Acoustic emission detection of upholstered furniture frame damage

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Abstract

Squeaking and creaking noise from selected components of two stationary three-seat bare sofa frames, one with glue applied to joints and the other one with no glue applied, were evaluated by subjecting them to the General Services Administration performance tests. The main purpose of this evaluation was to compare frame construction performance differences between the construction of joints with glue and without glue as it relates to the onset of squeaking. An acoustic emission apparatus utilizing microphones as noise detection sensors was used to detect the noise signals. Experimental results of recorded squeaking signal in terms of loading cycles completed until the first audible squeak indicated that, in general, the joints with no glue started squeaking earlier than the ones with glue applied, but their squeaking occurred at the same load level. The General Services Administration performance test standards define frame failures as frames suffering disability to resist testing loads applied on the frames. A frame strength performance rating is given to a tested frame based on the load level of which it passed. There was no difference in fatigue performance between glued and unglued frames. But, results of our acoustic emission study revealed that, in general, the load level corresponding to first squeak occurring was one to two load levels lower than the load level passed by a frame tested before it failed from broken components.

Squeaking or creaking noises from upholstered furniture frame components, especially from loose joints, during the furniture's lifetime has become a durability design issue for furniture manufacturers. This type of failure mode has not been addressed in current standards of furniture performance tests such as the General Services Administration (GSA) performance test regimen FNAE–80–214 A (General Services Administration 1998). **Table 1** shows schedule of the GSA loading schedule for the two cycling tests used in this study. Thus, loosening of a joint is not considered a failure as long as the members jointed together continue to function as intended (Eckelman and Zhang 1995). Therefore, performance tests continued until the frame or one of its components suffered disabling damage.

Acoustic energy is emitted from components in wood furniture frames as loading approaches and exceeds the yield limits of the components. Localized damage or deformation of frame components can create gaps that can cause loosening of joints during cyclic loads applied to furniture frames. The squeaking or creaking noise can result from loose joints when they are subjected to cyclic loads.

The acoustic emission (AE) investigations for wood products can be classified into five fields (Kawamoto and Williams 2002): (1) monitoring and controlling during drying, (2) prediction of deterioration, (3) estimation of strength properties, (4) fracture analysis, and (5) machining control. Most research work was using transducers or sensors to obtain AE signals with the frequency range greater than 20 kHz, and treating the AE output with the frequency range less than 20 kHz as low frequency noises.

Beall (1987), Suzuki and Schniewind (1987), Yoshimura et al. (1987), Quarles and Lemaster (1988), Sato et al. (1989),

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Table 1. — GSA loading schedule for cycling tests conducted on the frames.[a]

Test	Initial load	Load increments	No. of loads	Service acceptance level Light	Medium	Heavy
	-------- (lb) --------			-------------- (pound/ cycle) -------------		
Backrest frame	75	25	3	75/25,000	100/50,000	150/100,000
Arm outward	50	25	1	75/50,000	150/125,000	200/175,000

[a]pound = 4.448 N

Hwang et al. (1991); and Sato and Fushitani (1991) attempted to classify the known acoustic emission methods for the nondestructive testing of adhesive strength. They used the following headings: (1) to determine the curing time, which depends on the adhesive properties of wood interfaces and the elastic properties of the polymer; (2) to establish the relationship between adhesive strength in joints and the acoustic emission parameters or ultrasonic velocity and attenuation; and (3) to select the parameters most appropriate to predict nondestructively the strength of joints because this depends on many factors such as type of loading, wood species, the nature of adhesives, surface conditions, and moisture content (MC).

Many AE techniques can be used to locate and characterize the source by using different parameters that characterize an acoustic emission signal. Those parameters are: mode of emission, continuous or burst; rate of emission; the acoustic emission event, defined as a rapid physical change in a material that releases energy appearing as acoustic emission; the accumulated activity, the total number of events observed during a specific period of time; the threshold set at a selected discriminator level; the duration of the event; AE counts, and etc (Bucur 1995).

One of the most popular acoustic emission techniques is AE counts. The principle of this technique is to count the number of times a threshold voltage is exceeded by the oscillating transducer output. The main advantages of this technique are the simplicity of the measurement of acoustic activity, the suitability for comparative testing of identical samples, and the automatic improvement of noise rejection.

Limited AE application research has been conducted in detecting component damage of upholstered furniture frames as structures to resist service loads such as cyclic loads applied to them, especially in the audible range where frequency is less than 20 kHz. Durably designed upholstered furniture frames need a data acquisition system to monitor initiation and progression of component damage and a method to quantify frame failure modes for cyclic performance tests such as squeaking or creaking noise.

Therefore, the objectives of this project were to (1) measure squeaking signals emitted from joints constructed with staple-glue and staple-no glue using AE system, (2) compare the difference in terms of squeaking initiation and amplitude, and (3) develop an acoustic emission sensing system to measure performance of furniture joints in terms of squeaking initiation time during cyclic performance tests. Successful development of this evaluation technique will assist furniture manufacturers in evaluating their products at higher performance standard levels. Information obtained from this evaluation technique can improve the durability of their products in meeting customers' increasing demands for high quality and durable products.

Experimental procedure

Acoustic emission apparatus

The acoustic emission apparatus used for measuring the squeaking noise for this study has an acoustic emission measuring system box called DiSP (Digital Signal Process), a laptop computer with Physical Acoustics Corporation (PAC) AEwin (Acoustic Emission for Windows) installed, and microphones. AEwin is a software program that takes the data from DiSP, records the data in terms of AE hits and AE counts and represents it in the graphical form. For this particular study we used AE hits for the data analysis because we where only interested in being able to detect the presence of a squeak not any details about the squeak. Radio Shack microphones (model number 33–3033) were connected to AEwin system as AE signal input transducers. The microphones were electric condenser sensors with a frequency response range from 100 Hz to 10,000 Hz.

The acoustic emission measuring system is based upon an AE hit detection technique. An amplitude threshold is set in the system and whenever a sound is detected above the set threshold, an AE hit is recorded. The threshold for this study was set to 30 dB, which was chosen based upon preliminary data collected by the system, and to eliminate any ambient noise in the room.

Roughly speaking (Hall 1987), human hearing will detect a range of sound levels from a minimum of 0 dB (barely audible to a few people with the most sensitive ears) to a maximum of 130 dB (intolerably loud). **Table 2** gives a rough idea of what intensity and what sound level correspond to various sounds in everyday life.

In general, during testing, care was taken to reduce noise in the testing room because the microphones are sensitive to any kind of audible noise. The hardware settings in the AEwin and the calibration settings were set each time for each frame test. During the test, a squeak from the frame components such as joints was identified by a high rise in the amplitude of the sound signal. The data were analyzed based on the number of AE hits detected above the threshold, not the number of AE counts of an individual AE hit in the AEwin data.

Two stationary three-seat bare sofa frames were supplied by a local manufacturer for acoustic evaluation as shown in **Figure 1**.The frames were mainly constructed with pine plywood. Particleboard was used only for bottom side rails. One of the frames was constructed with both staples and glue and the other frame was constructed with staples only. The glue was a polyvinyl acetate emulsion adhesive with 52 percent solids content. Typical joints were mortise and tenon type, for instance, upright to stretcher (in-plane) and top arm rails to back posts (out of plane), and also end to face type with reinforced corner block, for instance, upright to top rail as shown in **Figure 1**. Each frame was subjected to two GSA frame performance tests, the backrest frame test and the horizontal sidethrust load on arm test outward. **Table 1** shows the testing load schedule for the frames. According to the GSA testing standards FNAE–80–214 A the load is applied to the frames at a frequency of 20 Hz. **Figures 2** and **3** show the air cylinder and pipe rack setups for the horizontal sidethrust load test on

Table 2. — Some typical sound levels.

Sound source	Sound pressure level (dB)
Factory	80
City traffic	70
Subdued conversation	60
Quiet auto interior	50
Library	40
Empty auditorium	30
Whisper at 1 m	20
Falling pin	10

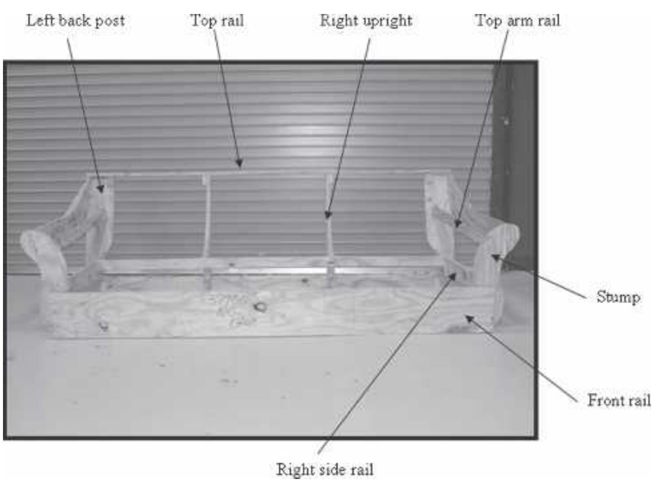

Figure 1. — A three-seat sofa frame used for this study.

Figure 2. — Set-up for the horizontal sidethrust load test on arms for sofas.

arms – outward and the backrest frame test, respectively. In general frames were tested in the lab room maintained at a temperature of 74 ± 2 °F and a relative humidity of 50 ± 2 percent.

Arm test

A horizontal force in an outward direction was applied using an air cylinder to the top arm rail end near to the intersection of the stump with the arm. Three microphones were placed at different locations to detect squeaking noise signals.

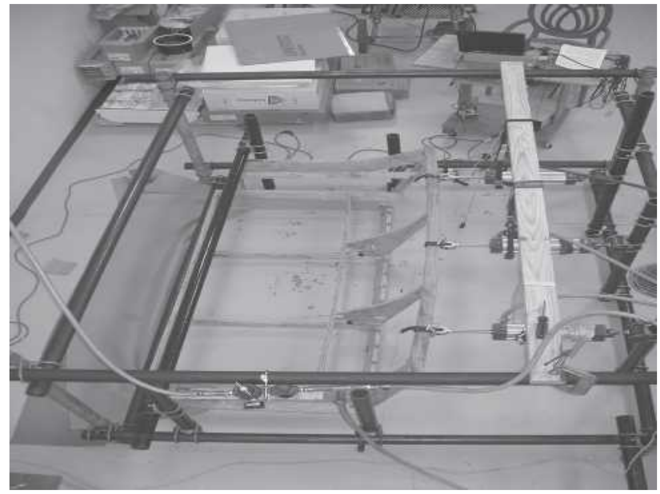

Figure 3. — Set-up for the sofa backrest frame test.

Microphones 1 and 2 (**Fig. 4**) were located right above the intersection of the stump to the bottom side rail and the intersection of the front rail to side rail. Microphone 3 (**Fig. 4**) was located at the rear of the arm at the top arm rail to back post intersection. Both of the arms were tested on each frame, the right side arm and the left side arm. The placements of the microphones were determined by observing the movement of the frame at these particular joints during the initial testing stage. A sheet of foam was placed underneath the frame in order to minimize any rubbing noise between the frame and the floor. The solenoids that control airflow to the cylinders were located away from the testing frames to reduce noise.

The testing was begun at 50 pounds (222 N) and the load was increased by 25 pounds (111 N) after 25,000 cycles. Data were collected through the sensors and recorded in the acoustical sensing system. Data collection started when the load was applied to the frame. Once any noticeable squeaking was detected, the microphones were removed from the frame. The testing continued until frame components suffered disabling broken damage. Failure modes and loads, and AE hits in amplitude versus cumulative cycle numbers, were recorded.

Backrest frame test

Three loads were applied by three air cylinders to the top rail of the frame in a front to back direction. These loads were applied at the center and at points 1/6 the length of the top rail from each end as shown in **Figure 3**. Four microphones were located at different joints to detect squeaking. Microphone #1 (**Fig. 5**) was located at the right side of the right intersection (mortise and tenon joint) of the back upright and the seat stretcher and back spring rail. Microphone #2 (**Fig. 5**) was located at the back of intersection of the right back post to back spring rail. Microphone #3 (**Fig. 5**) was located at the back post to top rail intersection. The locations of the microphones were based upon the observed movement of the joints at these locations when testing was first started. A sheet of foam was placed underneath the frame in order to minimize any rubbing noise generated by the frame and the floor.

The testing was begun at 75 pounds (334 N) per air cylinder and then each of the three loads was increased by 25 pounds (111 N) after each 25,000 cycles were completed. The testing was continued until any noticeable squeaking occurred in the frame. Once any noticeable squeaking was detected, the

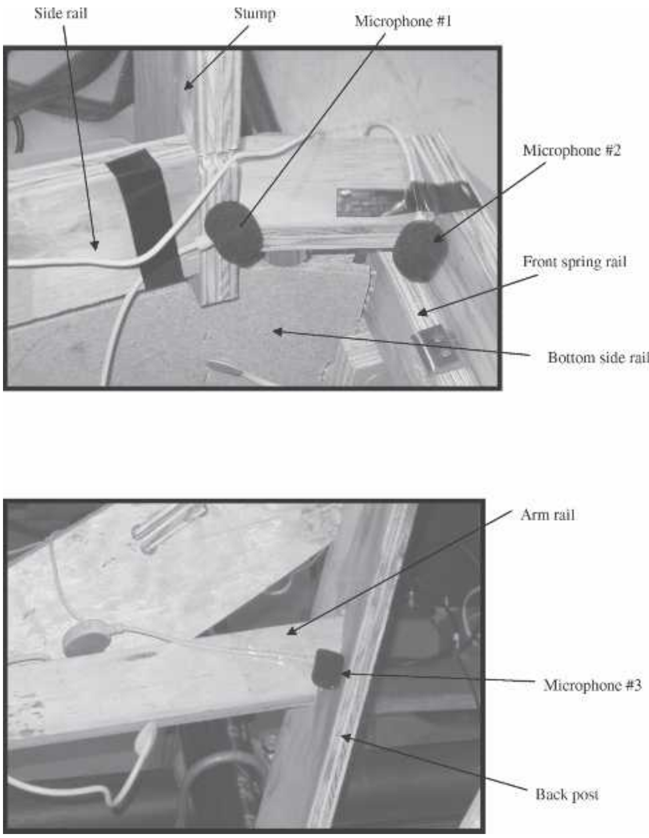

Figure 4. — Locations of microphones #1, #2, and #3 for the horizontal sidethrust load test on arms.

microphones were removed from the frame. The testing continued until frame components failed. Failure modes and loads, and AE hits in amplitude versus cumulative cycle numbers (**Fig. 6**), were recorded.

Results and discussion

Arm test

The results of the horizontal sidethrust load on arm test outward are summarized in **Table 3** for microphone #1 (**Fig. 4**) in terms of cycles and the average and range values of the amplitude of the first squeak region detected. No squeaking data were detected from microphones #2 and #3 located at the arm rail to back post intersection.

Frame with glue. — The first noticeable squeaks occurred at 22,792 cycles for the right arm and at 26,791 cycles for the left arm. The 22,792 cycles squeak occurred at a load level of 50 pounds (222 N), and the 26,791 cycles squeak occurred at a load level of 75 pounds. The average squeak amplitudes were 65 and 46 dB for right and left arms respectively. The mode of failure was stump to side rail joint failure where the bottom particleboard side rail broke and had staple withdrawal.

Frame with no glue. — The first noticeable squeaks occurred at 25,162 cycles for the right arm and at 26,112 cycles for the left arm. Both of the arms started squeaking during the 75 pound (334 N) load level. The average squeak amplitudes were 57 and 46 dB for right and left arms, respectively.

Results of squeak detection in terms of cycles to first audible squeak and their corresponding load levels indicated that not much difference existed between glued and unglued frames since very close cycles and load levels were observed for glued and unglued frames. The stump to side rail left joint with no glue started squeaking earlier than the one with glue applied, but the stump to side rail right joint with glue started squeaking earlier than the one with no glue.

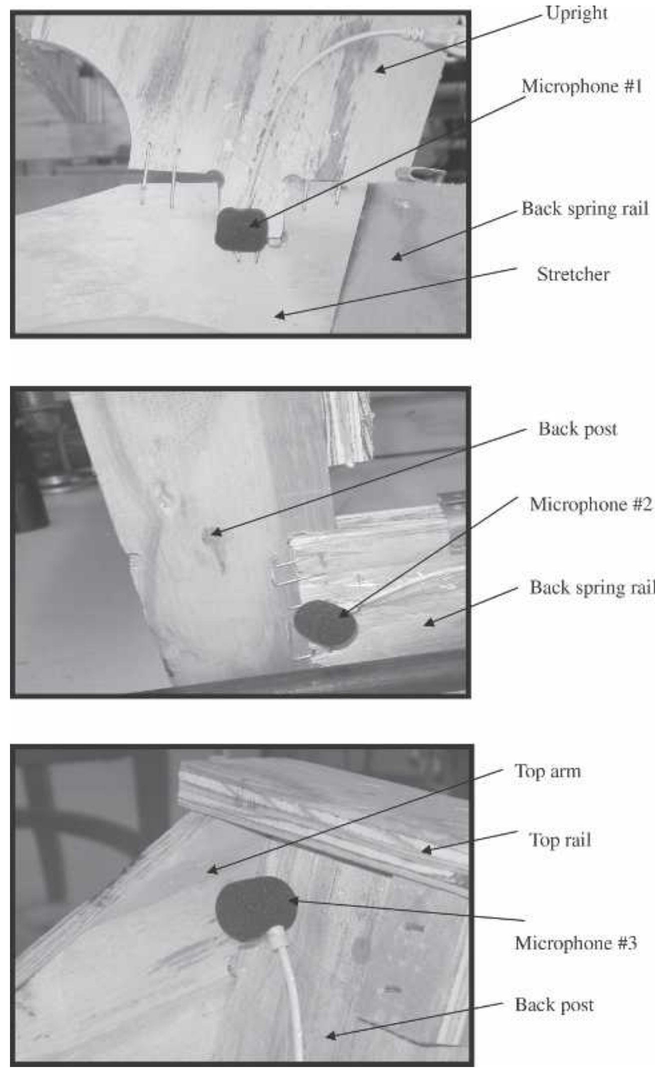

Figure 5. — Location of microphones #1, #2, and #3 for the backrest frame test.

Also, the results of arm tests showed that there was no difference in fatigue strength performance between frames with glue applied and without glue applied to joints since the joints of both frames failed at the same fatigue load level. Two right joints glued and unglued failed at the 75 pound (334 N) load level, showing that the frame did not pass light duty service level. Two left joints glued and unglued passed light duty, but failed at the 125 pound (556 N) level.

In this arm test, if the cycles-to-first audible squeak was used as the criteria to define frame failure, it yielded a different result in terms of passed fatigue load levels than if joint breakage was used as the failure criteria. It seems that if frame component breakage, such as a broken joint, is used as the failure criteria the frame will show better performance than that if the cycles-to-first audible squeak is used as the failure criteria.

Backrest frame test

The results of the backrest frame test were summarized in **Table 3** for microphones #1 and #3 in terms of cycles, and the average and range values of the amplitude of the first squeak

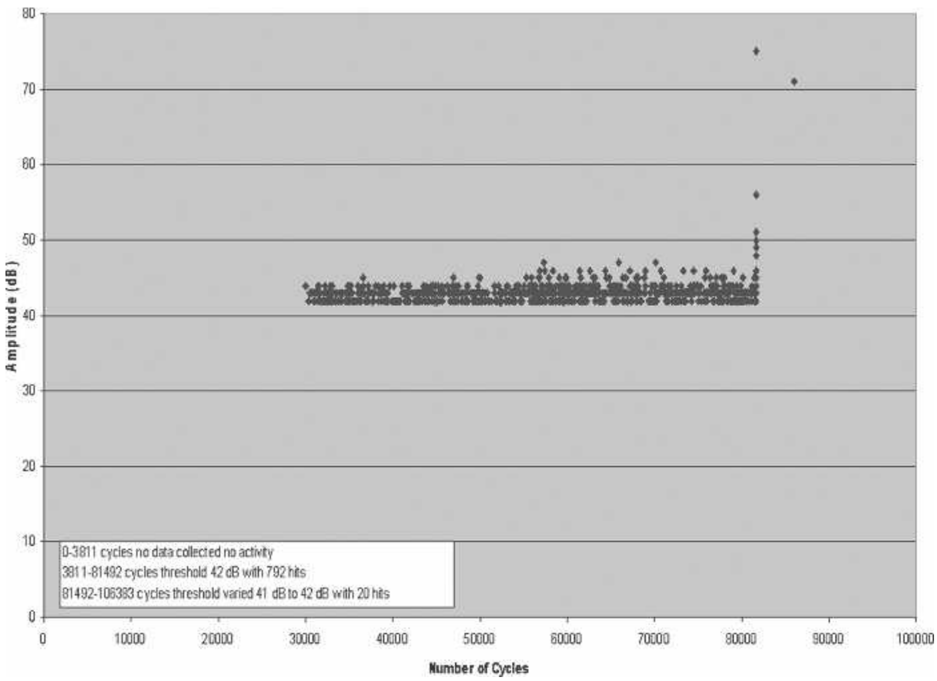

Figure 6. — A typical example of AE hit data (Amplitude vs. Number of cycles) collected by the acoustic emission measuring system through the microphone as noise detecting sensor.

Table 3. — Results of tests for the microphones.[a]

Test	Microphone #	Squeak source location	Cycles to first audible squeak/load level	Joint failure load level	AE Hits amplitude properties of first audible squeak region: Average	Range
			(No./lb)	(lb)	-------- (dB)	--------
Arm	1	Frame with glue				
		Stump to side rail—Right	22,792/50	75	65	63 to 69
		Stump to side rail—Left	26,791/75	125	46	42 to 51
		Frame without glue				
		Stump to side rail—Right	25,162/75	75	57	55 to 63
		Stump to side rail—Left	26,112/75	125	46	40 to 49
Back	1	Frame with glue				
		Upright to stretcher—Right	31,667/100	150	44	39 to 46
		Frame without glue				
		Upright to stretcher—Right	30,026/100	150	42	42 to 43
	3	Frame with glue				
		Top rail to back post—Left	27,721/100	150	39	38 to 40
		Frame without glue				
		Top rail to back post—Left	30,007/100	150	39	38 to 41

[a]pound = 4.448 N

region detected. No squeaking was detected in microphone #2 (**Fig. 5**) located at the bottom of the back spring rail to back post intersection.

Frame with glue. — The first noticeable squeaks occurred at 27,721 cycles in microphone #3 with average amplitude of 39 dB. The second noticeable squeaks occurred at 31,667 cycles in microphone #1 at an average amplitude of 44 dB. The squeaks occurred at a load level of 100 pounds (445 N). Under the backrest frame test loads, the frame with glued joints failed at the load level of 150 pounds (667 N) with the failure mode of top rail breakage.

Frame with no glue. — The first noticeable squeaks occurred at 30,007 cycles in microphone #3 with an average amplitude value of 39 dB. The second noticeable squeaks occurred at 30,026 cycles in microphone #1 at an average amplitude value of 42 dB. The squeaks occurred at a load level of 100 pounds (445 N). Under the backrest frame test loads, the frame with no glue applied to joints also failed at the load level of 150 pounds (667 N) with the failure mode of top rail breakage.

In general, the joints with no glue started squeaking earlier than the ones with glue applied (**Table 3**), but the squeaking noise occurred at the same load level of 100 pounds (445 N) for both glued and unglued joints. If the load level corresponding to the first squeak detected was used to define frame failure level then there was no difference between glued and unglued frames in terms of frame fatigue strength performance.

Similar to the arm test results, if the loss of ability to resist fatigue loads is defined as frame failure, then the frames passed the medium service acceptance level which is 100 pounds (445 N). If cycles to the first audible squeaking noise is defined as frame failure, then the frames passed the light service acceptance level which is 75 pounds (334 N).

Conclusions

Squeaking and creaking noises from selected components of two stationary three-seat bare sofa frames, one with glue applied to joints and the other one with no glue applied to joints, were evaluated by subjecting them to two GSA fatigue performance tests, arm horizontal sidethrust test outward, and backrest frame front to back test, respectively.

The initial purpose of this evaluation was to compare frame construction performance difference between the frame with glue applied to joints and the one with no glue applied joints in terms of which one starts squeaking first. An acoustic emission apparatus with microphones as noise detection sensors was used to detect the noise signal in terms of signal hits through setting the threshold of the AE system to 30 dB. Results of recorded squeaking signal in terms of cycles to the first audible squeak indicated that in general the joints with no glue started squeaking earlier than the ones with glue applied, but their squeaking noise occurred at the same load level.

There was no difference between glued and unglued frames in terms of frame fatigue strength performance if the load level corresponding to the first squeak detected is used as a measurement for quantifying frame performance.

GSA performance test standards define frame failures as frames suffering disability to resist testing loads applied on the frames. A performance rating is given to a tested frame based on the load level of which it passed. For arm performance evaluation tests, right and left stump to side rail joints of both frames with glue and without glue failed at 75 (334 N) and 125 (556 N) pound load levels, or passed 50 (222 N) and 100 (445 N) pound load levels, respectively. Results of backrest frame tests indicated that both frames passed the 125 pound (556 N) load level and failed at the 150 pound (667 N) load level.

Results of this AE squeaking study showed that in general the load level corresponding to first squeak occurring was one to two load levels lower than the load level passed by a frame tested until it failed with broken components. This study also leads into a future discussion of how one should define a failure for a tested frame, using squeak noise or components suffering disabling damage.

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