close to airport runways.

The recent proliferation of tourist sight-seeing flights has raised the possibility that low-flying helicopters, besides causing annoyance from noise, may actually result in noise-induced damage. Support for these concerns comes from the finding that sound pressures from overflights of heavy military helicopters can generate structural vibrations that have a definite risk of damage. Sound pressures from overflights of light helicopters are considered to be less of a problem, although measurements of noise-induced vibrations on the roof of an adobe building with viga construction from a light helicopter in hover mode showed definite structural resonance response (King, 1991). The vibrations measured by King were not great enough to exceed damage criteria, but there was a definite measurable structural response. Moreover, the literature survey indicated that sound pressures from helicopters are greater in the plane of the main rotor than below the aircraft. Consequently, the slight effect measured on structures below helicopters in overflight or hover modes could possibly change to a significant effect when aircraft fly at the same level as the structure. Unfortunately, very little is known about the effects of helicopter noise-induced vibration on structures exposed to the maximum sound pressures in the plane of the main rotor. An example of this situation is a helicopter passing by a cliff dwelling.

In addition to the studies of aircraft noise effects, there has been a limited amount of related research on seismic and surface transport vibration effects on cultural resources. These projects were largely driven by interest in preservation of antiquities. One example is an investigation at Chaco Culture National Historic Park carried out as part of a risk assessment process by the U.S. Geological Survey (King, et al, 1985).

In carrying out its mandate by Congress to evaluate injurious effects of overflights on cultural resources (16 USC 1a-1, Public Law 100-91, Section 1(C)), the National Park Service is concerned about the effects of all aircraft, including helicopter tour operations, on its historical and archeological structures. It is in the public interest to preserve cultural resources whether they be archeological antiquities, historical buildings or structures of special interest. As the HMMH report on literature review indicated, preliminary conclusions can be drawn from research that identify a potential risk of damage from helicopter operations in the immediate vicinity of fragile structures. Therefore, to ensure preservation of its cultural resources, the Park Service has the following options:

a. prohibit all helicopter operations in parks which have fragile cultural resources, and

b. prohibit helicopter operations within prescribed air space around fragile cultural resources. This air space could be defined either on a conservative basis from what is currently known <u>or</u> based upon further research.

Implementation of Option (a) would be unpopular with commercial tour operators and may unduly restrict commercial enterprise. Option (b) could be implemented using a conservative separation distance (such as the 1000 feet suggested by U.S. Army for the UH-1 helicopter described in the literature survey) without further study. However, commercial interests could challenge an airspace restriction on the basis that not enough is known about the adverse effects to adopt such a large separation distance without further study. Option 2 may be the best choice for the National Park Service, however, if research were done specifically to quantify the effects of helicopter operations on fragile structures, and the separation distance were established accordingly. This would provide a means by which potential for damage to cultural resources from close passbys of tourist helicopters can be evaluated, thereby placing any subsequent airspace restrictions on a foundation based on solid evidence. The next section outlines an approach for the recommended study.

3. RECOMMENDED RESEARCH PROJECT TO QUANTIFY THE EFFECTS OF COMMERCIAL HELICOPTERS ON FRAGILE STRUCTURES.

The research program described below is intended to define the effects on fragile structures that would lead to establishing reasonable limits on operations of commercial helicopters in the vicinity of cultural resources.

3.1 Site Selection

The National Park Service has many unconventional structures under its purview including historic buildings, prehistoric structures and geological/archeological sites. Focusing on prehistorical structures and archeological sites limits the scope of the study to provide protection for cultural resources which are among the most at risk. The Anasazi ruins of the Southwest are especially appropriate for study; besides being irreplaceable and spectacular, many are remote with difficult access. Consequently they are prime candidates for observation by helicopter. Tourists can easily be brought to an impressive observation point on the same level as the ancient structure. Tour operators are increasingly making close passbys of helicopters to these formerly inaccessible sites, thereby subjecting the fragile adobe walls to oscillating pressure loadings unlike any previous exposure. Consequently, the study site should contain cliff dwellings where response characteristics of the old adobe and stone walls can be measured along with oscillating pressure loadings from helicopters at known distances and orientations. A similar concern is for oscillating pressure loadings on flat roofs of structures built in the old pueblo style;

these structures are estimated to be especially susceptible to noise-induced vibrations. Deflections of the flat roof cause bending of the vigas and rotation at corners, resulting in potentially damaging shear stresses of the adobe materials. Consequently, the study site should also have some examples of flat roofed structures of viga construction.

Mesa Verde National Park is a likely candidate for a study of helicopter noise induced vibration. Balcony House in this park is a cliff dwelling suitable for the kinds of measurements required to determine the response of helicopters hovering at the same level as the structure. Kenneth King of the U.S. Geological Survey and co-author of the HMMH literature survey report believes that Balcony House is reasonably accessible for people with equipment. It also has suitable transducer mounting locations. The Park also has candidate structures for measurements of flat roofs of viga, as well as ruins with partial height walls. According to King, Superintendent Bob Hyder has supported U.S.G.S efforts to assess risks of vibration damage and has expressed his willingness to cooperate on further studies in the future.

3.2 Measurement Program

Characterization of helicopter noise-induced vibrations requires sound pressure measurements near the surface of the structure and vibration velocity measurements on the structure. These data are used to determine the ratio of the vibration velocity of a structural element to the imposed sound pressure; this ratio is called "admittance" and is used to evaluate the ability of a structure to respond to sound waves. In order to generalize the results, these measurements should be conducted with a wide range of helicopter types in commercial service and on a number of structures of various types. The following describes an approach for gaining the necessary information.

3.2.1 Helicopter Noise Measurements

The measured sound pressure level of a helicopter depends on the physical characteristics of the helicopter, such as size and weight, number of blades and number of rotors; the operating mode such as hover, ascent, descent or forward motion; and the position of the microphone with respect to the helicopter. The noise comes from several sources: each source is directional and each source produces noise in different parts of the frequency spectrum. Since structural response to noise occurs in the frequency range of 50 Hz and below, it is important to identify the sources which produce sound energy in this region and to identify the conditions under which these sounds are produced.

A wide variety of helicopters are used in commercial service. In order to characterize the noise from helicopters likely to be encountered at a site, measurements should be carried out on a representative sample of these types. The first step would be to determine the kinds of helicopters in use by tour operators by conducting a survey of the fleet. Representative helicopters would be then contracted for measurements at selected sites in Mesa Verde.

Noise measurements should be conducted on test helicopters operating like those in commercial use near cultural resources in the National Park. Such operations as hovering at the side, ascending, descending and level passbys are commonly experienced at a cliff dwelling. Similar operations could occur near all structures in a park including ones which have been found in the literature review to be especially sensitive, such as the intact flat roof of a pueblo type building. During the measurements separation distances should be varied for each operating condition from the closest safe distance to approximately 1000 feet. The position of the helicopter can be measured with an accurate rangefinder. Position and orientation of the helicopter with respect to the receiver during all measurements must be well documented in order to determine the effects of directivity.

Noise measurements should be made at representative locations using two or more microphones at each structural element of interest. The instrument chain should be capable of measuring to very low frequencies as low as 2 Hz. It should include Type 1 microphones with windscreens, sound level meters, multi-channel digital recording devices and associated calibrators and read-out instruments.

3.2.2 Structural Vibration Measurements

Structural response to acoustical input is measured by vibration transducers mounted directly to the surface of the element. The instrument chain must be capable of measuring root mean square velocities as low as 0.00003 in/sec (30 dB re 1 microinch/sec) over a frequency range of 2 Hz to 100 Hz. Vibration transducers and special signal conditioning and recording instrumentation are available to meet these requirements. Multiple tri-axial transducers should be used to simultaneously record response at different parts of the structural element from the same acoustical pressure input. These transducers must be carefully selected to meet the sensitivity requirements and still be light enough so as not to affect the response characteristics of the element. The vibration signals should be recorded simultaneously with noise on the same tape recorder, thereby allowing analysis of admittance functions by cross-correlation techniques.

In Mesa Verde the walls of Balcony House exposed to helicopter sound pressures should be instrumented at two or more locations (midwall, corner, lintel) to obtain a range of response characteristics. Similarly, the flat roof of a building of pueblo architecture should be instrumented at several locations (midspan, corner, on one of the vigas) so as to determine the vertical and rotational motions of the affected surfaces.

3.2.3 Analysis of Data

The key information to be gained from this study is as follows:

1. Helicopter sound pressures at the receiver for various types, directions, distances and operating conditions.

2. Structural vibrations corresponding to the sound pressures from measured helicopter operations.

3. Admittance functions of fragile walls and roofs for typical Anasazi and Pueblo buildings.

Noise levels for each measured helicopter as a function of distance, directivity and frequency are determined from the recorded sound channels. Similarly, the vibration signals are analyzed to determine the response characteristics of each structural element. In addition, the sound pressures from the helicopters and the vibration response of the structures are simultaneously analyzed on a multi-channel real time analyzer with FFT capability to determine the frequency dependent admittance functions of the structures.

3.2.4 Results

The results are ultimately used to estimate the potential for damage to a wide variety of cultural resources from operations of commercial helicopters. Comparison of measured vibration levels with criteria for damage based on structural velocities (Table 2.3 of Literature Review Report) will provide a family of restrictions on aircraft operations in the vicinity of sensitive structures. Such restrictions could take the form of minimum separation distances and prohibited maneuvers for helicopters.

The results of the study would be presented in a report as a set of recommended procedures for helicopter operations to avoid damage to prehistoric, historic, sensitive and conventional structures.

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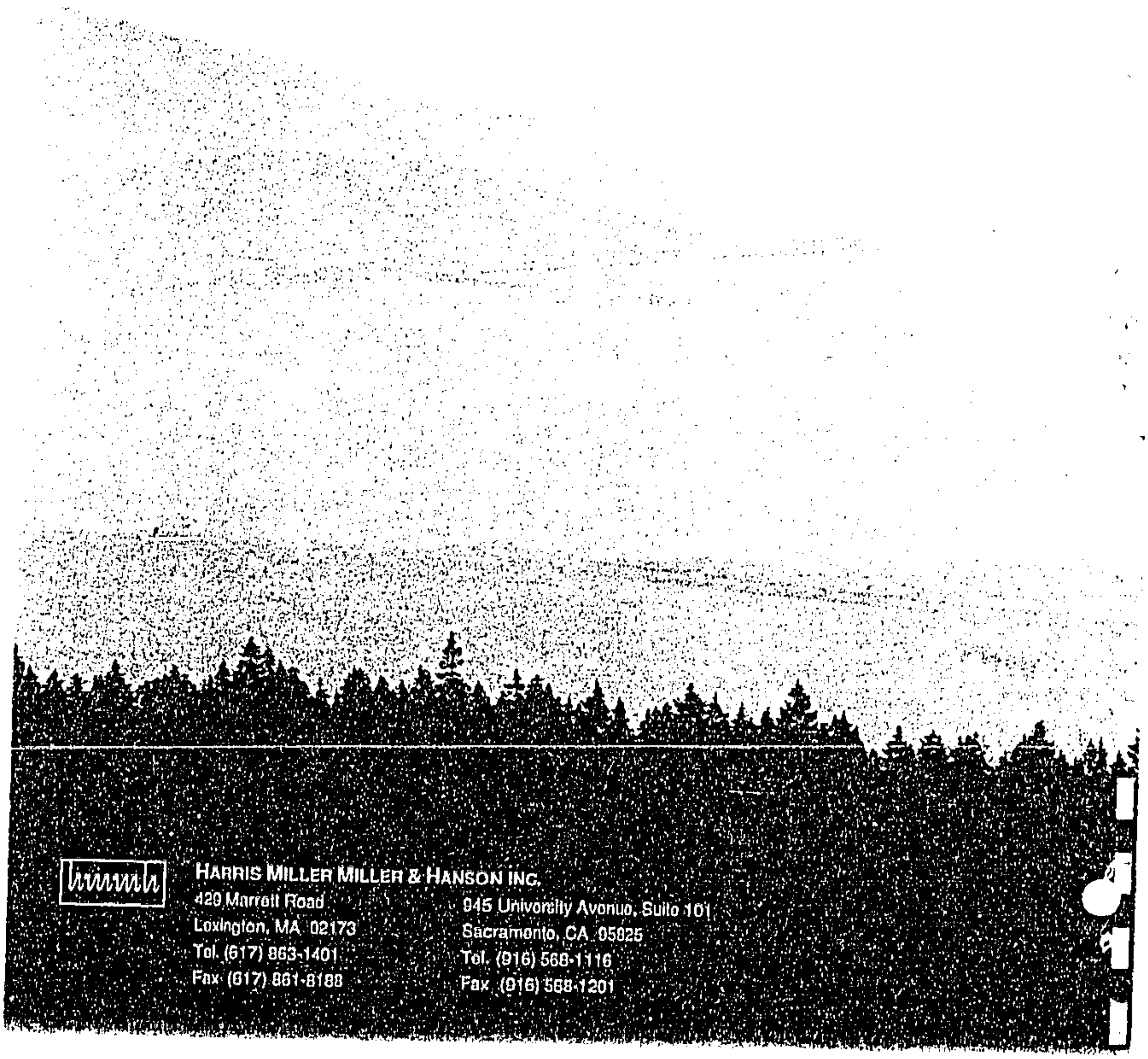
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