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USAAMRDL TECHNICAL REPORT 71-31

TEST AND EVALUATION OF A QUIET HELICOPTER CONFIGURATION HH-43B

By

Michael A. Bowes

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January 1972

EUSTIS DIRECTORATE
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CONTRACT DAAJ02-70-C-0004
KAMAN AEROSPACE CORPORATION
BLOOMFIELD, CONNECTICUT

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This report was prepared by the Kaman Aerospace Corporation under the terms of Contract DAAJ02-70-C-0004 and ARPA Order 1322, Amendment No. 1. The program was conducted as part of the Advanced Research Projects Agency's (ARPA) Quiet Helicopter Program.

The objective of the program was to modify the HH-43B helicopter so as to reduce its external noise level by 6 decibels over most of the audible frequency range above that achieved in a previous program. The previous program, which was conducted under Contract DAAJ02-69-C-0019, ARPA Order 1322, achieved a reduction in the standard HH-43B helicopter overall sound pressure level of 3 decibels as measured in a flyover directly overhead at 200 feet.

The program goal of an additional 6 decibel reduction in the noise signature of an HH-43B helicopter was met. Furthermore, the contribution of each major modification toward achieving this goal was determined by measuring noise levels as each was added to the helicopter.

The report has been reviewed by this Directorate, and it is technically sound. The technical monitor for this contract was Mr. R. C. Dumond, Applied Aeronautics Division.

Contract DAAJ02-70-C-0004
USAAMRDL Technical Report 71-31
January 1972

TEST AND EVALUATION OF A QUIET HELICOPTER CONFIGURATION HH-43B

Final Report

Kaman Report R-914

By

Michael A. Bowes

Sponsored by

The Advanced Research Projects Agency
ARPA Order Number 1322

Prepared by

Kaman Aerospace Corporation
Bloomfield, Connecticut

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, under Contract DAAJ02-70-C-0004.

SUMMARY

A series of noise control modifications was made to the HH-43B helicopter. Each modification was evaluated by direct comparison of acoustic signatures of modified and unmodified configurations.

Noise control modifications to the aircraft engine, drive and rotor systems were used and are evaluated. Testing was performed on ten aircraft configurations.

The noise control modifications resulted in substantial reductions in flyover noise. All octave bands of interest, i.e., 63 Hz to 4000 Hz, were significantly reduced.

The rotor system was the dominant noise source, in level flight, dominating each octave band in the modified aircraft's audible spectrum, i.e., with center frequencies from 31.5 Hz to 8000 Hz. This noise source was reduced through changes in rotor blade geometry and reduction in blade tip speed.

The program goal of an additional 6-decibel (dB) reduction in the noise signature of an HH-43B helicopter was met.

FOREWORD

The work reported was performed by Kaman Aerospace Corporation under Contract DAAJ02-70-C-0004. The project was conducted under the technical cognizance of Mr. R. Dumond, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

The Quiet Helicopter program was sponsored by the Advanced Research Projects Agency under ARPA Order Number 1322.

Consultation in the design of noise control modifications was provided by Mr. R. White of Rochester Applied Science Associates and the Engineering Staff of the Huyck Metals Company.

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INTRODUCTION

OBJECTIVES

The objectives of this effort were:

- To achieve and demonstrate an additional 6-decibel (dB) reduction in the noise signature of a modified HH-43B.
- To evaluate the effectiveness of each modification used to attain this reduction.

The noise signature was defined as: the sound pressure levels of those octave bands with center frequencies of 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz, together with the overall sound pressure level, as measured with a filter having a passband of 20 Hz to 20 kHz. This was to be measured 200 feet below the aircraft during steady level flight at 60 kts. Details of the measurement procedure, instrumentation, and data analysis techniques used are given in Appendix I.

The noise reduction was to be measured relative to the signature of the first quiet helicopter program HH-43B, as measured by NASA and presented in Figure 9 of Reference 1. These levels, as well as those established as goals for the present effort, are shown in Table I.

APPROACH

The major contributors to the HH-43B noise signature were established during the first quiet helicopter program, Reference 2. The modifications used in the present effort to achieve further reduction in noise signature are presented in Figure 1. Modifications were installed in groups, and a series of tests was performed to determine the resultant changes in noise signature.

Modification groups and test sequencing used are given in Table II. In this table the first entry, Configuration 1, represents a standard, unmodified helicopter, and the last entry, Configuration 9, is the final quiet helicopter, employing all of the modifications of Figure 1. Intermediate entries are aircraft configurations for which evaluation testing was performed.

TABLE I . BASELINE AND PROGRAM GOAL NOISE SIGNATURES

Octave Band Center Frequency - Hz	Baseline Spectrum dB(re.-.0002 μBar)	Noise Reduction* Goals - dB	Noise Spectrum Goal* dB(re.-.0002 μBar)
O/A	89.0	-6	83.0
31.5**	-	-	-
63	78.0	-6	72.0
125	81.0	-6	75.0
250	81.5	-6	75.5
500	77.0	-6	71.0
1000	75.5	-6	69.5
2000	75.0	-6	69.0
4000	73.5	-6	67.5
8000**	-	-	-

*As measured 200 feet below aircraft flight path during steady level flight.

**No goals established for these octave bands.

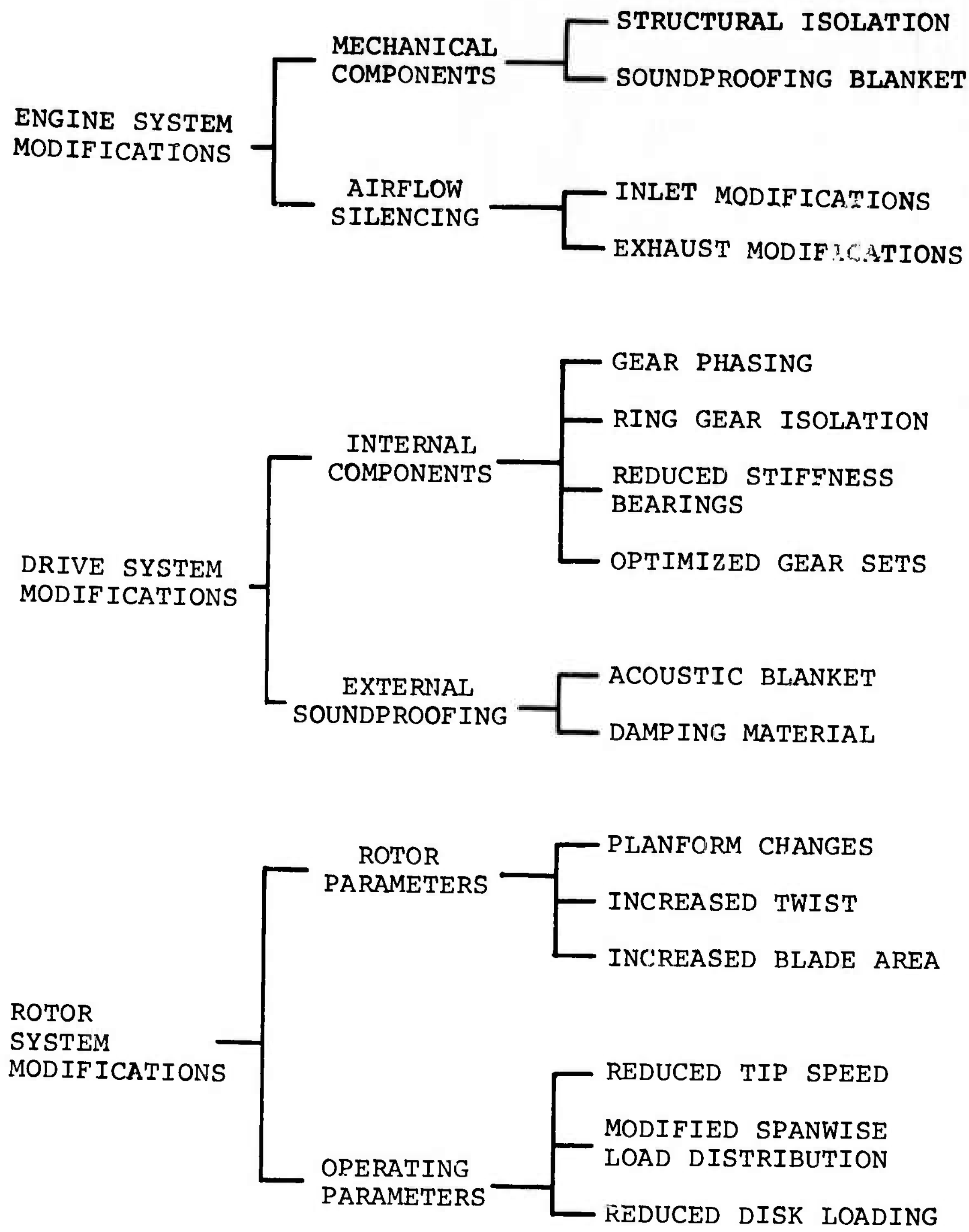


Figure 1. Quiet Helicopter Modification Areas.

TABLE II. AIRCRAFT CONFIGURATION DEFINITION

Configuration	Description
1	Standard HH-43B, Avg GW = 6146 lb
2	Engine isolation & soundproofing, clamshell doors removed, Avg GW = 6023 lb
3	Configuration 2 plus: inlet silencer, clamshell doors installed, Avg GW = 5960 lb
4A	Configuration 3 plus: exhaust silencer -A (exhaust direction reversed to +90°), Avg GW = 6470 lb
4B	Configuration 4A plus: exhaust silencer -B (exhaust direction shifted aft to +45°), Avg GW = 5851 lb
5	Configuration 4B plus: internal transmission mods., external lower transmission soundproofing, generator and blower removed, Avg GW = 6100 lb
6	Configuration 5 plus: exhaust silencer -C (exhaust direction shifted aft to 0°), external upper transmission soundproofing, Avg GW = 6170 lb
7	Configuration 6 plus: clamshell doors removed and replaced with soundproofing blanket, additional transmission soundproofing, Avg GW = 5900 lb
8	Configuration 7 plus: outboard vertical tails removed, tailpipe bellmouth aspirator installed, Avg GW = 5725 lb
9	Configuration 8 plus: modified rotor system installed, outboard vertical tails installed, Avg GW = 5178 lb

Acoustic and performance test data is tabulated in Appendix II, and is discussed in the main body of the report. This discussion is presented in two parts: comparison of achieved noise reductions with the established noise reduction goals; and, paired comparisons of each of the configurations of Table II.

INFRARED SIGNATURE SURVEY

As an adjunct to the acoustic evaluation program, testing was performed to determine the effect of the engine and drive system modifications on the aircraft infrared signature. A description of this testing, with results and conclusions, is presented in Appendix III.

RESULTS AND DISCUSSION

The program goal of an additional 6-decibel (dB) reduction in the noise signature of an HH-43B helicopter, shown in Figure 2, was met. To attain this goal, the HH-43B helicopter was configured as shown in Figure 3. Configuration details are presented in the next three sections of this report. The quiet helicopter noise signature measured 200 feet below the helicopter is shown in Figure 4. Also shown are signatures of the baseline aircraft and the program goal. In addition to these noise level results, noise measurements were made of each configuration listed in Table II, and are presented in the next three sections of this report.

All flyby noise levels of the helicopter were measured when the helicopter was at 60 knots airspeed and 200 feet altitude over a fixed course. All hover noise levels of the helicopter were measured when the helicopter was in a 10-foot hover. Table III lists the locations and flight conditions of the noise level measurements. Further details of the noise measurement procedures are contained in Appendix I.

ENGINE SYSTEM SILENCING

The following sources of HH-43 engine noise were determined from the first quiet helicopter program:

- Compressor blade passage and inlet airflow.
- Exhaust flow.
- Bearings, shafting, and combustion.

Inlet airflow noise is produced in a variety of ways. The airflow, reacting with the free stream air, is a source of broadband noise. Additional broadband noise is generated by vortex shedding from compressor blades, inlet guide vanes, and other obstructions within the flow. In addition to broadband noise, a discrete tone is associated with compressor blade passage. This tone is the result of the rotating pressure field of the compressor. All of these noise sources radiate forward, out of the inlet.

The exhaust flow is a source of broadband noise only. Noise is caused by the turbulent flow of the exhaust stream, and the shear boundary between exhaust flow and ambient air. Noise radiation is predominantly in the direction of flow.

Figure 2. Standard HH-43B Helicopter.

Figure 3. Fully Modified Quiet Helicopter Configuration HH-43B.

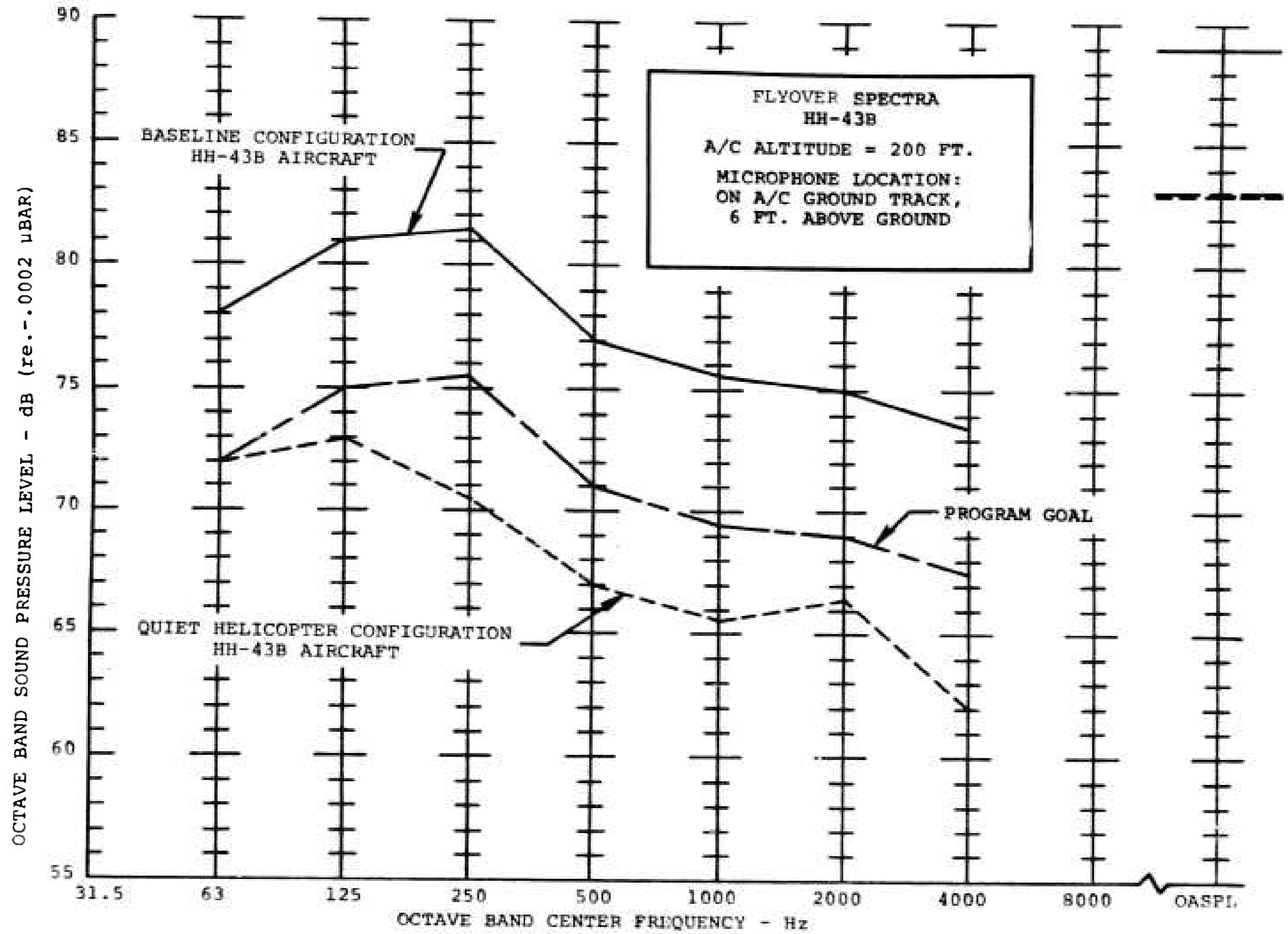


Figure 4. Baseline Vs Quiet Helicopter Vs Program Goal.

TABLE III. MEASUREMENT LOCATIONS AND FLIGHT CONDITIONS	
Measurement Position	Aircraft Flight Condition
200 ft below aircraft flight path (flyover)	Steady level flight @ 60 knots indicated airspeed (KIAS)
200 ft below, and 200 ft to side of aircraft flight path (flyby)	Steady level flight @ 60 KIAS
200 ft from aircraft centerline in forward direction	In-ground effect (IGE) hover @ 10 ft altitude
200 ft from aircraft centerline in starboard direction	IGE hover @ 10 ft altitude
200 ft from aircraft centerline in aft direction	IGE hover @ 10 ft altitude
200 ft from aircraft centerline in port direction	IGE hover @ 10 ft altitude

Mechanical components of the engine system, including rotating shafts, bearings, etc, are sources of broadband and discrete noise. The combustion process is a source of broadband noise. Engine noise radiation may be in any, or all, of the following ways:

- Direct radiation from the engine case.
- Transmittal, by structural vibration, through engine mounts, and re-radiation from aircraft structure and skin surfaces.
- Radiation from the engine inlet and engine exhaust.

Engine modifications for the present program were made in three steps:

- Engine/structure isolation and engine compartment soundproofing, for control of mechanical noise.
- Installation of a reverse flow, reactively lined engine inlet.
- Replacement of the standard exhaust duct with an expanded, reactively lined duct, employing exit plane flow expansion and redirection.

Mechanical Noise Reduction

A standard HH-43B was first evaluated to provide baseline data. Subsequent to this, mechanical noise control modifications were made. These two aircraft are identified as configuration 1 and configuration 2 in Table II.

Configuration 2 modifications included:

(1) Installation of elastomeric vibration isolators at all engine mounting points, designed to isolate all frequencies above 100 Hz; installation is shown in Figure 5.

(2) Installation of a soundproofing treatment enclosing the engine compartment. This was a sandwich construction consisting of a sheet of .87 lb/ft^2 lead impregnated vinyl between two layers of "AA" fiberglass blanket. Installation of this treatment is also shown in Figure 5.

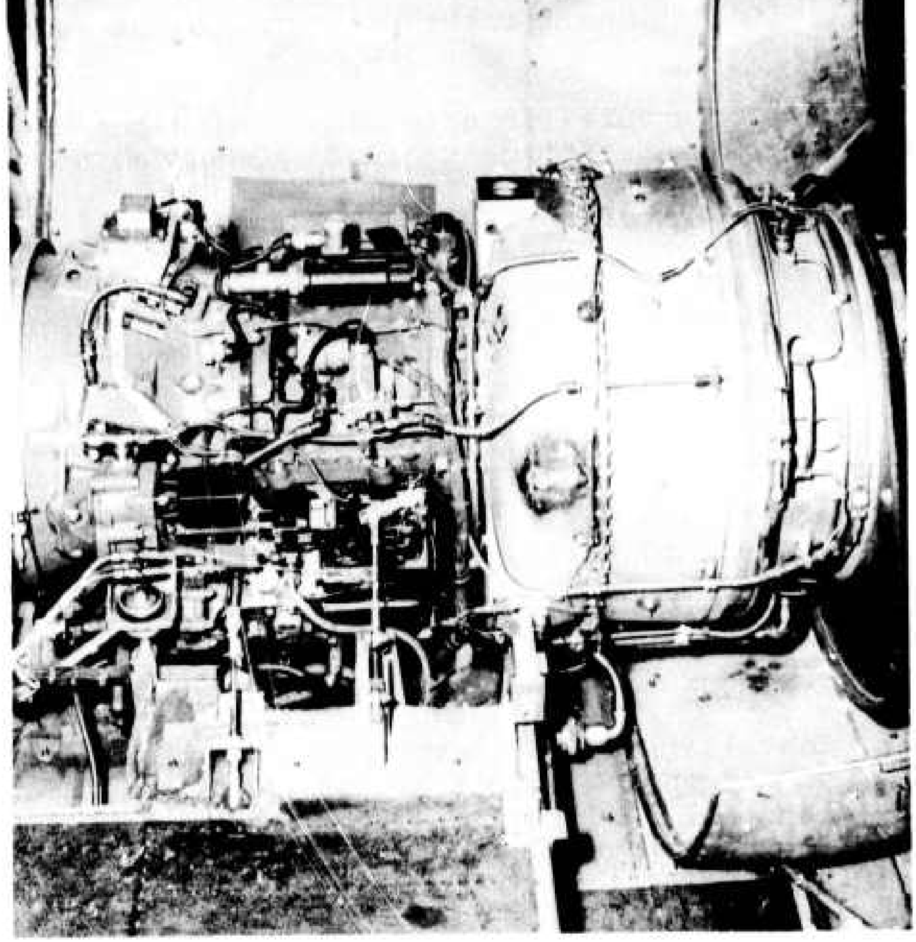


Figure 5. Engine Isolation and Soundproofing.

In addition, the aft cabin clamshell doors were removed to maintain a constant gross weight and center of gravity (cg). No change in the flyover noise signature was anticipated as a result of the door removal.

The values of all known, extraneous variables were recorded and, where possible, kept constant. This information is contained in Appendix II. To avoid variations in pilot technique, the same pilot was used throughout the program.

Data for configurations 1 and 2 is presented, for forward flight, in Figure 6. This data indicates that the modifications decreased the low frequency (31.5 Hz to 125 Hz) octave band flyover levels. The increase in the levels of the mid to high frequency bands (250 Hz to 4000 Hz) was probably caused by the removal of the aft cabin clamshell doors. The 1000 Hz, 2000 Hz and 4000 Hz octave bands dominate the cabin noise and, due to the high frequencies involved, are attenuated by the cabin walls and doors. Removal of the doors permits radiation of internal noise to the far field.

Conclusions:

- Vibration isolation of the engine and soundproofing of the engine compartment were not effective in reducing the HH-43B aircraft octave band flyover noise levels.

- Internal noise sources may contribute to external noise in the absence of an attenuation barrier.

Engine Inlet Noise Reduction

The test aircraft was reconfigured, incorporating modifications to the engine inlet, and designated configuration 3. The reverse-flow, reactively lined inlet silencer shown in Figure 7 was installed. Installation on the test aircraft is shown in Figure 8. In addition, the aft cabin clamshell doors, removed for the preceding test, were reinstalled.

Data for configuration 3 is shown in Figure 9. Reduction of all octave band sound pressure levels, with the greatest reduction in the middle to high frequency bands (500 Hz to 4000 Hz), is shown. The expected result of inlet silencer installation was reduction of the discrete compressor blade passage tone. Narrow-band analysis of hover data for this and the previous configuration indicated a substantial reduction in this discrete tone level, as shown in Figure 10.

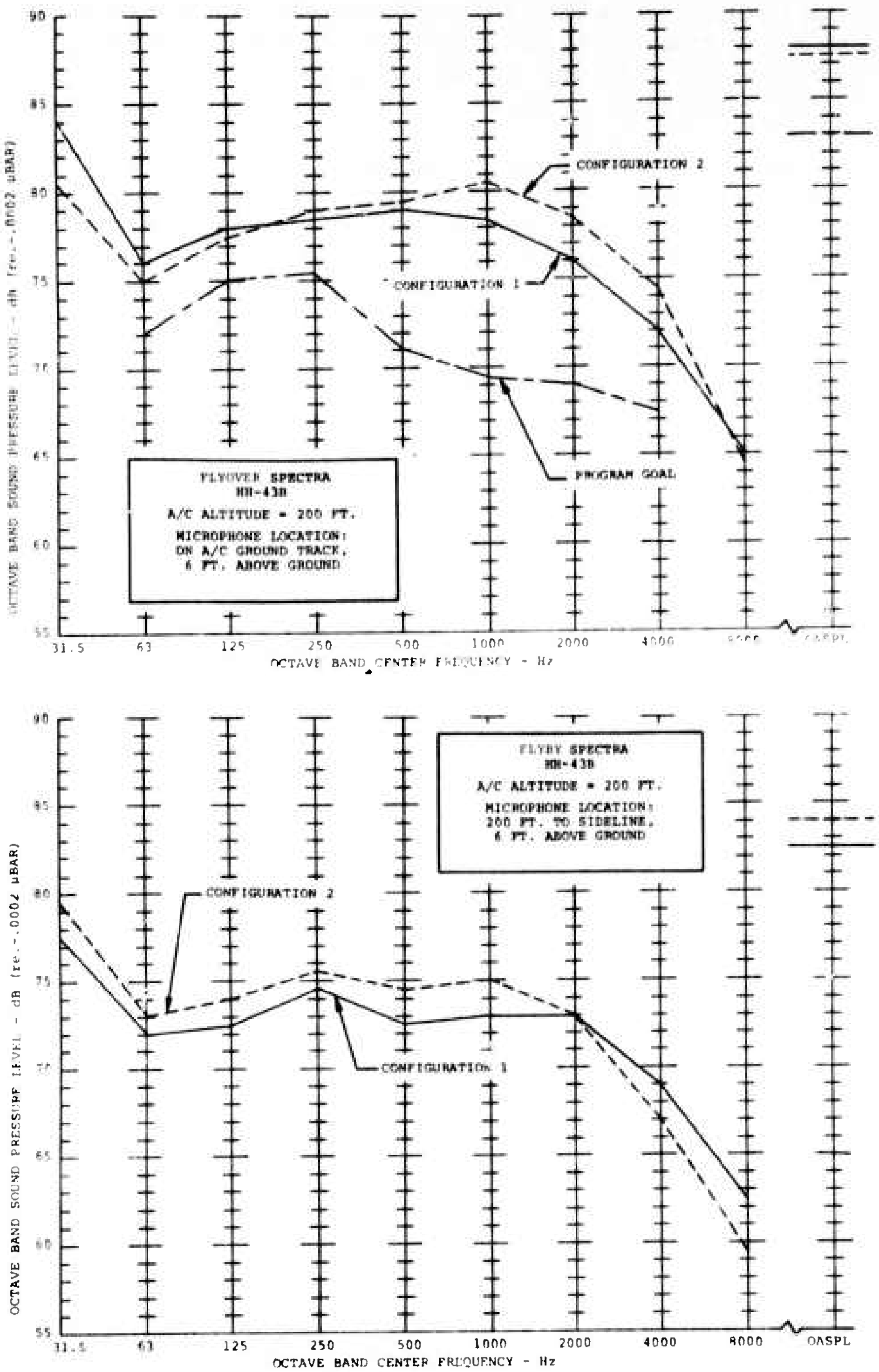


Figure 6. Configuration 1 Vs Configuration 2.

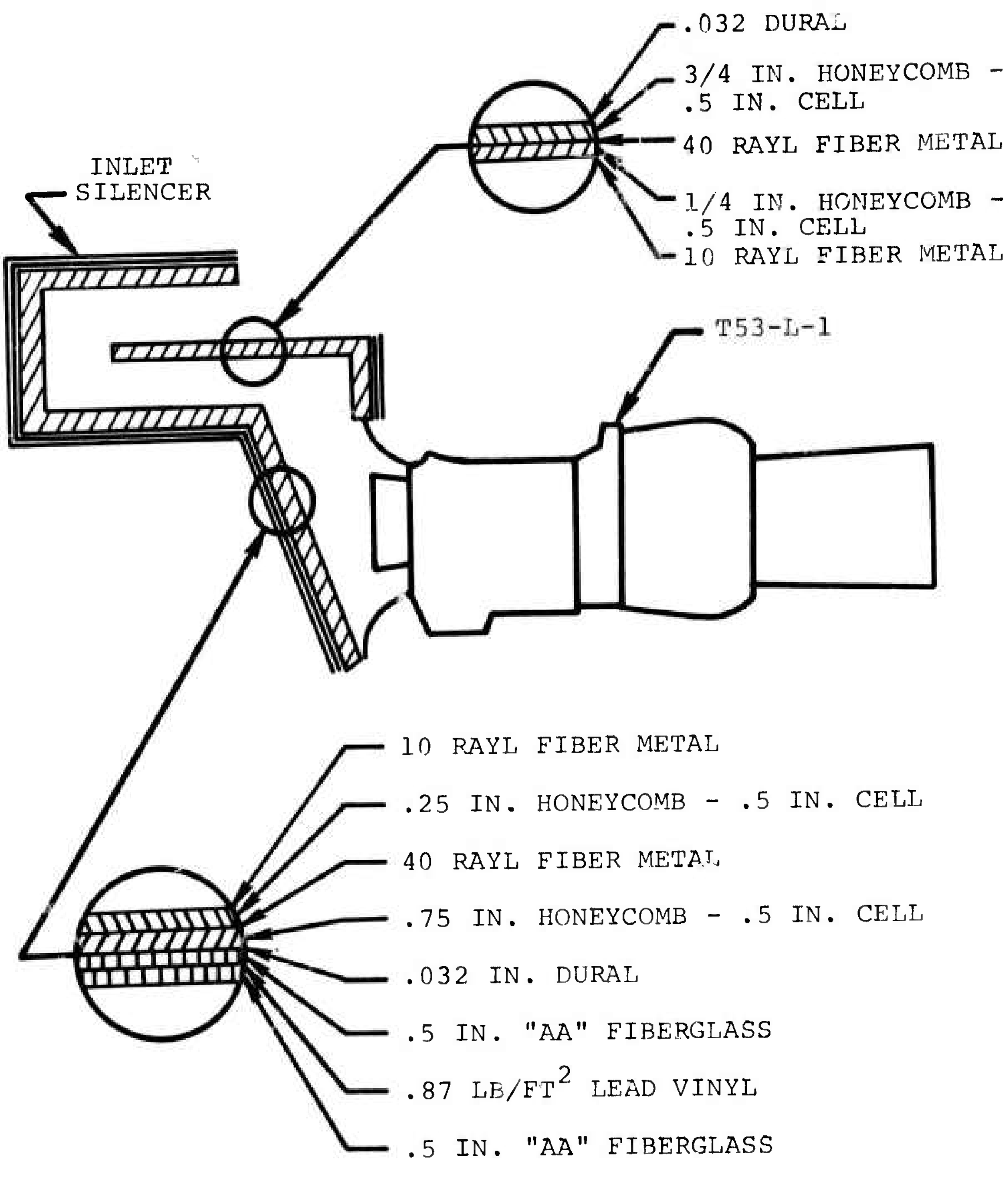


Figure 7. Inlet Silencer Construction.

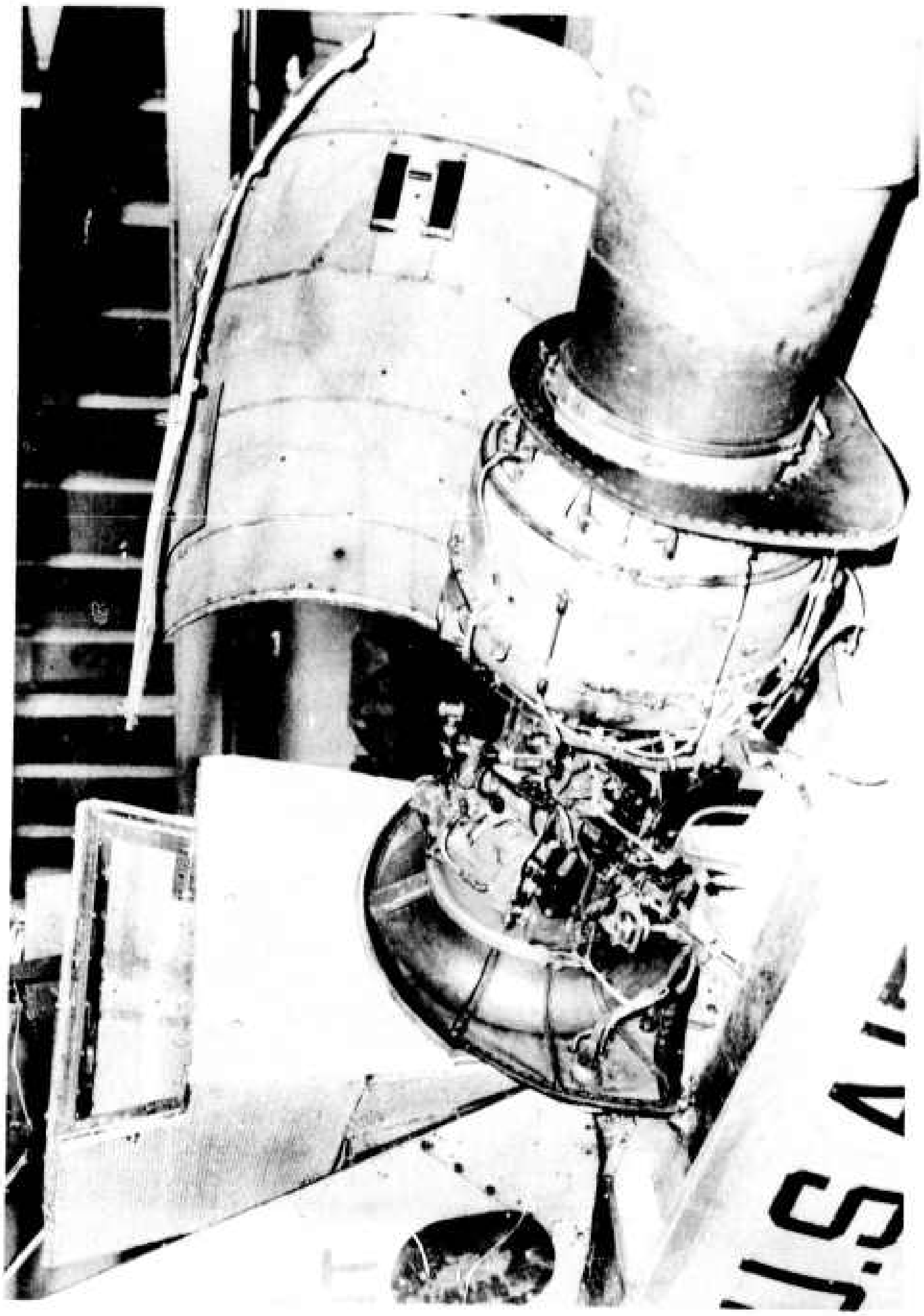
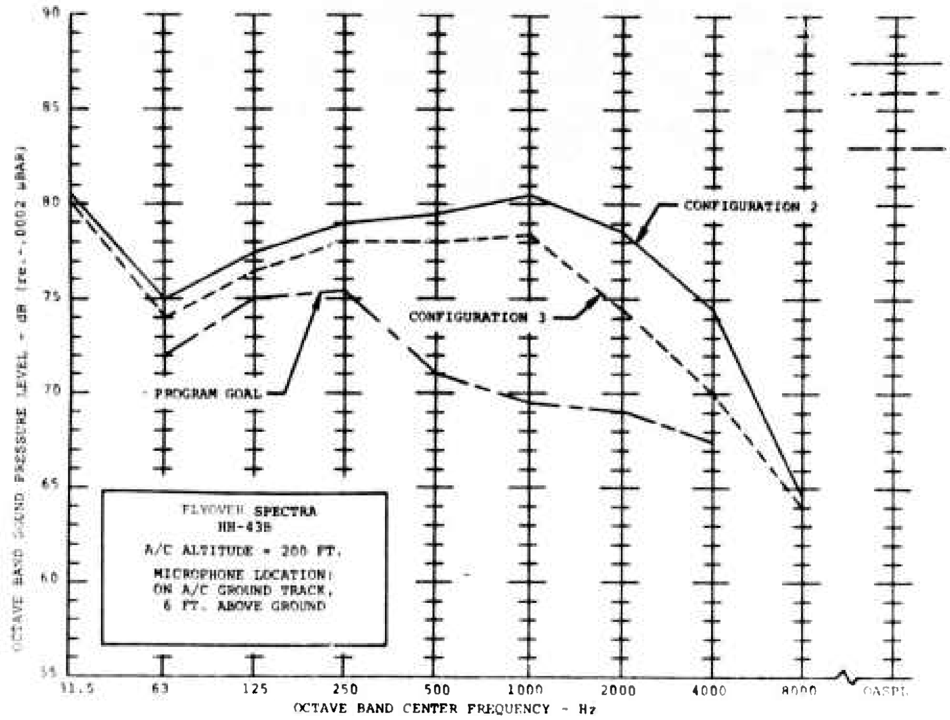


Figure 8. Inlet Silencer Installation.



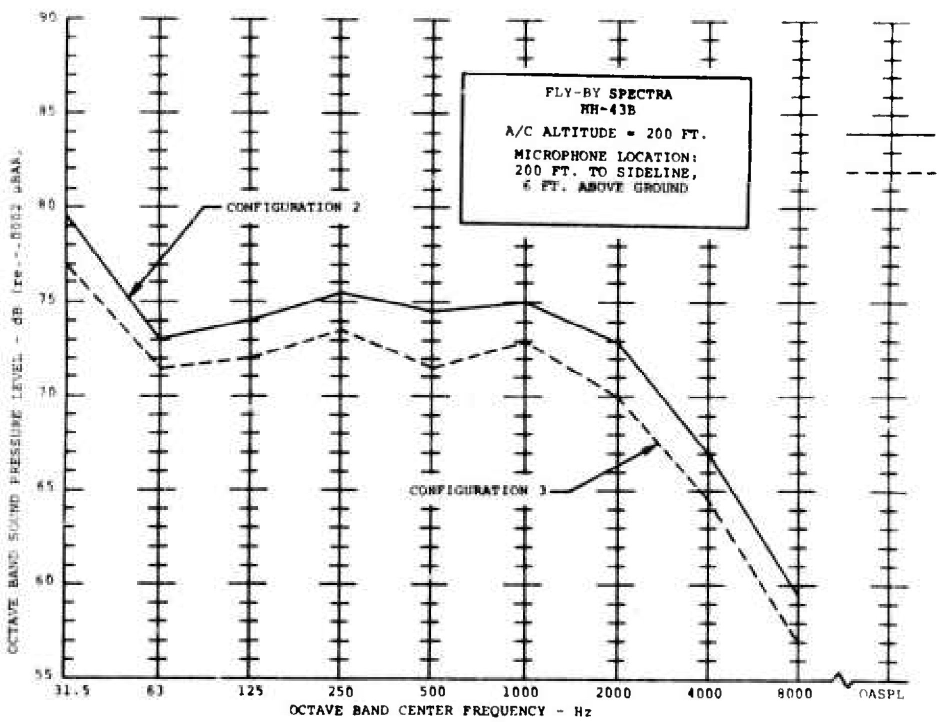
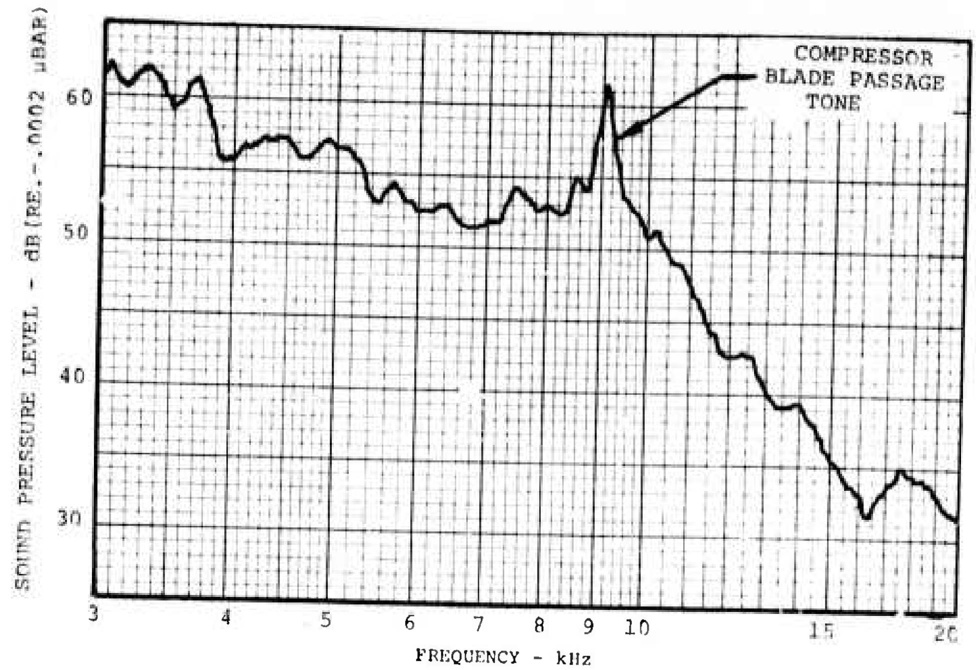
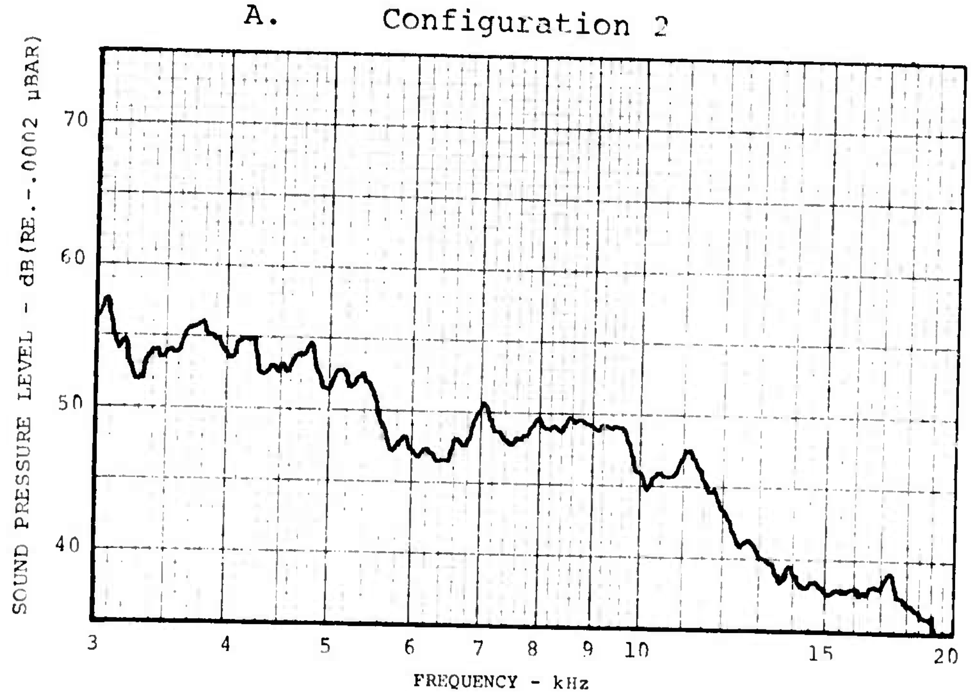


Figure 9. Configuration 2 Vs Configuration 3.



A. Configuration 2



B. Configuration 3

Figure 10. Compressor Blade Passage Tone Reduction.

The inlet silencer produced significant noise reductions in both low frequency (63 Hz to 125 Hz) and high frequency (1000 Hz to 8000 Hz) octave bands. The high frequency octave band noise level reductions, as well as the reduction in level of the compressor tone illustrated in Figure 10, are due to inlet flow silencing. The low frequency noise reductions result from the effect of physical installation of the silencer on fuselage/rotor flow patterns. Figures 3 and 8 show the inlet silencer installed between the rotor shaft fairings. On the standard HH-43B, this area is clear and, with the upward sloping cabin roof, forms a channel. During forward flight, free stream air flows and is accelerated through this channel, affecting the flow field of the rotor. This flow increases the nonsteady blade airloading, thereby increasing the rotor noise. With the inlet silencer installed, air flow is interrupted, lowering the rotor noise.

Conclusions are:

- The modified engine inlet reduced engine inlet noise.
- The engine inlet flow is a significant noise source.
- Rotor/fuselage flow interference effects contribute to the aircraft noise signature.

Exhaust Noise Reduction

Gas turbine exhaust noise is produced within the exhaust ducting as well as at the duct exit. Noise generation due to small scale turbulence within the exhaust flow is enhanced by the presence of the duct, which acts as a reflecting plane as well as a vibrating surface radiator. At the duct exit a layer of highly turbulent air is produced through the reaction of the high velocity exhaust flow with the free stream air. This turbulent boundary layer is a strong source of broadband noise. In addition to noise produced by the exhaust flow, internally produced engine noise is transmitted by the exhaust flow. A silencer was designed to control all of these exhaust noise sources.

Three exhaust configurations were tested. These are described below. All changes in flow characteristics were determined through observation of the exhaust plume.

- Configuration 4A - Initial installation of the exhaust silencer. This silencer, shown schematically in Figure 11, incorporated the following:

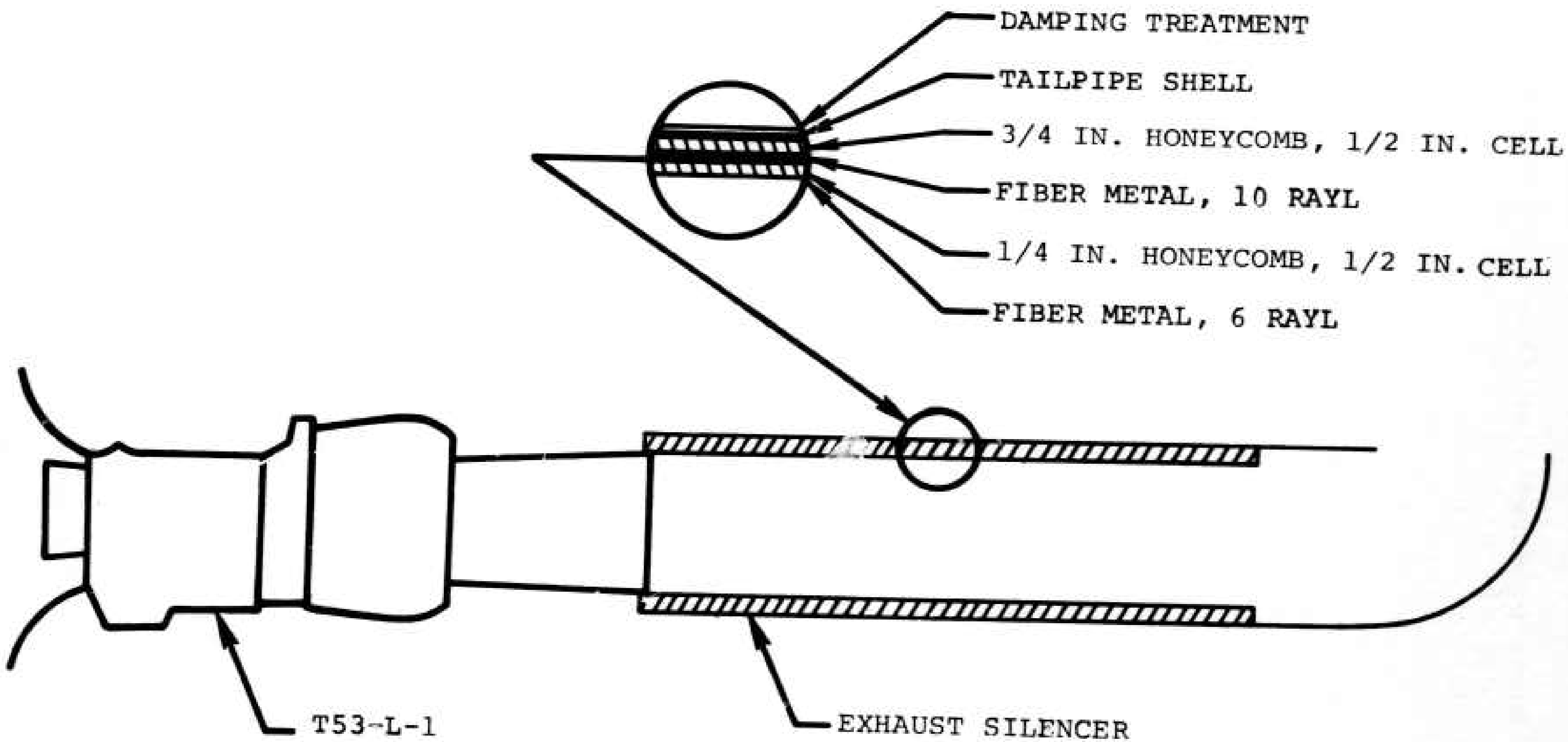


Figure 11. Initial Exhaust Silencer.

(1) A composite reactive lining, to absorb engine and in-duct turbulence noise.

(2) Damping, to reduce noise radiation by vibration of the tail pipe skin.

(3) Increase in the duct area at the exit plane from 254 sq.in. to 560 sq.in., to reduce noise at the end of the tail pipe.

(4) Redirection of the exhaust flow, from approximately 60 degrees down to 90 degrees up, to direct remaining noise away from the ground.

Exhaust modification caused a shift of the cg and an increase in gross weight. These changes were offset by forward ballast and removal of nonessential equipment.

- <u>Configuration 4B</u>

  (1) The exhaust duct exit geometry was changed, as shown in Figure 12A, to direct the exhaust flow more to the rear, 45 degrees to the horizontal.

  (2) Exit guide vanes were installed to promote smooth flow.

- <u>Configuration 6</u> - Exhaust exit geometry was again changed as illustrated in Figure 12B. Additional modifications were:

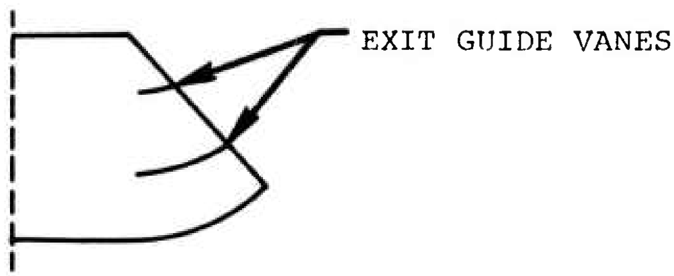
  (1) Damping material on the rotor shaft housings.

  (2) A soundproofing blanket on the transmission housing upper surface and rotor shaft housings.

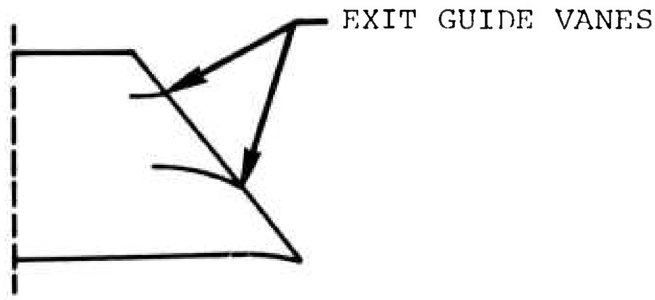
Data taken during testing of the initial exhaust silencer is shown in Figure 13. Large decreases are shown in the middle frequency bands (250 Hz to 2000 Hz), with an increase in the low frequency (31.5 Hz to 125 Hz) region.

Configuration 4B data is shown in Figure 14. Little difference between the configuration 4A and 4B noise signatures is evident.

Data for configuration 6, with the final exhaust silencer installed, is given in Figure 15. This shows decreases in the noise levels of the low frequency (31.5 Hz to 125 Hz) octave bands.



A. Configuration 4B



B. Configuration 6

Figure 12. Exit Geometry Modifications to Exhaust Silencer.

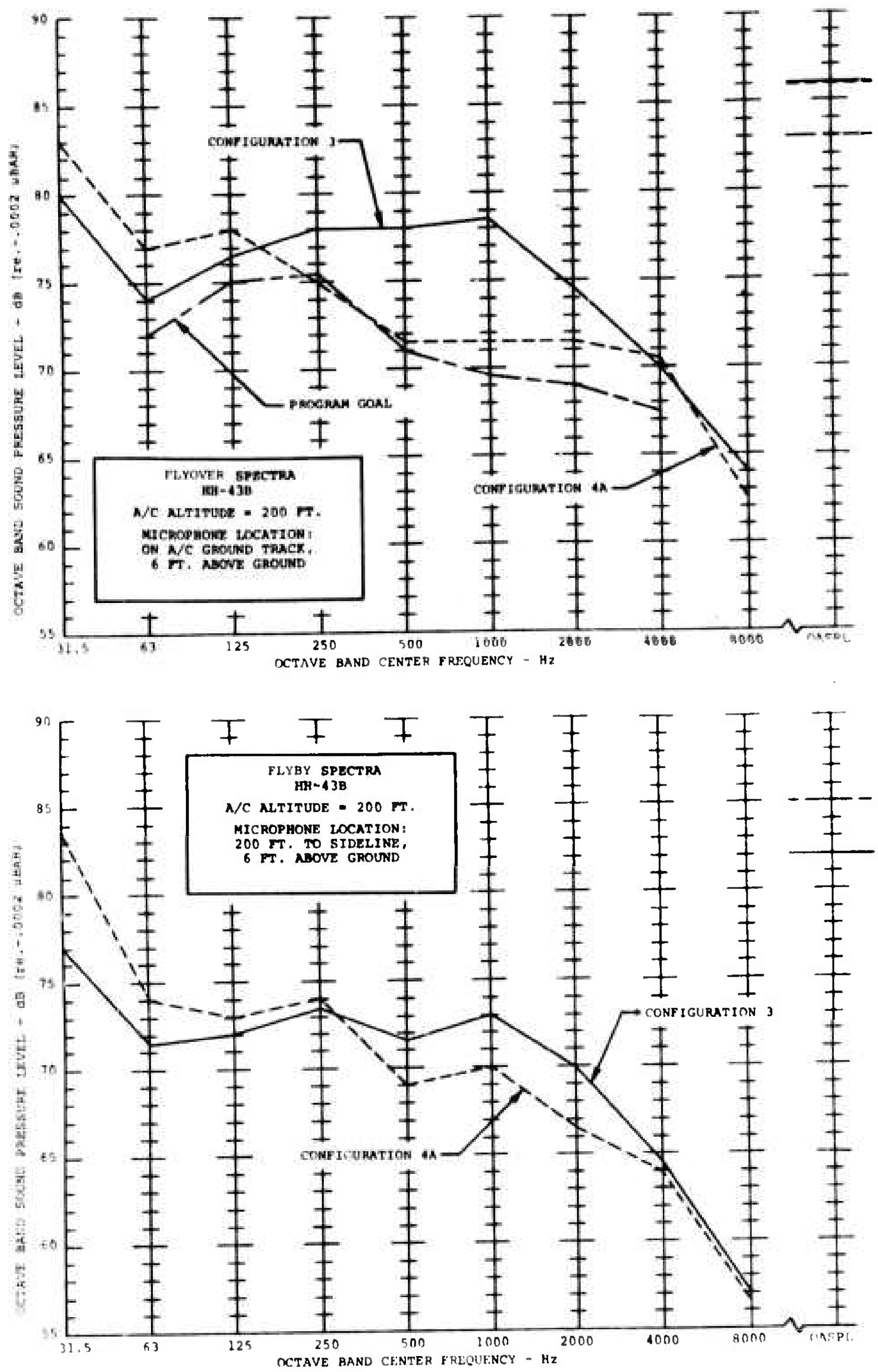
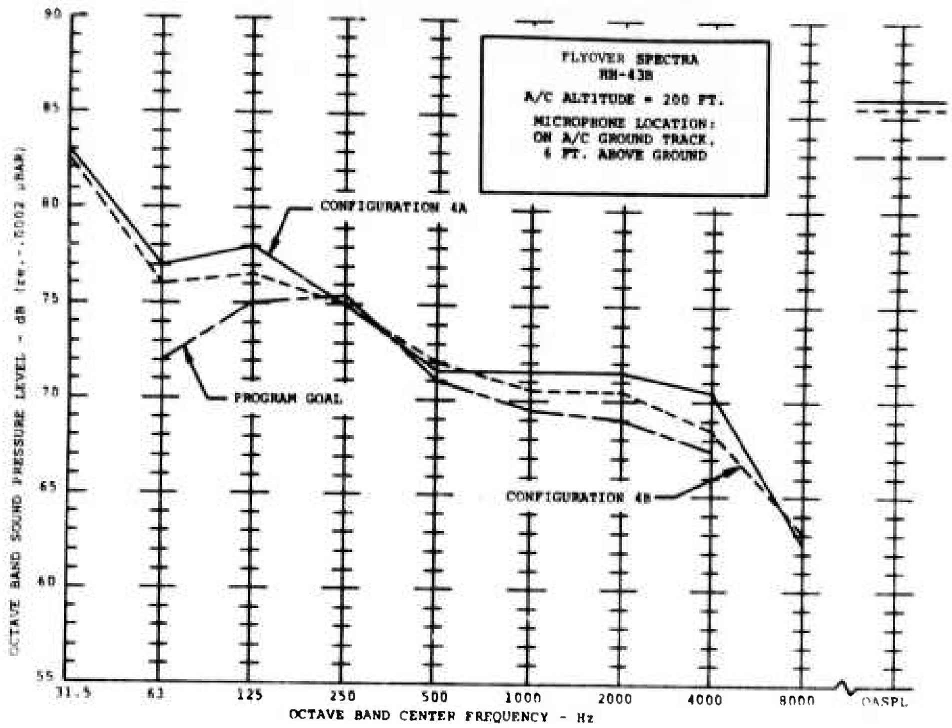


Figure 13. Configuration 3 Vs Configuration 4A.



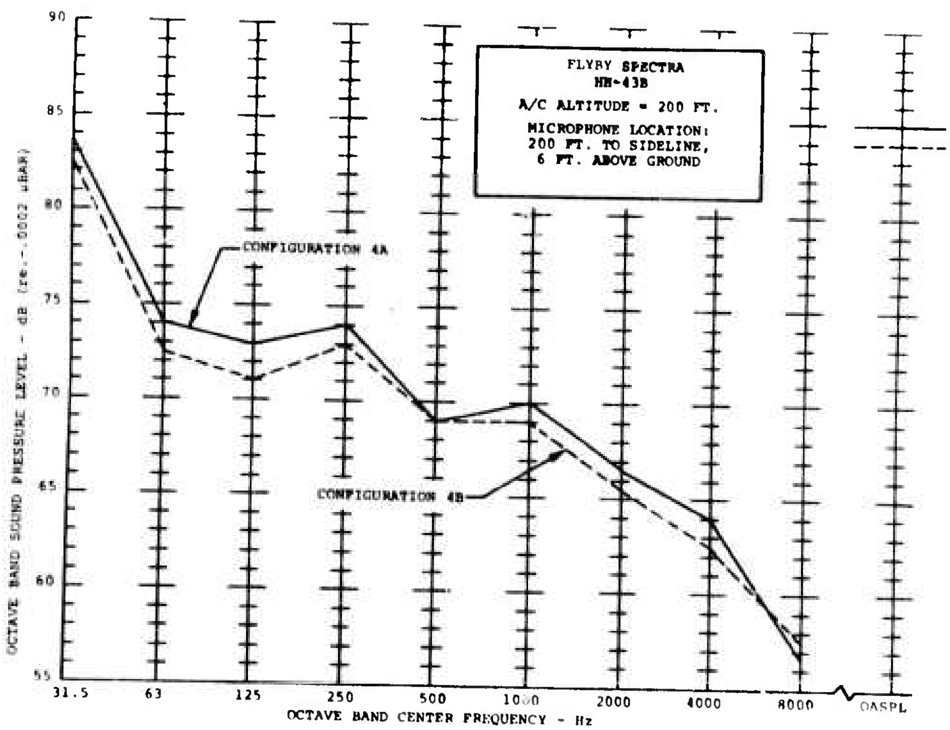


Figure 14. Configuration 4A Vs Configuration 4B.

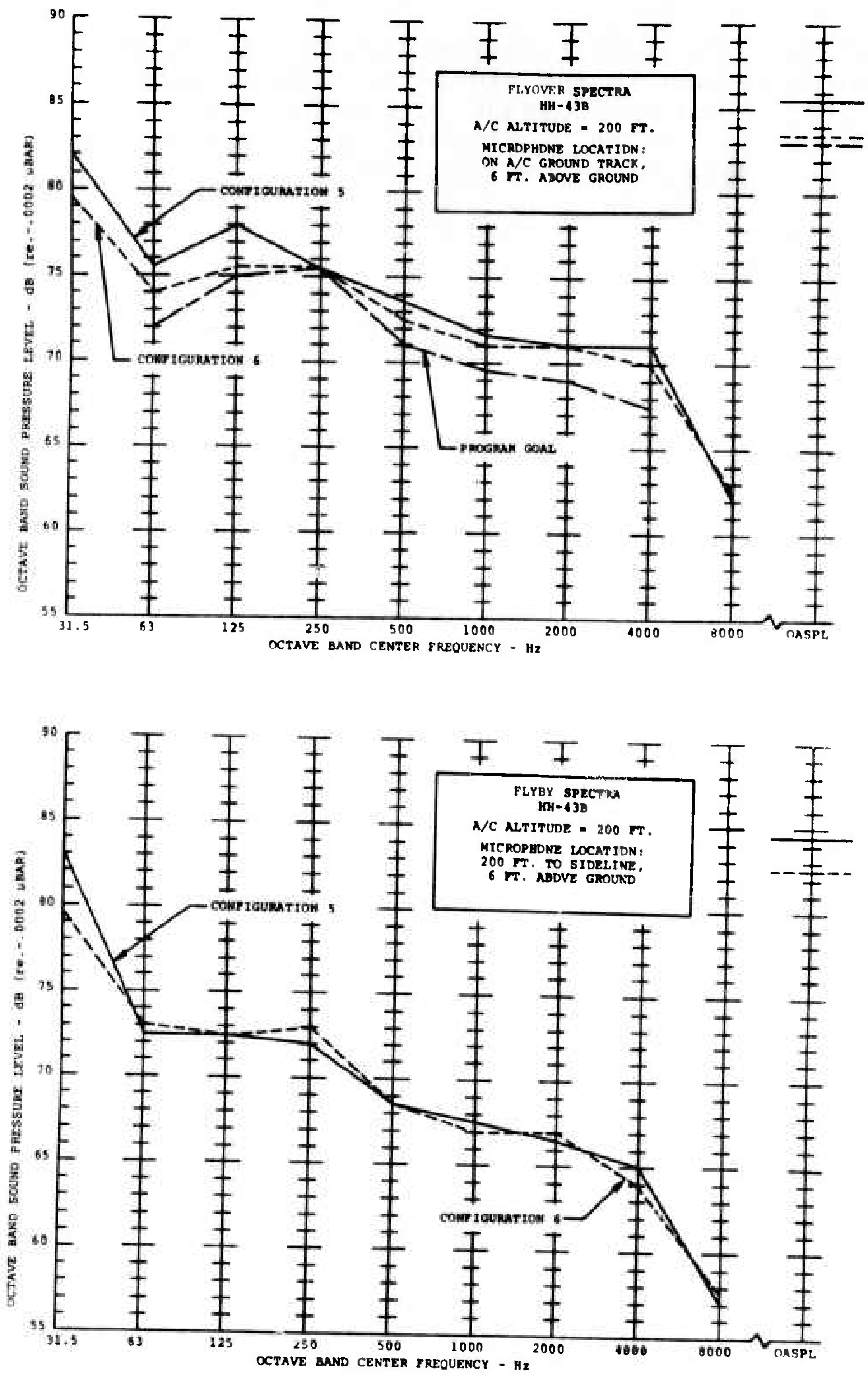


Figure 15. Configuration 5 Vs Configuration 6.

The initial exhaust duct modification, configuration 4A, caused decreases in the middle to high frequency octave bands, but also an increase in the low frequency region. Configurations 4B and 6 were designed to eliminate the unexpected increase in low frequency noise.

The increase in low frequency noise was caused by reversal of the exhaust flow direction which resulted in rotor/exhaust interference. This increased the nonsteady blade airloading, causing an increase in rotor noise. Therefore, the exhaust silencer was modified to configuration 4B.

The results of this change were inconclusive. Decrease in low frequency noise was only observable in the 125 Hz band, with no significant reduction in the 31.5 and 63 Hz bands. However, no degradation in silencer performance was measured in the higher frequency bands.

The exhaust duct modification for configuration 6 redirected the flow parallel to the rotor plane. Test results showing a decrease in low frequency noise substantiate the initial conclusion, i.e., that the increase in low frequency noise was due to rotor/exhaust interference. The low frequency noise reductions are due to the exhaust flow redirection.

Conclusions:

- The HH-43B engine exhaust is a significant noise source whose contribution to flyover noise may be reduced through modification of the exhaust duct.

- Redirection of the exhaust flow upward, toward the rotor plane, causes an increase in low frequency rotor noise.

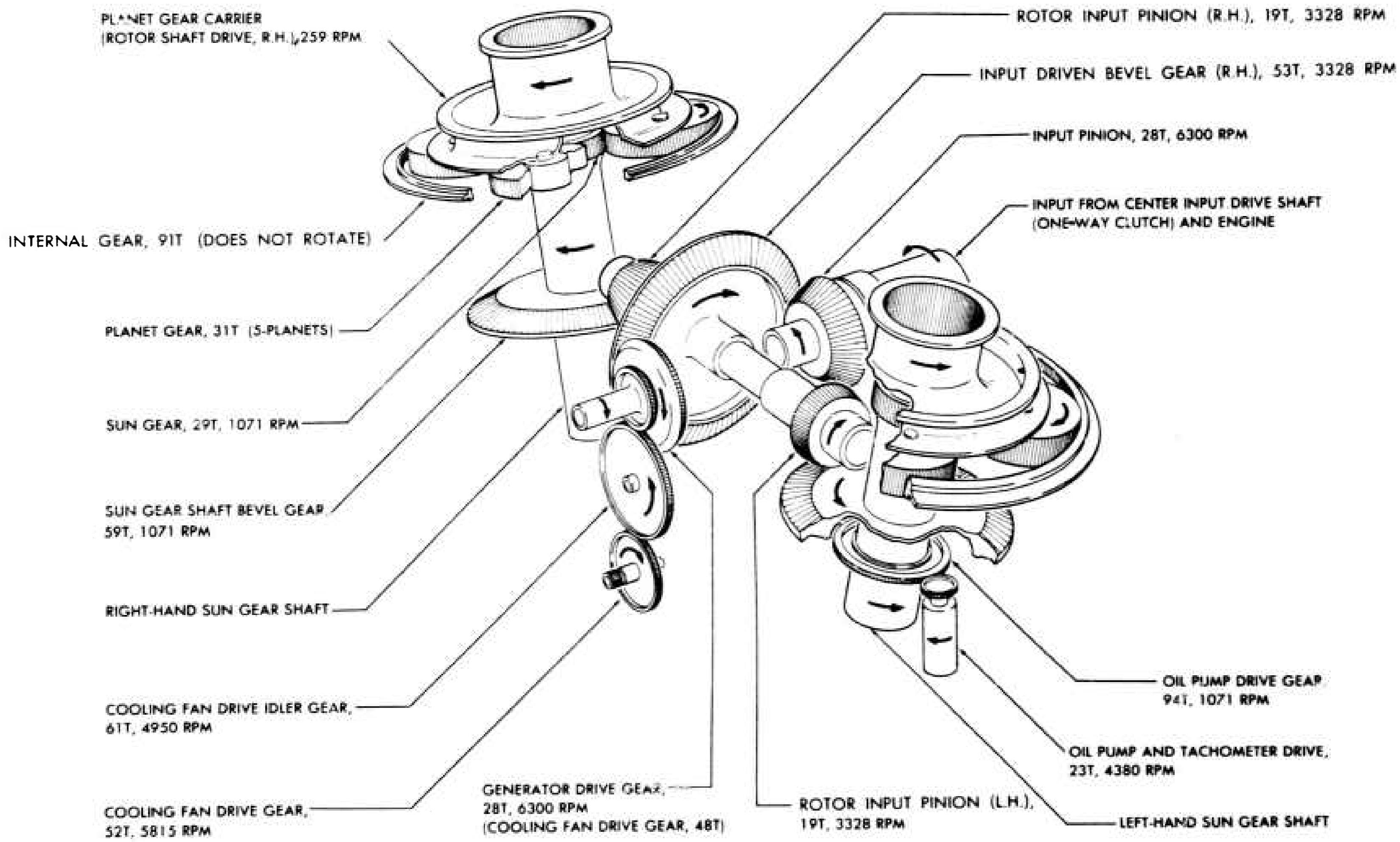
DRIVE SYSTEM SILENCING

The HH-43B drive system is shown in Figure 16. Sources of drive system noise are:

- Gear clash.

- Auxiliary components.

- Miscellaneous mechanical components such as bearings, rotating shafts, and couplings.



NOTES:
1. T = TEETH
2. R.H. and L.H. GEAR TRAIN ARE IDENTICAL EXCEPT AS NOTED

Figure 16. Drive System Schematic.

The gear noise contribution to the HH-43B noise signature is a set of discrete tones with frequencies equal to the gear tooth pass rates and their harmonics. Amplitudes of these tones are not predictable; however, factors affecting the magnitude of gear noise have been identified and include the following:

(1) Magnitude of excitation, affected by such factors as tooth pitch, contact ratio, tooth profile, profile accuracy, and tooth impulse phasing.

(2) Transmission of excitation to the gearbox housing, including the effects of gear, gear shaft and bearing transmission properties.

(3) Gearbox housing properties, resonance characteristics and transmissibility.

(4) Gearbox housing/fuselage structure interface characteristics.

(5) Fuselage structure characteristics, with respect to transmission and radiation of vibration and sound.

Drive system modifications affecting the first three factors listed above were incorporated and evaluated.

Sources of miscellaneous drive system mechanical noise are:

- Shaft imbalance, or eccentricity, causing noise radiation at frequency equal to shaft rotation rate.

- Rolling elements (bearings), causing "white" noise radiation.

- Rolling element (bearing) irregularities, causing discrete frequency noise generation.

Drive system mechanically produced noise was minimized through careful inspection of components to assure acceptable balance and condition. Also, many of the modifications to reduce gear noise are effective in reducing miscellaneous mechanical noise.

Auxiliary components of interest were the oil cooler blower, with its drive gears, and the main generator, also with drive gears. Noise sources of the oil cooler blower/drive gearing are:

- Blower/fan rotational and vortex noise.
- Gear noise.
- Shaft rotation, bearings, and other miscellaneous mechanical components.

Noise sources of the electrical generator/drive gearing include:

- Rotor rotation.
- Gear noise.
- Shaft rotation, bearings and other miscellaneous mechanical components.

To evaluate the effects of auxiliary component noise control, the above components were removed.

<u>Internal Modifications and Auxiliary Components Removal</u>

(U)Configuration 5 modifications consisted of internal transmission changes as well as the removal of nonessential auxiliary components. The modifications were:

- Installation of a transmission using the following:

  (1) A selected gear set exhibiting good wear patterns and minimum tolerances.

  (2) Plating of gear teeth with lead indium to improve interface surface finishes.

  (3) MIL-L-6086 high viscosity oil.

  (4) One quarter pitch misphasing of left- and right-hand rotor drive gears (see Figure 16).

  (5) Elastomeric isolation of the planetary ring gears.

- Removal of the following auxiliary components:

  (1) Transmission oil cooler blower and blower drive gearing.

  (2) Main electrical generator and its drive gearing.

- Addition of external soundproofing to the lower portion of the transmission housing. This treatment consisted of lead impregnated vinyl (.87 lb/ft^2) and "AA" fiberglass blanket in a fiberglass-lead-fiberglass-lead sandwich construction.

Data taken during testing of configuration 5 is shown in Figure 17. Little change in noise signature is apparent.

Hover data was analyzed for changes in level of discrete tones. This analysis indicated a substantial decrease in the level of tones due to the input driven bevel gear/input pinion clash, and the planetary system clash. An example of the narrow band analyzed data used is shown in Figure 18.

On a subjective basis, the configuration 5 aircraft was less detectable acoustically than those tested previously. This subjective reaction was substantiated by narrow band analysis of steady-state hover data, which showed reduction in discrete tones.

Conclusions are:

- The pure tones produced by the HH-43B drive system do not contribute to the sound pressure level of any octave band.
- These discrete tones do add to the subjectively determined acoustic detectability of the aircraft.
- The modifications made were effective in reducing the subjectively evaluated detectability.

External Soundproofing

The objective of the external soundproofing treatment was to eliminate airborne radiation of sound from the drive system. An acoustic barrier was installed enclosing the drive system. This treatment consisted of .87 lb/ft^2 lead impregnated vinyl and "AA" fiberglass in a fiberglass-lead-fiberglass-lead sandwich construction.

Installation was made in three steps. Prior to configuration 5 testing, blanketing was installed over the lower portion of the transmission providing approximately 30 percent drive system coverage. Prior to configuration 6 testing, additional blanketing was installed over the upper portions of the transmission and shaft housings, raising drive system coverage to approximately 80 percent. The remainder of the soundproofing was installed prior to the configuration 7 testing.

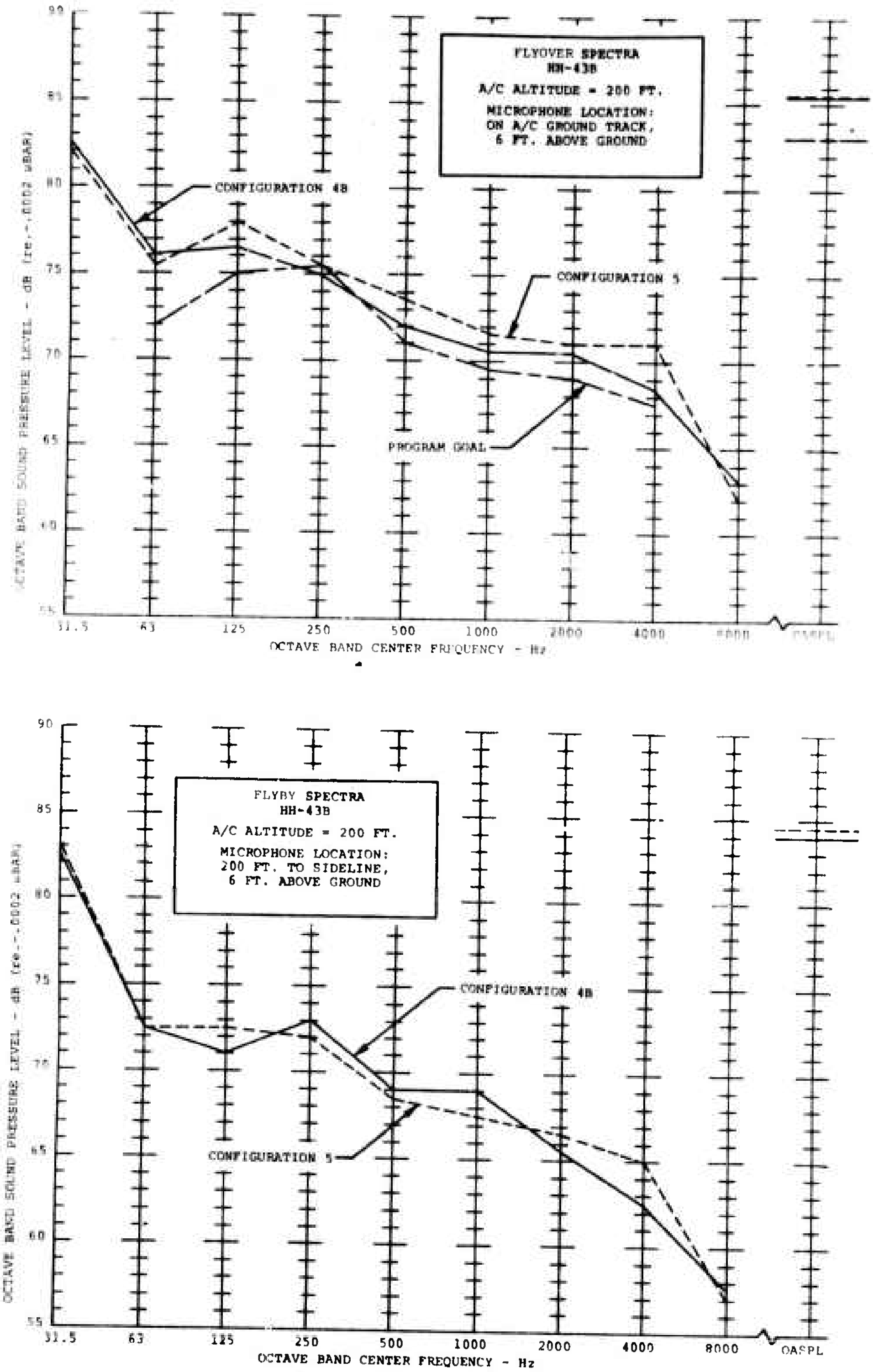
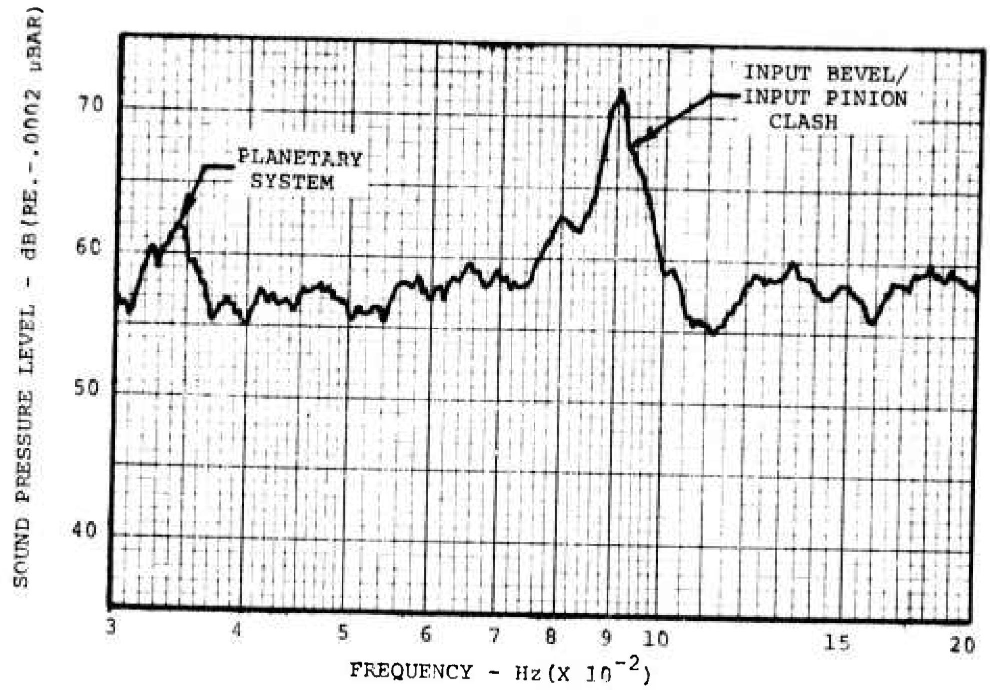
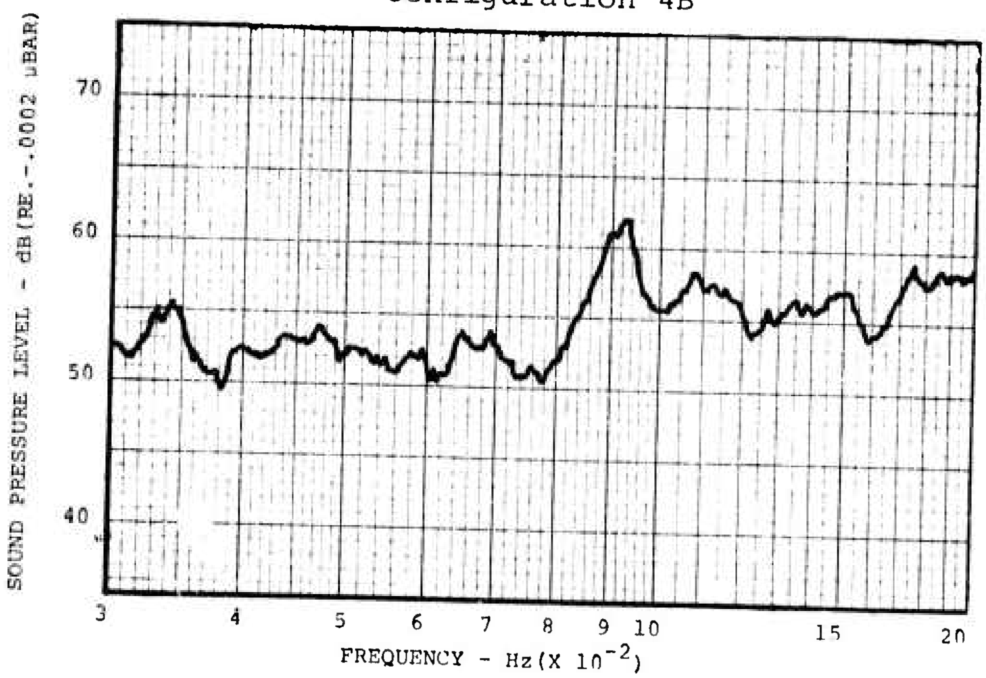


Figure 17. Configuration 4B Vs Configuration 5.



A. Configuration 4B



B. Configuration 5

Figure 18. Drive System Discrete Tone Level Reduction.

Configuration 7 modifications were:

- Installation of soundproofing treatment surrounding the transmission compartment.

- Replacement of the aft cabin clamshell doors with an acoustical barrier, shown in Figure 19, consisting of two layers of .87 lb/ft^2 lead impregnated vinyl.

Results are shown in Figure 20. Noise level increased moderately in the 31.5 Hz to 250 Hz octave bands, with no significant change in the higher frequency bands containing most of the drive system noise. These tests were conducted in higher ambient winds (10 kt) than the previous tests (less than 5 kt). Increased low altitude turbulence may have caused higher rotor noise.

Conclusion:

- Drive system external soundproofing treatment did not alter the total aircraft octave band sound pressure level spectrum.

ROTOR SYSTEM SILENCING

Baseline Testing - Unmodified Rotor System

Modifications incorporated for configuration 8 were:

- Installation of a bellmouth to the exhaust aspirator for drawing free stream air into the exhaust.

- Removal of the outboard vertical tails to reduce weight and control the aircraft cg.

Configuration 8 test data is shown in Figure 21. Measured differences are moderate reductions in the low to middle frequency (31.5 Hz to 1000 Hz) bands.

Configuration 8 tests were performed in calm wind conditions. The low frequency noise levels returned to those of configuration 6, also flown in low wind velocities, confirming that the higher levels measured during the configuration 7 testing were indeed the result of windier conditions. The absence of any significant effect of configuration 8 above 250 Hz suggest no change in engine or exhaust system performance due to the bellmouth.

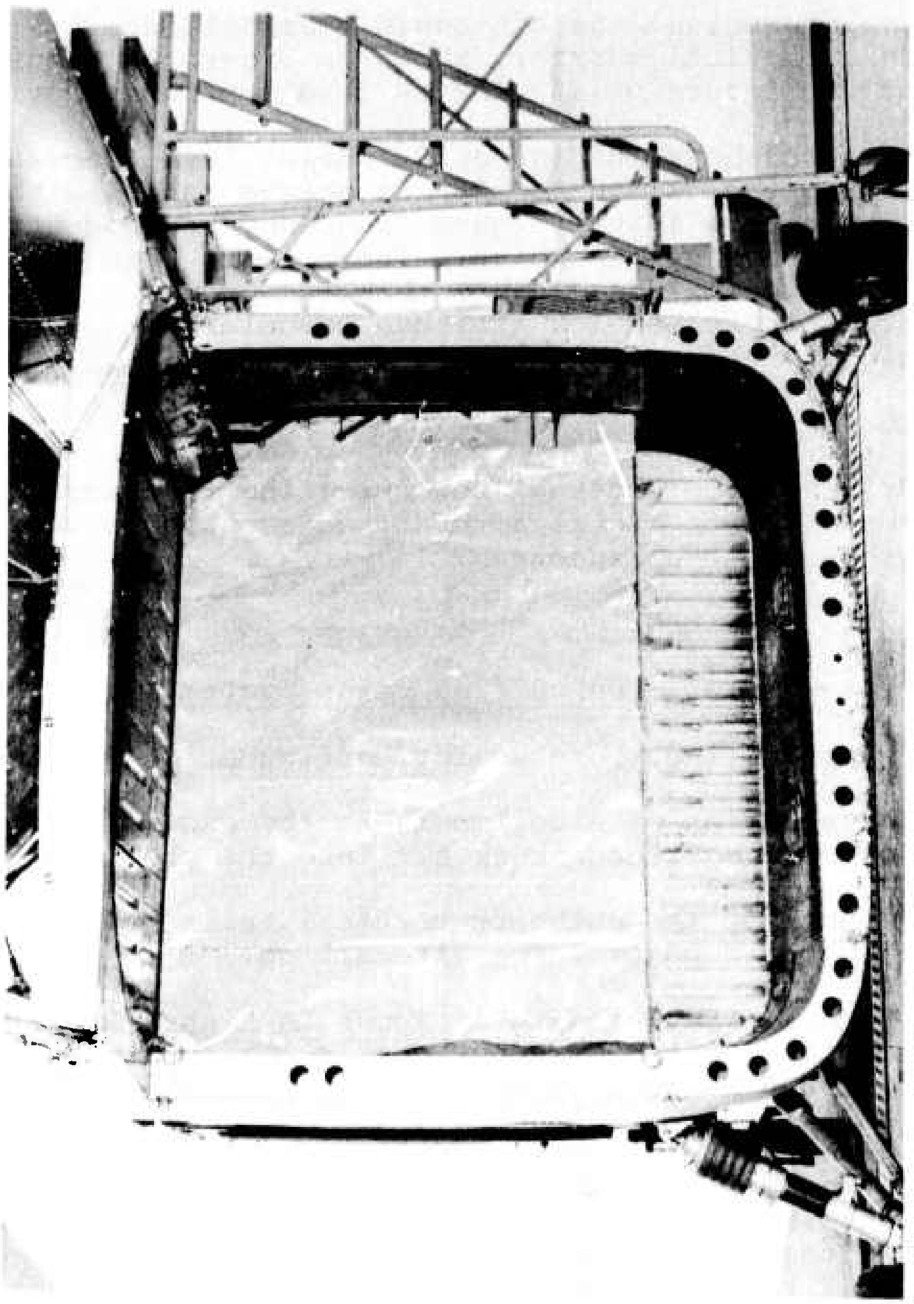


Figure 19. Aft Cabin Acoustical Barrier.

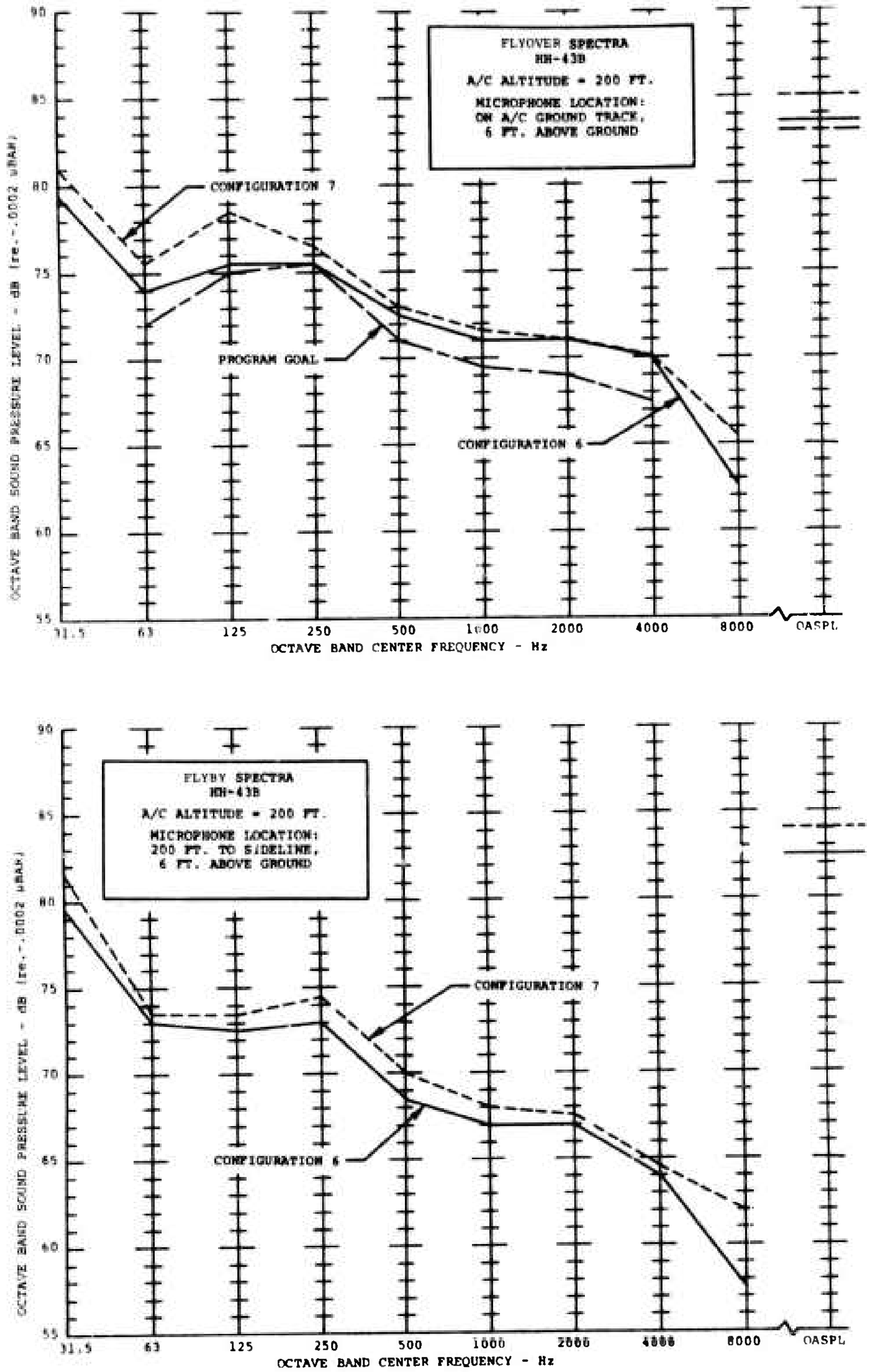


Figure 20. Configuration 6 Vs Configuration 7.

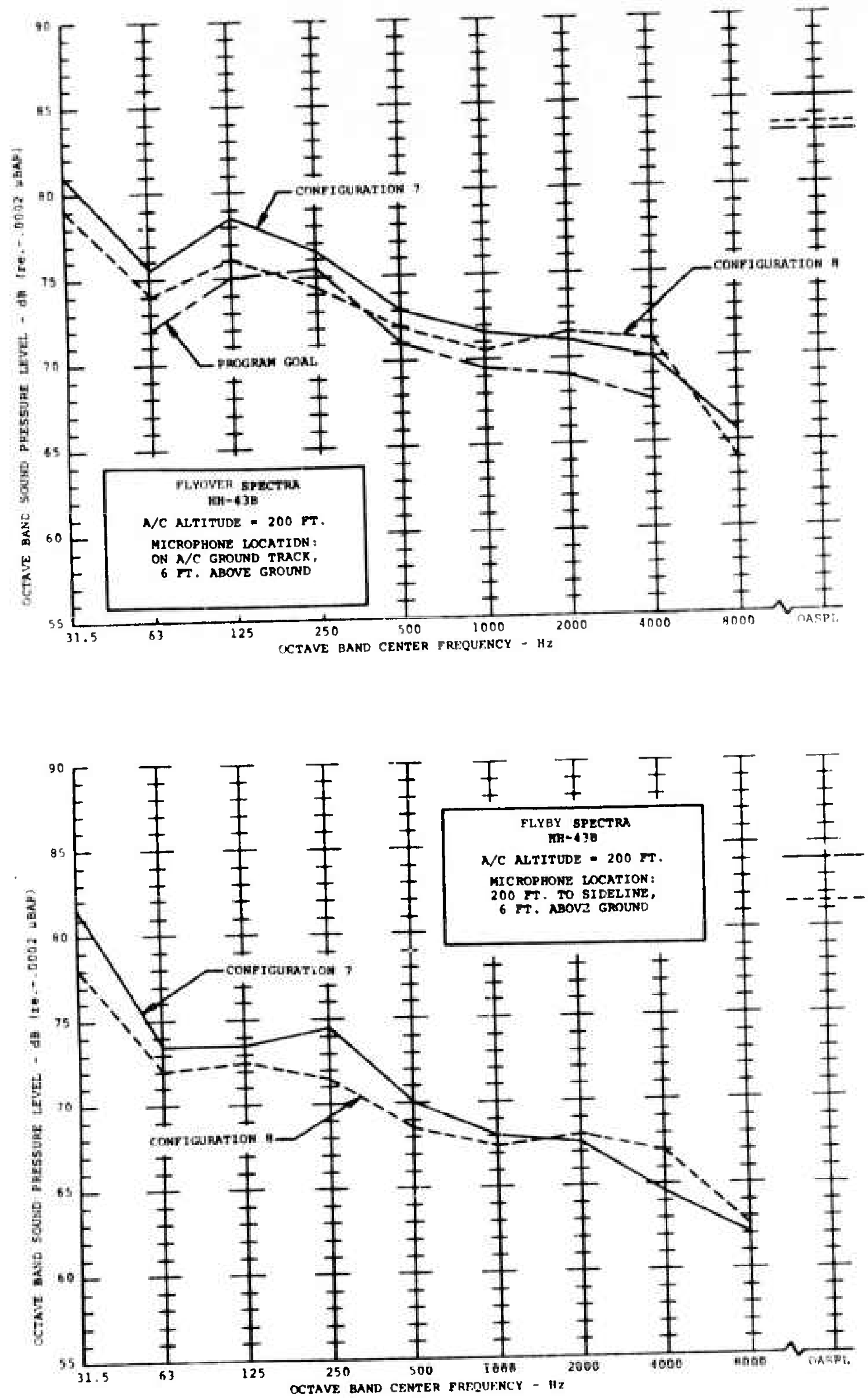


Figure 21. Configuration 7 Vs Configuration 8.

Conclusions:

- Use of a bellmouth for drawing free stream air into the exhaust duct produces no change in HH-43B flyover noise.

- Removal of the outboard vertical tails from the HH-43B produces no change in flyover noise.

- To assure the maximum degree of accuracy in recorded acoustic data, it is necessary to maintain the ambient wind velocity at substantially less than 10 knots.

Modified Rotor Testing

The noise spectrum of the HH-43B rotor system is characterized by both discrete tones and broadband noise. The pure tone contribution, or rotational noise, extends over the range of frequencies from below 20 Hz to approximately 100 Hz, and dominates the overall noise level. The broadband, or vortex, noise contribution covers the entire audible frequency range, dominating the spectrum above 100 Hz. The rotor system modifications were designed to reduce both the rotational and vortex noise.

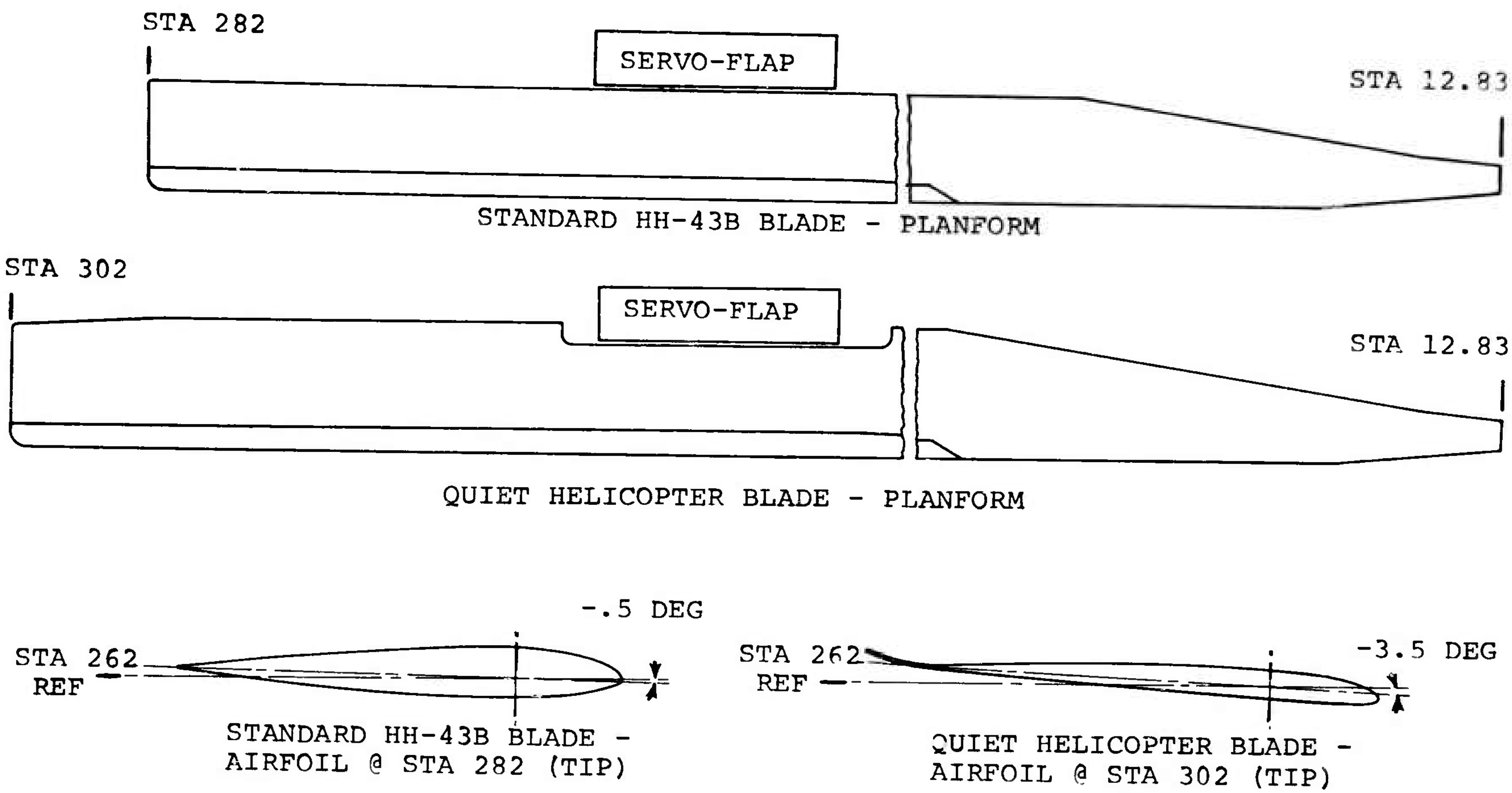
Rotor system evaluation was in two steps. The modified rotor system was first tested at a tip speed equal to that used in the previous (configuration 8) test to isolate the effects of changes exclusive of a change in tip speed. A test was then performed to assess the effect of tip speed reduction. Rotor speeds used for these two tests were, respectively, 205 rpm and 175 rpm.

Modifications for the configuration 9, 205 rpm test (reference Figure 22) were:

- Reduced rotor rpm from 220 rpm to 205 rpm, to maintain a constant tip speed relative to the baseline.

- Blade radius and chord increased to reduce rotational and vortex noise components through decrease in blade loading.

- Increased negative twist rate over outboard blade section, to reduce rotational and trailing vortex noise through reduced tip loading.



A. Planform and Tip Airfoil Shape Comparison.

Figure 22. Modified Vs Standard HH-43B Rotor System - Physical Characteristics.

Characteristic	Standard HH-43B	Quiet Helicopter HH-43B
Blade Radius	23.5 ft	25.17 ft
Blade Chord	15.69 in.	18.69 in.
Total Blade Area	122.8 ft^2	156.5 ft^2
Disk Area	1735 ft^2	1990 ft^2
Twist Rate	-.34 deg/ft-full span	-.34 deg/ft-inner 262 in. of span, -1.0 deg/ft-outer 40 in. of span
Torsional Stiffness	290 in.-lb/deg	210 in.-lb/deg
Tip Planform	Standard rectangular	Moderately relieved over outboard 20 in. of trailing edge*
Airfoil Type	22010 full span	Taper from 22010 to modified 0006 over outboard 40 in. of span, slight reflex T.E. and drooped L.E. over outboard 40 in. of span*

*As shown in Figure above

B. Rotor System Parameter Comparison

Figure 22. (Continued).

- Decreased blade torsional stiffness, to provide adequate controllability at reduced rotor rpm.

- Tip planform moderately relieved at trailing edge, to reduce strength of tip vortex.

- Tip airfoil modified as shown in Figure 22 to reduce rotational and vortex noise components through reduction in tip loading.

- Reduced gross weight from 5725 to 5239 to reduce blade loading.

- Reinstalled outboard vertical tails to improve directional stability.

Modification for the configuration 9, 175 rpm test was a reduction of rotor rpm from 205 rpm to 175 rpm, resulting in a 15-percent decrease in tip speed, from 543 fps to 462 fps.

Configuration 9, 205 rpm test data is presented in Figure 23. Changes in noise level include moderate increases in the low frequency bands (31.5 Hz to 125 Hz) with substantial decreases in the frequency bands above 125 Hz.

Configuration 9, 175 rpm test data is presented in Figure 24. The measured result of the tip speed reduction is a general decrease in noise level extending over the entire frequency range of interest.

The modifications in blade geometry, coupled with the decrease in thrust, rotate the noise spectrum curve, raising the sound pressure levels below 250 Hz and lowering the levels at and above this frequency. The modifications raised the rotor rotational noise component while lowering the vortex noise. A reduction in vortex noise level was expected because of the decreased blade loading and modified spanwise load distribution, which reduces the strength of the shed vorticity and the trailing tip vortices. The reason for the increase in rotational noise is not known.

Large changes in aircraft noise, extending over the entire audible frequency range, resulted from changes in blade geometry alone. The decrease in gross weight alone was not of sufficient magnitude to produce the changes.

An average 3.0-dB reduction in rotational noise (31.5 Hz to 125 Hz bands) and vortex noise (250 Hz to 8000 Hz bands) resulted from the 15-percent reduction in tip speeds. The magnitude of rotational noise reduction is half that predicted

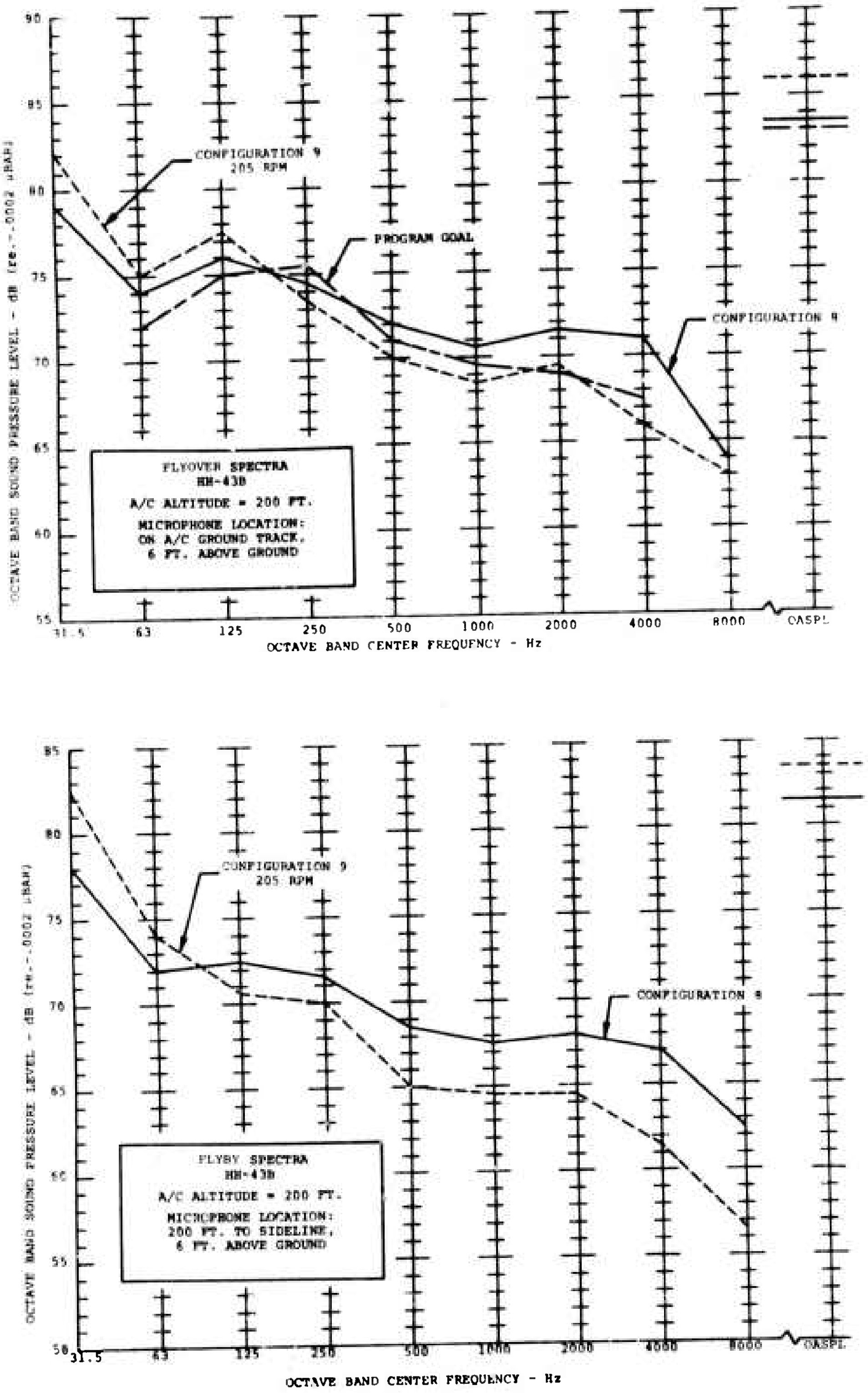
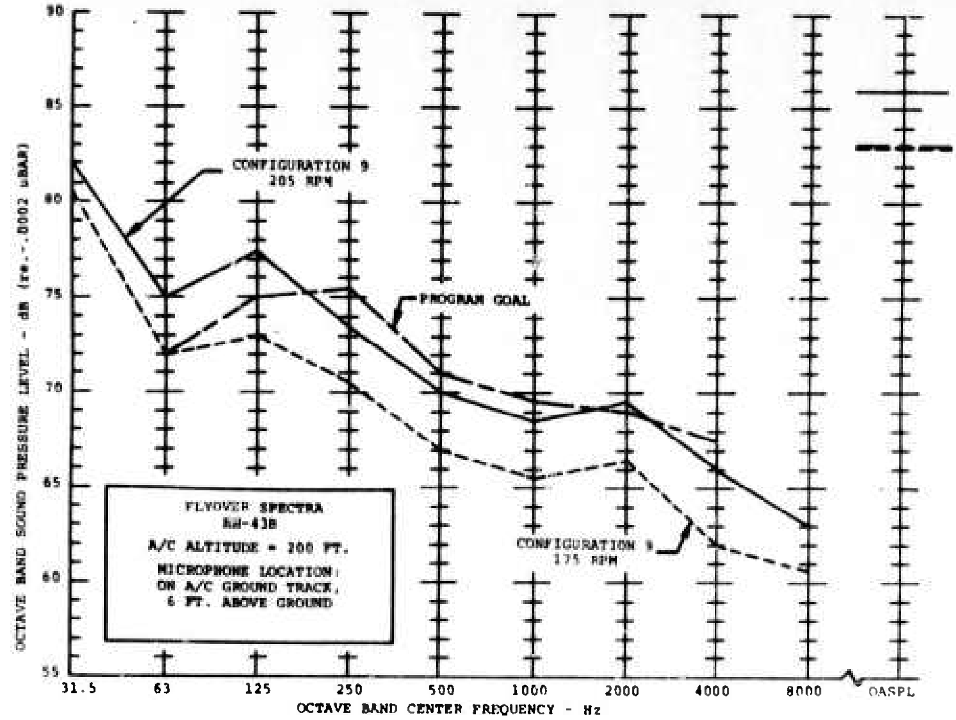


Figure 23. Configuration 8 Vs Configuration 9, 205 RPM.



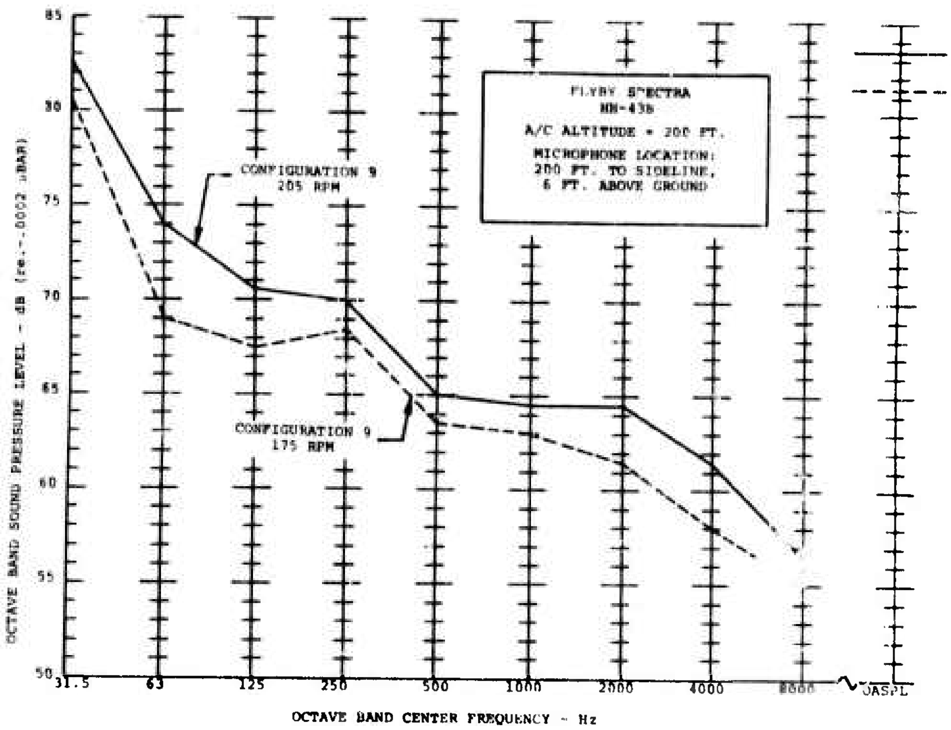


Figure 24. Configuration 9, 205 RPM,
Vs Configuration 9, 175 RPM.

using published trending data, such as that of Reference [3], while the reductions in vortex noise are twice those predicted.

Conclusions:

- Rotor blade geometry modifications reduced vortex noise but at the expense of increases in rotational noise.

- The 15-percent reduction in rotor blade tip speed reduced the octave band sound pressure levels from 31.5 Hz to 8000 Hz.

- The rotor system of the quiet helicopter configuration HH-43B is the dominant noise source throughout the audible frequency range.

CONCLUSIONS

The HH-43B Quiet Helicopter Program demonstrated that substantial noise reduction may be achieved using known noise control methods. The program goal of an additional 6-decibel (dB) reduction in the noise signature of a modified HH-43B helicopter was met. Actual reductions achieved are illustrated in Table IV.

SYSTEM MODIFICATIONS

Helicopter systems which were modified are:

- Engine
- Drive system
- Rotor system

Conclusions for the individual systems are:

- Engine system

(1) Vibration isolation of the engine and soundproofing of the engine compartment was not effective in reducing the helicopter noise signature.

(2) Internal noise may propagate to the external field in the absence of normal cabin wall attenuation.

(3) The modified engine inlet reduced engine inlet noise.

(4) The modified engine inlet changed the rotor/fuselage interference flow characteristics and resulted in a rotor noise reduction.

(5) The HH-43B engine exhaust is a significant source of noise.

(6) Engine exhaust noise was substantially reduced through modification of the exhaust duct.

(7) Directing the exhaust flow upward increased rotor noise through exhaust flow/rotor flow interference.

TABLE IV. NOISE REDUCTIONS, GOALS VS ACHIEVED

Octave Band Center Frequency - Hz	Noise Reduction* - dB	
	Goal	Achieved
O/A	6	6
31.5**	-	-
63	6	6
125	6	8
250	6	11
500	6	10
1000	6	10
2000	6	8.5
4000	6	11.5
8000**	-	-

*As measured 200 feet below the aircraft flight path during steady level flight.

**No goals established for these octave bands.

(8) Use of a bellmouth to increase the flow of free stream air into the exhaust duct did not change the helicopter noise signature.

- Drive System

  (1) Discrete tones due to the HH-43B drive system do not add significantly to the octave band sound pressure levels of the total aircraft; however, these tones do contribute to the subjectively evaluated detectability.

  (2) Drive system internal modifications were effective in reducing the discrete tone levels.

  (3) Drive system external soundproofing was not effective in reducing the helicopter noise signature.

- Rotor System

  (1) The rotor blade geometry changes produced a reduction in rotor vortex noise but an increase in rotational noise.

  (2) The 15-percent reduction in tip speed reduced the helicopter noise signature throughout the entire audible spectrum.

  (3) The rotor system of the HH-43B quiet helicopter is the dominant helicopter noise source over the audible frequency range.

GENERAL

- The dominant noise source of the standard HH-43B above 125 Hz is the engine system. Substantial reduction of this noise source is effected through inlet and exhaust silencing.

- Rotor rotational noise is strongly influenced by external disturbances of the rotor inflow; major changes in rotational noise resulted from changing the fuselage flow characteristics, through inlet silencer installation, and disturbance of the rotor flow field, produced by redirection of the engine exhaust.

- The dominant noise source of the standard HH-43B below 125 Hz is the rotor system; in the quiet helicopter configuration, dominance of rotor noise extends over the audible frequency range.

RECOMMENDATIONS

The quiet helicopter rotor system incorporated numerous changes in blade geometry, each designed to reduce rotor noise. The result of these modifications was a reduction in vortex noise, with an increase in rotational noise. It is recommended that a whirl stand test program be conducted to determine the effect on rotor noise of each individual blade geometry modification. This program would have the following objectives:

(1) Identification of useful geometry changes and quantification of reductions in rotational and vortex noise resulting from each.

(2) Determination of the effects of combining individual useful changes.

(3) Definition of the optimum blade geometry for low noise signature requirements.

The result of this test program would be a reduction in rotor rotational noise, and a probable reduction in vortex noise, resulting in a reduction in the quiet helicopter noise spectrum.

Previous helicopter noise studies have considered the rotor to be independent of other aircraft components. Changes in rotor noise resulting from nonrotor component modifications have not been considered significant. The present test program has proven that this assumption is not valid, as evidenced by the effects of inlet installation and exhaust redirection on rotor noise. It is recommended that a study be conducted to:

(1) Quantify the extent to which rotor noise generation is affected by disturbance of the flow field.

(2) Investigate the extent to which principles developed in (1) above may be applied to reduce the rotor noise of existing helicopters.

The goals would be accomplished through a combined test and study program involving three steps:

(1) Experimental determination, utilizing the full-scale whirl stand, of the rotor noise changes resulting from flow disturbance.

(2) Study of existing data, primarily from smoke and tuft studies, to identify instances of rotor flow interference on existing helicopters.

(3) Recommendation of modifications designed to eliminate or minimize flow interference.

The modified engine inlet and exhaust used in the present program were effective. For practical applications, however, usefulness is limited by size and weight restrictions. It is recommended that a study program be conducted to optimize the silencer construction, taking into consideration minimum weight, minimum size, maximum reliability, and maximum acoustic effectiveness. These considerations would be incorporated in a flexible design having application to all existing Military helicopters. In addition, detail designs for particular installations would be generated, and an assessment of the effectiveness of each made.

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4. Society of Automotive Engineers, DETERMINATION OF MINIMUM DISTANCE FROM GROUND OBSERVER TO AIRCRAFT FOR ACOUSTIC TESTS, Society of Automotive Engineers, Inc., AIR 902, Society of Automotive Engineers, Inc., New York, New York, May 1966.

APPENDIX I
ENGINEERING TEST PLAN

TEST PROGRAM DESCRIPTION

INTRODUCTION

The noise-reduction program proposed involved substantial changes in each of the major noise-producing sources. The test sequence was planned to isolate the individual acoustic effect of each one of the major modifications, insofar as practical in an economic program. Flight testing for each modification involved both qualification and noise testing. Qualification testing was carried out only to the extent necessary to qualify the modification for the number of flight hours required to complete the tests.

REQUIRED TEST LISTING

A. Standard aircraft at 200 rotor rpm.

B. Engine isolation and external soundproofing.

C. Engine inlet.

D. Tailpipe (modified).

E. Transmission internal and lower external soundproofing.

F. Transmission external coating.

G. Modified rotor blades.

TEST METHODS

Qualification Testing

1. Standard aircraft at 220 rpm - No qualification tests were necessary for this configuration. Vibration data was taken to provide base reference data for the following tests.

2. Engine isolation and external soundproofing - Testing consisted of a functional test flight to check for adequate cooling, during which vibration measurements were made at selected locations in the engine area and compared to measurements taken in the same area prior to modification.

3. Engine inlet - Only functional test flight was required. The engine has operated satisfactorily in the past during Air Force icing tests with a more restricted inlet.

4. Tailpipe - Vibration measurements were taken in the elevator area before and after modification. The aircraft was ground and flight tested with balsa sticks mounted on the tailpipe to check for rotor clearance.

5. Transmission internal changes - The transmission was "green run" following assembly and then disassembled to inspect the condition of the new parts. Following assembly, a second phase green run was conducted. No specific tests were required after installation into the aircraft other than functional tests.

6. Transmission external coating - The only test required for the external coating was a functional flight test where transmission oil temperature was monitored.

7. Modified rotor blades -

   - Rig tests - The standard and modified rotor blades were subjected to stability tests on the rotor whirl rig. In addition, the modified rotor blades were subjected to a whirl test with a specified thrust loading imposed.

   - Aircraft tests - Initially, a complete set of hangar rotor clearance measurements was taken to avoid all possible interference problems. A series of ground run-up tests was conducted to ensure freedom from mechanical instability and to determine the need for any change to standard run-up and shutdown procedures. Flight testing was conducted through a specified envelope of airspeeds and rotor speeds to ensure adequate control margins for the required test flight envelope. Strain and vibratory measurements were taken during the rotor tests.

Acoustic Testing

The acoustic testing consisted of external measurements of helicopter level flight and hover noise. The instrumentation used is documented in the Instrumentation section of this appendix. The procedures which were used during testing are described in the following sections.

TEST PERSONNEL

Referring to the microphone positions illustrated in Figure 25, the location and function of personnel involved in the flyby testing are described in the following paragraphs. The total number of personnel required for this phase of testing was five. This figure included the aircraft pilot and four ground test personnel.

Microphone station 1, located on the aircraft's projected flight path, was manned by a microphone operator. Responsibilities included:

(1) Monitoring the sound level meter (SLM) at this station and calibrating the data channel (method of calibration described in the Instrumentation section of this appendix).

(2) Determining the aircraft altitude for each run. The method of altitude determination is described in Reference 4.

Microphone station 2 was manned by a second microphone operator. Responsibilities were:

(1) Monitoring the SLM at station 2 and calibrating the data channel.

(2) Marking the overhead position of the aircraft on the data tape with a tone (the method is described in the Aircraft Position Determination section of this appendix).

The test coordinator was located in a central control building. The functions of the test coordinator, in addition to general monitoring of the testing, were:

(1) Operating the tape recorder and maintaining the data log.

(2) Maintaining voice communication with aircraft and tower.

The remaining man was located on the aircraft projected flight path, a distance of 1000 feet from microphone station 1. The function of this man was to mark the overhead position of the helicopter at the 1000-foot point by putting a tone on two tape recorders.

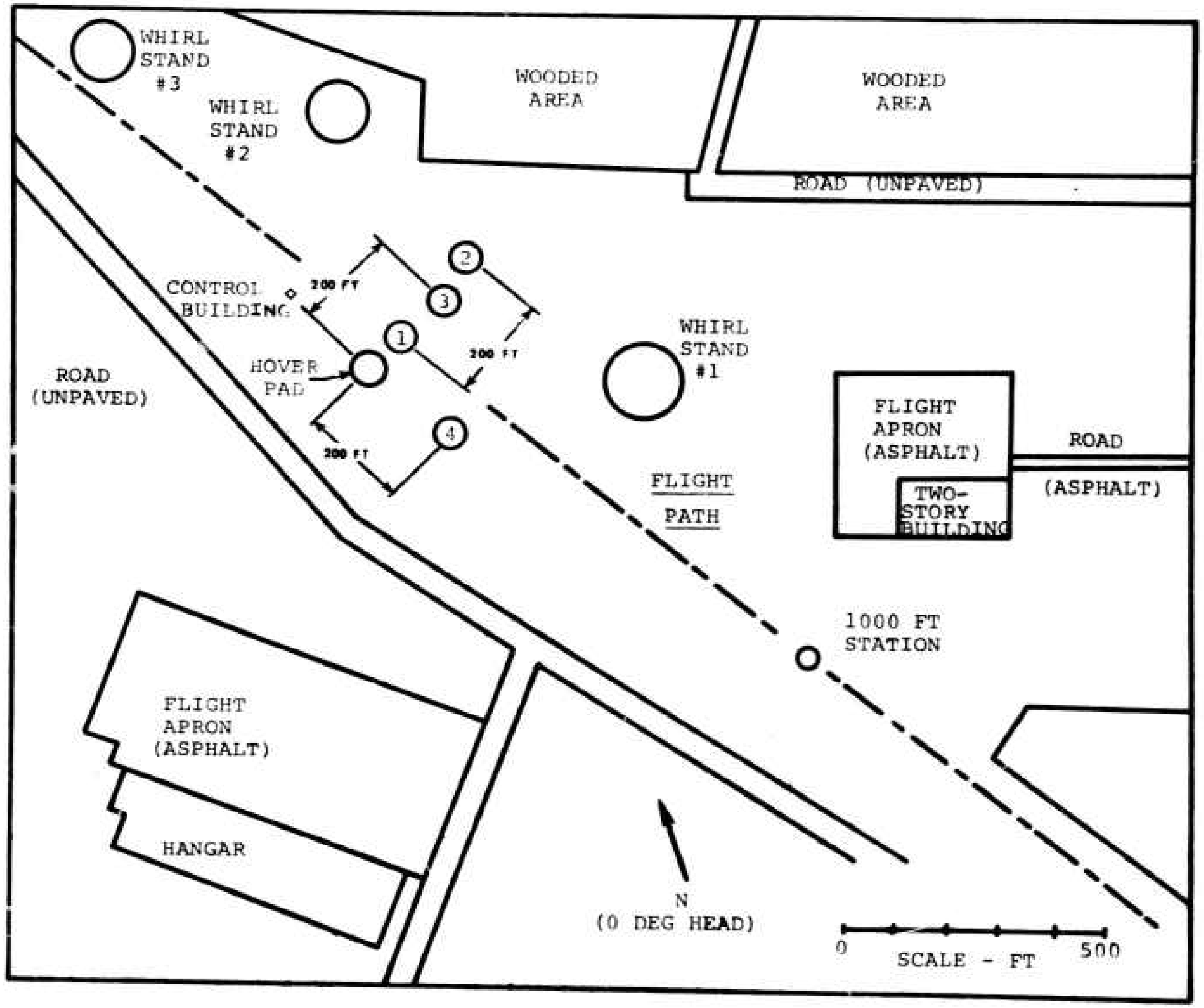


Figure 25. Acoustics Test Site Map.

Microphone stations 3 and 4 were utilized during the hover noise measurement phase of testing. The number of test personnel used was four. Responsibilities were the same except that it was not necessary to mark the helicopter overhead position, so the 1000-foot station was not manned.

TEST PROCEDURE

Level Flight Test

Measurements of level flight noise were taken for each configuration at 60 knots airspeed and at 200 feet altitude over a fixed course. For a given modification, five flights (each flight conducted in both directions) were flown over the course. One microphone position was directly under the flight path and the other was 200 feet laterally offset from the first.

A block diagram of the acoustic test equipment arrangement is shown in Figure 26. The microphone locations correspond to those of Figure 25. The procedure followed during this phase of testing was:

(1) The two data channels were calibrated, ambient conditions were noted in the master data log, and an ambient noise recording was made.

(2) The aircraft made one pass through the course, at the test speed and altitude, and the sound level meter attenuators were set. The attenuators were adjusted in such a manner that the peak noise level produced a dial indication of less than +8 dB, using a FAST meter speed (low damping). Also during this pass, the aircraft altitude was measured using the method described in Reference 4.

(3) The aircraft made its first data run (a combination of two passes in opposite directions) in the following manner:

   (a) The test altitude and airspeed were respectively 200 feet and 60 knots.

   (b) The aircraft stabilized its altitude, attitude, heading, and velocity before entering the 2000-foot course.

   (c) Upon entering the course, the pilot maintained a constant velocity and altitude until the course had been completed.

STATION LOCATIONS

1. MICROPHONE STATION 1 ....LOCATED ON FLIGHT PATH

2. MICROPHONE STATION 2 ....200 FT LATERALLY OFFSET FROM STATION 1

3. 1000-FOOT POSITION STATION......1000 FT AWAY FROM MICROPHONE STA. 1 ON FLIGHT PATH

4. TEST COORDINATOR STATION........CENTER FOR ALL RECORDING AND COMMUNICATION EQUIPMENT

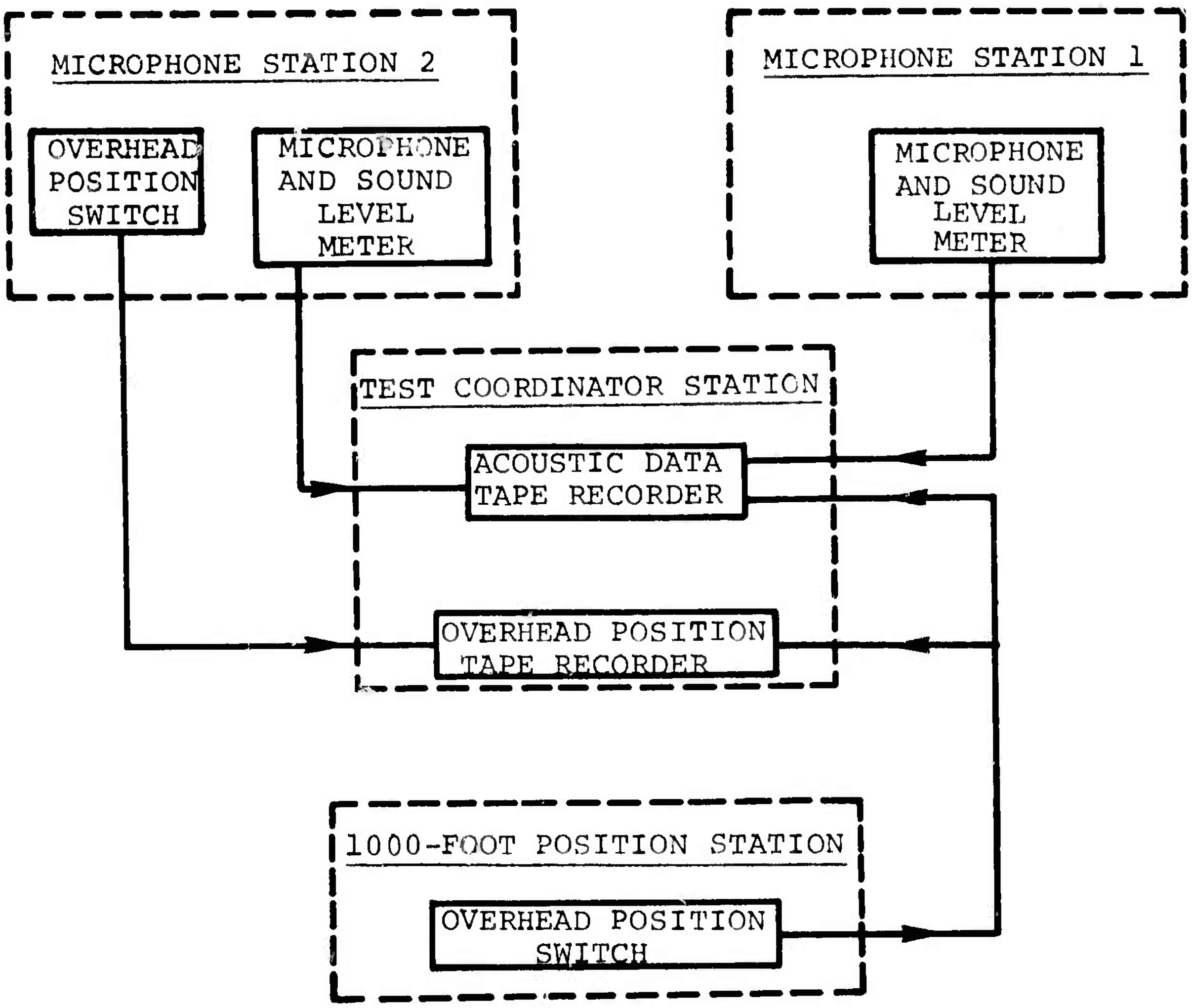


Figure 26. Test Equipment Block Diagram - Level Flight Test.

(4) During the data run, acoustic data was taken for each pass in the following manner:

(a) Prior to initiation of the first pass, a notation was made in the data log, and recorded on tape, defining the test conditions and the identifying number and letter of the test pass.

(b) Recording commenced before the course was entered, and was terminated after the course had been completed.

(c) During each pass of the test run, the true altitude was measured and the helicopter overhead position was noted on the position tape recorder.

(5) Steps (3) and (4) of this procedure were repeated until a total of (5) data runs had been completed.

(6) Step (1) (calibration and ambient notation) was repeated at the end of the level flight test.

<u>Hover Tests</u>

The hover tests required moving the microphones to stations 3 and 4 as shown on Figure 25. The procedure used in this phase of testing was:

(1) Calibration signals were applied to both microphone systems and the ambient conditions were noted; ambient noise level recordings were made.

(2) The aircraft stabilized in hover at a 10-foot altitude in the azimuth position shown in Figure 27A.

(3) Acoustic data was taken as follows:

(a) The sound level attenuator settings were adjusted so that the dial indication at each station was less than +8 dB, using a FAST meter speed (low damping).

(b) Flight condition and attenuator settings were recorded and noted in the data log.

(c) The recorder was started and a recording of at least 30 seconds duration made.

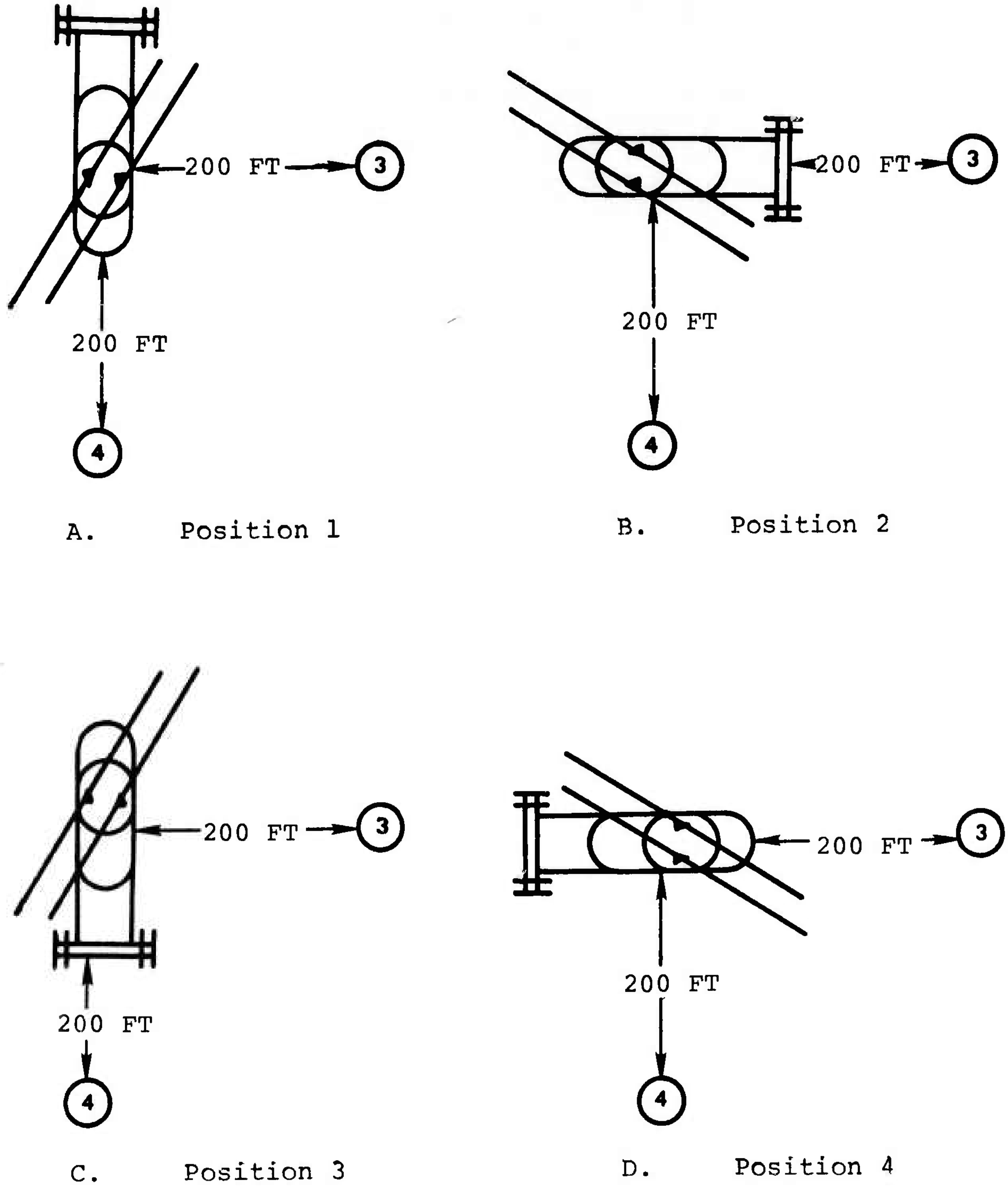


Figure 27. Aircraft Hover Azimuth Sweep.

(4) Steps (2) and (3) above were repeated for each azimuth position of Figure 27.

(5) Step (1) was repeated.

Test Conditions

Acoustic tests were not conducted in wind velocities exceeding 10 knots, and for the final rotor test series, the wind was required to be less than 7 knots. Overall sound pressure level for ambient noise was required to be at least 10 dB less than the sound being measured. Testing did not commence on any day where the above conditions were not met. In addition, if the wind or ambient noise limitations were exceeded during testing, the test was terminated until such time that the required conditions were met.

Vibration Measurements

Vibration data was taken for the tests specified in the Qualification Testing section of this appendix. The installed vibration sensors were located as noted in Table V.

ACOUSTIC DATA ANALYSIS

Level Flight Data

The analysis procedure as described herein was applied to the evaluation of the sound pressure level of the helicopter overall noise and to the octave bands with center frequencies at 31.5, 63, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz.

Sound pressure level time histories were generated using a graphic level recorder operated at paper speed, and a writing speed that did not distort the signal trace, thereby providing the smoothest possible recorded signal.

The sound pressure level with the helicopter overhead at 200 feet was determined from the resulting curves. This procedure was followed for all flyover event measurements to yield ten values of sound pressure level for the helicopter overall noise, and for each of the octave bands mentioned above. The ten readings were obtained to the nearest whole dB.

TABLE V. VIBRATION SENSOR LOCATIONS		
No.	Location of Sensor	Measurement Direction
1	Engine-fwd frame - right side	Lateral
2	Engine-structure - right side (fwd)	Vertical
3	Engine-structure - right side (fwd)	Lateral
4	Engine-structure - right side (aft)	Vertical
	Transmission aft-right pad structure	Lateral
	Transmission aft-right pad structure	Fore & Aft
	Transmission aft-strut right structure	Vertical
8	Transmission fwd-strut right structure	Vertical
9	Shear tie-right side	Lateral
10	Pilot seat	Vertical
11	Pilot seat	Lateral
12	Pilot seat	Fore & Aft

Hover Data

The hover data was analyzed on an "as-required" basis to determine changes in pure tone components. Where required, a 1/10 octave constant percentage bandwidth analysis was performed.

VIBRATION DATA ANALYSIS

Vibration data analysis was conducted on an "as-required" basis. If the modification in question was obviously working well, then only rough comparison analysis was conducted. As a minimum, the following checks were made:

(1) Engine isolation - Initial tests were conducted to determine the engine vibration at standard engine test frequencies. The data was reduced to engine displacement in mils. A comparison was made of the test data and the normal allowable vibration limits for the engine.

(2) Miscellaneous checks - Vibration data was compared to the standard helicopter in several areas to assess the effect of the modifications on control vibration, skin vibration, and tailpipe vibration.

INSTRUMENTATION

ACOUSTIC TEST APPARATUS

The test apparatus used during the acoustic evaluation of aircraft modifications are listed and described in Table VI. A block diagram of this instrumentation is shown in Figure 28.

In order to insure the accuracy of the test results, it was imperative that the data acquisition and reduction systems be maintained in calibration. For this reason, the calibrations described below were applied to the system periodically during the course of testing.

Tape Recorder Frequency Response Calibration

Proper operation of the tape recorder was fundamental to the proper operation of both the data acquisition and reduction systems. For this reason, a frequency response calibration of the tape recorder was performed on each day of testing, and for each period of data reduction system use. This calibration is described below:

(1) The General Radio Beat-Frequency Audio Generator (Model No. 1304-B) was mechanically connected to the General Radio Graphic Level Recorder (Model No. 1521-B). This arrangement provides synchronization between the rate of frequency sweep of the generator and the output of the level recorder (chart speed).

(2) The output of the generator, a constant voltage source, was fed into the tape recorder. The output from the tape recorder was fed into the graphic level recorder, as shown in Figure 28.

(3) The generator output was swept through the frequency range 20 Hz to 20 kHz, at a constant signal level, and the output of the tape recorder plotted by the graphic level recorder. A tape recorder frequency response curve was provided from which corrections to data were made, if necessary.

TABLE VI. ACOUSTIC TEST APPARATUS

Equipment	Manufacturer	Model No.	Qty	Characteristics		
				Range	Accuracy	Location*
Sound Level Meter	Bruel & Kjaer	2203	2	20 Hz-25 kHz	±1dB	1,2,3,4
Microphone	Bruel & Kjaer	4133	2	20 Hz-30 kHz	±1dB	1,2,3,4
Pistonphone Calibrator	Bruel & Kjaer	4220	1	124dB	±.2dB	1,2,3,4
Sound and Vibration Analyzer	General Radio	1564-A	1	2.5 Hz-25 kHz	±1.5dB	N.A.
Graphic Level Recorder	General Radio	1521-B	1	20 Hz-20 kHz	±2dB	N.A.
Tape Recorder	Revox	A77-1224	1	20 Hz-20 kHz	+1/2/-2dB**	1,2,3,4
Beat-Frequency Audio Generator	General Radio	1304-B	1	20 Hz-40 kHz	±(1%+.5Hz)	N.A.

*Refer to Figure 1

**At 7.5 IPS tape speed

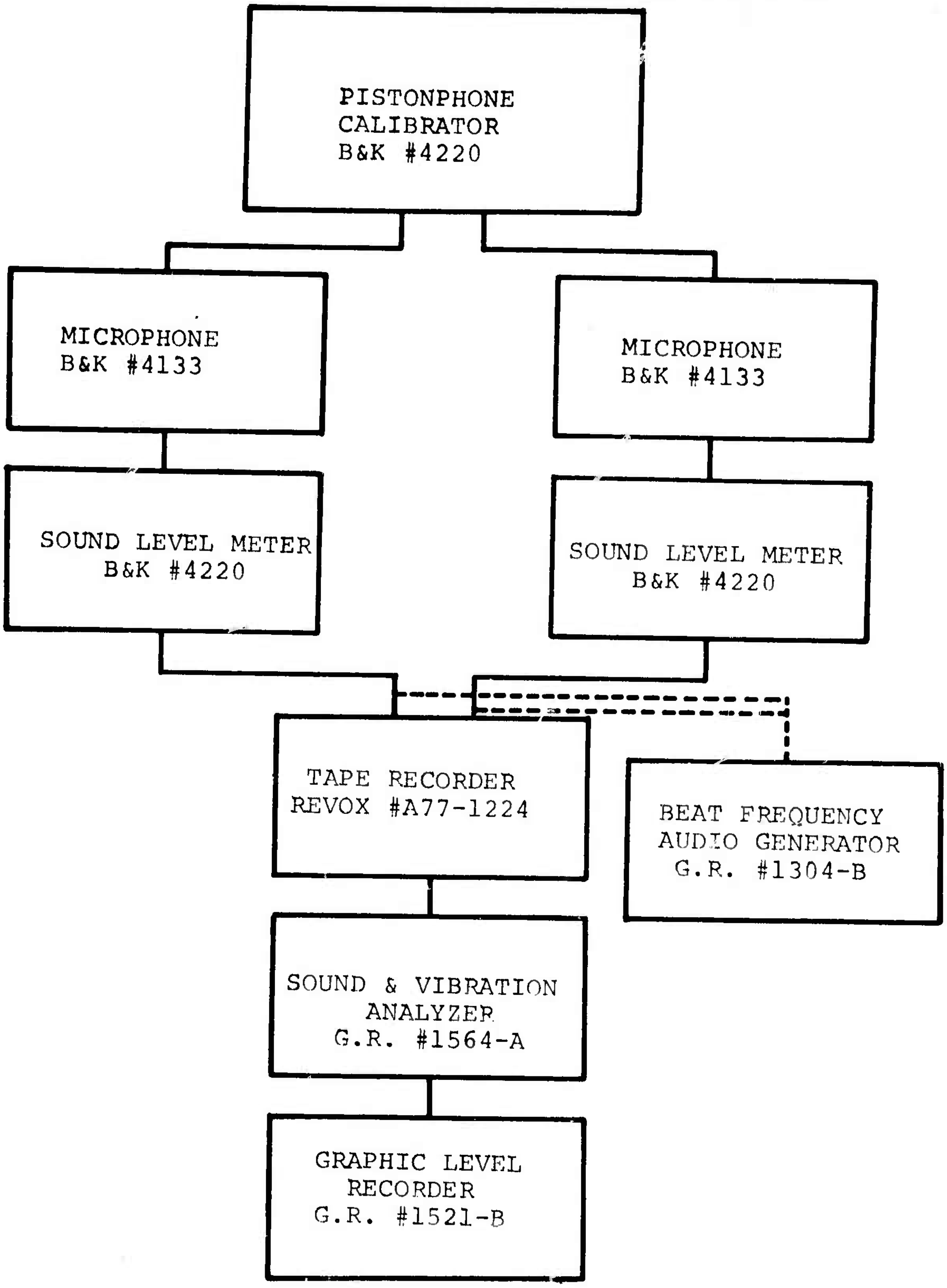


Figure 28. Acoustic Test Instrumentation.

System Reference Level Calibration

In addition to calibrating the data acquisition/reduction system for relative signal level vs frequency, it was necessary to calibrate the system to an absolute signal level. This calibration procedure is described as follows:

(1) As shown in Figure 28, an acoustic signal of known level and frequency was fed into the data acquisition system through the microphone using the Bruel and Kjaer Pistonphone Calibrator Model No. 4220.

(2) This signal was recorded, and the attenuator setting of the sound level meter was noted.

(3) This reference signal was used to set the level of the analyzer and graphic level recorder for use in data reduction.

The absolute calibration described above was applied to each individual tape at the beginning of the record and, where possible, at the end of the data record.

GENERAL AIRCRAFT INSTRUMENTATION

Vibration tests were conducted to assure the structural and control integrity of the helicopter. Instrumentation was provided to monitor vibrations in the area of the transmission and engine at predetermined locations. Accelerations induced by the rotor system were measured at the pilot seat where previous Air Force data had been accumulated. Rotor rpm was measured using a magnetic pickup (Blooper) to sense the rotor shaft position.

Higher frequency vibration measurements (engine and transmission frequencies) were taken utilizing MB type .124 velocity pickups having a nominal natural frequency of 4.75 Hz with .65 damping. These sensors have an acceptable frequency response to 2000 Hz.

The pickups were fed into CEC type 1-112B or 1-112C amplifiers used in either the linear or integrating mode as dictated by the particular test requirement. A recording oscillograph, CEC type 5-114, was utilized to obtain the raw data.

The accelerometers used (for lower frequencies representing the rotor and rotor dependent frequencies) were Statham type A3-4-350 or A-5A-2-350, having a flat frequency response to

42 and 60 Hz, respectively. Signal conditioning of these accelerometers was performed using B&F type 6-102 balance boxes with Trygon type PS12-900F power supplies (bridge power). The accelerometer signals were also fed into the CEC recording oscillograph.

Galvanometers used in the oscillograph were compatible with the frequency response and sensitivity of the applicable transducers. Typical higher frequency galvanometers (for use with the amplifiers) were CEC 7-363 or 7-317 having a flat frequency response of 0-1000 Hz and 0-2200 Hz, respectively. Lower frequency galvanometers (for use with the accelerometers) were CEC 7-315 having a flat frequency response to 60 Hz.

Each accelerometer channel and amplifier channel, including its respective galvanometer, was calibrated prior to the tests throughout the frequency range in use. Calibration of the amplifiers utilized the same mode (linear or integrate) that was used for the test.

A standard 100,000-ohm calibration resistance check (bridge unbalance) was recorded for each accelerometer before each flight when data was taken. Similarly, a standard voltage of 100 milivolts was used to calibrate the amplifier channels.

AIRCRAFT POSITION DETERMINATION

BACKGROUND

The contract work statement required that acoustic data be analyzed for the helicopter position directly over the flight path microphone. It was necessary, therefore, to relate the helicopter position with the recorded acoustic data. The correlation method described in the following paragraphs provided exact correlation between helicopter position and recorded noise data when the aircraft was directly above the flight path microphone.

CORRELATION METHOD

Helicopter Position Observers

Helicopter position marking observers were located at microphone station 2, and at a point 1000 feet from microphone station 1, directly on the course flight path, as shown on Figure 25. Each observer was provided with a "tone switch" which was used for marking the helicopter position.

Equipment (Refer to Figure 26)

1. Acoustic Data Tape Recorder - Received a position marking tone only when the helicopter was 1000 feet away.

2. Position Marking Tape Recorder - A second tape recorder which received a position mark when the helicopter was 1000 feet away and when the helicopter was directly over microphone station 1.

3. Position Marking Tone Switches - Used for marking helicopter position on tape with a discrete tone.

Position Marking Method

The helicopter entered the test course and as it passed over the 1000-foot position station, the observer operated his switch, placing a tone on both the acoustic data tape recorder and the position marking tape recorder. The helicopter continued along the flight path and as it passed over microphone station 1, the observer at microphone station 2 operated his marking switch, placing a tone only on the position marking tape recorder. This action completed the marking procedure for the test pass.

A test pass in the opposite direction was marked by the same observers but in reverse order to that described above.

Data Reduction - Position Correlation

Reduction of data from the two tape recorders produces sound pressure level vs time plots as shown in Figure 29. The interruptions in the traces are the position marks. The two plots have a common point (the two 1000-foot position marks) and a common time scale so that they may be overlaid to obtain the exact overhead position with regard to noise data taken at microphone station 1.

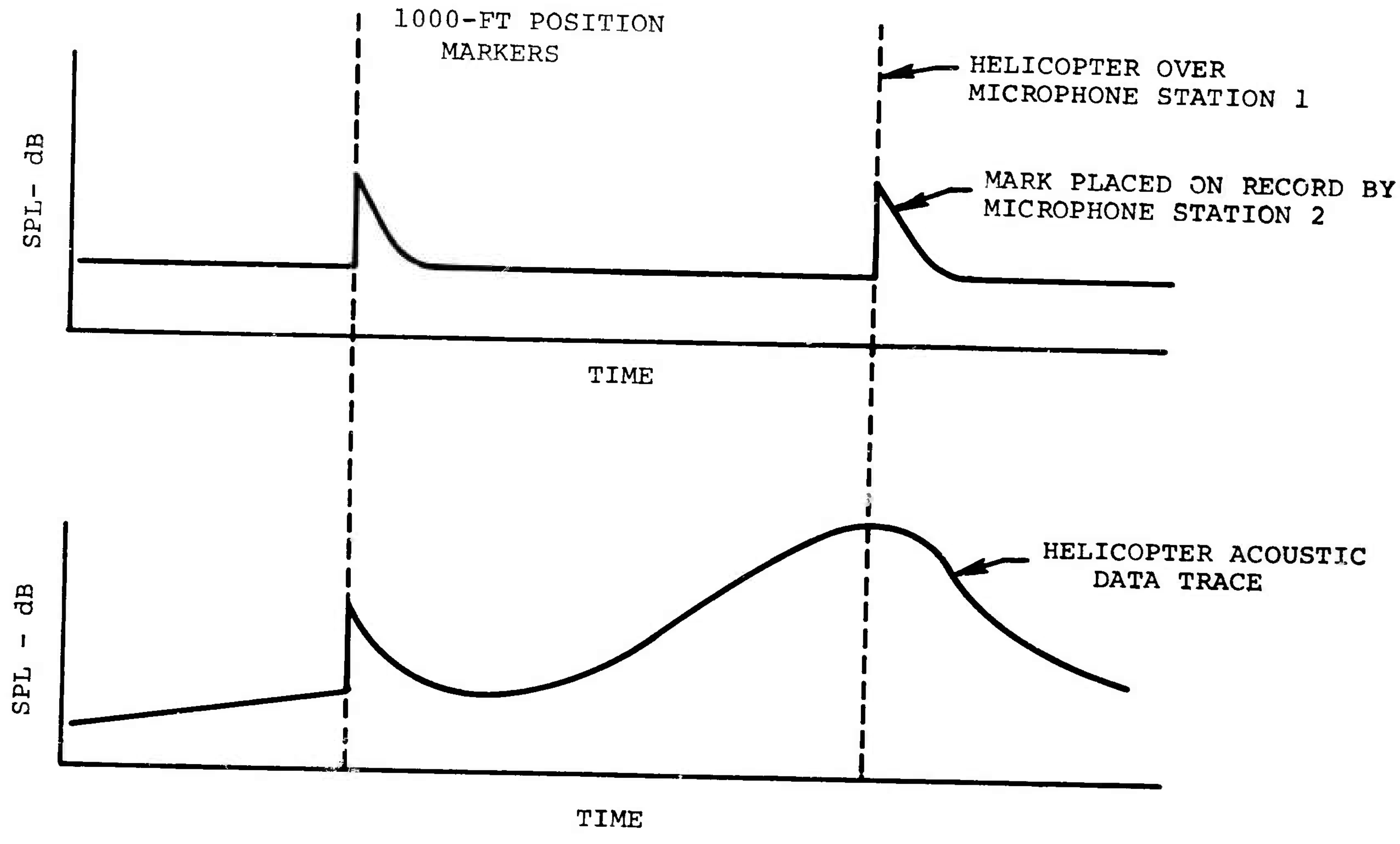


Figure 29. Overhead Position Marks With Acoustic Test Data.

APPENDIX II
ACOUSTIC AND PERFORMANCE DATA

The acoustic data used to generate the mean value octave band sound pressure level spectra presented in the main body of this report is contained in Tables VII through XVII. Also presented are the pertinent aircraft parameters and ambient wind conditions for each data point. All acoustic data has been corrected to a flat record/reproduce system frequency response.

TABLE VIIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 1, FLYOVER

IAS = 60 KTS ΩR = 543 FPS CG = STA 122.1

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
1N	196	355	6265	330	1.5	310	88.5	84.0	75.5	78.0	78.5	80.0	79.0	77.0	73.0	66.5
1S	196	326	6260	150	1.5	300	88.0	84.0	75.5	78.0	79.0	79.0	79.0	76.0	72.5	65.5
2N	196	326	6245	330	2.0	295	88.5	84.5	76.5	78.0	78.5	80.0	79.0	77.0	73.0	65.0
2S	196	336	6220	150	2.0	295	88.0	83.5	76.5	78.0	79.0	79.0	79.0	76.0	72.5	65.5
3N	216	336	6060	330	1.25	275	87.0	82.0	74.5	77.5	77.0	79.0	78.0	77.0	72.0	64.5
3S	190	326	6050	150	1.0	278	88.0	84.5	77.0	78.0	79.0	79.0	78.0	75.0	72.0	65.0
4N	190	326	6040	330	1.0	290	88.0	84.0	76.5	77.5	78.5	79.5	79.0	77.0	73.0	65.5
4S	202	326	6030	150	0.0	-	87.0	83.5	75.5	77.0	77.5	78.0	78.0	73.5	68.5	60.5

TABLE VIIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 1, FLYBY

IAS = 60 KTS ΩR = 543 FPS CG = STA 122.1

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
1S	196	326	6260	150	1.5	300	82.5	77.0	72.5	71.5	74.0	72.0	74.0	73.5	69.5	63.0
2N	196	326	6245	330	2.0	295	83.0	77.0	73.0	73.5	76.0	73.0	74.0	73.0	69.0	64.0
2S	196	336	6220	150	2.0	295	82.5	77.0	74.0	72.5	73.5	72.0	73.0	73.0	69.0	61.5
3N	216	336	6060	330	1.25	275	82.5	77.0	71.5	71.5	74.0	72.5	73.5	73.5	69.0	63.0
3S	190	326	6050	150	1.0	278	82.0	78.0	71.5	71.5	74.0	71.0	72.0	71.5	67.0	59.0
4N	190	326	6040	330	1.0	290	83.5	79.0	72.5	72.5	75.0	73.5	74.0	73.5	69.0	62.0
4S	202	326	6030	150	0.0	-	82.5	77.0	70.5	73.5	74.0	72.0	72.0	72.5	69.0	63.0
5N	200	326	6025	330	0.0	-	82.5	78.0	70.5	72.5	74.0	73.0	73.0	72.5	69.0	63.0

TABLE VIIIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 2, FLYOVER

IAS = 60 KTS ΩR = 543 FPS CG = STA 123.37

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
14N	200	308	6080	330	1	50	87.5	80.5	75.5	78.0	79.0	79.0	81.0	78.0	74.5	65.5
14S	205	327	6070	150	0	-	87.5	81.0	75.5	77.5	78.5	79.0	80.5	79.0	75.0	64.0
15N	190	318	6040	330	0	-	88.0	80.5	74.0	77.5	80.0	80.0	81.5	78.5	74.5	65.5
15S	202	318	6030	150	0	-	87.5	80.5	75.5	76.5	79.0	79.0	80.5	78.5	75.0	64.0
16N	200	318	6020	330	0	-	87.5	80.5	75.5	77.5	80.0	79.0	80.0	77.5	73.0	64.0
16S	190	318	6010	150	0	-	88.0	80.5	75.5	77.0	78.5	80.0	81.0	79.5	75.0	65.0
17N	190	318	6000	330	0	-	87.5	80.5	75.0	77.0	79.0	79.5	80.5	78.5	73.5	64.5
18S	193	318	5935	150	0	-	87.5	80.5	75.0	77.0	78.0	80.0	80.5	78.5	75.0	65.0

TABLE VIIIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 2, FLYBY

IAS = 60 KTS ΩR = 543 FPS   CG = STA 123.37

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
14N	200	308	6080	330	1	50	84.5	79.0	74.0	75.0	76.0	75.0	75.0	74.0	69.0	62.0
14S	205	327	6070	150	0	-	84.5	80.0	73.0	76.0	76.0	74.0	74.0	72.0	66.0	60.0
15N	190	318	6040	330	0	-	84.0	78.5	74.5	74.0	76.5	75.0	75.0	73.0	67.0	58.0
15S	202	318	6030	150	0	-	84.0	80.0	72.5	74.5	75.5	75.0	75.0	72.0	65.5	58.0
16N	200	318	6020	330	0	-	83.5	78.0	72.5	74.5	76.0	75.0	75.0	72.5	66.0	57.0
16S	190	318	6010	150	0	-	84.0	80.0	73.0	73.0	75.0	74.0	75.0	72.5	66.5	60.5
17N	190	318	6000	330	0	-	83.5	79.0	71.5	73.5	75.5	74.0	75.0	73.0	68.5	61.0
18S	193	318	5935	150	0	-	84.0	80.0	72.5	73.0	75.0	73.0	75.0	73.0	67.0	61.0

TABLE IXA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 3, FLYOVER

IAS = 60 KTS　　ΩR = 543 FPS　　CG = STA 122.0

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
21S	196	346	6030	150	0	-	86.5	80.5	74.0	77.0	77.0	78.0	79.0	75.0	70.0	64.5
22N	195	346	6000	330	0	-	86.5	81.0	74.0	77.0	78.0	78.0	77.5	74.5	69.5	64.0
22S	200	346	5975	150	0	-	86.0	80.0	74.0	76.0	78.0	78.0	79.0	74.5	70.0	64.5
23N	191	346	5970	330	0	-	86.0	80.0	73.0	76.0	79.5	78.0	77.5	74.5	70.0	63.5
23S	200	346	5950	150	0	-	86.5	80.0	75.0	77.0	78.5	78.0	79.0	74.5	70.0	63.5
24N	200	346	5940	330	0	-	86.0	80.0	74.0	76.0	78.5	78.0	78.0	74.5	70.0	63.5
24S	200	346	5920	150	0	-	86.0	79.0	74.5	76.5	77.5	78.0	79.0	74.5	70.0	64.5
25N	191	346	5900	330	0	-	86.0	80.0	73.0	77.0	77.0	78.5	77.0	74.5	69.5	63.0

TABLE IXB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 3, FLYBY

IAS = 60 KTS　　ΩR = 543 FPS　　CG = STA 122.0

Run	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
20S	196	346	6040	150	0	-	82.0	78.5	70.5	72.0	74.0	70.5	71.5	68.0	62.5	54.0
21N	158	346	6030	330	0	-	83.5	78.5	74.5	73.0	74.0	73.5	74.5	71.0	66.0	61.0
21S	196	346	6030	150	0	-	81.5	77.0	70.5	73.0	73.0	71.0	71.5	68.0	63.5	57.0
22N	195	346	6000	330	0	-	82.0	75.5	72.5	72.0	74.0	73.0	73.5	71.0	64.5	58.0
22S	200	346	5975	150	0	-	81.5	77.5	68.5	71.0	74.0	70.5	71.5	69.0	64.5	59.0
23S	200	346	5950	150	0	-	81.0	77.0	69.5	71.5	72.5	71.0	72.5	69.0	63.5	55.0
24N	200	346	5940	330	0	-	82.0	76.5	72.5	72.0	73.0	72.0	75.0	72.0	65.5	54.0
25N	191	346	5900	330	0	-	81.5	76.5	72.5	71.0	73.0	72.0	73.5	70.0	64.0	57.0

TABLE XA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 4A, FLYOVER

IAS = 60 KTS ΩR = 543 FPS CG = STA 121.45

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
30S	197	374	6592	150	3	210	87.0	84.0	78.0	78.0	76.0	72.0	72.0	72.5	71.0	64.0
31N	195	374	6562	330	3	190	86.0	83.0	77.0	77.0	75.0	72.0	71.5	71.5	71.0	62.5
32N	180	392	6522	330	1	195	86.0	83.0	76.5	77.0	75.5	72.5	71.5	71.5	71.0	63.0
32S	196	374	6462	150	0	-	85.5	83.0	77.0	77.0	74.0	71.0	70.5	71.5	70.0	62.5
33N	209	374	6442	330	0	-	85.5	82.5	76.0	77.0	75.0	71.0	70.5	70.5	70.0	61.5
33S	209	374	6432	150	0	-	86.0	83.0	77.0	79.0	74.5	71.5	71.0	71.5	70.0	62.5
34N	191	374	6392	330	0	-	86.5	83.5	77.0	79.0	75.0	72.0	72.0	71.5	70.5	62.5
34S	203	392	6362	150	0	-	86.0	83.0	76.0	78.0	74.5	71.0	71.0	71.0	70.0	62.0

TABLE XB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 4A, FLYBY

IAS = 60 KTS ΩR = 543 FPS   CG = STA 121.45

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
30N	203	374	6622	330	1.5	195	87.0	86.0	73.5	74.5	74.5	69.0	71.0	68.0	65.5	57.0
30S	197	374	6592	150	3.0	210	84.0	82.5	74.5	71.0	74.0	68.0	69.0	65.5	62.5	55.0
31S	190	374	6552	150	3.0	200	85.0	83.5	73.5	71.5	74.0	70.5	69.5	66.5	64.0	57.0
32N	180	392	6522	330	1.0	195	85.0	83.0	74.0	72.0	74.5	69.0	72.5	67.0	64.5	58.0
32S	196	374	6462	150	0.0	-	85.5	84.0	74.0	72.0	73.5	69.0	68.5	66.0	63.5	56.0
33N	209	374	6442	330	0.0	-	85.5	84.0	74.0	74.5	73.5	68.0	73.5	68.0	65.5	58.5
33S	209	374	6432	150	0.0	-	84.5	83.0	74.5	72.5	73.5	69.0	68.0	66.5	63.5	56.0
34S	203	392	6362	150	0.0	-	85.0	83.0	74.5	75.0	73.5	69.5	68.5	66.0	63.5	56.0

TABLE XIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 4B, FLYOVER

IAS = 60 KTS ΩR = 543 FPS CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
40N	171	355	5905	330	0	-	86.5	83.0	77.5	76.5	77.5	74.0	72.0	71.5	70.5	65.0
40S	216	336	5885	150	0	-	84.5	81.0	75.5	77.5	74.5	71.5	69.5	70.0	67.5	62.5
41N	203	336	5870	330	0	-	85.5	83.0	75.5	76.0	75.0	71.0	70.0	69.5	68.5	62.0
41S	203	336	5855	150	0	-	85.5	82.5	76.0	76.5	75.0	72.0	70.0	70.5	68.5	63.0
42N	184	336	5850	330	0	-	85.0	82.0	75.5	76.5	76.0	71.5	71.0	71.0	69.0	63.0
42S	190	336	5835	150	0	-	85.0	82.0	76.5	76.5	74.0	72.0	70.0	71.0	68.5	63.0
43N	200	336	5815	330	0	-	85.5	83.5	75.5	75.0	74.0	71.5	70.5	69.5	68.0	62.0
43S	200	336	5795	150	0	-	86.0	83.5	76.0	77.0	75.0	72.0	70.5	70.5	68.5	63.0

TABLE XIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 4B, FLYBY

IAS = 60 KTS　　ΩR = 543 FPS　　CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)										
							Octave Band (Hz)										
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
40N	171	355	5905	330	0	-	84.0	82.5	72.0	69.5	75.0	69.5	70.0	65.5	62.0	56.5
40S	216	336	5885	150	0	-	83.5	82.0	72.0	71.0	72.0	68.5	67.0	64.5	61.5	56.0
41N	203	336	5870	330	0	-	84.5	83.5	72.5	71.0	72.5	69.0	70.0	66.0	63.0	58.0
41S	203	336	5855	150	0	-	84.0	82.5	72.5	71.0	72.0	69.5	68.5	65.0	61.5	57.0
42N	184	336	5850	330	0	-	83.5	81.5	72.5	72.0	73.5	68.5	71.0	66.5	63.5	59.0
42S	190	336	5835	150	0	-	84.5	83.0	73.0	71.0	72.5	69.0	68.5	65.0	62.0	57.0
43N	200	336	5815	330	0	-	83.5	82.0	72.0	71.0	72.5	67.5	70.5	66.5	63.0	58.0
43S	200	336	5795	150	0	-	84.0	83.0	72.5	70.5	72.5	69.0	66.5	65.0	61.5	57.0

TABLE XIIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 5, FLYOVER

IAS = 60 KTS $\qquad$ ΩR = 543 FPS $\qquad$ CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
50N	190	355	6160	330	2.0	50	85.0	81.5	75.0	76.5	76.0	73.5	71.5	70.5	70.0	61.0
50S	203	355	6160	150	1.0	20	85.5	82.0	76.0	78.0	75.5	72.5	71.5	71.5	71.5	61.0
51S	202	355	6130	150	.5	30	86.0	83.0	77.0	78.5	75.0	73.5	71.5	71.5	71.0	62.5
52N	195	355	6100	330	.5	0	85.5	82.0	76.0	78.5	75.0	73.5	71.5	70.5	70.5	61.0
52S	203	355	6090	150	0.0	-	85.5	82.0	75.0	77.0	75.0	73.5	71.5	71.5	71.5	62.5
53N	203	355	6080	330	.5	60	85.0	82.0	74.5	77.0	75.0	73.0	71.5	71.0	70.5	61.5
53S	203	355	6060	150	.5	0	86.0	82.5	77.0	79.0	76.0	73.5	72.0	71.0	71.5	62.5
54S	203	355	6020	150	0.0	-	85.5	82.0	75.0	77.5	74.5	73.0	71.5	71.0	71.0	62.0

TABLE XIIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 5, FLYBY

IAS = 60 KTS ΩR = 543 FPS CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar) Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
50N	190	355	6160	330	2.0	50	84.0	82.5	74.0	72.0	72.0	69.5	66.5	67.0	65.0	57.5
51N	204	355	6140	330	1.5	350	84.0	82.5	72.0	72.5	71.5	68.0	69.5	66.5	65.0	57.5
51S	202	355	6130	150	.5	30	84.5	83.5	73.0	72.5	72.0	68.0	67.0	66.5	64.5	56.5
52N	195	355	6100	330	.5	0	85.0	83.5	73.0	72.5	72.0	69.0	67.5	67.0	65.5	57.5
53N	203	355	6080	330	.5	60	84.0	82.5	72.0	73.0	72.0	68.0	66.5	66.5	65.0	57.0
53S	203	355	6060	150	.5	0	84.5	83.0	73.0	73.0	72.0	69.0	67.0	66.5	64.5	56.5
54N	203	355	6040	330	0.0	-	84.0	82.5	72.0	72.0	72.0	69.5	69.0	67.0	65.5	58.0
54S	203	355	6020	150	0.0	-	84.0	83.0	72.5	72.0	71.5	68.0	67.0	66.0	64.0	56.0

TABLE XIIIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 6, FLYOVER

IAS = 60 KTS | ΩR = 543 FPS | CG = STA 122.7

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
								Octave Band (Hz)								
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
60N	203	336	6275	330	3	170	84.0	80.0	73.5	75.5	75.0	72.5	71.5	71.0	69.5	62.0
60S	209	336	6235	150	3	160	83.0	79.0	74.0	75.0	74.0	72.0	70.5	70.0	69.5	62.0
61S	203	336	6215	150	4	170	83.5	79.5	74.0	75.0	75.5	72.0	70.0	71.0	70.0	63.0
62N	200	336	6195	330	4	160	84.5	80.0	74.0	76.0	76.5	73.0	71.5	71.5	70.5	63.0
62S	203	336	6150	150	3	190	84.0	79.0	74.5	75.5	76.0	73.5	71.0	71.0	69.5	63.0
63S	203	336	6110	150	4	170	83.5	79.0	75.0	75.5	75.0	72.5	71.0	70.5	70.0	62.5
64N	203	336	6100	330	5	170	84.0	79.0	74.0	76.0	75.5	73.5	71.5	71.5	70.0	63.0
64S	196	336	6080	150	4	0	83.5	79.5	74.0	74.5	75.0	72.5	70.5	70.5	69.5	62.5

TABLE XIIIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 6, FLYBY

IAS = 60 KTS | ΩR = 543 FPS | CG = STA 122.7

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 uBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
60N	203	336	6275	330	3	170	81.5	77.5	73.5	73.0	72.0	68.0	68.5	66.5	64.0	57.5
60S	209	336	6235	150	3	160	83.0	81.0	73.0	72.0	73.5	68.0	66.5	66.0	62.5	55.5
61N	203	336	6225	330	3	170	82.0	78.5	73.5	72.5	73.0	69.0	67.5	68.0	65.0	59.0
62N	200	336	6195	330	4	160	82.0	78.0	74.0	73.0	73.5	68.0	67.0	67.5	65.5	59.0
62S	203	336	6150	150	3	190	83.0	80.5	72.5	72.0	73.5	69.0	67.0	67.0	64.0	58.0
63N	196	336	6130	330	4	165	82.0	79.0	73.5	72.5	73.0	69.0	67.5	68.0	65.5	59.0
63S	203	336	6110	150	4	170	82.5	80.5	72.5	72.0	73.0	68.0	66.5	67.0	63.5	57.0
64S	196	336	6080	150	4	0	82.5	80.5	72.5	72.5	72.5	68.5	67.0	66.5	63.5	57.0

TABLE XIVA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 7, FLYOVER

IAS = 60 KTS ΩR = 543 FPS   CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)										
							Octave Band (Hz)										
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
70N	205	336	6000	330	4	130	83.5	79.0	74.5	76.0	74.5	71.5	70.5	68.5	68.0	63.0
70S	203	336	5980	150	5	120	85.0	81.0	74.0	78.0	77.0	73.5	71.5	71.5	69.5	65.5
71N	203	336	5970	330	8	120	84.5	80.5	76.5	77.0	75.5	72.5	70.5	68.5	69.5	64.0
71S	203	336	5940	150	10	120	86.5	81.0	76.0	81.0	78.5	74.0	71.5	71.5	70.0	65.5
72N	203	336	5900	330	9	120	86.5	82.0	76.0	79.5	78.0	74.5	73.0	71.5	70.5	65.5
73S	203	336	5880	150	6	90	8[illegible].0	82.0	76.0	79.0	77.5	73.5	71.5	72.0	71.5	67.0
74N	203	336	5840	330	10	130	85.0	81.0	74.5	78.5	75.5	73.0	72.0	71.5	71.0	66.5
74S	209	336	5840	150	10	130	84.5	81.0	76.0	77.0	74.5	71.5	70.0	71.0	70.0	65.5

TABLE XIVB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 7, FLYBY

IAS = 60 KTS | ΩR = 543 FPS | CG = STA 122.7

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
70N	205	336	6000	330	4	130	82.5	79.5	72.5	73.5	73.0	69.0	68.0	67.0	64.0	60.5
70S	203	336	5980	150	5	120	83.5	81.5	73.5	73.0	74.0	71.0	68.0	67.0	63.5	60.0
71S	203	336	5940	150	10	120	85.0	82.0	74.0	76.0	77.0	72.0	69.5	68.0	64.5	62.0
72N	203	336	5900	330	9	120	84.5	82.5	73.0	74.0	74.0	70.5	68.0	68.0	66.5	63.5
72S	203	336	5900	150	7	120	84.0	82.0	73.0	73.5	74.5	70.0	69.0	68.5	65.5	63.0
73S	203	336	5880	150	6	90	84.0	82.0	73.5	73.5	75.0	69.5	67.0	67.0	64.5	61.5
74N	203	336	5840	330	10	130	83.5	81.5	73.5	73.0	74.0	69.5	67.0	68.0	66.0	62.5
74S	209	336	5840	150	10	130	84.0	82.5	74.0	71.5	72.5	69.5	67.0	67.5	63.0	61.5

TABLE XVA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 8, FLYOVER

IAS = 60 KTS | ΩR = 543 FPS | CG = STA 122.7

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
81N	209	336	5770	330	3	30	84.0	79.0	74.5	77.0	75.0	72.0	71.0	71.0	71.0	64.0
81S	209	318	5760	150	3	20	84.0	80.0	73.5	75.5	75.0	72.5	71.0	71.5	72.0	65.5
82N	209	318	5745	330	4	30	83.0	78.0	73.0	75.0	73.5	71.5	71.0	71.0	70.0	63.5
82S	209	318	5730	150	3	5	83.5	79.0	73.5	75.5	74.0	72.0	70.5	71.5	71.0	64.5
83N	209	318	5720	330	3	20	83.0	78.0	73.5	75.5	74.0	71.5	70.5	71.0	71.0	63.5
83S	209	318	5705	150	3	25	83.5	79.0	74.0	75.5	74.5	72.0	70.5	71.5	71.5	64.5
84N	209	318	5690	330	3	30	83.0	78.0	74.0	75.5	73.5	72.5	70.5	71.0	70.0	63.0
84S	209	318	5680	150	3	20	84.0	79.5	74.0	77.5	75.0	72.5	70.5	72.0	72.0	65.0

TABLE XVB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 8, FLYBY

IAS = 60 KTS   ΩR = 543 FPS   CG = STA 122.7

	A/C Parameters				Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
80N	227	336	5800	330	3	20	81.0	77.5	71.5	71.5	71.0	68.0	67.0	67.0	66.0	61.0
81N	209	336	5770	330	3	30	82.0	79.0	72.0	74.0	72.0	69.0	68.5	69.0	68.0	63.5
81S	209	318	5760	150	3	20	81.0	77.0	72.5	70.5	71.5	68.0	66.5	68.0	67.0	62.0
82N	209	318	5745	330	4	30	81.5	78.5	72.0	73.5	72.0	68.5	67.5	68.0	67.5	62.5
82S	209	318	5730	150	3	5	81.0	77.5	72.0	72.0	71.5	68.5	67.5	67.0	66.0	61.5
83N	209	318	5720	330	3	20	81.0	77.5	71.5	72.5	71.5	68.0	67.5	68.0	67.0	63.0
83S	209	318	5705	150	3	25	81.5	78.5	72.5	71.5	72.0	69.0	67.5	68.0	67.0	62.5
84N	209	318	5690	330	3	30	81.5	78.0	72.0	72.5	72.0	68.0	68.0	68.5	68.0	63.0

TABLE XVIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 9, 205 RPM, FLYOVER

IAS = 60 KTS ΩR = 540 FPS CG = STA 122.6

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP* (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
90N	197	-	5328	330	0	-	86.0	82.0	72.0	78.0	73.0	70.0	68.0	70.0	66.0	63.0
90S	200	-	5298	150	0	-	86.0	82.0	76.0	77.0	73.0	70.0	69.0	70.0	67.0	64.0
91N	200	-	5268	330	0	-	86.0	82.0	76.0	78.0	74.0	70.0	68.0	69.0	65.0	63.0
91S	201	-	5248	150	0	-	86.0	82.0	75.0	77.0	73.0	70.0	69.0	70.0	67.0	64.0
92N	202	-	5228	330	0	-	85.0	82.0	74.0	78.0	73.0	69.0	68.0	70.0	65.0	62.0
92S	203	-	5208	150	0	-	86.0	82.0	74.0	77.0	74.0	70.0	68.0	70.0	67.0	63.0
93N	209	-	5188	330	0	-	85.0	82.0	76.0	78.0	73.0	70.0	68.0	68.0	64.0	62.0
94S	210	-	5148	150	0	-	86.0	82.0	76.0	77.0	73.0	71.0	69.0	69.0	66.0	63.0

*No shaft horsepower data taken during acoustic testing; power required for this configuration and flight condition, as measured during qualification testing, was 296 horsepower at 205 rpm.

TABLE XVIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 9, 205 RPM, FLYBY

IAS = 60 KTS							ΩR = 540 FPS							CG = STA 122.6		
A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP* (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
90N	197	-	5328	330	0	-	87.0	81.0	75.0	70.0	69.0	64.5	65.5	64.5	63.5	58.0
90S	200	-	5298	150	0	-	88.0	83.0	74.0	71.0	72.0	65.5	64.5	64.5	61.5	57.0
91S	202	-	5228	150	0	-	86.0	80.0	73.0	70.0	69.0	64.5	64.5	63.5	59.5	53.0
92S	203	-	5208	150	0	-	88.0	83.0	75.0	71.0	70.0	64.5	64.5	64.5	61.5	57.0
93N	209	-	5188	330	0	-	87.0	82.0	73.0	71.0	69.0	65.5	64.5	64.5	61.5	57.0
93S	203	-	5168	150	0	-	88.0	84.0	74.0	71.0	71.0	64.5	64.5	65.5	61.5	57.0
94N	215	-	5158	330	0	-	86.0	81.0	72.0	69.0	69.0	64.5	63.5	64.5	61.5	56.0
94S	210	-	5148	150	0	-	88.0	84.0	74.0	71.0	71.0	65.5	64.5	64.5	60.5	57.0

*No shaft horsepower data taken during acoustic testing; power required for this configuration and flight condition, as measured during qualification testing, was 296 horsepower at 205 rpm.

TABLE XVIIA. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 9, 175 RPM, FLYOVER

IAS = 60 KTS ΩR = 462 FPS CG = STA 122.6

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP* (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
95N	215	-	5248	330	1	160	83.0	80.0	72.0	73.0	71.0	66.0	65.0	66.0	61.0	60.0
95S	215	-	5233	150	1	155	83.0	81.0	72.0	72.0	69.0	67.0	66.0	66.0	62.0	61.0
97N	202	-	5188	330	.5	155	84.0	81.0	73.0	74.0	72.0	66.0	66.0	67.0	62.0	60.0
97S	197	-	5178	150	.5	140	84.0	81.0	73.0	73.0	71.0	66.0	66.0	67.0	63.0	61.0
98N	202	-	5163	330	0	-	83.0	80.0	71.0	74.0	71.0	66.0	65.0	67.0	61.0	60.0
98S	203	-	5148	150	0	-	83.0	79.0	71.0	74.0	70.0	68.0	65.0	66.0	61.0	61.0
99N	202	-	5138	330	0	-	83.0	80.0	71.0	73.0	71.0	67.0	66.0	66.0	62.0	60.0
99S	202	-	5128	150	0	-	83.0	80.0	71.0	73.0	70.0	68.0	65.0	66.0	63.0	61.0

*No shaft horsepower data taken during acoustic testing; power required for this configuration and flight condition, as measured during qualification testing, was 268 horsepower at 175 rpm.

TABLE XVIIB. ACOUSTIC AND PERFORMANCE DATA, CONFIGURATION 9, 175 RPM, FLYBY

IAS = 60 KTS ΩR = 462 FPS   CG = STA 122.6

A/C Parameters					Wind		Sound Pressure Level - dB(re.-.0002 μBar)									
							Octave Band (Hz)									
Run	Alt (ft)	SHP* (hp)	Gr Wt (lb)	Head (deg)	Vel (kts)	Head (deg)	O/A	31.5	63	125	250	500	1000	2000	4000	8000
95S	215	-	5233	150	1	155	83.0	79.0	70.0	67.0	68.0	63.5	62.5	61.5	57.5	55.0
96S	203	-	5203	150	.5	150	84.0	80.0	69.0	67.0	68.0	62.5	62.5	61.5	57.5	54.0
97N	202	-	5188	330	.5	155	84.0	82.0	67.0	67.0	68.0	63.5	63.5	61.5	58.5	55.0
97S	197	-	5178	150	.5	140	84.0	80.0	71.0	67.0	69.0	63.5	63.5	61.5	57.5	55.0
98N	202	-	5163	330	0	-	83.0	82.0	67.0	68.0	68.0	63.5	62.5	61.5	58.5	55.0
98S	203	-	5148	150	0	-	83.0	78.0	70.0	68.0	68.0	63.5	61.5	61.5	57.5	55.0
99N	202	-	5138	330	0	-	84.0	82.0	68.0	68.0	69.0	63.5	63.5	61.5	59.5	55.0
99S	202	-	5128	150	0	-	83.0	79.0	69.0	67.0	68.0	64.5	62.5	61.5	57.5	54.0

*No shaft horsepower data taken during acoustic testing; power required for this configuration and flight condition, as measured during qualification testing, was 268 horsepower at 175 rpm.

APPENDIX III
INFRARED SIGNATURE SURVEY

On two occasions, infrared thermograms of a Kaman HH-43B helicopter were made. The objective of this program was to determine qualitatively the changes in heat radiation characteristics of this aircraft following modifications to the aircraft drive and engine systems.

INSTRUMENTATION

The instrumentation used in this comparison test was a Barnes Model T-101 Infrared Camera with 4.0 to 5.5 micrometer spectral sensitivity.

TEST PROCEDURE

In November 1969, the standard HH-43B was thermographed in flight from the following positions:

(a) Aft (Figures 30A and 30B)

(b) Left Side (Figures 31A and 31B)

After modification in June 1970, the thermograms were again taken of the aircraft from the aft (a) and left side (b) positions.

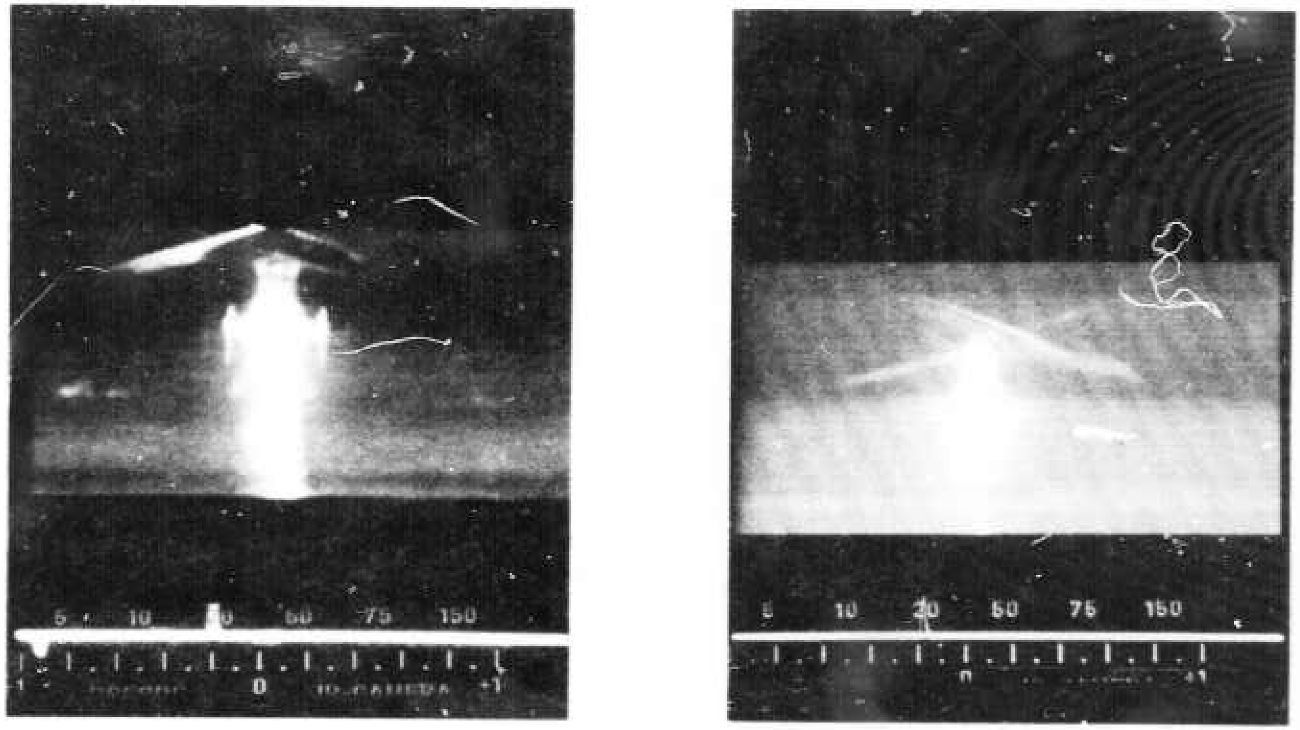
The aircraft hovered approximately 60 feet above the ground and 150 to 200 feet in front of the infrared camera and maintained a fixed orientation to the camera for approximately 5 seconds for each of the infrared thermograms.

DATA INTERPRETATION

The test data represents a qualitative study rather than a quantitative one. The thermogram provides a picture of the spatial distribution of radiant emittance from the aircraft. The thermogram contrast (black to white) indicates the relative level radiant emittance where white is an indication of the greatest emittance and black the lowest. The scope of this program did not require the use of radiation references for determination of absolute radiation levels.

Standard HH-43B

The thermograms indicate that the engine and exhaust radiate high levels. Areas that reflect or radiate at lower levels are the rotor blades, clamshell doors, and transmission.



A. STANDARD

B. MODIFIED

Figure 30. Thermograms, Aft View HH-43B.

A. STANDARD

B. MODIFIED

Figure 31. Thermograms, Left Side View HH-43B.

Modified HH-43B

The thermograms indicate lower levels of radiation in the engine and exhaust duct areas. The exhaust flow pattern has been changed substantially. Radiation is absent in the transmission and aft cabin area. Radiation from the underside of the aircraft is caused by reflection of heat from the tar surface of the landing pad. The modified helicopter was tested in summer whereas the standard helicopter was tested in late fall.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Kaman Aerospace Corporation Bloomfield, Connecticut	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP
3. REPORT TITLE TEST AND EVALUATION OF A QUIET HELICOPTER CONFIGURATION HH-43B	
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report	
5. AUTHOR(S) (First name, middle initial, last name) Michael A. Bowes	

6. REPORT DATE January 1972	7a. TOTAL NO. OF PAGES 106	7b. NO. OF REFS 4
8a. CONTRACT OR GRANT NO. DAAJ02-70-C-0004 b. PROJECT NO. ARPA Order No. 1322 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) USAAMRDL Technical Report 71-31 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) Kaman Report R-914	

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Eustis Directorate U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia

13. ABSTRACT

A series of noise control modifications was made to the HH-43B helicopter. Each modification was evaluated by direct comparison of acoustic signatures of modified and unmodified configurations.

Noise control modifications to the aircraft engine, drive and rotor systems were used and are evaluated. Testing was performed on ten aircraft configurations.

The noise control modifications resulted in substantial reductions in flyover noise. All octave bands of interest, i.e., 63 Hz to 4000 Hz, were significantly reduced.

The rotor system was the dominant noise source, in level flight, dominating each octave band in the modified aircraft's audible spectrum, i.e., with center frequencies from 31.5 Hz to 8000 Hz. This noise source was reduced through changes in rotor blade geometry and reduction in blade tip speed.

All program noise signature reduction goals were met or exceeded.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Noise control modifications						
Helicopter flyover noise						
Rotor system noise						
Engine noise						
Drive system noise						