NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division

April 10, 2018

Sound Spectrum Study

Group Chairman's Study Report
By Christopher Babcock

1. EVENT SUMMARY

Location:	Palm Bay, Florida
Date:	September 6, 2016
Aircraft:	Sikorsky S-61N, Registration N805AR
Operator:	AAR Airlift Group
NTSB Number:	ERA16FA311

On September 6, 2016, about 1340 eastern daylight time, a Sikorsky S-61N, registration N805AR, was destroyed when it impacted a field under unknown circumstances near Palm Bay, Florida. The airline transport pilot, commercial copilot, and maintenance crewmember were fatally injured. The helicopter was registered to EP Aviation LLC and operated by AAR Airlift Group as a post-maintenance flight conducted under the provisions of Title 14 *Code of Federal Regulations* Part 91. Visual meteorological conditions prevailed, and a company flight plan was filed for the local flight that departed Melbourne International Airport (MLB), Melbourne, Florida, at 1324.

Three sound spectrum group meetings were held to examine engine, generator, and rotor sounds found on the aircraft's CVR recording. A third sound spectrum group was convened to correlate the CVR to witness video using sound spectrum data, develop a more precise time history of Ng and Nr, and document other sound spectrum observations

2. GROUP

Sound spectrum group meetings were convened on October 2, 2016, March 22, 2017, and December 18, 2017.

Chairman:	Christopher Babcock (3rd group meeting) Aerospace Engineer National Transportation Safety Board
Chairman:	James Cash (1st and 2nd group meeting) Electrical Engineer National Transportation Safety Board
Member:	Stuart K. Drost (1st, 2nd, and 3rd group meeting) Lead Acoustics Engineer Sikorsky Aircraft

Member:	David Gridley (1st and 2nd group meeting) Flight Safety Investigator GE Aviation
Member:	Patrick Hempen (1st and 2nd group meeting) Air Safety Investigator Federal Aviation Administration
Member:	Richard Wallace (1st and 2nd group meeting) Pilot AAR Airlift Group
Member:	Bruce Widzgowski (3rd group meeting) Manager, Flight Safety Department AAR Airlift Group

3. DETAILS OF INVESTIGATION

3.1 First sound spectrum group meeting

The sound spectrum group convened on October 2, 2016, to examine the accident aircraft's CVR recording and document significant rotor system and engine sounds that could be heard during the flights. During the 2-hour recording, the aircraft made three engine starts, three takeoffs and two full stop landings.

The audio sounds recorded on the cockpit area microphone (CAM) channel of the cockpit voice recording recording were digitized and examined using a software frequency analysis program to document the sounds. Sound signatures were identified on the audio recording that correspond to the rotational frequencies of the "gas producing" Ng compressor of the engine. In addition to the Ng sound signatures, several tones were identified that could be associated with the rotation of the main rotor system, Nr, of the helicopter. Using conversion documentation supplied by the helicopter's manufacturer, the recorded sounds were converted from the recorded frequencies to engineering units.

The following conversions from measured frequency to engineering units were used:

For Ng engine conversion: Engine frequency of 438.33 Hz equals 100% Ng speed. For Nr conversion: Apparent planetary mesh frequency of 659.8 Hz equals 100% Nr speed.

The speed of the main rotor system was measured by identifying the planetary gear mesh sound signature. This meshing of the gears produces an actual sound signature of 663.1 Hz at 100% Nr; however, according to Sikorsky, phase and measurement effects will show an apparent planetary mesh frequency of 659.8 Hz at 100% Nr. The planetary gear sound signature is very loud and quite pronounced on the spectrogram of the CAM channel of the CVR (see Figure 1).

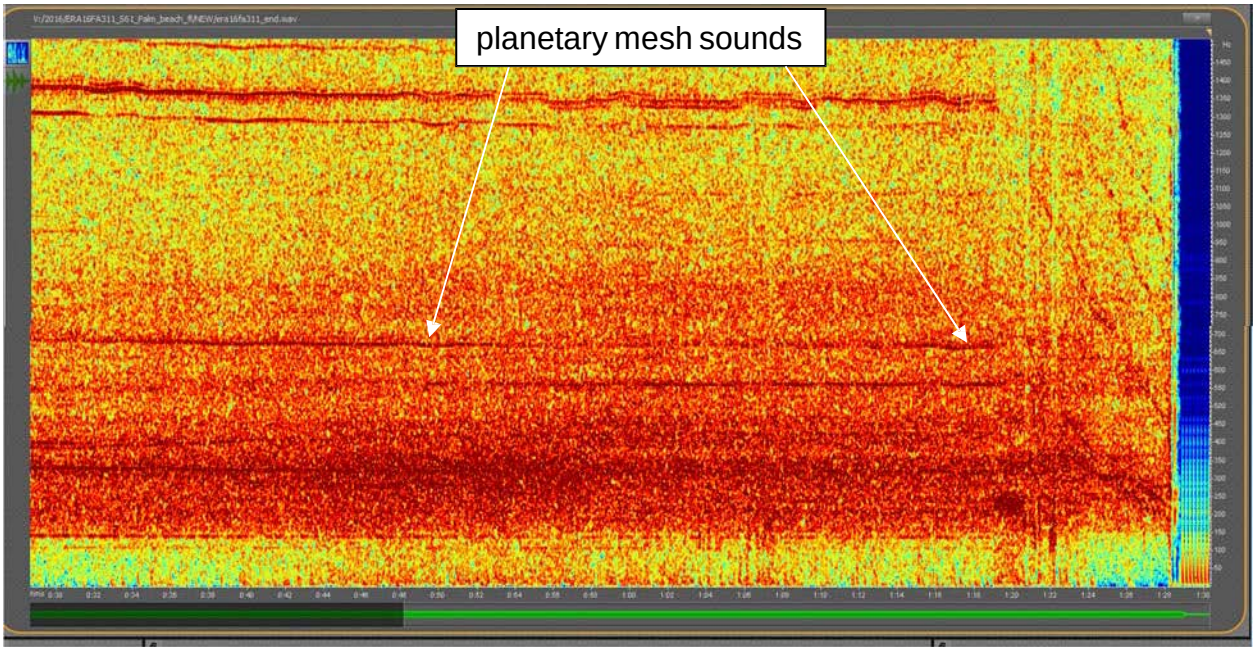

Figure 1. Apparent planetary mesh frequency for the last minute of flight.

A spectrogram is a three-dimensional presentation of the time, frequency, and energy contained in the various signals. This spectrogram depicts time along the bottom axis of the chart. Frequency in Hertz is presented along the vertical axis. Energy of the sounds is presented by the different colors associated with the signals. The colors range from the darker blue-green colors that represent low energy signals to the lighter yellows and reds that represent higher energy signals.

Similar techniques were used to identify and measure sounds associated with the rotational frequencies of the gas generators of each engine. The rotating gas generator of the engine produces noise at the fundamental (primary) frequency and at integer multiples or harmonics of that frequency. The sixth harmonic of the gas generators produced the most identifiable sound signature during operation (see Figure 2).

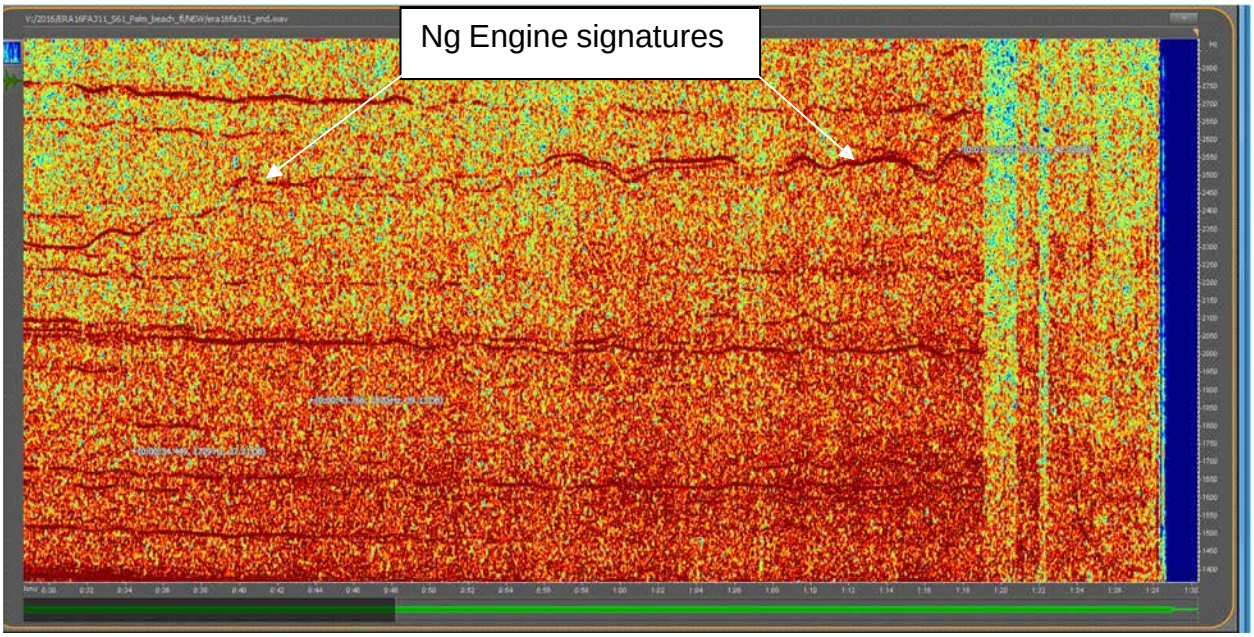

Figure 2. Sixth harmonic of Ng fundamental frequency for the last minute of flight.

The various traces were measured from Figures 1 and 2 and the resulting measured frequency data were converted to Nr and Ng speeds in % RPM.

3.2 Second sound spectrum group meeting

On March 22, 2017, the sound spectrum group reconvened to examine another portion of the accident aircraft's CVR recording. During the accident flight, the crew performed another rearward flight maneuver similar to the accident maneuver. During this previous maneuver, the crew noted that an engine compressor stall had occurred. This portion of the CVR recording was examined to document the aircraft's Nr and Ng speeds during the rearward flight maneuver using the same techniques used during the first sound spectrum group meeting. Figure 3 depicts the aircraft's apparent planetary gear mesh sounds related to the rotor system during the rearward flight maneuver. Figure 4 depicts the various engine Ng sound signatures during the previous rearward flight maneuver.

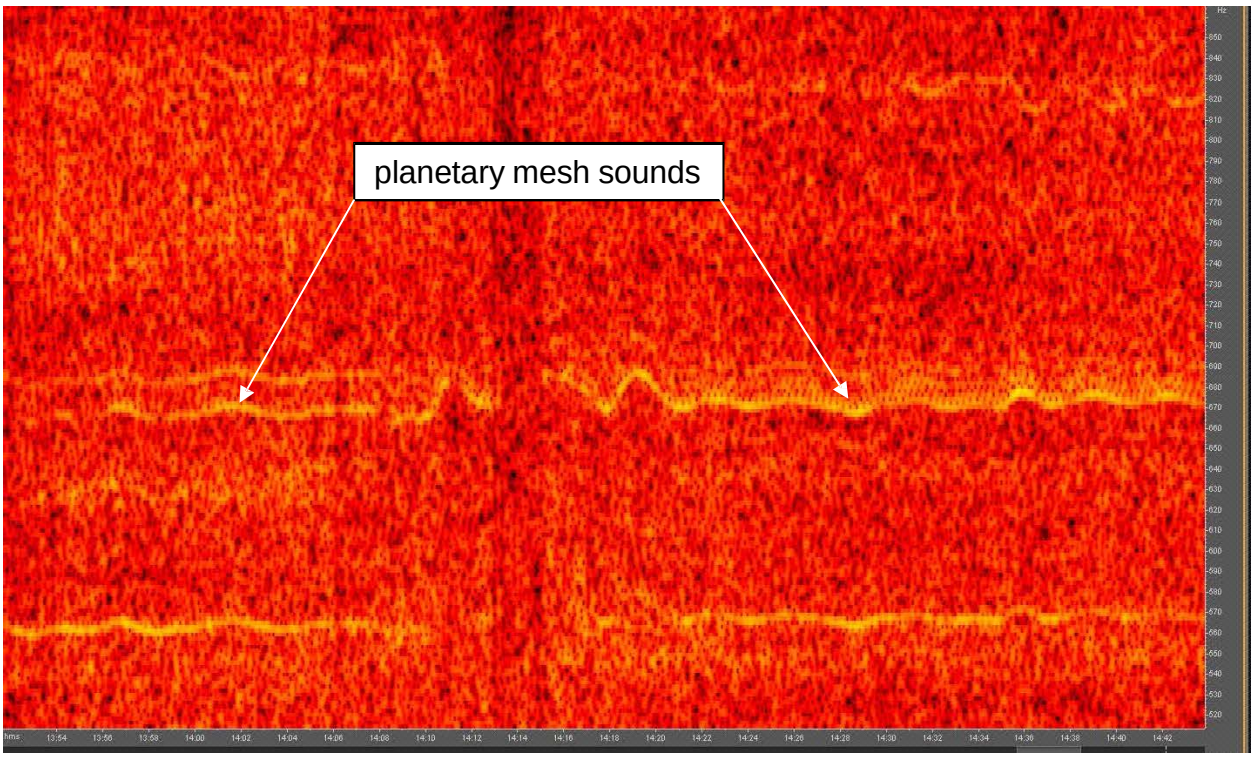

Figure 3. Apparent planetary mesh frequency for the first rearward flight maneuver.

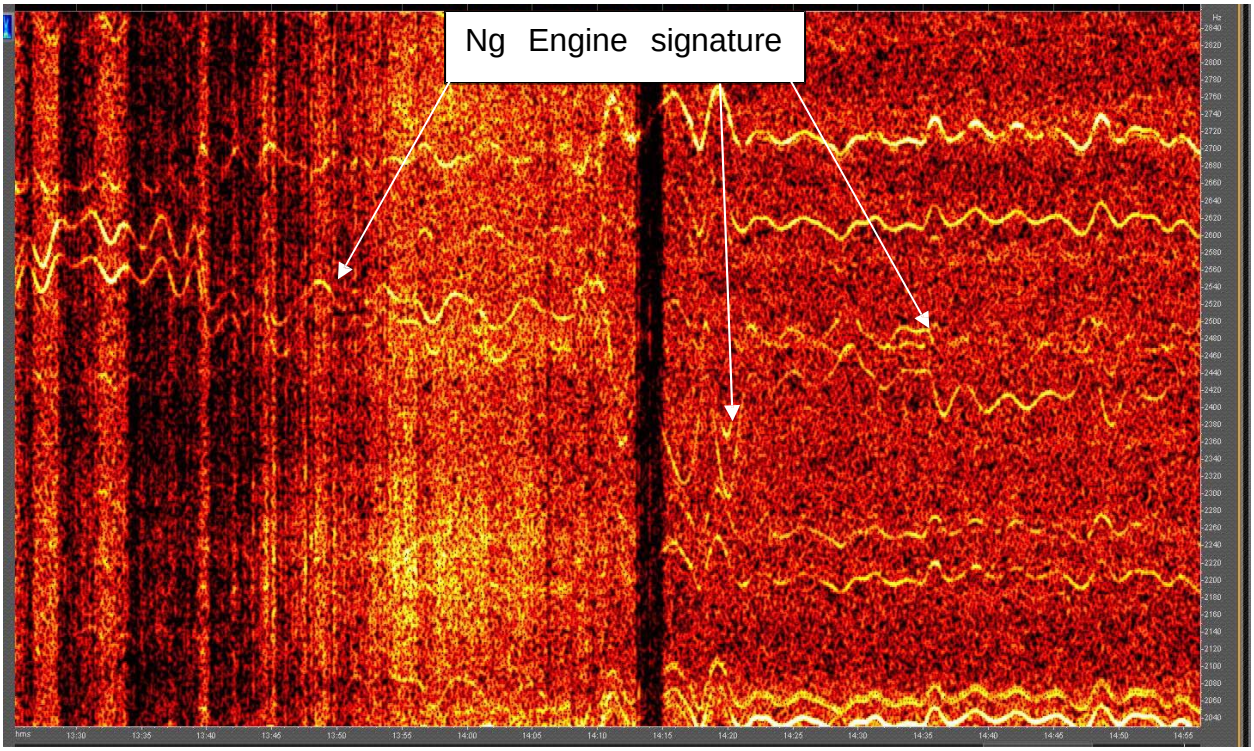

Figure 4. Sixth harmonic of Ng fundamental frequency during first rearward flight maneuver.

3.3 Third sound spectrum group meeting

On December 18, 2017, the sound spectrum group convened for a third time in order to more precisely quantify Nr speed using electrical generator bleed through on a crew

channel and to time correlate a witness video recorded on the ground of the first rearward flight maneuver.

Witness video was provided to the NTSB that showed the first rearward flight maneuver and recovery. The color video was recorded using an unknown mobile device with a resolution of 1920 x 1080 pixels, a framerate of 60 frames per second (fps), audio sampled at 44,100 Hz and 24-bit depth. A time correlation was attempted to match the flightpath shown in the video with the crew conversation and events occurring on the CVR.

Examination of the video showed spectral content in the range of 11200-12500 Hz. This frequency range is similar to the frequency range of the blade passage frequency of the first stage compressor on the engine where 100% Ng is 13150 Hz blade passage frequency. Because this frequency is too high to be seen on the CVR, the shape of this trace was fit to the 6th harmonic of the Ng core trace on the CAM channel of the CVR to determine a time offset to match the video (Figure 5). Using the timing determined in the *CVR Group Chairman Factual Report*, the start of the video occurred at 1336:55.2 EDT.[1]

While Doppler effects exist, they are small in this case as the helicopter was moving slowly with respect to the witness. Because the helicopter was very close to witness at the time where the spectra were matched, the delay due to the travel time of the sound waves was small as well. A copy of the video with a time stamp applied can be found in the public docket as Attachment 2 to this study. [2]

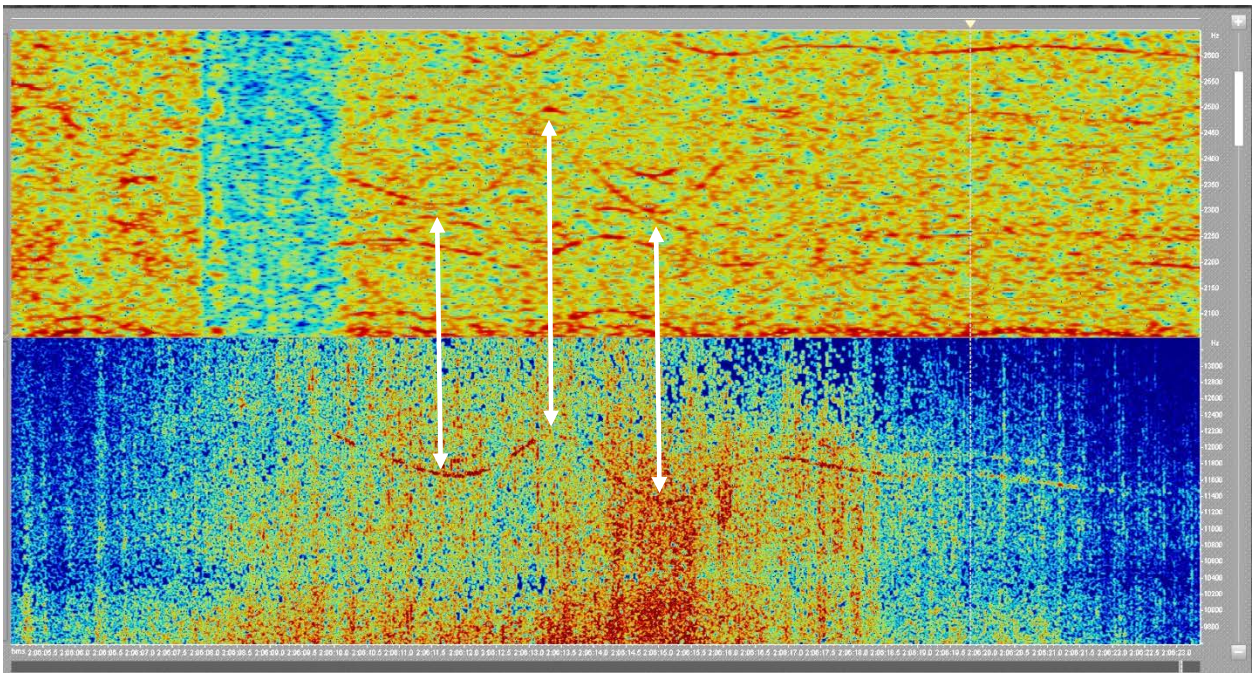

Figure 5. Matched spectrum of the CVR CAM channel (upper) and the witness video (lower).

A plot was prepared after the first two sound spectrum groups that showed a trace of rotor speed through the two events based on the analysis of the CAM channel. A frequency trace on the CAM channel was identified as the planetary mesh frequency from which the

[1] The CVR Group Chairman Factual Report can be found in the public docket for this accident

[2] The timestamp uses frames instead of decimal seconds to provide the most precise format for presenting time on the 60 fps video.

rotor speed could be determined. This plot was continuous through a section of audio during each event that was overdriven and thus did not provide enough valid data to continue the trace through those regions. Overdriven, or clipped, audio exhibits a distortion when an input signal's amplitude is beyond the maximum level the recording system is able to handle.

An alternate means to determine the rotor trace over the entirety of the two events was proposed. Analysis of one of the unused crew channels contained very low levels of electrical bleed through AC generators. As the generators are directly linked to the aircraft drivetrain, a continuous determination of rotor speed through the entirety of the two events could be determined because this channel did not suffer from the overdriven audio problem present on the CAM channel and was subject to less noise than what was found on the CAM channel. At 100% Nr, the frequency of the generator bleed through on the crew channel of the CVR is 400.5 Hz, according to Sikorsky. Figure 6 shows a spectrogram of the electrical bleed through on the crew channel during the accident sequence and Figure 7 shows a spectrogram of the electrical bleed through during the first rearward flight maneuver.

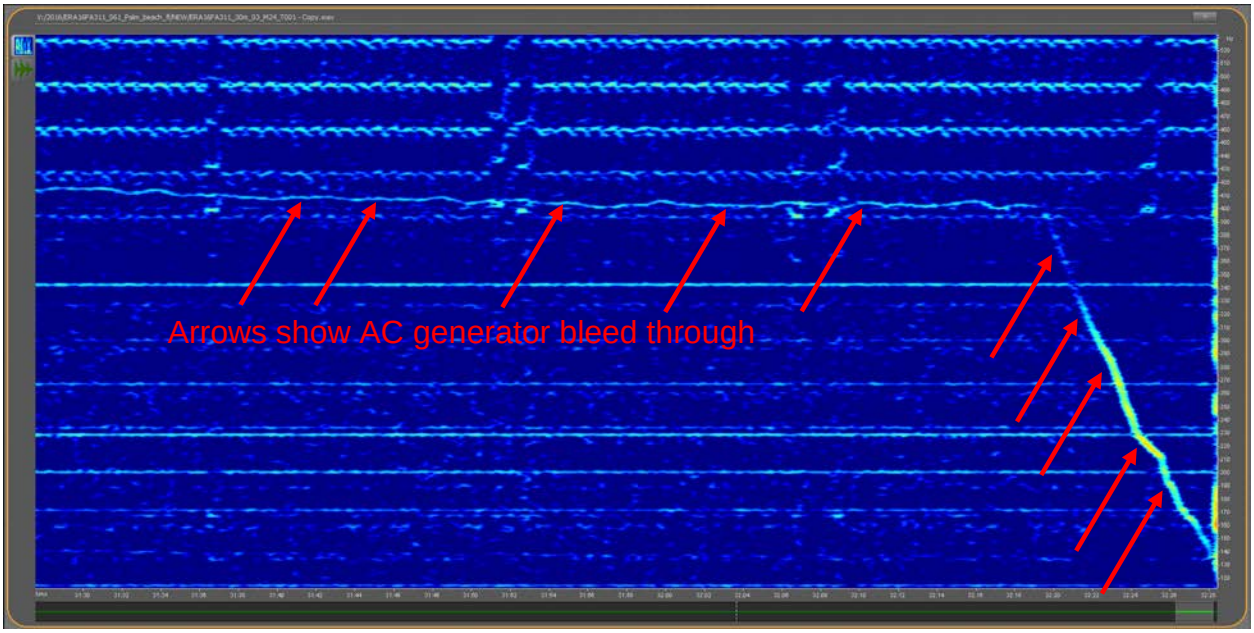

Figure 6. Spectrogram of AC generator bleed through during last minute of the accident flight.

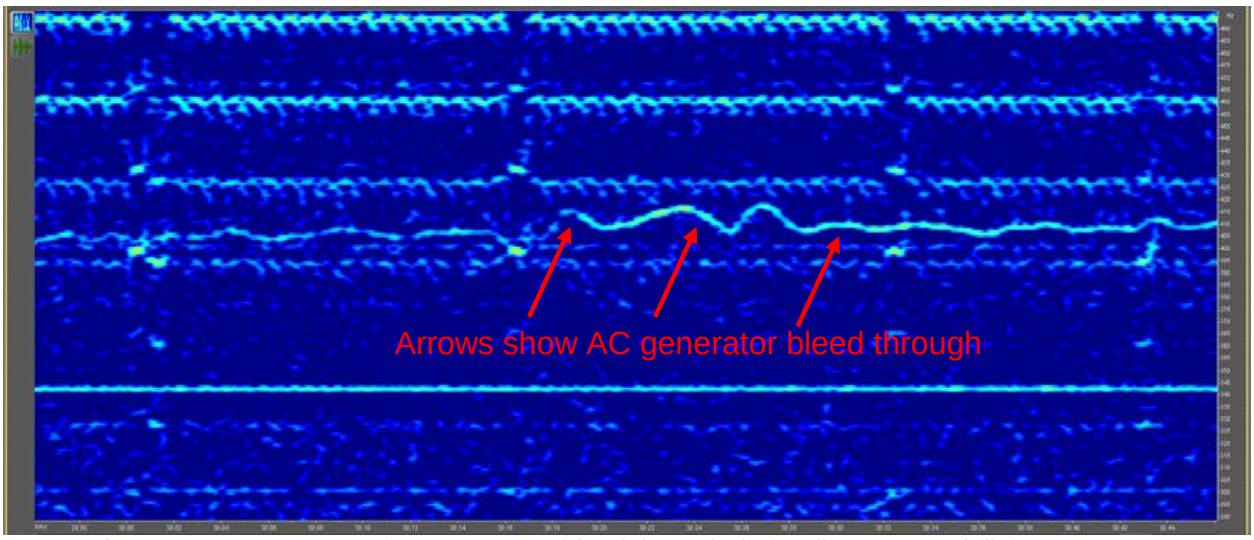

Figure 7. Spectrogram of AC generator bleed through during first rearward flight maneuver.

3.4 Results

Figure 8 shows a plot of the conversion of the rotational frequencies into engineering units for the last minute of flight. It is not possible to determine which engine produced which Ng sound so they are labeled as Engine A and Engine B on the plot. Because the audio on the CAM channel was overdriven between 13:39:45.5 and 13:39:47.8, it was not possible to determine which trace corresponded with Engine A or Engine B for the points identified after the gap so the traces corresponding to Ng speeds are depicted in different colors. Figure 9 shows a similar plot for the first rearward flight maneuver. It is not possible to determine which engine produced which Ng sound so they are labeled as Engine A and Engine B on the plot. A comma separated value file (csv) containing the data used to generate the plots can be found in the public docket for this accident as Attachment 2 to the Group Chairman's Sound Spectrum Study.

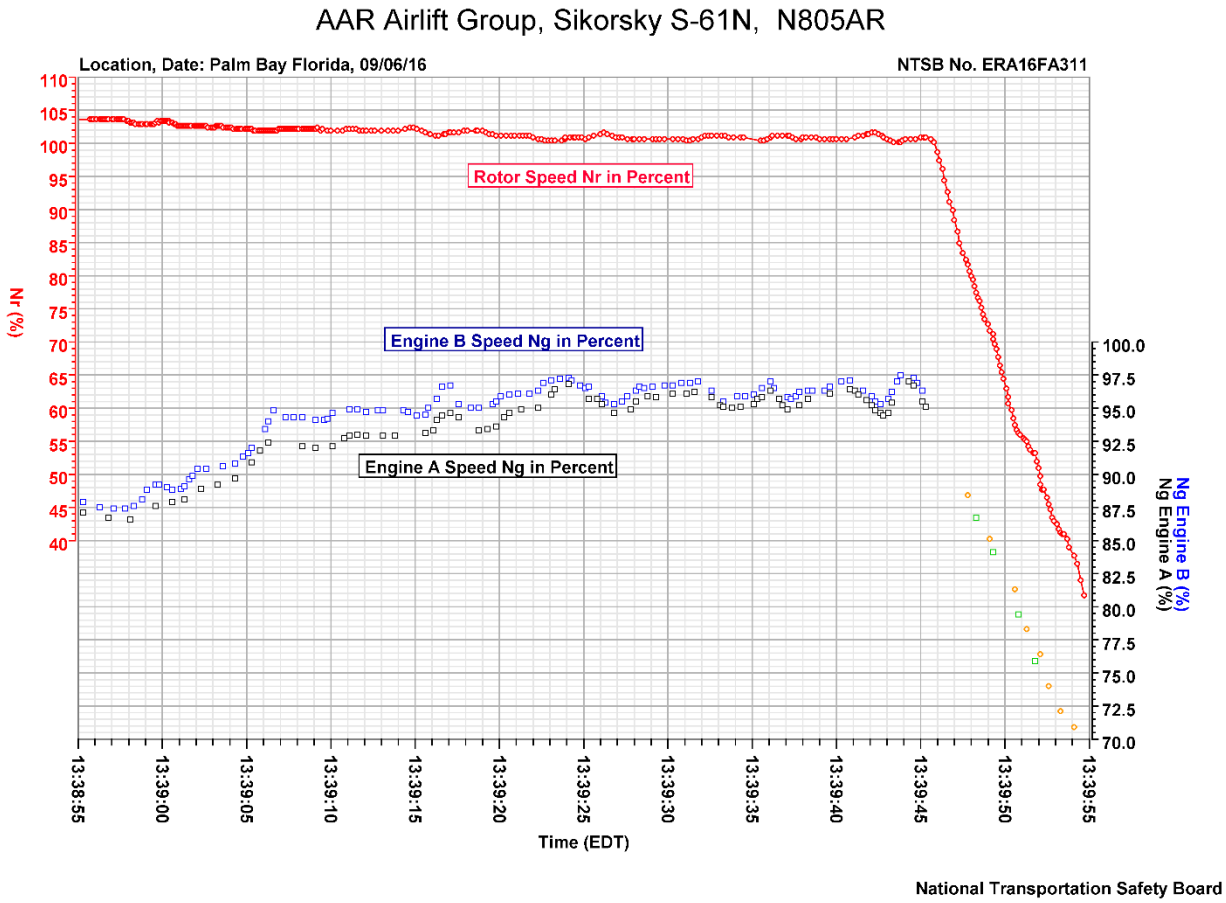

Figure 8. Derived Ng and Nr speeds for last minute of flight.

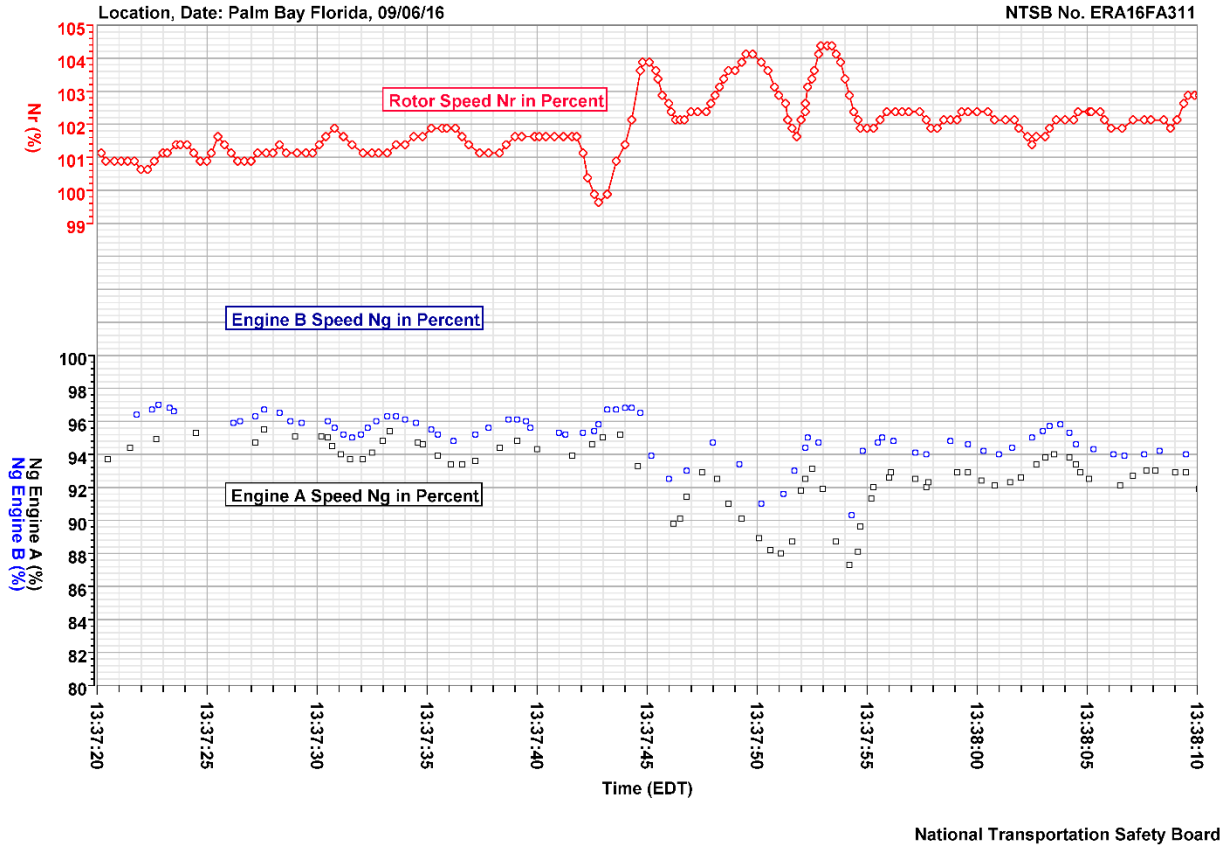

Figure 9. Derived Ng and Nr speeds for first rearward flight maneuver.