Acoustics • Shock • Vibration • Signal Processing **April 2003 Newsletter**

Svenska

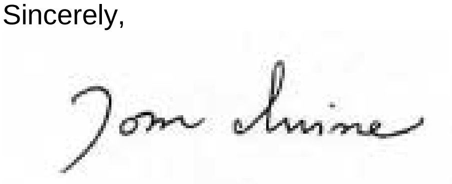
The Boeing Helicopter plant that designs and manufactures Apache helicopter is located in Mesa, Arizona, which is also my hometown. The image of an Apache on the right was taken over the desert outside of the city. Helicopters are fascinating sources of sound and vibration. This month's newsletter describes some of these sources and gives an acoustic analysis of the Apache helicopter.

On another note, I invite readers to participate in the Shock & Vibration Response Spectra and Software Training Course described on page 2. Students receive hands-on vibration analysis training as part of this course.

Students who cannot attend the three-day seminar may take the course as a correspondence, or distance learn course. Recently, one student from Thailand and another from Australia have chosen this option.

Please let me know if you have any questions.

Sincerely,



Tom Irvine
Email: tomirvine@aol.com

Feature Articles

Vibrationdata Announces

Shock & Vibration Response Spectra & Software Training Course

Course Benefits

This training will benefit engineers who must analyze test data, derive test specifications, and design isolation systems, with respect to shock and vibration environments.

Engineers in the aerospace, automotive, medical, petroleum and semiconductor industries can apply the course materials to solve real-world vibration problems.

Course Description

- The course includes PowerPoint slide presentations as well as hands-on software training
- Each student will receive a licensed copy of MIT's EasyPlot software
- Each student will receive software programs which perform the following calculations:

  Power Spectral Density (PSD), Fast Fourier Transforms (FFT), Shock Response Spectrum (SRS), and digital filtering
- Students will receive data samples so that they can practice using the software programs
- Students are also welcome to bring their own data samples

Dates for 2003 Courses

May 7-9

July 9-11

September 17-19

November 5-7

Location

Dynamic Labs
1720 W. Parkside Lane
Phoenix, Arizona 85027

Students may also arrange for onsite training.

For Further Information Please Contact

Tom Irvine
Course Instructor
Vibrationdata
Email: tomirvine@aol.com

Voice: 480-814-6439
Fax: 240-218-4810

http://www.vibrationdata.com/

Apache Helicopter Noise

By Tom Irvine

Figure 1. Boeing AH-64 Apache Helicopter

Introduction

Helicopters serve many functions, including

- Military and police duty
- Medical evacuation
- Search and rescue
- Tours
- Firefighting
- Business transportation
- Moving heavy items

Helicopters are also referred to as rotary-wing aircraft, or rotorcraft.

Helicopter rotors produce distinct sounds. The purpose of this article is to characterize these sounds. Noise from an Apache helicopter is used as a specific example.

Noise Sources

Helicopter noise consists of a complex mixture of sounds.

The repeating impulse noise from the rotor blades is the dominant source of distinct spectral tones. The fundamental tone occurs at a characteristic frequency depending on the number of blades and their rotation speed. The blade-passing frequency (BPF) is the shaft rotation frequency times the number of rotor blades. Noise occurs at the BPF as well as at integer harmonics. Furthermore, both the main rotor and the tail rotor generate this type of noise.

Rotor-vortex interaction noise is another source. This source is also referred to as blade-vortex interaction (BVI) noise. This source is significant in descent or level flight at low and medium velocities. Vortices form in the wake of the blades. A given rotor blade can run into the tip vortex shed by a preceding blade. This causes a distinctive type of noise: the annoying "blade-slap" of helicopters with slow-turning rotors, or a sharp fluttering noise for rotorcraft with fast-turning rotors.

Furthermore, the velocity at the tips of the advancing blades in high-speed forward flight may approach Mach 1. Shock waves begin to form at this condition, leading to shock induced flow separation. The shock waves and turbulent flow generate further noise. This source is referred to as high-speed impulsive (HSI) noise.

In addition, most helicopters are powered by turbine engines. Engine and gearbox noise consists of distinct spectral peaks as well as broadband random noise.

Helicopter Rotor Blades

Rotor blades are not entirely rigid. The advancing blade has higher airspeed than the retreating blade. A fully rigid blade would generate more lift on the advancing side and tip the helicopter over.

Rotor blades are thus designed to lift and twist so that the advancing blade flaps up and develops a smaller angle of attack, thus producing less lift than a rigid blade would.

Conversely, the retreating blade flaps down, develops a higher angle of attack, and generates more lift.

Helicopters have rotor adjustments for height and pitch, to reduce vibration. Most also have vibration dampers for height and pitch. Some also use mechanical feedback systems to sense and counter vibration.

Apache Characteristics

The Apache is a twin-engine army attack helicopter, as shown in Figure 1. It was developed by McDonnell Douglas (now Boeing). It entered service with the US Army in 1984.

The Apache is equipped with two General Electric T700-701C turboshaft engines each providing 1696 horsepower (1265 kW).

Each engine turns a drive shaft, which is connected to a gear box. The gear box shifts the angle of rotation about 90 degrees and passes the power on to the transmission. The transmission applies the power to the main rotor assembly and to a long shaft leading to the tail rotor.

The rotor head is fully articulated as opposed to the more traditional seesaw configuration. As a result, each blade can lead or lag individually, reacting to its individual conditions. This greatly increases aircraft agility. The individual blades are able to move due to the elastomeric bearings where the blade meets the rotor hub. These appear as large blocks at the root of each blade.

The Apache's maximum speed in level flight is 186 mph. The ceiling is 10,200 feet for hover.

The Apache fleet consists of two aircraft models, the AH-64A and the newer Longbow Apache (LBA), AH-64D. The Longbow has an advanced fire control radar.

Apache Noise Data

A sample acoustic pressure time history from an Apache is shown in Figure 2. This data is a subset of the complete record, which is 7.8 seconds long. The data was taken at a ground station as the Apache flew overhead. The original source of this data is the Boeing company website.

The sound file is also posted at

http://www.vibrationdata.com/apache.wav

The corresponding Fourier magnitude is shown in Figure 3. The frequencies of the dominant spectral peaks are shown in Table 1.

Table 1. Spectral Peaks, Ranked in terms of Amplitude

Frequency (Hz)	RPM
153	9240
204	12,120
357	21,480
306	18,360
510	30,600

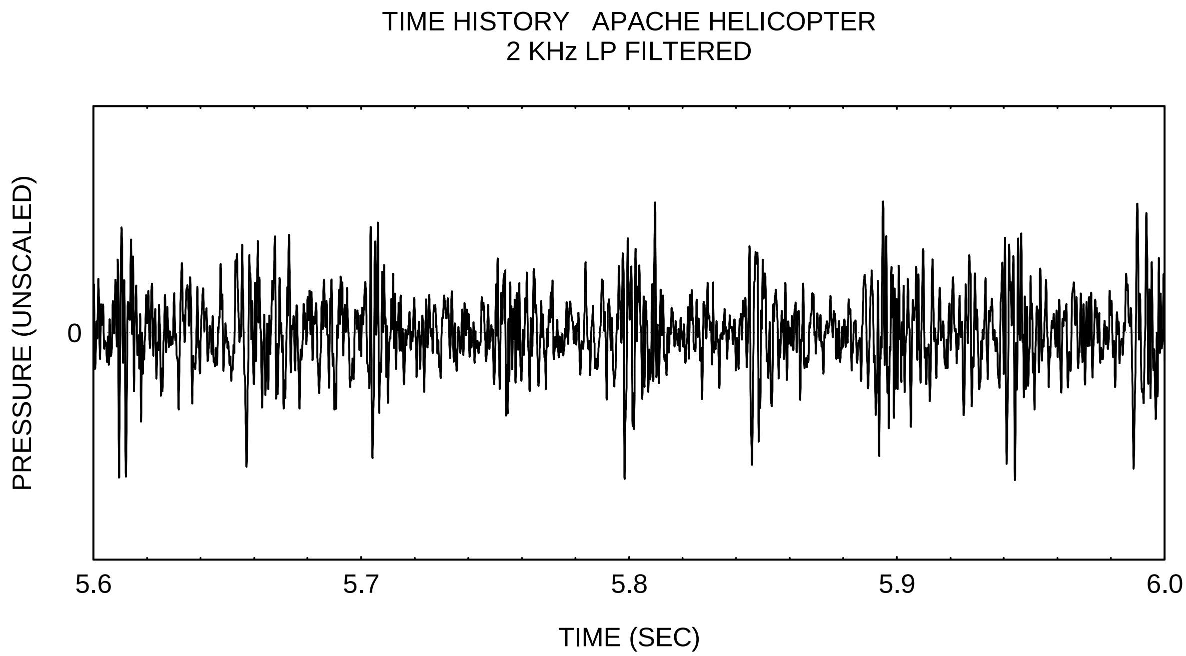


Figure 2.

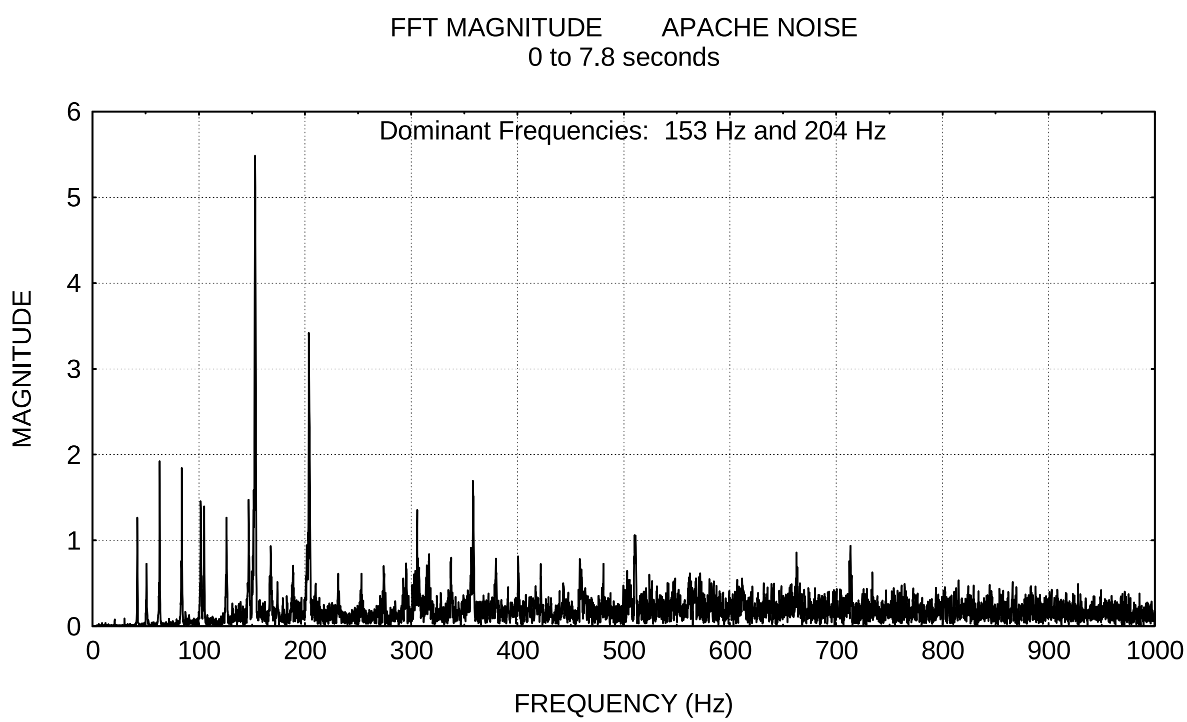


Figure 3.

Figure 4. Main Rotor Hub

Main Rotor Blade Passing Frequency

Again, the four main rotor blades of the Apache are part of a fully articulated rotor system. A fully articulated rotor system allows the rotor blades to flap up and down, lead and lag (fore and aft movement), and twist, all in response to aerodynamic forces and the control inputs made by the pilot.

The main rotor hub of typical helicopters spins from 120 to 400 rpm, or from 2 to 6.7 Hz.

The blade passing frequency for the Apache would thus be from 8 to 26.8 Hz, based on this generic assumption.

The sample Apache data gives several indications that the blade passing frequency is about 20 Hz.

First, the transient pulses in the time history in Figure 2 occur at the rate of about 20 per second.

Furthermore, the Fourier transform in Figure 3 shows a series of spectral peaks separated by about 20 Hz.

For example, peaks occur at 43, 62, 84, and 105 Hz. These spectral peaks are most likely integer harmonics of a fundamental peak at 21 Hz.

The Fourier transform in Figure 3 shows only a very small peak near 20 Hz, however. This may have been due to the lower frequency response limit of the recording equipment.

Note that the lower frequency limit of human hearing is about 20 Hz, which may or may not be coincidental.

Nevertheless, the zoom FFT of the data in Figure 5 shows a spectral peak at 21.0 Hz. The zoom FFT is technique to enhance the spectral resolution of a peak.

Again, note that there is a spectral peak at 105 Hz. This frequency is approximately equal to 5 times 21.0 Hz.

Moreover, a frequency of 21.0 Hz corresponds to a blade passing rate of 1260 rpm.

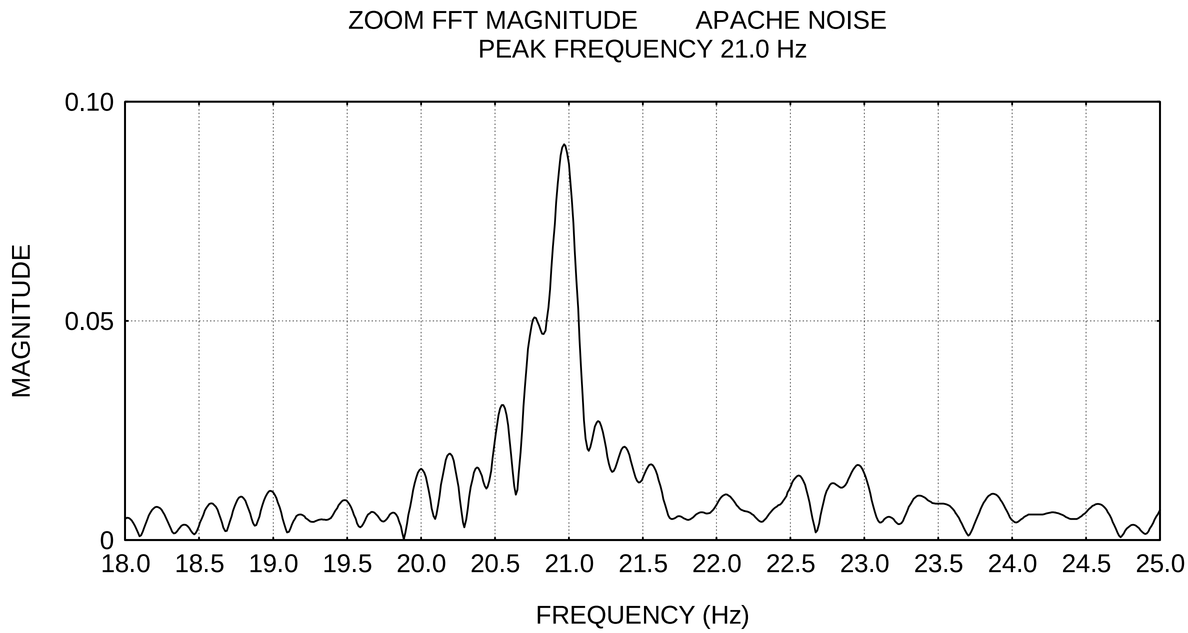


Figure 5.

The main hub spin rate would thus be 315 rpm, which is one-quarter of the blade passing rate. This rate is equivalent to 5.25 Hz.

The FFT is repeated in Figure 6 but with tic marks place every 21 Hz to show the harmonics of the blade passing frequency.

A second set of harmonic begins at 51 Hz with integer multiples thereof. The FFT is thus repeated in Figure 7 with tic marks spaced at 51 Hz.

Turboshaft Engine Speed

The engine spin rate is 72.498 times greater than the main rotor hub rate. The expected engine is speed is thus 380.6 Hz based on the main rotor rate of 5.25 Hz.

The main engine rate in the sample data is thus 22,836 rpm.

The FFT magnitude indeed has a spectral peak near 380 Hz as shown in Figure 8. This peak, however, is more likely the 18^{th} harmonic of the 21 Hz blade passing frequency.

Thus the engine does not appear to contribute a distinct spectral component.

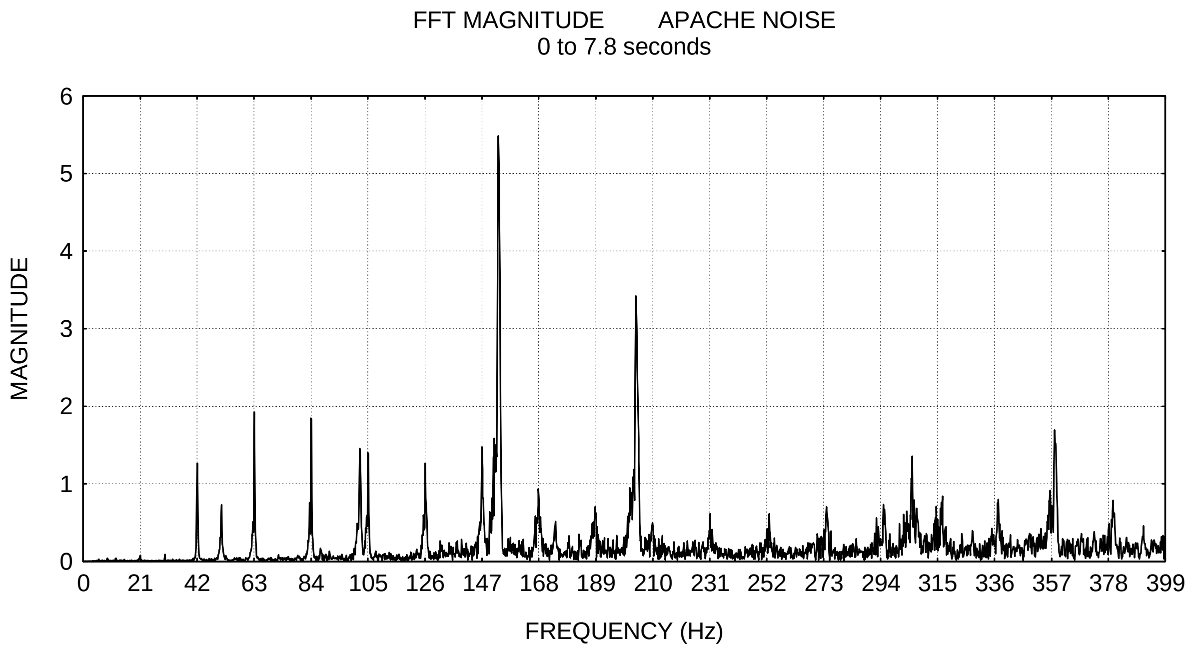


Figure 6.

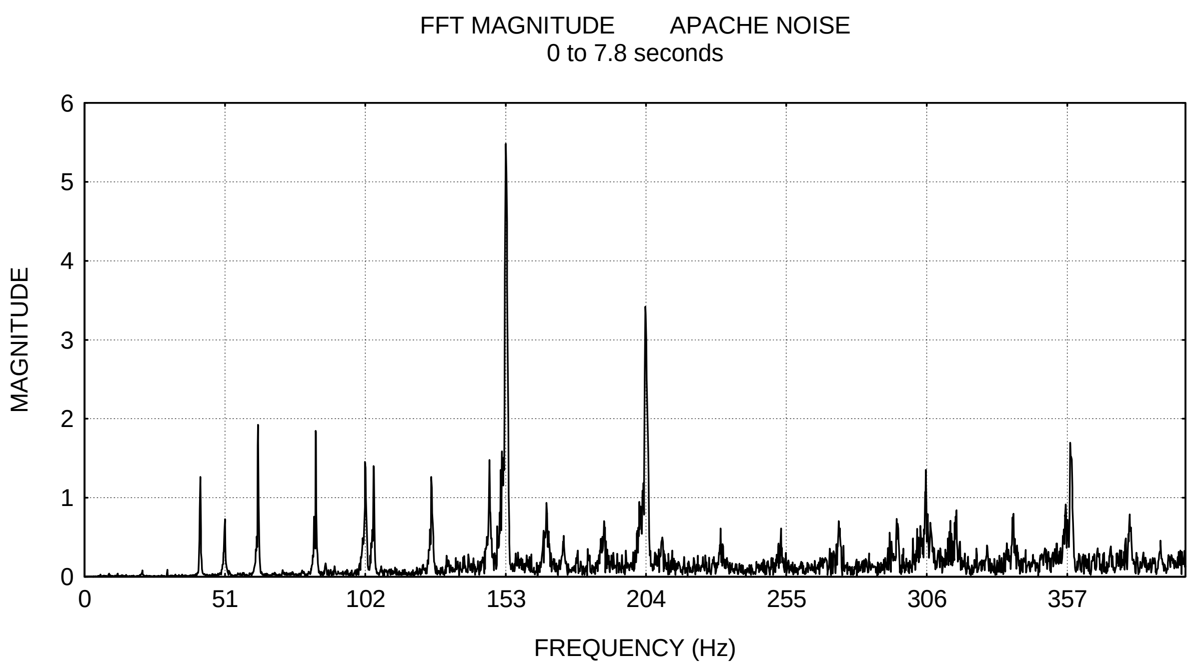


Figure 7.

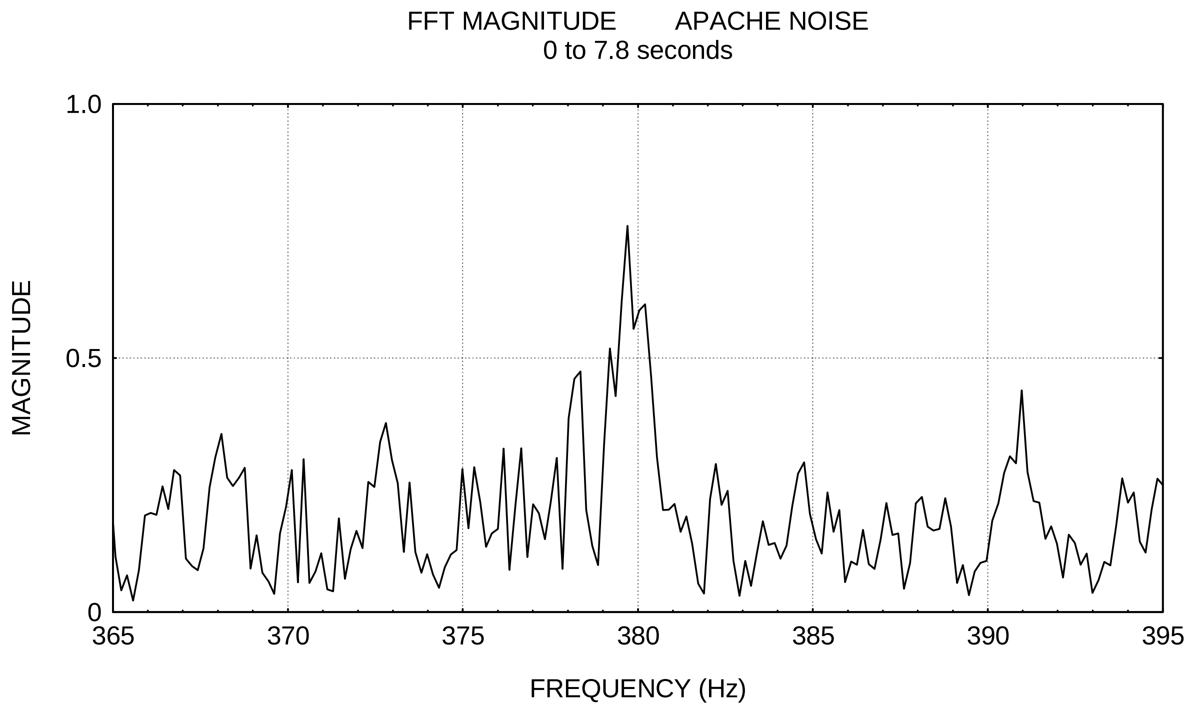


Figure 8.

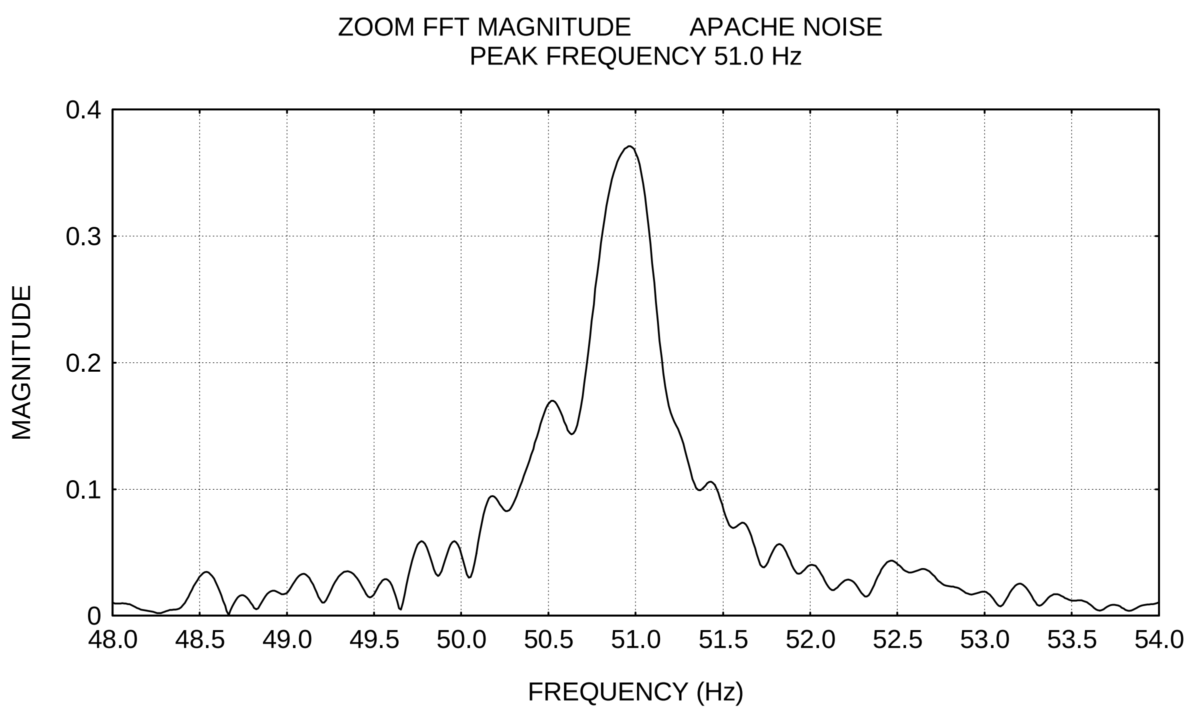


Figure 9.

Figure 10. Apache Tail Rotor

Tail Rotor Blade Passing Frequency

David Lednicer, a fluid dynamics engineer, wrote:

> The worst noise from almost any helicopter is tail rotor noise. Rotors don't like being dragged through the air sideways.

Furthermore, the tail rotor interacts with the main rotor wake.

The Apache tail rotor has four blades. The blades, however, are not oriented 90° (perpendicular) from each other as in most helicopters.

Specifically, one set in front of the other at a 55° angle. The supplementary angle is 125°.

This unusual arrangement is required because the two sets of blades use a "Delta-Hinge" which allows the blades to simultaneously flap and feather.

The purpose of this design is to render the blades more efficient and to reduce noise.

Note that the tail rotor spin rate in typical helicopters is 1000 to 3000 rpm, or 16.7 to 50 Hz.

The main rotor hub and the tail rotor hub are driven by the same source. Thus, there is a fixed ratio between the spin rates of each rotor.

The tail rotor spin rate is about 4.86 times higher than the main rotor rate. An exact ratio is given in Reference 1.

Again, the main rotor spin rate is 5.25 Hz, or 315 rpm. The tail rotor spin rate is 25.5 Hz, or 1530 rpm, per the fixed ratio.

The unique configuration of the blades yields a 2X blade passing frequency at 51 Hz. The blades behave as two pairs rather than as four individual blades. A zoom FFT of this spectral peak is shown in Figure 9.

Integer harmonics of this frequency occur at 102, 153, and 204 Hz. Recall that 153 Hz was the dominant peak in the Fourier transform in Figure 3.

Postscript

The author came across some clarifying information after the initial release of this article.

MIL-STD-810F, Method 514.5 gives the Apache main rotor and tail rotor frequencies as 4.86 Hz and 23.6 Hz, respectively.

The values given previously in this report from measured data were 5.25 Hz and 25.5 Hz, respectively. The measured values were 8.0% higher for each frequency with respect to the corresponding MIL-STD-810F values.

Assume that the Apache main rotor and tail rotor frequencies were operating at the nominal frequencies from MIL-STD-810F for the flyover analyzed previously.

The measured data apparently had a Doppler shift because the helicopter was most likely flying toward the measurement location for most of the time history. Indeed, this is suggested by the corresponding audio file.

Recall that the measurement location was at a fixed location in the ground.

The helicopter was thus traveling toward the microphone at approximately Mach 0.08, or 60 miles per hour, under the nominal rotor speed assumption. Further analysis would be required to verify this.

On the other hand, MIL-STD-810F, Method 514.5, paragraph 2.3.3, subparagraph b states:

> The dominant sinusoids are generated by rotating components of the helicopter, primarily the main rotor(s), but also tail rotor, engine(s), drive shafts, and gear meshing. The normal operating speeds of these components are generally constant, varying less than five percent. However, recent designs have taken advantage of variable rotor speed control that generates a pseudo steady state rotor speed at values between 95 and 110 per cent of the nominal rotor speed.

Whether the Apache has variable rotor speed control is not immediately clear.

Reference

V. Giurgiutiu, et al, Helicopter Health Monitoring and Failure Prevention Through Vibration Management Enhancement Program, Accepted for Publication in the International Journal of Condition Monitoring and Diagnostics Engineering Management, 2001.