NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

August 23, 2017

Cockpit Voice Recorder Sound Spectrum Study

Group Chairman Report
by Bill Tuccio, Ph.D.

1. EVENT

Location:	Teterboro, New Jersey
Date:	May 15, 2017
Aircraft:	Gates Learjet 35A, Registration N452DA
Operator:	Trans-Pacific Jets
NTSB Number:	CEN17MA183

On May 15, 2017, at 1529 eastern daylight time (EDT), a Gates Learjet 35A, N452DA, operated by Trans-Pacific Air Charter LLC doing business as Trans-Pacific Jets, departed controlled flight while on a circling approach to runway 1 at the Teterboro Airport (TEB), Teterboro, New Jersey, and impacted a commercial building and parking lot. The captain and first officer died; no one on the ground was injured. The airplane was destroyed by impact forces and postcrash fire. The airplane was registered to A&C Big Sky Aviation LLC and operated by Trans-Pacific Air Charter LLC under the provisions of *14 Code of Federal Regulations* (CFR) Part 91 as a positioning flight. Visual meteorological conditions prevailed, and an instrument flight rules (IFR) flight plan was filed. The flight departed from the Philadelphia International Airport (PHL), Philadelphia, Pennsylvania, about 1504 and was destined for TEB.

2. DETAILS OF STUDY

The Investigator-in-Charge (IIC) requested engine speeds for this investigation, specifically during the time period of the recording after the landing gear was extended on approach to TEB. The aircraft was not equipped with a flight data recorder (FDR), nor was it required to by 14 CFR 91 (or 135[1]). Further, all non-crashworthy devices that may have recorded engine speeds were destroyed in the accident. The aircraft was equipped with a cockpit voice recorder (CVR). An indirect way to determine engine speeds is by examining the frequency distribution of aircraft sounds recorded by the CVR.[2,3] During the development of aircraft and engines, manufacturers typically develop a dataset of component frequencies related to engine operating speeds. For example, a rotating oil pump geared to the high pressure compressor (N2) may

[1] The flight prior to the accident was operated under 14 CFR Part 135.
[2] The CVR transcript is contained in the public docket for this investigation.
[3] Tuccio, W. A., Schuster, B., & Gregor, J. (2017). "Deriving engine power from a cockpit voice recording in an accident investigation." *Proceedings of the Audio Engineering Society (AES) International Conference: Audio Forensics,* Arlington, VA. Section 3-2. doi:10.17743/aesconf.2017.978-1-942220-14-5.

generate ("excite") a frequency of 800 Hz at 100% N2. All components have varying amplitudes (loudness), affecting the ability of the CVR to record frequency components. As such, the component frequencies may be outside the frequency range of the CVR installation and/or quality at the time of recording (i.e., degradation since installation). Additionally, background noise (such as, turbulent airflow around deployed landing gear and/or flaps) can over saturate the cockpit area microphone's (CAM's) ability to capture all the frequencies of interest for this study.

2.1. Purpose of the Study

The purpose of the study was to determine engine speeds from the CVR recorder sound spectrum, specifically during the end of the recording after the landing gear was extended.

2.2. Group

A sound spectrum group was convened on August 4, 2017.

Chairman:	Dr. Bill Tuccio Aerospace Engineer NTSB
Member:	David Gerlach Senior Air Safety Investigator Federal Aviation Administration
Member:	Dr. Bill Schuster Acoustics Staff Engineer Honeywell Aerospace

2.3. Methodology

The CVR recorded 30 minutes of audio on four channels.[4] Honeywell provided component frequency data for the Honeywell TFE731-2/3 engines. The Honeywell data provided linear relationships between observed component frequencies, low and high pressure compressor speeds (N1 and N2, respectively), and N1 and N2 speeds expressed as percent RPM. These data were used as follows:

1. CVR recorded frequency spectrum data from all channels were examined to find the most appropriate tonal frequency source(s) for engine speeds.

2. Tonal frequency traces were considered as potentially related to a component identified on the Honeywell known component frequency dataset, with particular focus paid to the time period after the landing gear was extended, comparing this time period to other recorded periods, such as takeoff.

[4] See the CVR Group Chairman Report in the public docket for this accident for a full description of the CVR and the related transcript.

3. The group decided if tonal frequencies could be identified after the landing gear was extended; if so, frequencies for the entire flight would be converted to N1 and N2; if not, an explanation would be made as to the plausible reasons engine speeds could not be determined.

2.4. Results

A review of all four recorded channels indicated engine-related tonal frequencies were only observed on the cockpit area microphone (CAM); therefore, all information presented for the remainder of this study references the CAM channel.

Figure 1 and figure 2 show the sound spectrum for the entire recording, with the takeoff and the time period after landing gear extension annotated. Traces associated with engine were clearly discernable below 400Hz through most of the recording, though not at certain periods (such as after the landing gear was extended).

Figure 1. Sound spectrum of the entire 30-minute recording.

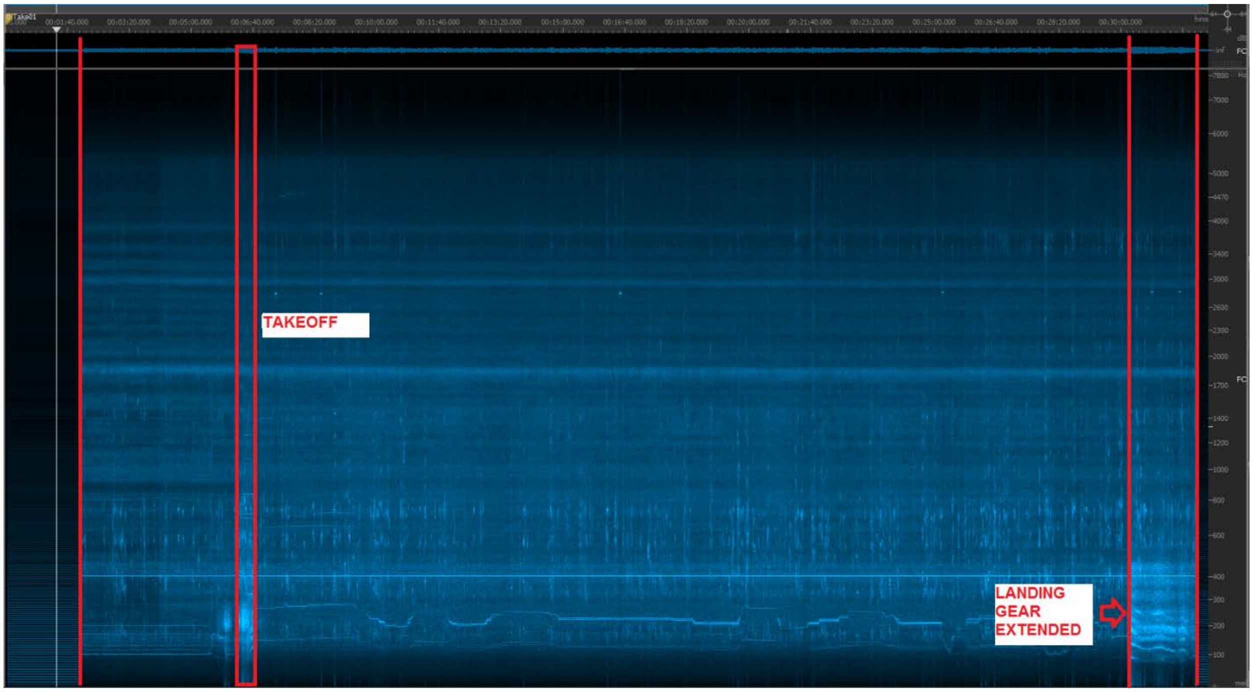
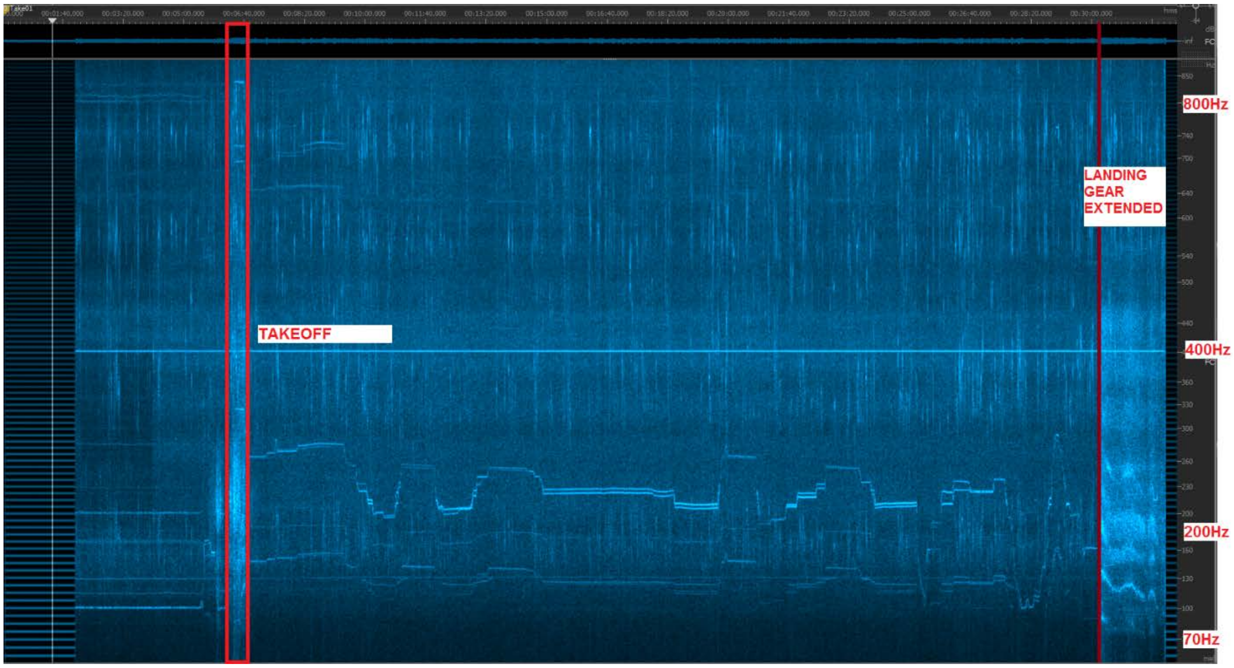
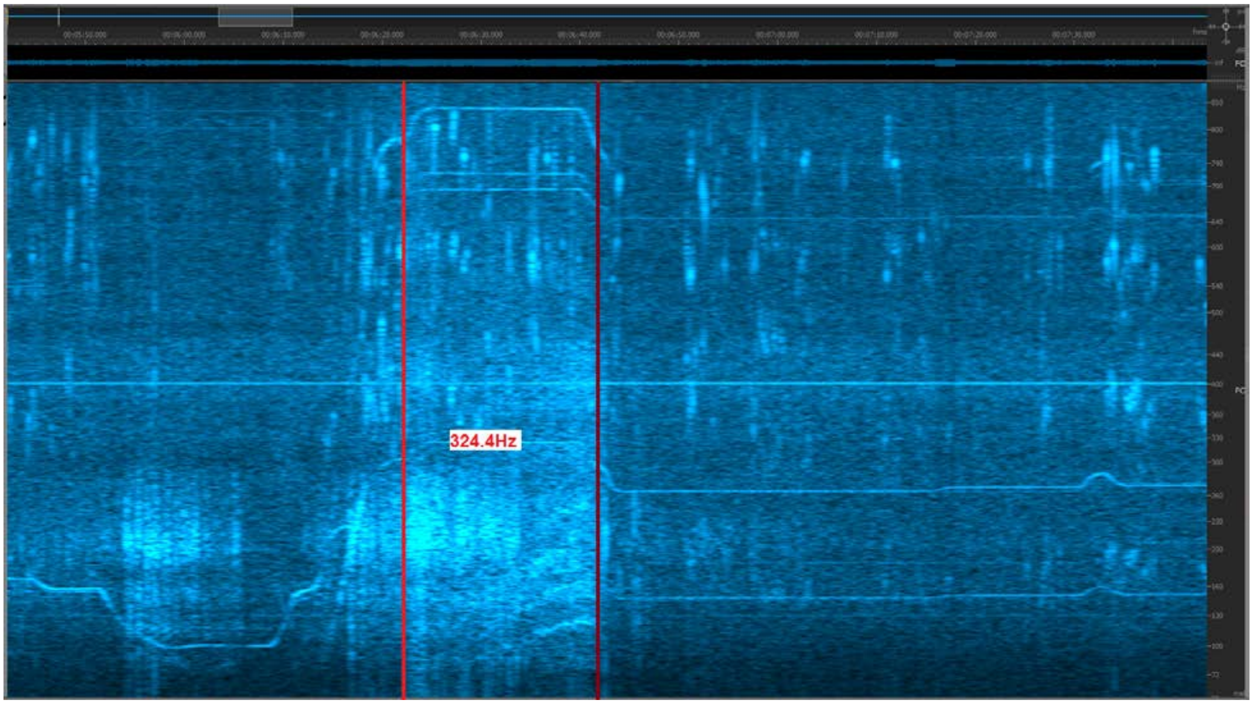


Figure 2. Entire 30-minute recording, frequencies below 850Hz.



The Low Pressure (LP) Spool rotational frequency was identified in the sound spectrum during the takeoff as 324.4Hz, corresponding to 94.1 %N1,[5] as shown in figure 3.

Figure 3. Takeoff focus, with LP Spool component frequency identified.

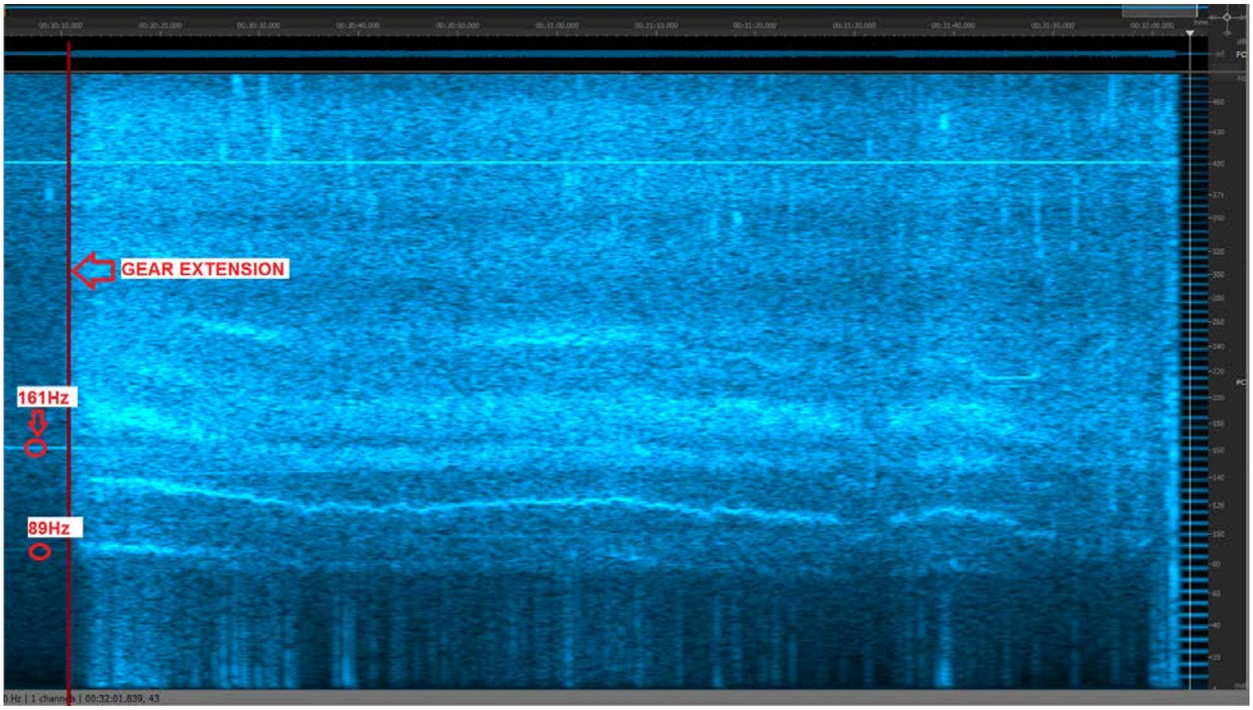


[5] Based on the Honeywell empirically developed relationship as described in Section 2, LP Spool %N1 = (Tonal Frequency) * 60 / (20688/100). Also see the Group Chairman's Factual Report in the public docket for crew comments regarding the N1 power setting for takeoff.

The takeoff LP Spool trace was followed throughout the recording, to just before gear extension. Figure 4 shows the LP Spool-related tonal frequency just before gear extension reduced to about 161Hz, corresponding to 46.7 %N1.[5] As a means of validating that the 161Hz frequency was associated with the LP Spool, a frequency trace at 89Hz was also identified, and was attributed to the Fan Speed known to be a factor of 1.8 less than the LP Spool.

Figure 4 also shows a dearth of identifiable tonal frequency traces that could be reliably associated with engine speeds after the gear was extended. For example, the large trace between 161Hz and 89Hz was most likely aerodynamic noise proportional to aircraft speed, rather than engine-related tonal frequencies.

Figure 4. Sound spectrum from just before gear extension until the end of the recording.



2.5. Discussion and Conclusions

Just prior to gear extension, it is likely both engines were operating at about 46.7 %N1.

After the landing gear was extended, the signal to noise ratio was insufficient to definitively extract engine speed. Two possibilities exist for this outcome:

1. Engine speed was low (that is, near idle) after the gear was extended.
2. Engine speed was changed/increased at some point(s) after the gear was extended (possibilities include engine speeds increased, but less than takeoff power).

It is possible that for this particular make/model of aircraft with this particular CVR installation at the particular speed/configuration/attitude of the aircraft, the cockpit noise obscured engine frequencies—regardless of engine speeds—when the gear was down.

One way to lend greater certainty to the two possibilities would be an experimental flight test in a similar make/model of aircraft, with a similar CVR installation, with aircraft speed/configuration/attitude similar to the conditions experienced by the accident aircraft after the landing gear was extended. Of course, such a flight test would benefit from the collection of parametric data.