ACOUSTICS OF UH-60 BLACK HAWK WITH GROWTH ROTOR BLADES

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Abstract

Acoustic data were acquired during a flight test in 1995 of a UH-60L Black Hawk equipped with Growth Rotor Blades (GRB) performing terminal area operations. Limited acoustic data from the same aircraft equipped with Standard Rotor Blades (SRB) were also acquired. These data were analyzed and compared with data from a 1993 flight test of a UH-60A aircraft to assess differences in acoustics characteristics between the two types of blades. This paper presents dBA and Sound Exposure Level (SEL) acoustic data from level flight and approach conditions for the GRB, and the SRB, both from this test and the earlier, 1993 test. An expected increase in levels with increase in air speed of the GRB-equipped aircraft was observed in both level flight and approach. Comparisons between the GRB and the SRB data from the same 1995 test show no acoustic improvement in level flight, but a significant improvement in approach for the helicopter equipped with the GRB. Comparisons between GRB data from the 1993 test and SRB data the 1995 test show similar results.

Introduction

An acoustics flight test was performed in 1995 on a UH-60L Black Hawk equipped with both Growth Rotor Blades (GRB) and Standard Rotor Blades (SRB). The primary purpose of this test was to obtain an acoustic database for the UH-60 GRB and to compare the trends of its noise characteristics with that of the SRB. The GRB are principally characterized by their unique tapered, anhedral tips. Previous wind tunnel and computational studies have shown tip shape can have a significant effect on noise (ref. 1). A secondary purpose was to provide validation data for noise prediction code development. This test was a joint effort between NASA, United Technologies Sikorsky Aircraft, and the U.S. Army. Figure 1 shows the UH-60L with the GRB.

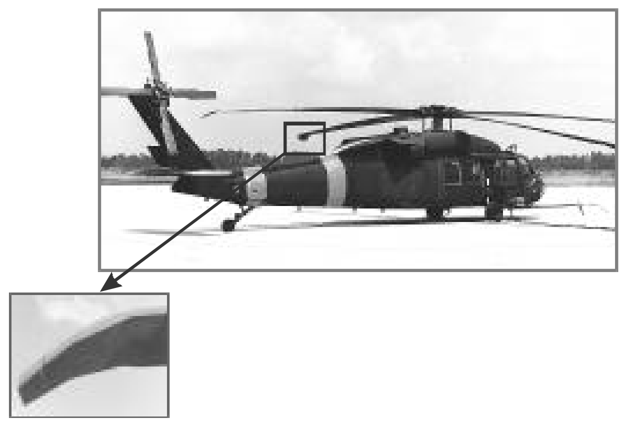

Figure 1. UH-60L Black Hawk with Growth Rotor Blade

Flight conditions for terminal area operations include low-altitude level flight, approach, takeoff, and low-altitude turns. The noise levels associated with these operations by helicopters greatly impact communities, therefore there is an effort to study the noise of helicopters performing terminal area operations. For example, blade-vortex interaction is of great concern during approach, as it propagates extremely high and annoying noise levels to the ground (refs. 2-4).

In 1993, a comprehensive acoustic test was accomplished using a UH-60A Black Hawk "Airloads" aircraft equipped with the SRB performing maneuvers associated with terminal area operations (ref. 5). This test, which is referred to as the Crows Landing Test, was conducted at Crows Landing, CA, in conjunction with

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NASA Ames Research Center and the U.S. Army. During this test, far-field acoustics, tracking, weather, flight dynamics, and other variables associated with the main rotor (including upper and lower surface pressures from which blade airloads could be obtained) of a UH-60A helicopter were measured. These measurements, obtained as the helicopter flew standard flight profiles and maneuver profiles typical of those which occur during airport terminal area operations, were all synchronized in time to permit a detailed study of their relationships to each other (refs. 7-8). These data were used to establish a high quality database, thus providing researchers with data which may be used to validate current and future analysis and prediction techniques, compare and study full scale results to existing model data, and to investigate the potential noise benefits which result from a helicopter performing nonstandard terminal area flight operations.

Both the GRB and the SRB main rotors have a radius of 26.833 ft and operate at the same rotor speed of 258 rpm. The GRB incorporates an SC-2110 primary airfoil with a 16% chord increase over the SRB. The swept, tapered anhedral blade tip is a high performance SSC-A09 airfoil that is skewed relative to the main body of the blade through a swept non-linear twist. Additional details of the GRB design can be found in reference 6.

Test Description

The flight test was conducted at the Sikorsky Acoustics Test Range in West Palm Beach, FL, using a U.S. Army UH-60L operated and maintained by Sikorsky. Sikorsky also recorded aircraft state data and obtained weather data using an Atmospheric Instruments Research, Inc. (AIR) tethered weather balloon system. NASA Langley Research Center was responsible for test development, acoustic data acquisition and subsequent data analysis. NASA Ames provided personnel and hardware for the laser tracking and on-board guidance system.

Site Description

Figures 2 and 3 show aerial photographs of the Sikorsky acoustic test site in West Palm Beach, Florida, and the Crows Landing acoustic test site in California, respectively. These figures show the significant difference in surface condition between the West Palm Beach site and the Crows Landing site. At the West Palm Beach site, the acoustic signals propagated over scrub brush, trees, and a marsh-like environment. At Crows Landing, the test area was a dry, flat, cultivated surface without any trees or scrub brush. Due to these differences between the West Palm Beach and Crows Landing test sites, a comparison of absolute values of the acoustic data measured at the two sites would require many considerations. Such a comparison would require adjustments for site differences in: 1) ground and topographic impedance due to the marsh surfaces, the dense brush and trees, and hard, flat surfaces, 2) reflection and diffraction, and 3) atmospheric absorption. Since the scope of this paper was not to compare absolute values, but to compare trends between the GRB and the SRB data these corrections were not considered.

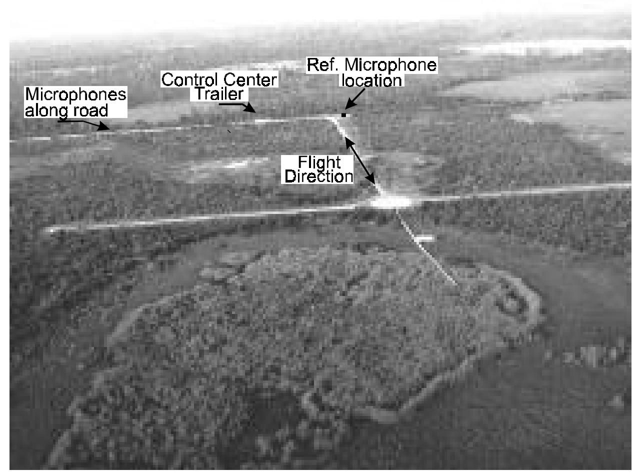


Figure 2. Aerial view of Sikorsky Acoustics Test Range, West Palm Beach, FL.

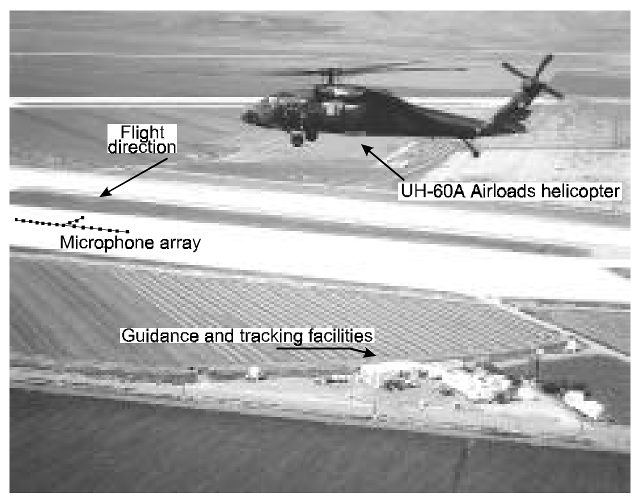


Figure 3. NASA Crows Landing Moffett Federal Airfield.

An array of 18 microphones was set up at the test site, 15 of which formed a line perpendicular to the flight track along a road as shown in Figure 4. The distances between microphones were chosen so that sideline angles in approximate 10-deg increments were formed from 10° to 90° when the aircraft was directly overhead at 250 ft altitude. In addition to the reference microphone, three microphones were positioned along the flight track. Ensemble averaging of the data recorded directly beneath the flight track is possible using data from these three microphones and the reference microphone. The microphone array was the same as that of the Crows Landing test in 1993, except for the microphone furthest west, which had to be placed about 30 feet closer to the center of the array due to the terrain.

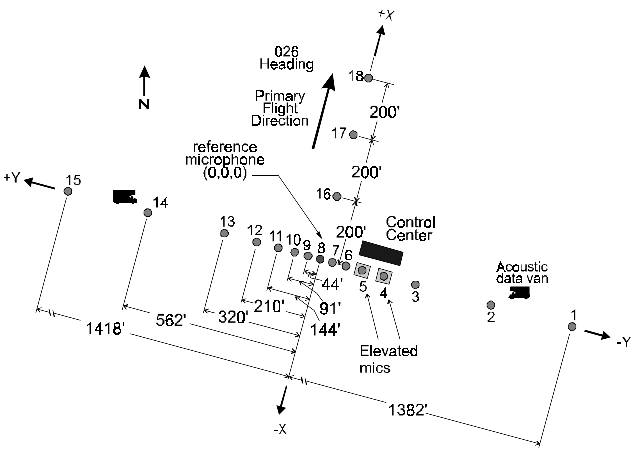


Figure 4. Layout of microphone array.

Each of the microphones used in the array were ½ inch diameter microphones configured with a grid cap and wind screen. All microphones were oriented for parallel or grazing acoustic incidence. Each microphone was placed, lying on its side, in the center and on top of a ¾-inch thick PVC ground board which was 40 inches on a side. All ground boards were placed on the ground except for those at locations 4 and 5, which were closest to the control center trailer shown in Figure 4.

Figure 5 shows a ground level photograph of a portion of the microphone array as it was distributed along the road at the West Palm Beach site. The view looks east from the reference microphone. Several of the ground board microphones and the control center trailer can be seen, along with the scaffolding used to elevate microphones 4 and 5 above the ground. This scaffolding was used in an effort to minimize the shielding and reflection effects produced by the nearby control center trailer. The effect of the proximity of this structure to the array will be addressed.

The sensitivity, distortion, and noise floor of each acoustic system was calibrated in the laboratory and documented to be linear to within ± 1 dB before it was placed in the field. The frequency range of calibration was 5 Hz to 10 kHz. A piston phone operating at 250 Hz, 124 dB sound pressure level (SPL), was used in the field for calibration at the beginning and end of each day. Also, at the beginning and conclusion of data acquisition for each flight test, ambient noise levels were recorded.

Two data vans from NASA Langley Research Center, each supporting nine microphones, were located between microphones in the array, as noted in Figure 4. The vans were equipped with analog FM tape recorders used to record the acoustic data, as well as with diagnostic and calibration instrumentation. The microphone signals were recorded on analog wide band 14 track magnetic tape recorders, operating at a tape speed of 30 inches per second in the FM mode, resulting in a flat frequency response to 20 kHz.

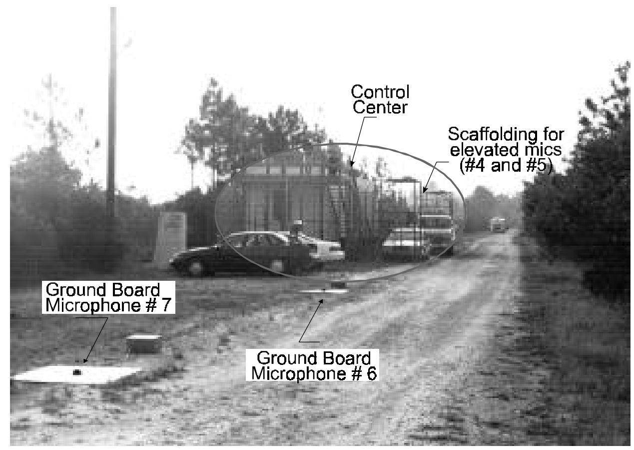
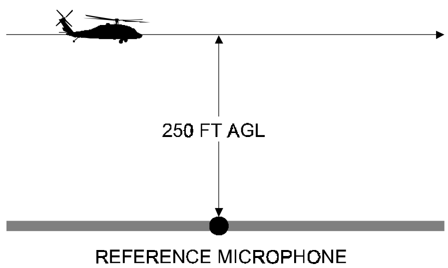


Figure 5. Ground level view of microphone array, West Palm Beach, FL.

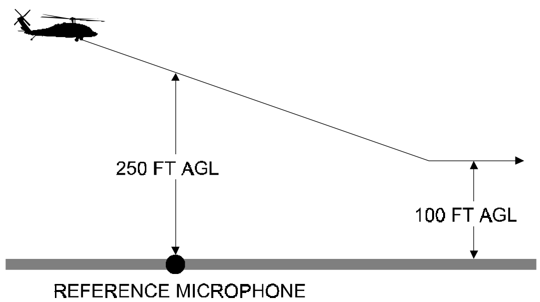
Flight tracks

A series of level flyovers, approaches, departures, and turns were flown over the microphone array with the GRB. Only data from the level flights and approaches will be presented in the paper. The desired flight profiles and altitudes for the level flyovers and approaches are illustrated in Figure 6. To document terrain effects between the West Palm Beach and the Crows Landing sites, data were also obtained for a limited number of level flights and approaches with the SRB installed.

Aircraft tracking was provided by personnel from the Moffett Range Systems Branch (MRSB) of NASA Ames Research Center using the Precision Automated Tracking System (PATS). The PATS system uses a pulsed laser beam with a 100 Hz pulse rate to measure the position of the aircraft within 0.1 mrad in azimuth and elevation and ±1 ft in range. These measurements are then converted to absolute X, Y, and Z coordinates for the aircraft with respect to the acoustic reference location (Fig. 4). Along with tracking aircraft position, the MRSB's Instrument Positioning System (IPS) was used to provide flight path guidance information to the pilots. The IPS system compares the actual aircraft position to a preselected desired flight profile, and transmits an error signal to a traditional Instrument Landing System (ILS) receiver and display installed on board aircraft. This system provides real-time feedback to the pilots regarding their positioning with respect to the desired flight profile.



(a) Level Flyover



(b) Approach

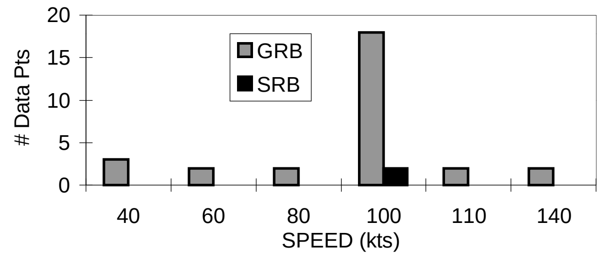
Figure 6. Desired altitudes for level flyover and approach.

Flight direction

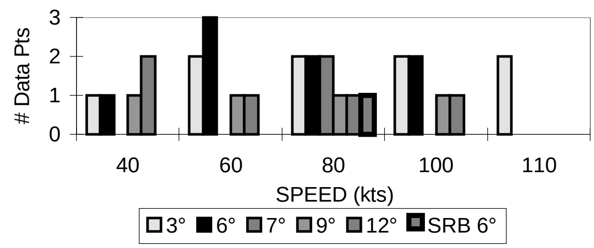
The primary flight direction was a 026 deg heading, as shown in Figure 4. Since the density of the foliage varied significantly from the north side of the microphone array to the south side, a secondary flight direction of 206 deg, 180 deg opposite the primary, was also flown to determine any difference in acoustic characteristics. There were flights centered over the control center trailer as well, to assess its effects on the acoustic data.

Results

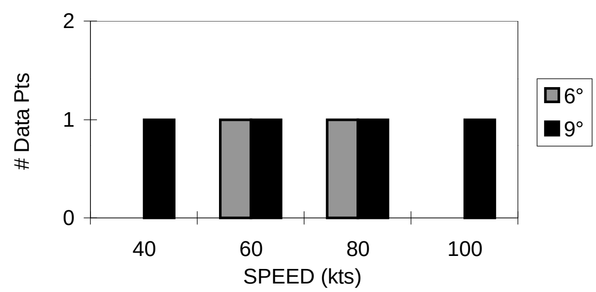
A GRB acoustic database was established for 80 flight conditions as shown in Figure 7. In addition, there were three SRB flyovers obtained at the West Palm Beach test site as described above. All acoustic data have been normalized with respect to unspecified reference levels.



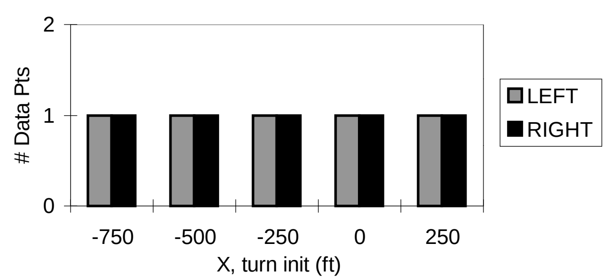
(a) Level Flyovers, 36



(b) Approaches, 27



(c) Departures, 6



(d) Turns, 10

Figure 7. Growth and Standard Rotor Blade Flight Test Conditions in West Palm Beach, FL.

Weather

Wind speed and direction, dry bulb temperature, relative humidity, and barometric pressure were recorded using the weather balloon system. Meteorological data were recorded up to 300 ft above ground level. Figure 8 shows an example of a weather profile acquired during a level flyover.

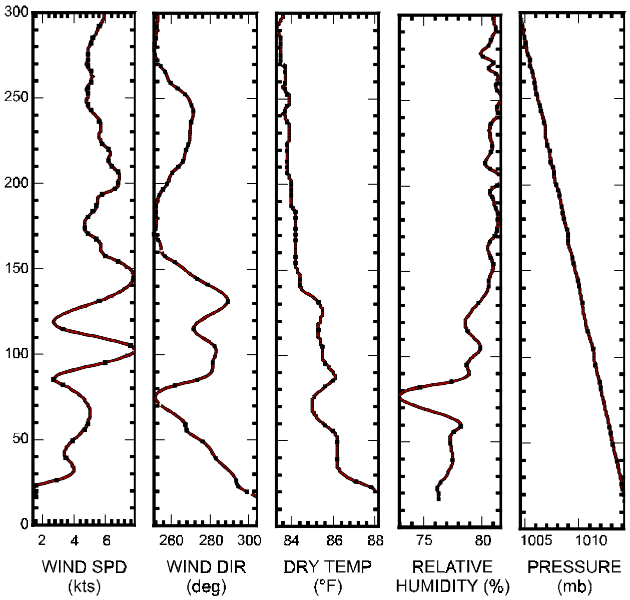
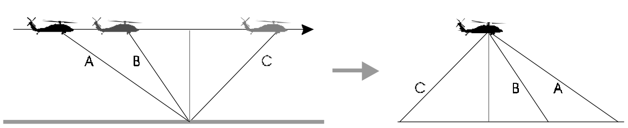


Figure 8. Meteorological data profiles for a level flyover.

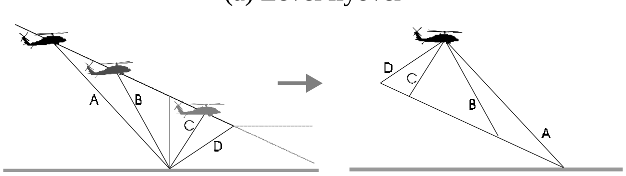
Data Processing and Analysis

The analog data was digitized at a rate of 50 kHz using the ADDRAS system described in reference 9. Various metrics were obtained from the data following procedures in reference 7. The A-weighted, overall sound pressure level (dBA) was chosen for the contour graphics. To describe an entire flyover, the sound exposure level (SEL) was chosen. Data from the three microphones along the flight track, numbers 16, 17, and 18 in Figure 4, were not included in the analysis.

The dBA per half-second of a flyover was matched to the tracking data in order to generate the contour graphics. Figures 9 (a) and (b) illustrate the coordinate transformations performed to produce the contour graphics. The segments A, B, C, and D are shown in the figures before and after the transformations. These transformations produce contour plots of levels as observed on the ground with the aircraft at a given distance. The data is thus displayed as if coming from a single, fixed source, projecting noise to various points on the ground. Reference 7 presents the details of these transformations.



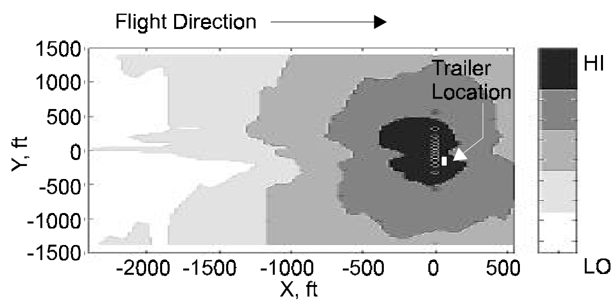
(a) Level flyover



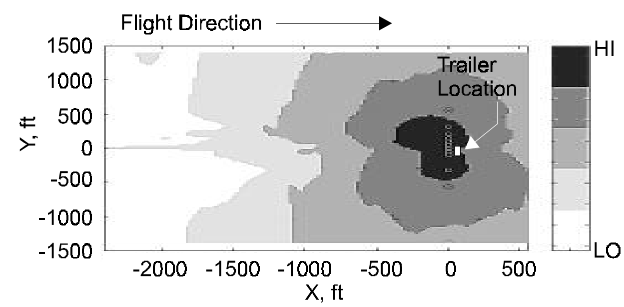
(b) Approach

Figure 9. Coordinate transformations used to generate contour graphics.

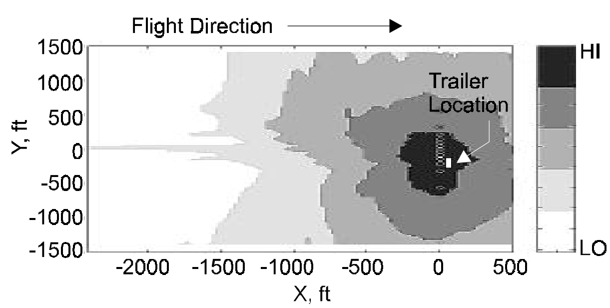
Control Trailer Shielding Effects. As mentioned in the test description, two microphones were mounted on 10-ft scaffolding to minimize the reflection and shielding effects of the control center trailer. To assess the influence of these two microphones on the data, contour graphics of three conditions as shown in Figure 10 were compared. Figure 10(a) shows a level flyover with data from all the microphones. Figure 10(b) shows the same level flyover excluding data from the two elevated



(a) Data from all 15 microphones.



(b) Data from elevated microphones removed.



(c) Flight track directly over trailer, all 15 microphones.

Figure 10. Relative dBA contours in 10 dB increments of level flyovers showing effects of elevated microphones near the control center trailer.

microphones. Figure 10(c) shows data from a level flyover with the aircraft flying in the primary direction, but directly over the trailer.

The contours from Figure 10(b) more closely resemble those of Figure 10(c). Assuming that by flying directly over the trailer and the elevated microphones, the shielding and reflection effects are a minimum, the contours of Figure 10(b) appear to show less "trailer effects" than those of Figure 10(c). However if the data from the elevated microphones were to be presented, they would have to be adjusted for these shielding effects (in addition to other adjustments). As earlier noted, the purpose of this paper is to compare trends between the GRB and SRB data sets and not to compare absolute values of data. Because of this, data from the elevated microphones (numbers 4 and 5) will not be presented.

Level Flight

Data from 36 level flyovers with GRB and three with SRB were obtained. All level flyovers were flown at 250-ft altitude, for a range of 40 to 140 knots indicated air speed (KIAS). Figure 11 shows the relative SEL values for indicated air speeds of 40, 60, 80, 100, 110, and 140 knots. For most microphone locations, an expected increase of SEL proportional to an increase in air speed can be observed from this graphic.

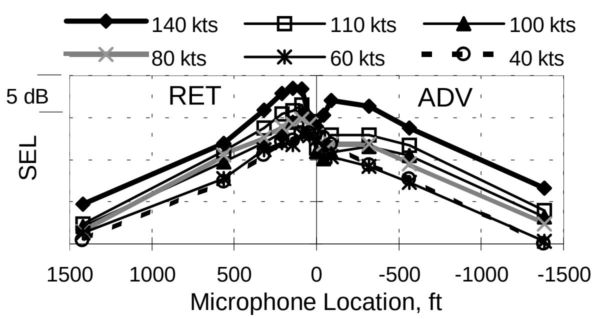


Figure 11. SEL for GRB in level flight for a range of speeds (knots indicated air speed).

Approaches

Data from 27 approaches with GRB and one with SRB were obtained. Approaches were all flown such that the aircraft was at 250 ft altitude when directly over the reference microphone, which is labeled in Figure 5. Figure 12 shows the SEL values for various angles of approach for an indicated air speed of 80 knots. Perhaps because the handling characteristics of the aircraft are very unusual in this condition, the 12° approach data varies noticeably from the other conditions. The SEL peaks on the advancing side in the 12° approach condition, which suggests a change in BVI-noise generation.

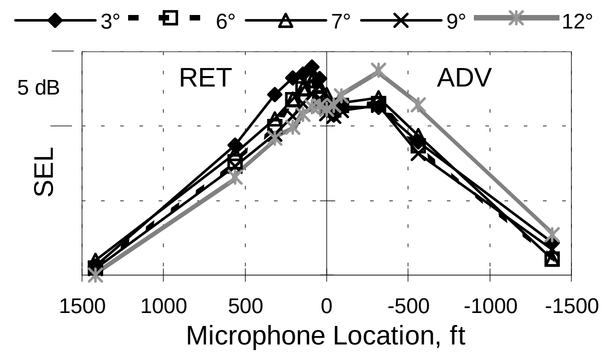


Figure 12. SEL values for 80-kt approach condition.

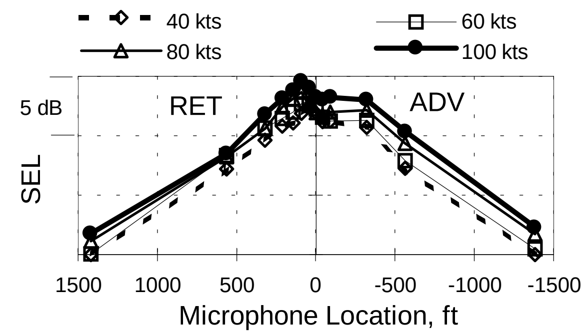


Figure 13. SEL values for 6° approach condition.

GRB vs SRB, Level Flight

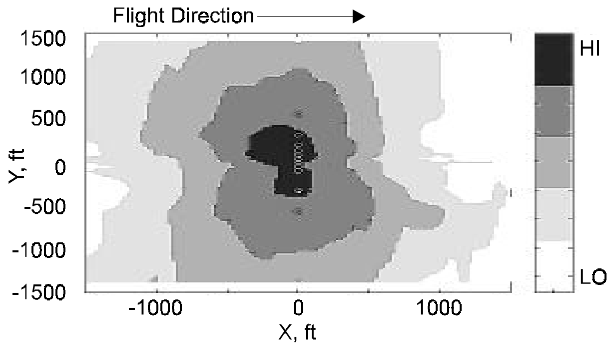
West Palm Beach Test Results. Figures 14 (a) and (b) are contour footprints of the dBA of the GRB and West Palm Beach SRB, respectively, in level flight at 100 knots indicated air speed. A comparison of two contours reveals very little variation in the dBA between the two blades. This is illustrated in Figure 15, which shows the area of each dBA level as a function of dBA for the 15 highest levels. The values shown on the vertical axis of Figure 15, are calculated using the following expression:

$$Y = Area \times \text{antilog}_{10}\left(\frac{NdBA_{OASPL}}{10}\right)$$

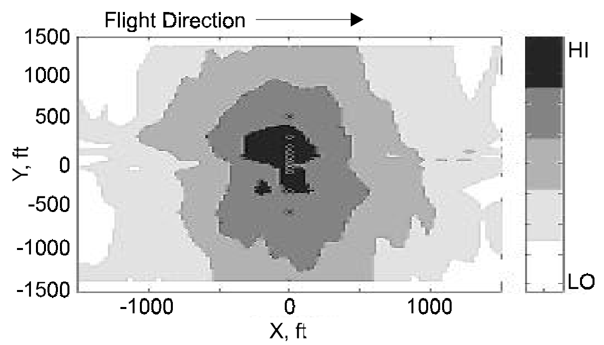
where $NdBA_{OASPL} = 20\log\frac{P(A-weighted)}{P_{ref}(A-weighted)}$

and $P_{ref}(A-weighted)$ is the unspecified normalizing factor.

This measure was chosen as a means to weight the areas as a function of noise level. It emphasizes the areas occupied by the higher levels in the footprints, which are of greater impact to the observer on the ground. The data shown in Figure 15 suggests no improvement with the GRB over the SRB in dBA in level flight.



(a) GRB



(b) SRB (West Palm Beach)

Figure 14. Relative dBA contours in 10 dB increments for 100-kt, level flight condition.

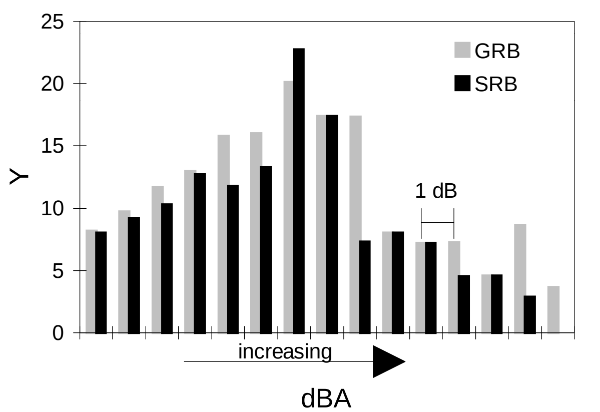


Figure 15. Weighted level flyover contour areas for the 15 highest dBA levels.

Results from West Palm Beach, FL, and Crows Landing Tests. Figure 16 presents a comparison of the trends between the level flight test conditions as obtained for the West Palm GRB and for the Crows Landing SRB. As noted, speed was varied from 40 knots to 140 knots.

The figure shows the changes in SEL values for each microphone relative to the SEL for the minimum speed condition of 40 knots. By comparing these trends, the

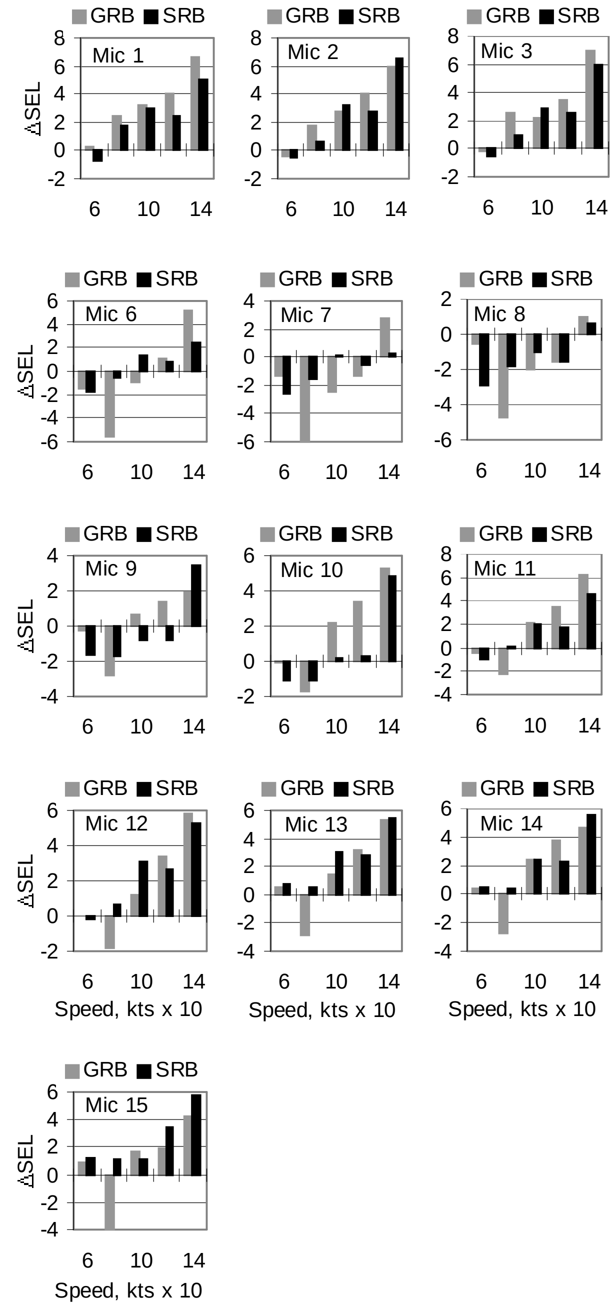


Figure 16. Delta Sound Exposure Levels relative to the 40-knot level flight for the Growth and Standard Rotor Blades.

terrain and environmental effects associated with each site are essentially removed. The figure shows that as the speed increased, the changes in the SEL values for the GRB and the SRB at the microphones were not always consistent. Several examples may be used to show this. Notice at microphone 1, for the 60-knot speed, as the SEL for the GRB slightly increased with respect to its 40 knot speed, the SRB SEL actually decreased with respect to its 40 knot speed. Another example to illustrate the inconsistencies is to observe the data for microphone 10. As the SEL increased by approximately 2 dBA at 100 knots over its relative level at 40 knots for the GRB, the SEL for the SRB only barely increased.

Table 1 is presented in order to place the data into perspective for the level flight conditions. The table was

Table 1. A comparison of SEL trends for level flight conditions relative to the 40-knot condition.

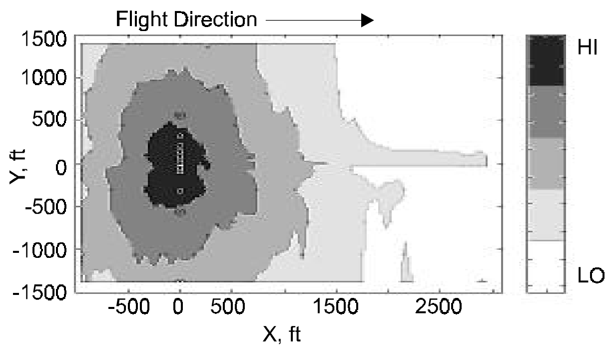
Mic #	60 knots		80 knots		100 knots		110 knots		140 knots	
	GRB	SRB	GRB	SRB	GRB	SRB	GRB	SRB	GRB	SRB
1	--	--		--	--	--		X		X
2	--	--		X	--	--		X	--	---
3	--	--		X	--	--		X		X
6	--	--	X		X		--	--		X
7		X	X		X		--	--		X
8		X	X		X		--	--	--	--
9		X		X		X		X	X	
10		X	--	--		X		X	--	--
11	--	--	X		--	--		X		X
12	--	--	X		X		--	--	--	--
13	--	--	X		X			X	--	--
14	--	--	X		--	--		X	--	--
15	--	--	X		--	--	X		X	
Tot	0	4	8	3	5	2	1	8	2	5

Note: An X indicates a more favorable change as explained in the text, a "--" means the changes were equivalent.

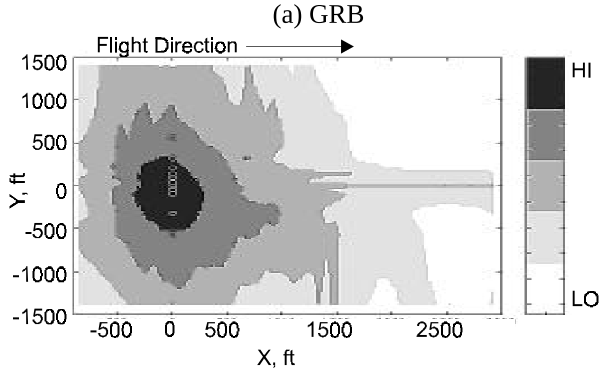
constructed by subtracting the SRB Δ SEL's from the GRB Δ SEL's of Figure 16. If the difference was greater than 1 dB, signifying that the GRB SEL increased more, or decreased less than the SRB SEL, an X was placed in the SRB column. If the difference was less than -1 dB, signifying that the GRB SEL increase less, or decreased more, an X was placed in the GRB column. If the difference was within ±1 dB, the differences were determined to be equivalent, and "--" were placed in both GRB and SRB columns. For example, there were equivalent changes for both the GRB and the SRB for microphone 8 for the 110-knot condition. The table shows there to be a greater number of X's for the SRB, suggesting no improvement in SEL trends with the GRB in level flight as the speed increases from 40 to 140 knots. This appears to substantiate the data presented in Figure 15.

GRB vs SRB, Approach

West Palm Beach Test Results. Figures 17 (a) and (b) are contour footprints of the dBA of the GRB and SRB for the 80-kt, 6° approach case. In these graphics, a marked decrease in areas of the higher dBA levels can be observed. As shown in Figure 18, which uses the weighted-area metric previously introduced, the areas for the higher levels are reduced with the GRB. This is most likely due to the difference in tip designs of the two blades, which would affect BVI-noise generation in approach conditions.



(a) GRB



(b) SRB (West Palm Beach)

Figure 17. Relative dBA contours in 10 dB increments for 80-kt, 6° approach condition.

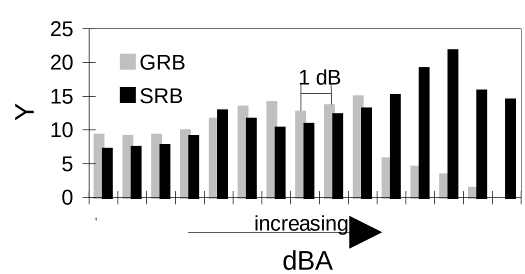


Figure 18. Approach flyover contour areas as a function of normalized dBA level.

Results from West Palm Beach and Crows Landing tests. A comparison of the trends between the Florida GRB data and the California SRB data for all of the approach conditions is presented in Figures 19 and 20.

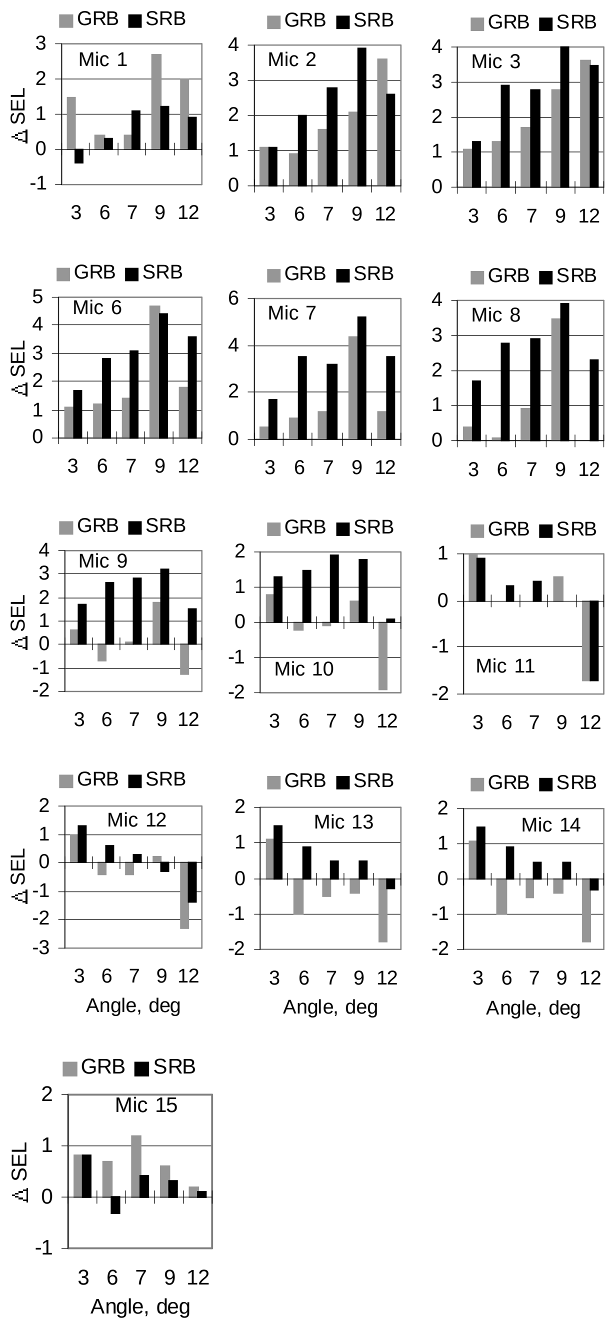


Figure 19. Delta Sound Exposure Levels as a function of angle, relative to a 80-knot level flyover.

Figure 19 compares the trends which occur at each microphone in the array perpendicular to the flight track as the approach angle is varied from 3 deg to 6, 7, 9, and 12 deg as speed is maintained at a constant 80 knots. The figure shows the differences in SEL values for each microphone relative to the SEL for the constant 80 knot level flight, or 0-deg approach angle condition. This comparison permits an examination of the approach effects of the GRB vs. the SRB as they relate to the level flight condition. As noted earlier, such a comparison tends to remove the environmental effects associated with each site. Figure 19 shows that GRB SEL increased at consistently lower increments than the SRB SEL as the approach angle is increased. Figure 19 also shows that the GRB SEL decreased at consistently larger increments than the SRB SEL. In the cases of some microphones, the data show that whereas the SRB SEL tended to increase relative to its level flight SEL, the GRB SEL tended to decrease relative to its level flight SEL.

Table 2 was created in the same manner as Table 1. In general, Table 2 shows that for all of the approach conditions relative to the level flight condition at 80 knots, the GRB column for each of the approach conditions had more X's than the SRB column. There was a grand total of 35 X's for the 13 microphones as compared to a grand total of 5 X's in the GRB columns. This suggests that for approach conditions at a constant speed of 80 knots, the SEL values associated with the GRB offer an improvement over those for the SRB.

Table 2. A comparison of SEL trends for 80-knot approaches relative to a 80-knot level flyover

Mic #	3°		6°		7°		9°		12°	
	GRB	SRB	GRB	SRB	GRB	SRB	GRB	SRB	GRB	SRB
1		X	--	--	--	--		X		X
2	--	--	X		X		X			X
3	--	--	X		X		X		--	--
6	--	--	X		X		--	--	X	
7	X		X		X		--	--	X	
8	X		X		X		--	--	X	
9	X		X		X		X		X	
10	--	--	X		X		X		X	
11	--	--	--	--	--	--	--	--	--	--
12	--	--	X		--	--	--	--	--	--
13	--	--	X		X		--	--	X	
14	X		X		X		X		X	
15	--	--		X	--	--	--	--	--	--
Tot	4	1	10	1	9	0	5	1	7	2

Note: An X indicates a more favorable change as explained in the text, a "--" means the changes were equivalent to within ±1 dB.

Figure 20 compares the trends at each of the same microphones as in Figure 19, as the approach speed is varied from 60 to 80, and 100 knots as the approach angle is maintained at 6 deg. The figure shows the ΔSEL for the GRB and SRB with increase in speed, relative to the 40-knot, 6-deg approach case.

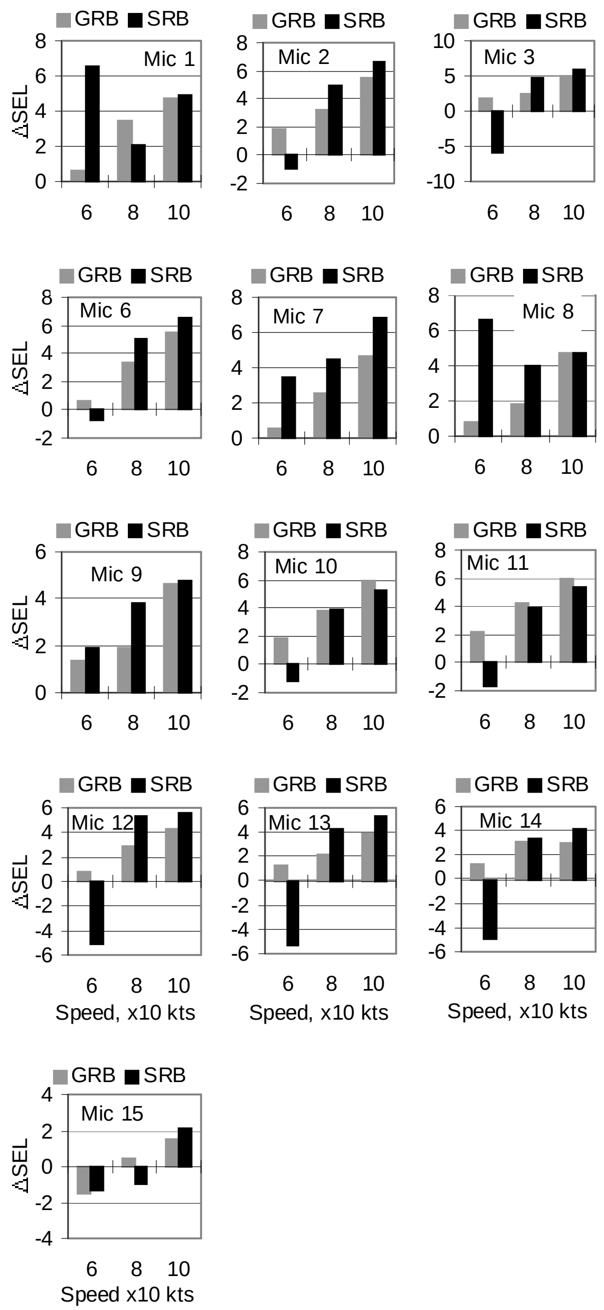


Figure 20. Delta Sound Exposure Levels as a function of speed, relative to the 6-deg, 40-knot approach.

Table 3 presents the results of Figure 20, and was created using the same methodology used to construct Tables 1 and 2. For the constant 6 degree approach, as the approach speed changed from 60 to 80 to 100 knots, relative to the 40 knot speed condition, an X was placed in the SRB column if the SRB levels were lower than the GRB and vice versa. If the values were equivalent to within ±1 dB, a "--" was placed in both columns. In general, the table shows that for 60 knots, the SRB column has 8 microphones which were marked with an X as compared to 3 microphones for the GRB column. For the higher speeds of 80 and 100 knots, the GRB columns have 8 and 6 microphones marked with an X respectively, as compared to 2 and 0 microphones for the SRB. This suggests that at an approach angle of 6 deg and a speed of 60 knots the SEL's relative to the 40 knot descent speed are lower for the SRB than for the GRB. However for the higher descent speeds of 80 and 100 knots, relative to the 40 knot speed, the GRB SEL's are lower than the SRB SEL's. As observed in Tables 2 and 3, the approach SEL trends for the GRB and SRB suggest that there is a decrease in BVI noise for the GRB, perhaps because of the GRB tip design.

Table 3. A comparison of SEL trends for constant 6° approach conditions relative to a 40 knot, 6° approach condition.

Mic #	60 kts		80 kts		100 kts	
	GRB	SRB	GRB	SRB	GRB	SRB
1	X			X	--	--
2		X	X		X	
3		X	X		--	--
6		X	X		X	
7	X		X		X	
8	X		X		--	--
9	--	--	X		--	--
10		X	--	--	--	--
11		X	--	--	--	--
12		X	X		X	
13		X	X		X	
14		X	--	--	X	
15	--	--		X	--	--
Total	3	8	8	2	6	0

Note: An X indicates a more favorable change as explained in the text, a "--" means the changes were equivalent to within ±1 dB.

Concluding Remarks

An acoustics flight test of a full scale UH-60L Black Hawk Helicopter equipped with Growth Rotor Blades (GRB) was conducted at the Sikorsky acoustics test range in West Palm Beach, Florida. Test conditions consisted of level flyovers at speeds from 40 to 140 knots; a constant approach angle of 6 deg at speeds from 40 to 100 knots; and a constant approach speed of 80 knots at approach angles from 3 to 12 deg. Testing was also conducted with the aircraft equipped with standard rotor blades (SRB) so that a minimal amount of data could be collected at 100 knots level flyover and at 80 knots, 6-deg approach conditions. Resulting GRB acoustic data obtained from this test were compared to UH-60 Standard Rotor Blade data acquired during this test and from a previous test of the UH-60 Airloads aircraft flown at Crows Landing, California. A comparison of level flyover dBA contours calculated from the GRB and SRB data show no significant noise improvement by the GRB over the SRB. This result appears to be substantiated by a comparison of the ground areas associated with 15 different levels of dBA. A comparison of the level flyover SEL trends between the GRB and the Crows Landing SRB results shows the same results. A comparison of approach dBA and SEL results, both for the GRB and West Palm Beach SRB data compared to each other and for the West Palm Beach GRB data trends as compared to the Crows Landing SRB trends suggest that in general the GRB produces lower noise on the ground than does the SRB. This is thought to be due to the influence of the GRB tip design on blade-vortex interaction noise.

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