NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division

April 25, 2023

Sound Spectrum Study

Specialist's Study Report
By Kyle Garner

1. ACCIDENT

Location:	Bedford, New Hampshire
Date:	December 10, 2021
Airplane:	Swearingen SA-226AT
Registration:	N54GP
Operator:	Castle Aviation Inc
NTSB Number:	ERA22FA086

2. GROUP

A group was not convened.

3. DETAILS OF INVESTIGATION

The purpose of this sound spectrum study was to determine the operating speed of the airplane's engines prior to the accident using Automatic Dependent Surveillance-Broadcast (ADS–B) data and audio data from a nearby residential security camera.

3.1 Accident Airplane

The accident airplane was a Swearingen SA-226AT. The airplane was equipped with two Honeywell TPE331-10UA turboprop engines, each outfitted with a three-bladed propeller. According to the type certificate data sheet (TCDS)[1], the engine was rated to a maximum continuous output of 2000 revolutions per minute (RPM).

3.2 Security Video[2]

A residential security camera, located at approximately 42.9217° N latitude and 71.4819 ° W longitude, captured video and audio of the accident airplane on approach to Manchester-Boston Regional Airport (MHT). The video was eight minutes

[1] Federal Aviation Administration (FAA) TCDS No. E4WE, Rev. 34.
[2] For more information about the video files recovered see the *Video Summary – Specialist's Factual Report*, which is available in the docket for this accident.

and eight seconds in duration and included audio recorded at a rate of 11,025 Hertz (Hz). The accident airplane was only audible for about 40 seconds of the recording.

3.3 ADS-B Data

ADS-B data from the accident flight was sourced for use in this study. The data included information about the airplane's location (latitude and longitude), groundspeed, altitude, and ground track. Data were sampled at a rate of about 1Hz.

3.4 Time Correlation of Video and ADS-B Data

The security video did not include any reference to real-time, thus a time correlation was performed. The final ADS-B data return was at 23:30:51 eastern standard time (EST) and was located about 600 feet from the reported wreckage location. While the airplane's impact with terrain was not visible on the security video, a noise likely from the impact was audible on the recording and visible in the spectrum at 04:01 video elapsed time.

Equation 1 approximates the speed of sound, c, in feet per second in still air:

$$c = \sqrt{\gamma R(T + 459.67)} \qquad \text{(eqn. 1)}$$

where γ is the specific heat ratio for air, R is the molar gar constant for air, and T is the temperature of the air in Fahrenheit. Using a reported air temperature of 28.4 degrees Fahrenheit from the nearby weather station at MHT, the speed of sound at the time of the accident was about 1083 feet per second.

The security camera was located about 7500 feet from the reported wreckage location. Ignoring any effects due to wind[3], the sound of the impact would have taken about 6.9 seconds to reach the security camera.

Using the information above, it was determined that the video started (video elapsed time of 00:00) at about 23:26:50 EST.

3.5 Observed Frequency Determination

A sound spectrum study was performed to determine the observed engine frequencies recorded at the security camera's location. The noise generated by the propeller for this type of engine configuration is generally the strongest at the fundamental blade passage frequency (BPF)[4]. For example, at 2000 RPM the noise from a three-bladed propeller would be most evident at the BPF of 100Hz (eqn. 2).

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[3] The 23:21 METAR at MHT, issued prior to the accident, reported the wind as calm.
[4] Smith, M. (1989). "Aircraft Noise." Cambridge University Press.

$$RPM = BPF \left[\frac{blades}{sec}\right] \times \frac{1}{3} \left[\frac{rev}{blades}\right] \times 60 \left[\frac{sec}{min}\right] \qquad \text{(eqn. 2)}$$

A three-dimensional (3D) spectrogram was generated, as shown in Figure 1, from the audio extracted from the video file from 02:30 to 04:10 video elapsed time (23:29:20 to 23:31:00 EST). The x-axis represents time in elapsed seconds and the y-axis represents sound frequency in Hz. The color represents sound intensity, with blue being the lowest intensity sound and red being the highest intensity. A dotted line referencing the BPF at 2000 RPM (100Hz) and the first and second harmonic (200 and 300Hz, respectively) are shown for reference.

Of note in the 3D spectrogram is the split of the intense frequency bands between about 03:35 and 03:40 video elapsed time (23:30:25 to 23:30:30 EST). The cause of this split was not able to be determined in this study.

Also, note the gradual downward slope of the lines of intense frequency as time passes, suggesting that the influence of the Doppler effect should be considered.

The Doppler effect causes sound frequencies emitted from a source to appear higher to a stationary observer if the source is moving toward the observer, equal as the source passes the observer, and lower as the source moves away from the observer. The source frequency, f_s, is given by the following expression for a stationary observer[5]:

$$f_s = \frac{c - v_s \cos\theta}{c} f_o \qquad \text{(eqn. 3)}$$

where f_o is the observed frequency, c is the speed of sound, v_s is the magnitude of the source velocity, and θ is the angle between the source velocity vector and the line-of-sight vector from the source to the observer.

Two-dimensional (2D) spectrum plots were then generated, using a 32,768-point Fast Fourier Transform (FFT) algorithm to determine the fundamental observed engine frequencies when the airplane was audible on the recording from about 03:01 to 03:38 video elapsed time (23:29:51 to 23:30:28 EST). After 03:38 video elapsed time (23:30:28 EST), the signal-to-noise ratio was low enough such that the fundamental observed engine frequencies were no longer discernable on the 2D spectrum plots.

[5] Note that this formula is simplified and a result of several assumptions, including but not limited to: (1) the observer is stationary, (2) the source is moving toward the observer, (3) the source is in linear unaccelerated motion, and (4) the source is far enough from the recording device that the elevation angle does not change appreciably.

3.6 Source Frequency & RPM Determination

The source frequency and engine RPM was then determined for each point in time using the Doppler equation (eqn. 3) and the BPF equation (eqn. 2). A summary of the results of this computation is shown in Table 1. Full results are provided in comma-separated values (CSV) format as Attachment 1 to this report.

Table 1. Doppler shift and calculated engine RPM[6].

Sound Emitted Time (EST)	Sound Received Time (EST)	Observed BPF (Hz)	Calculated Source BPF (Hz)	Calculated Engine RPM (RPM)
23:29:51.6	23:29:59.0	135.9	110.9	2218
23:29:52.4	23:29:59.7	120.5	98.9	1977
23:29:53.5	23:30:00.6	120.5	99.5	1991
23:29:54.6	23:30:01.5	120.5	100.2	2003
23:29:55.6	23:30:02.4	119.1	99.7	1995
23:29:56.5	23:30:03.1	117.8	99.2	1983
23:29:57.7	23:30:04.1	117.8	100.0	2000
23:29:58.7	23:30:04.9	117.1	100.0	2000
23:29:59.5	23:30:05.6	115.7	99.6	1992
23:30:00.3	23:30:06.3	115.7	100.2	2004
23:30:01.3	23:30:07.2	115.0	100.3	2007
23:30:02.1	23:30:07.9	115.0	101.2	2023
23:30:02.9	23:30:08.6	113.7	100.7	2014
23:30:04.1	23:30:09.6	112.4	100.6	2012
23:30:05.2	23:30:10.6	112.4	101.6	2031
23:30:06.2	23:30:11.5	111.0	101.3	2026
23:30:07.2	23:30:12.4	109.7	101.0	2020
23:30:08.3	23:30:13.3	109.7	101.9	2037
23:30:09.3	23:30:14.3	108.3	101.5	2030
23:30:10.4	23:30:15.3	107.0	101.2	2025
23:30:11.3	23:30:16.1	107.0	102.0	2041
23:30:12.3	23:30:17.0	105.6	101.5	2031
23:30:13.3	23:30:17.9	103.6	100.5	2009
23:30:14.3	23:30:19.0	103.6	101.5	2030
23:30:15.2	23:30:19.8	102.3	101.2	2025
23:30:16.2	23:30:20.8	100.9	100.6	2012
23:30:17.1	23:30:21.6	100.9	101.5	2031
23:30:18.1	23:30:22.6	98.9	100.5	2010
23:30:19.2	23:30:23.7	98.2	100.6	2013
23:30:20.2	23:30:24.7	98.2	101.6	2032
23:30:21.1	23:30:25.6	96.9	101.1	2021
23:30:22.2	23:30:26.7	95.6	100.5	2009
23:30:23.1	23:30:27.7	95.6	101.2	2023
23:30:24.2	23:30:28.8	94.2	100.4	2007
23:30:25.2	23:30:29.8	94.2	101.0	2020
23:30:26.2	23:30:30.9	94.2	101.4	2029
23:30:27.2	23:30:32.0	92.9	100.4	2008
23:30:28.3	23:30:33.1	92.9	100.7	2013

3.7 Summary

A sound spectrum study was performed to determine engine speed in RPM prior to the accident using recorded audio from a stationary security camera at a nearby residence. Because the airplane was moving relative to the security camera at the time of the accident, the Doppler frequency shift had to be calculated. The study determined the time history of engine RPM during the audio recording.

[6] Note that only one value for calculated engine RPM is provided, however, the airplane was equipped with two engines. The calculated engine RPM is assumed to be the same for both engines. This study was not able to determine a calculated engine RPM for each engine independently.

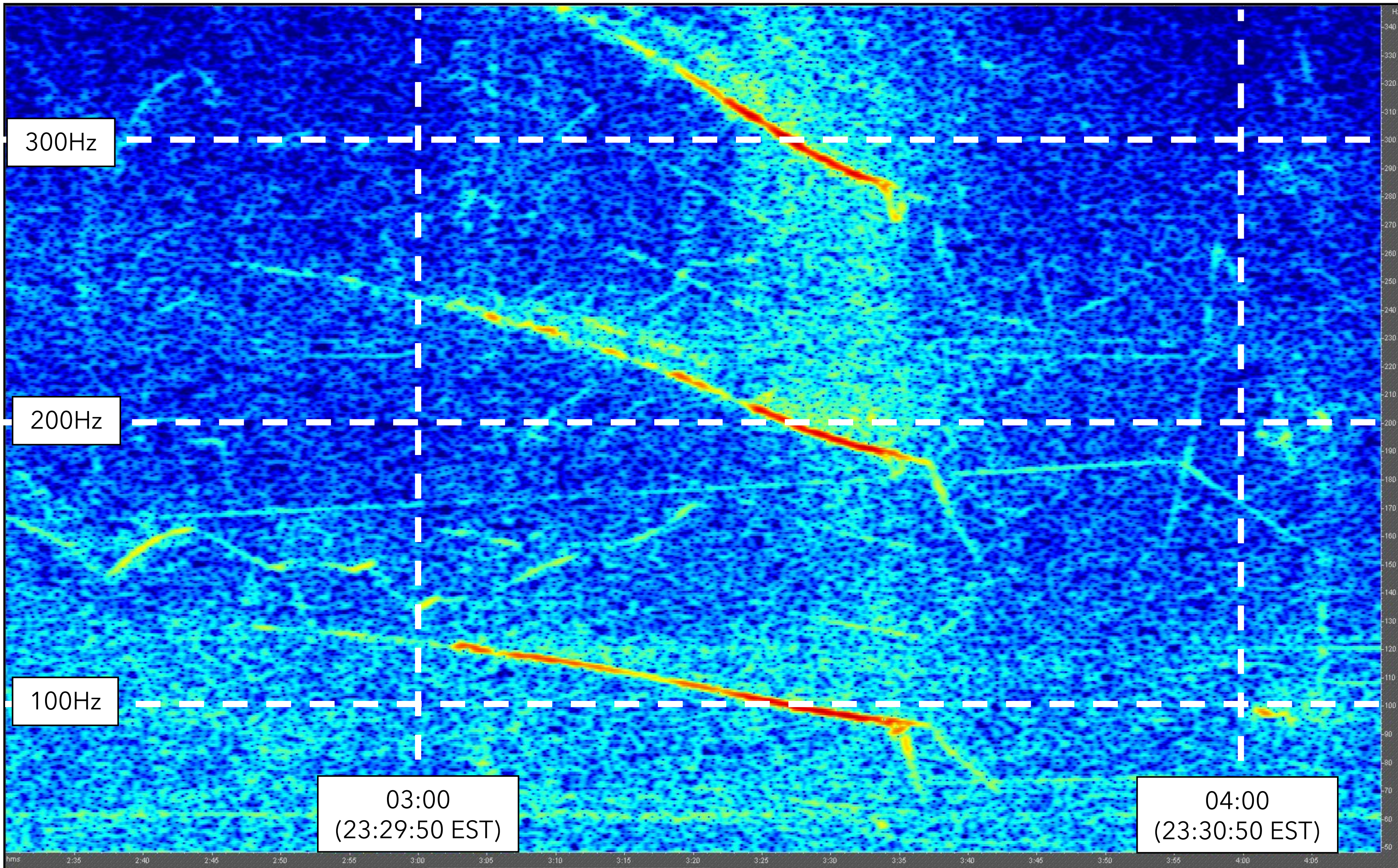

Figure 1. 3D spectrogram of audio – 02:30 to 04:10 video elapsed time (23:29:20 to 23:31:00 EST).