NASA Technical Memorandum 78756

(NASA-TM-78756) EXPERIMENTAL DETERMINATION OF THE RATTLE OF SIMPLE MODELS (NASA) 22 p
HC A02/MF A01 CSCL 20K
N78-30291
Unclas
G3/31 28581

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JULY 1978

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EXPERIMENTAL DETERMINATION OF THE RATTLE OF SIMPLE MODELS

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SUMMARY

An investigation was conducted to study the effect of the excitation frequency on the rattle boundaries of simple models. The frequency range investigated was from 40 to 4,000 Hz. To aid in the understanding of the basic physical phenomenon of the rattling of objects, a 1-inch steel ball was studied to determine the rattle boundary for both vertical motion and for the ball suspended as a pendulum. Effects of surface contact and weight were also studied. Results indicated that the shape of the rattle boundary depends on the particular configuration being investigated as well as the range of frequency being investigated. In general, the level of acceleration required to cause rattle is independent of excitation frequency.

INTRODUCTION

The vibratory response of buildings resulting from aircraft operations has been of concern from the standpoint of structural damage and human annoyance for many years. The effects of sonic boom and aircraft overflights are discussed in references 1 through 4. More recently, the effects of Concorde operations have been of concern and have been studied both at Dulles and John F. Kennedy International Airports (refs. 5-10). It was conjectured that vibration induced in walls and floors would cause rattling of windows, hanging pictures, dishes, and other items which would in turn result in increased annoyance.

The physical phenomenon associated with rattle was studied in reference 11 as part of a general study of the vibration response characteristics of houses to aircraft noise. It was concluded that rattle was a type of nonlinear vibration response phenomenon and that the rattling of wall-mounted decorative objects was associated with smaller amplitude displacements as the frequency of excitation was increased. The data shown in figure 21, reference 11, indicate that the rattle acceleration boundary (the lower level of acceleration at which rattle could be heard) was essentially independent of frequency. The frequency range was from 20 to 400 Hz.

To further investigate this rattle phenomenon and, in particular, to study the effects of excitation frequency over a wider range, the present study was conducted using simple laboratory models. The study consisted of using a small exciter to force the separation of a ball from its contact in the vertical direction and when the ball was suspended as a pendulum. The effects of surface contact and weight were also studied and are discussed in the appendix. Results are presented herein.

APPARATUS AND TEST PROCEDURE

Test Configuration

Various models were utilized for this study. All tests were conducted either in an audiometric room or the Interior Effects Room within the Aircraft Noise Reduction Laboratory.

Vertical rattle.- A 10-pound peak force electrodynamic vibration exciter was used (figure 1(a)) with a steel ball that weighed 0.15 pounds (68 g). A miniature accelerometer was used in line with the driving force on top of the exciter. The force gage had a threaded hole in its upper surface forming a circular line contact with the ball.

Pendulum-type rattle.- A 10-pound force exciter was used to obtain rattle of the same steel ball suspended as a pendulum. The ball was allowed to rest directly against the force gage as shown in figure 1(b). In another configuration (figure 1(c)), the exciter was outside the wall of the Interior Effects Room (IER) whereas the ball was suspended against the force gage on the inside surface with the same angle (0.05 radians) as used in the setup of figure 1(b). The wall was of standard dry wall construction with 1/2-inch thick plaster board on the inner surface. The exciter was connected to one of the 2 x 4 inch studs.

Instrumentation and Test Procedure

The acceleration level at which rattle was heard was recorded when a listener reported that he heard the rattle. The occurrence of physical separation of the test model and the exciter was also determined by observing the acceleration and/or a force gage output voltage on an oscilloscope and on a narrowband (1 Hz) spectrum analyzer. The acceleration level for separation always occurred at the same or at a lower level than the acceleration level for rattle since the listener had to hear the model impacting the exciter, whereas, separation could be seen on a real-time spectrum analyzer. A slight impact caused a second or third harmonic to appear on the oscilloscope of the analyzer; the larger the impact, the greater number of harmonic responses. Examples of outputs of the real-time analyzer are shown in figure 2 for a forcing frequency of 100 Hz. Figure 2(a) shows the spectrum of either the force gage or the accelerometer (their shapes are identical) prior to separation or rattle. After the amplitude was increased sufficiently to hear the rattle, the spectrum shown in part (b) of the figure was observed.

The test procedure was as follows: (1) The acceleration level as measured on the ball was continuously increased until harmonics could be observed on the narrowband analyzer or oscilloscope. (2) The acceleration was further increased until a listener with good hearing capability reported that he could hear the rattle. If there was a question of initial separation or rattle, the experiment was repeated. Both levels were recorded. This process was repeated at select frequencies from 40 to 4,000 Hz.

RESULTS AND DISCUSSION

The results of this study are shown graphically in figures 3 through 6. The results of vertical rattle, rattle of a pendulum, and a comparison to previous data will be discussed in this section. Results of weight and contact effects are found in the appendix.

Effect of Frequency on Vertical Rattle

Figure 3 shows the data for a 1-inch diameter steel ball resting on the hole in the upper surface of a force gage mounted on a 10-pound force exciter (figure 1(a)). The boundaries between audible rattle, separation but no audible rattle, and no separation as functions of frequency are indicated. Based on simple physical arguments, it would be expected that separation would occur at $1 g_{peak}$ (g_p), throughout the frequency range. (See prediction line on figure 3.) The upper curve on the figure represents the rattle boundary (rattle could be heard at accelerations above the curve and could not be heard at accelerations below the curve). With the exception of the data point at 1,500 Hz, all points on the curve lie within +4 and -6 dB of the $1g_{\text{peak}}$ line. Audible rattle is relatively independent of frequency in the range studied.

The lower curve of figure 3 indicates the acceleration boundary between separation and no separation of the ball and the exciter. The boundary is very irregular and indicates that the separation phenomenon is very complex. Although it was expected that the separation boundary would be lower than the rattle boundary, it was also expected that the boundaries would be smooth. It is noted later (see appendix) that the amount of contact has an effect on the rattle boundary. It is possible that in this simple test configuration, any slight unbalance of the exciter moving components or any slight side forces due to the exciter could affect the rattle boundary. It may be noted that the audible level of rattle is within a few dB of the separation level at frequencies up to about 1,200 Hz. At higher frequencies, the difference becomes greater (over 11 dB at 4,000 Hz).

Effect of Frequency on Pendulum-Type Rattle

Figures 4 and 5 show the data for a 1-inch diameter steel ball suspended as a pendulum against a force gage mounted either on a 10-pound force exciter or on a wall surface (test setups as in figures 1(b) and 1(c)). When the suspended ball is excited directly by the exciter (figure 4), both the rattle and separation boundaries are very irregular. When the ball is rattled through the wall (figure 5), the boundaries appear less irregular. Although the data points for rattle of the ball in the Interior Effects Room in the frequency range to 1,000 Hz (figure 5) are somewhat erratic, data from 1,000 to 3,000 Hz have a ±1 dB scatter band and indicate no effect of frequency on the rattle boundary. At frequencies below about 1,000 Hz, the acceleration levels corresponding to audible rattle are within a ±5 dB scatter band. It may have been expected that the rattle boundary of acceleration level with frequency would be a constant (ref. 11, fig. 21). However, the reference data cover frequencies only below 400 Hz and show a scatter range up to ±7.5 dB for plaques and a mirror on a wall. The current study shows much less scatter over a much greater frequency range indicating that rattle is relatively independent of frequency.

The prediction line shown at -26 dB on both figures was determined as a component of g acting on the steel ball. For small angles, α, as shown in figure 1, the g component is equal to α in radians. Thus $g = \alpha = 0.05$ rad or 0.05 g_p and is equal to -26 dB. The angle was the same for configurations 1(b) and 1(c); thus, the prediction lines have the same value.

There appears to be a large difference in the acceleration level of the rattle boundaries between the two configurations. The mean acceleration level of the rattle boundary of the ball on the force gage attached to the exciter is about -12 dB (0.25 g_p) whereas the mean level of the rattle boundary of the ball on the force gage attached to the wall is about -20 dB (0.10 g_p). This difference may be due to the difference of point and line contact on the balls (discussed in the appendix) or it may be due to transverse forces in the exciter system.

Comparison with Previous Data

Figure 6 shows a comparison of the data up to 400 Hz for the ball suspended as a pendulum against the wall of the IER with the data of reference 11. The reference data were obtained with plaques hung on an interior wall. For reference, the prediction for the steel ball suspended as a pendulum is shown. The current data have a similar characteristic as previous data, namely, that the rattle boundary is rather erratic in the frequency range to 400 Hz, and that there is no pronounced effect of frequency.

CONCLUDING REMARKS

An investigation was conducted to study the effect of excitation frequency on the acceleration boundaries or levels for the initiation of rattle. The frequency range investigated was from 40 to 4,000 Hz. To aid in the understanding of the basic physical phenomenon of the rattling of objects, a 1-inch steel ball was studied to determine the rattle boundary for both vertical motion and for the ball suspended as a pendulum. Effects of surface contact and weight were also studied. Results suggest that the shape of the rattle boundaries depends on the range of frequency investigated. For vertical motion, the acceleration levels to cause rattle fell in a scatter band of +4 to -6 dB of the $1g_{peak}$ line. For the ball suspended as a pendulum, the acceleration level scatter band was ±5 dB from 50 to 1,000 Hz and only ±1 dB from 1,000 to 3,000 Hz. The level of acceleration required to cause rattle is relatively independent of the excitation frequency.

APPENDIX

EFFECTS OF WEIGHT AND CONTACT ON RATTLE BOUNDARIES

In addition to the effects of frequency on rattle boundaries that were observed during this study, other effects were also noted. The amount of contact between masses forced to rattle apparently had considerable effect. Also, the absolute weights of the masses had an effect on the rattle boundaries. The purpose of this appendix is to describe experiments using different weights and contact surfaces and show the results.

Apparatus and Test Procedures

In addition to the four test configurations shown in figure 1, other setups were used as shown in figure A1. Additional balls, blocks, and cylinders were used as follows: plastic balls of 0.15 lb (68 g) and 0.62 lb (281 g); a steel ball of 1.13 lb (513 g); an aluminum block of 0.1 lb (45 g); brass cylinders (flat side down) of 1.10 lb (499 g) and 1.5 lb (680 g); and a steel cylinder (round side down) of 2.5 lb (1,134 g). The same instrumentation and test procedures as described in the main text were used.

Results

The effects of weight (with point loading) on rattle boundaries are shown in figure A2. The peak acceleration levels, g_p, at which rattle first occurred for various masses are given for the frequency range from 20 to 90 Hz. It is expected that the lowest g_p for rattle to occur is at a very small increment over 1 g_p. However, only the masses with flat bottoms (cylinders and block) in contact with the driving plate (figure A1(d)) gave results close to 1 g_p. The various balls or cylinder with essentially point contact resulted in lower g_p's depending on its weight. Thus, when the ball or cylinder is driven by a point load, the peak acceleration level at which rattle occurs decreases with increases of the weight of the item.

The effect of line contact on rattle boundaries is indicated in figure A3. One set of data were obtained with point contact, shown as essentially zero line contact on the ball. The next set of data were obtained with a ball resting on the open end of the force gage. The third set of data were obtained with the ball resting on a washer glued to the top of the force gage (figures A1(a), (b), and (c)). As the line contact became larger, the g_p for rattle increased toward the expected 1 g_p level. The effect of weight is again indicated in that the heavier ball required a lower g_p to cause rattle.

The weight effect is again apparent when the balls are suspended as pendulums. Figure A4 shows the acceleration levels required for the balls to start to rattle as a function of angle with the vertical (α). The excitation frequency was 20 Hz. As expected, the greater the pendulum angle, the larger the acceleration level. However, for the same angle, the heavier ball is again shown to start rattling at a lower acceleration level. As in the main text, the prediction line shown on figure A4 is based on the component of 1 g acting on the ball due to the pendulum hang angle, α.

Concluding Remarks

It was noted that the amount of contact (from point to surface) between rattling masses had considerable effect on the rattle boundaries; the less surface contact, the lower the boundary. When the amount of contact approached point contact, the heavier balls had lower rattle boundaries.

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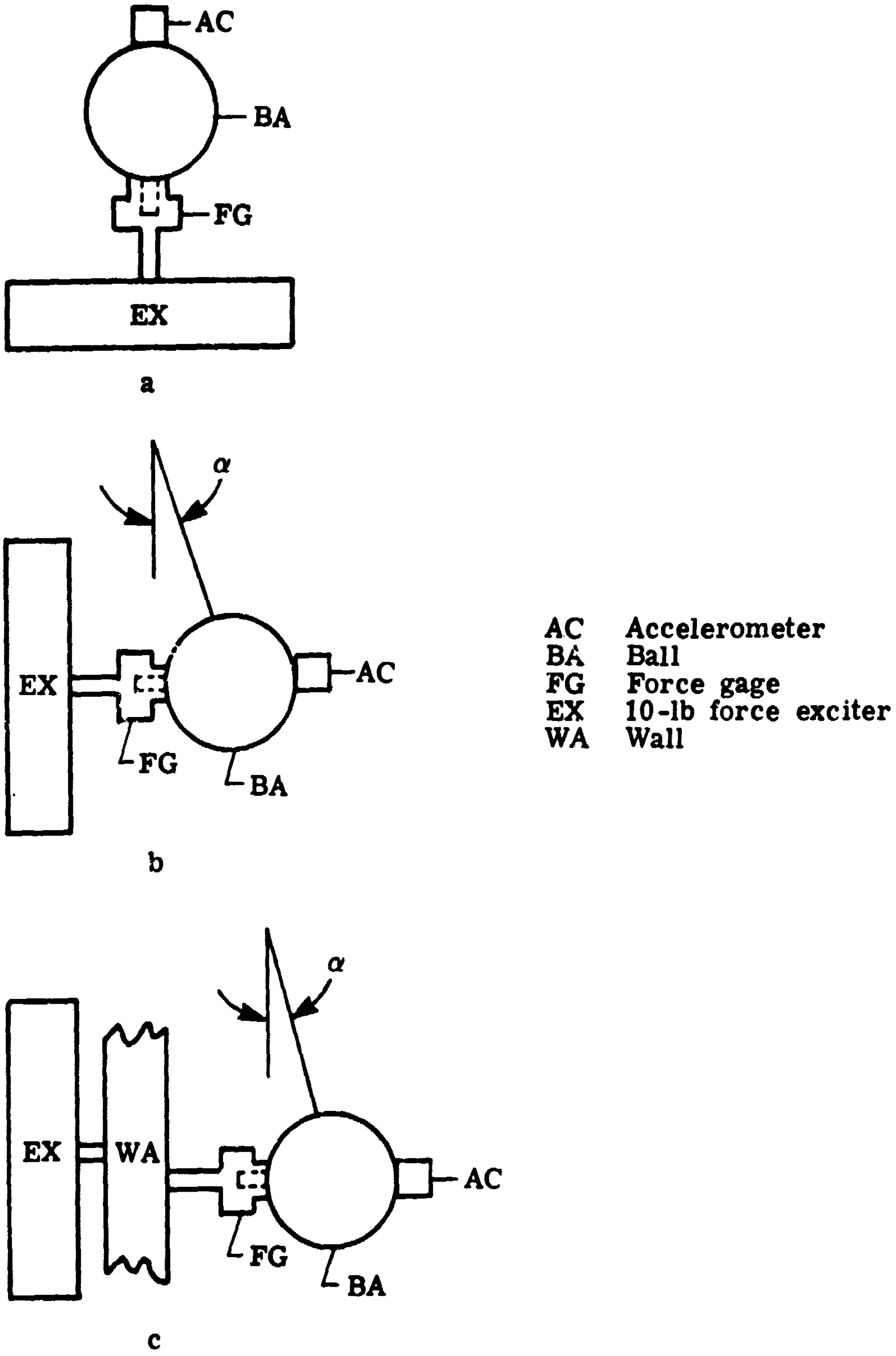
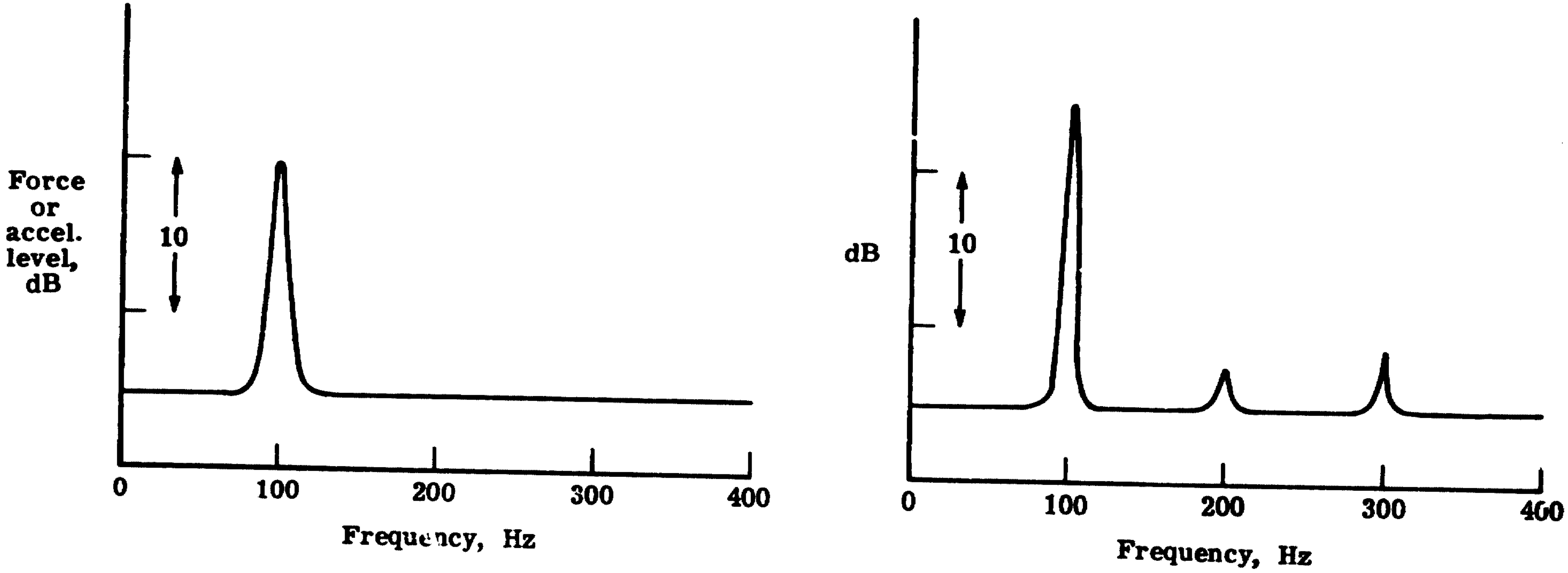


Figure 1.- Experimental setups for obtaining rattle (separation) vertically and as pendulums.



(a) Before separation.

(b) At rattle.

Figure 2.- Accelerometer or force gage output spectra indicating rattle.

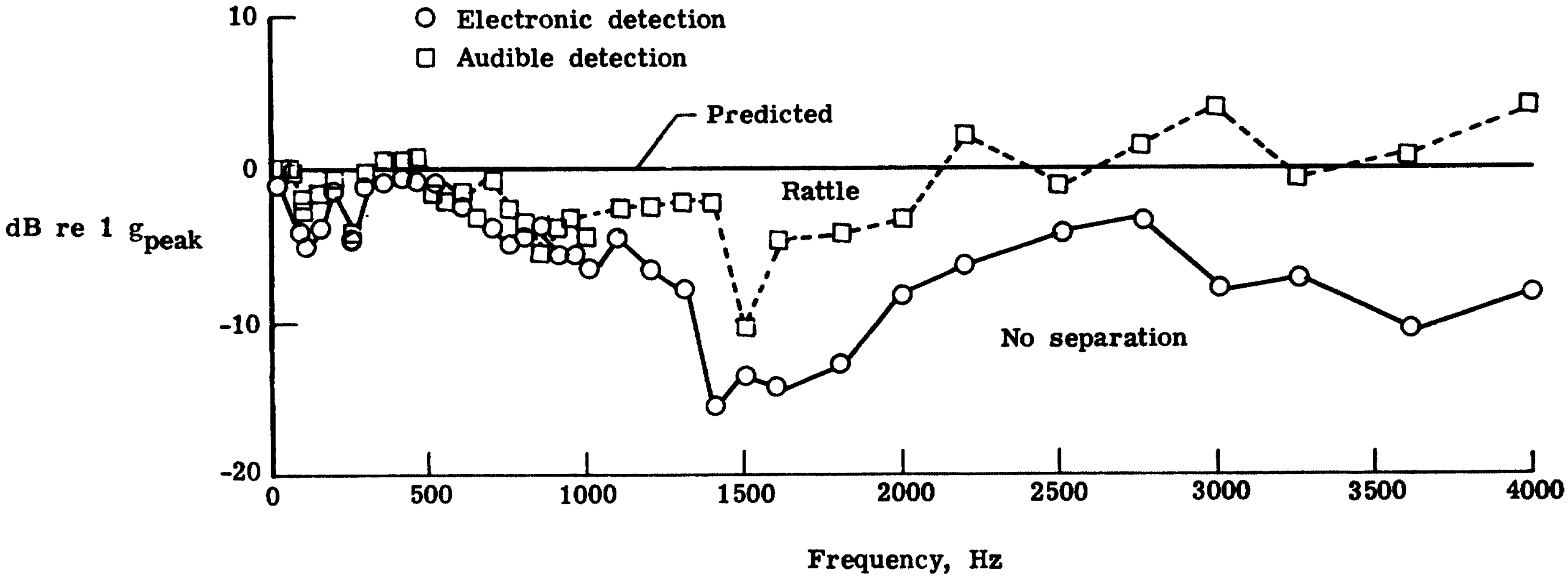


Figure 3.- Rattle and separation boundaries of a 1-inch diameter steel ball shaken vertically (see fig. 1a).

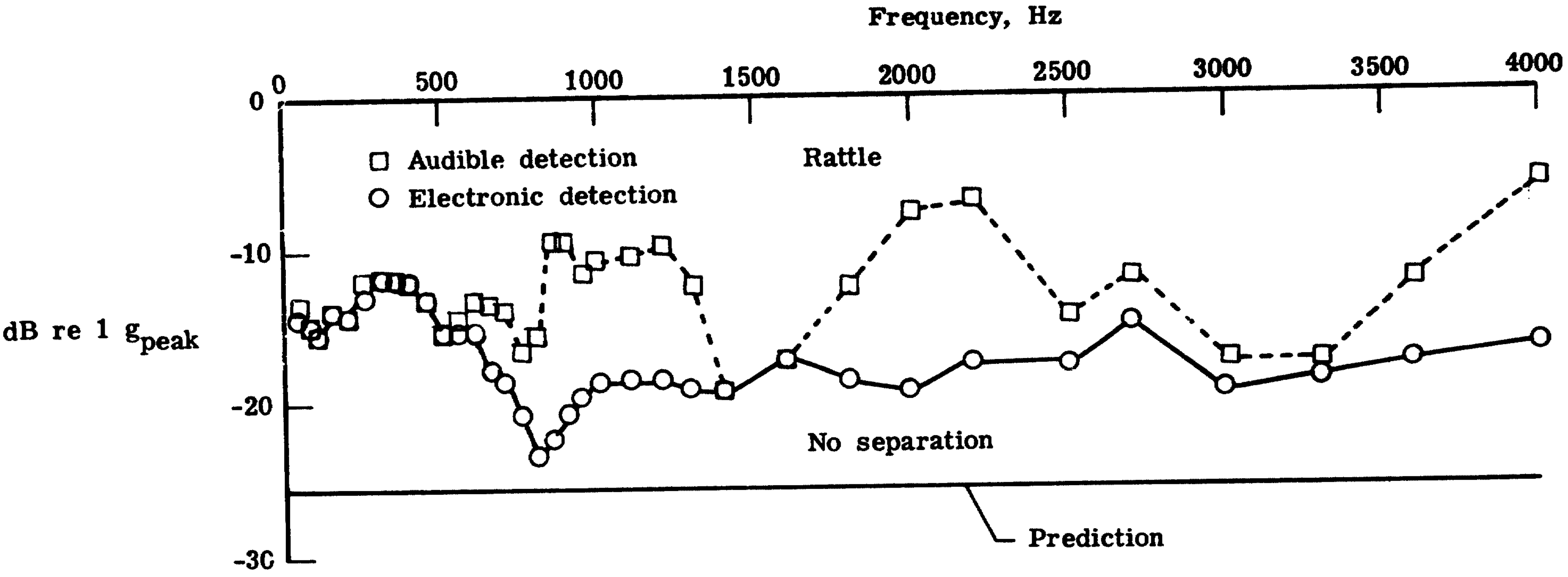


Figure 4.- Rattle and separation boundaries of a 1-inch diameter steel ball suspended as a pendulum (see fig. 1b).

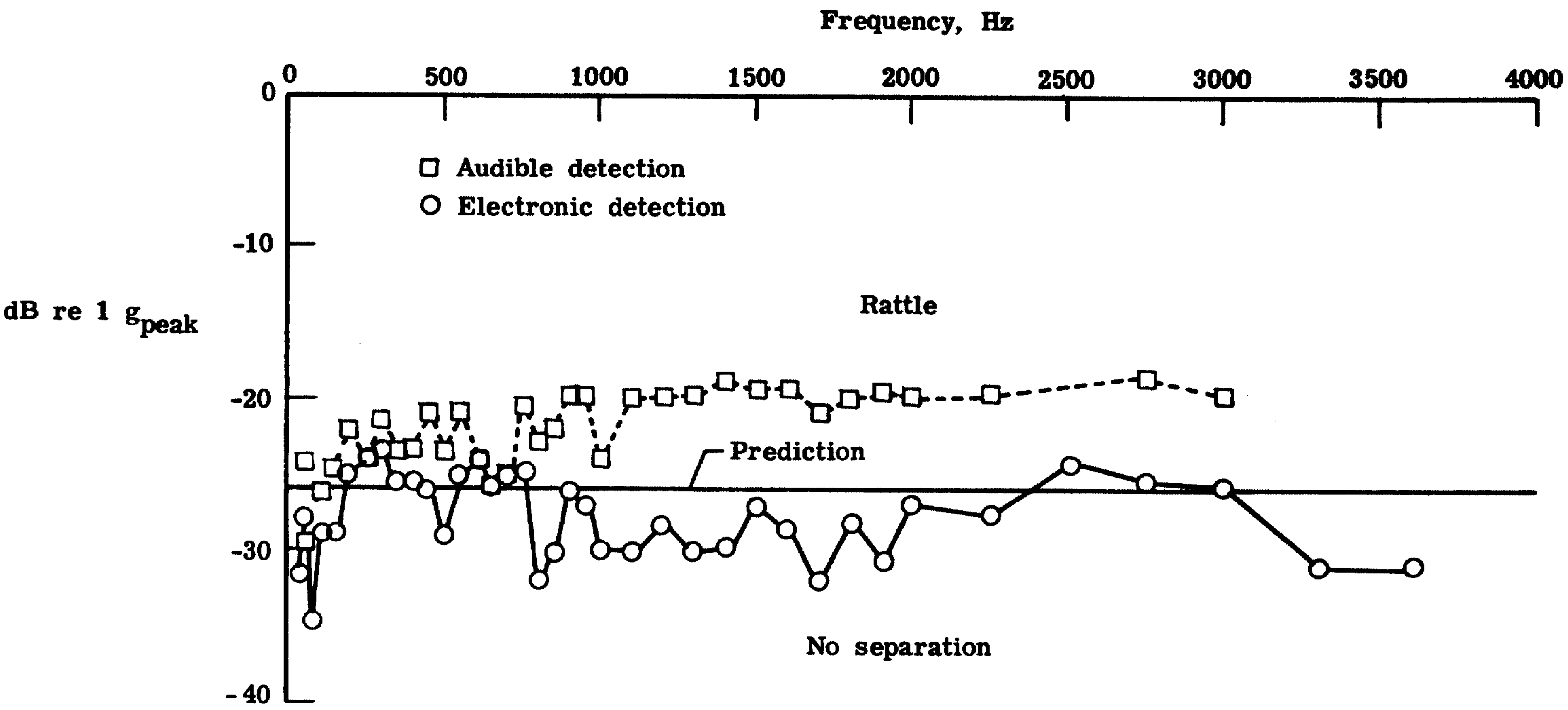


Figure 5.- Rattle and separation boundaries of a 1-inch diameter steel ball suspended as a pendulum on the wall of the interior effects room (see fig. 1c).

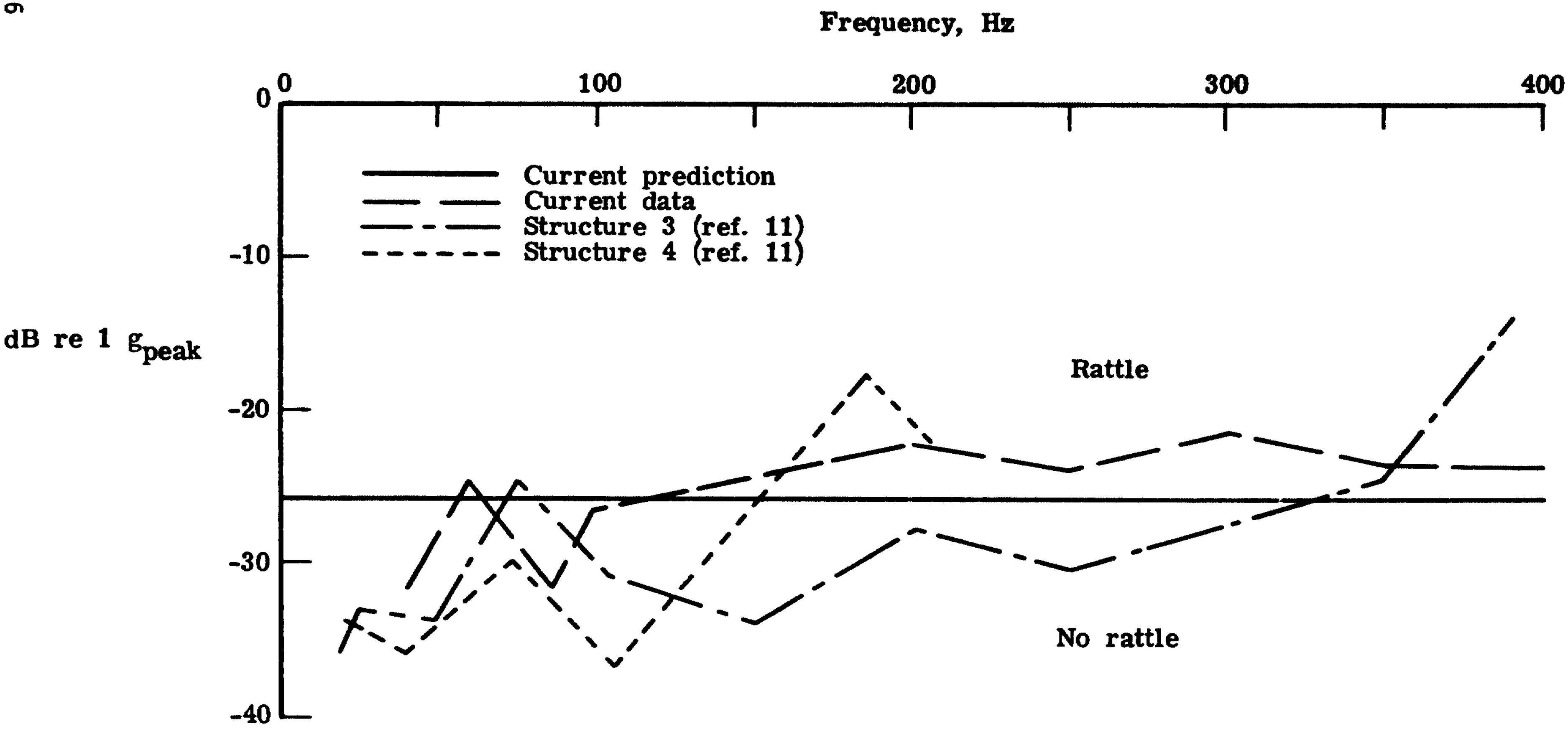
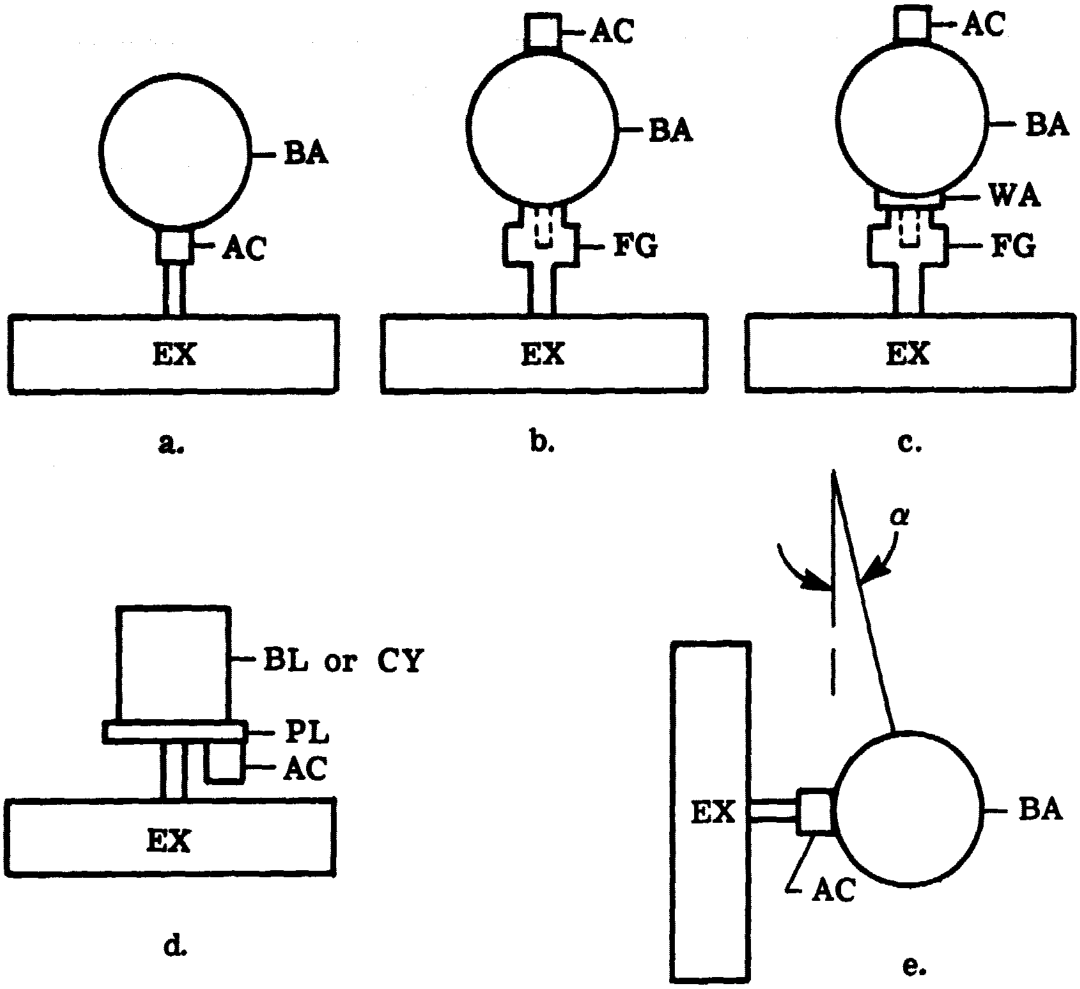


Figure 6.- Comparison of rattle data of current study with prediction and with data of reference 11.



AC	Accelerometer	FG	Force gage
BA	Ball	CY	Cylinder
BL	Block	PL	Plate
EX	10-lb exciter	WA	Washer

Figure A1.- Setups for obtaining effects of surface contact and weight on rattle boundaries.

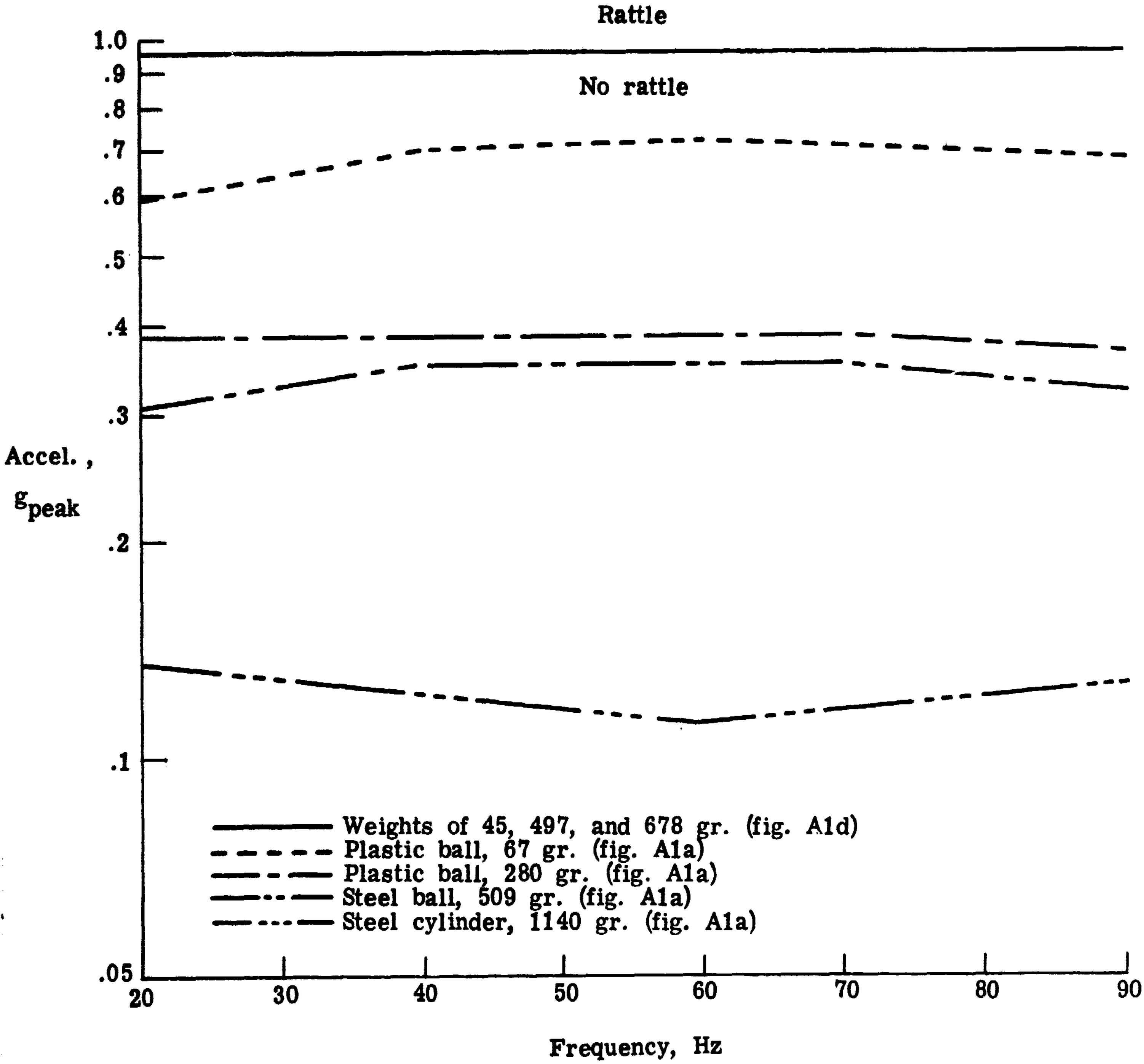


Figure A2.- Rattle boundaries indicating effects of weight (using point contact).

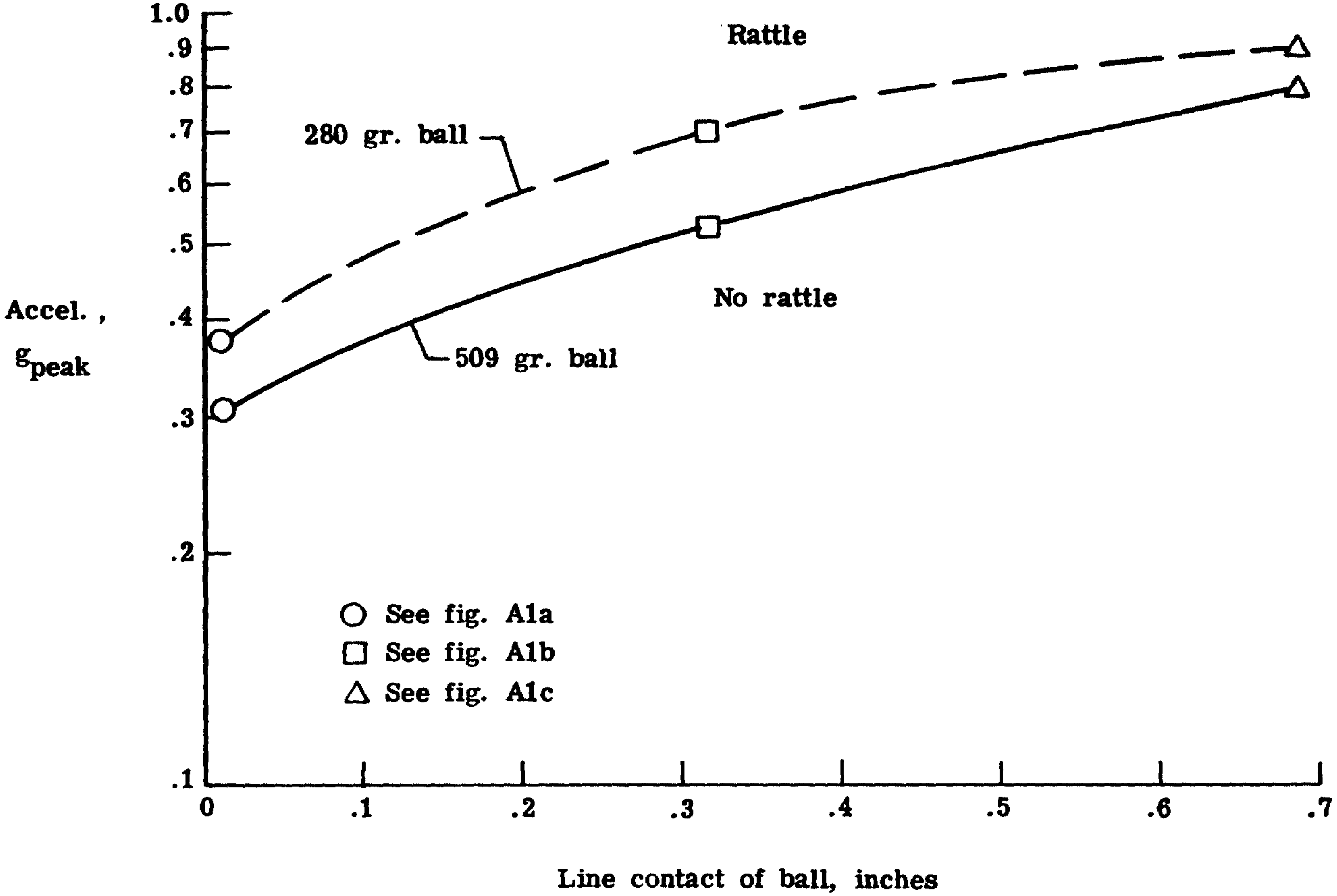


Figure A3.- Effect of line contact on rattle boundaries, 20 Hz.

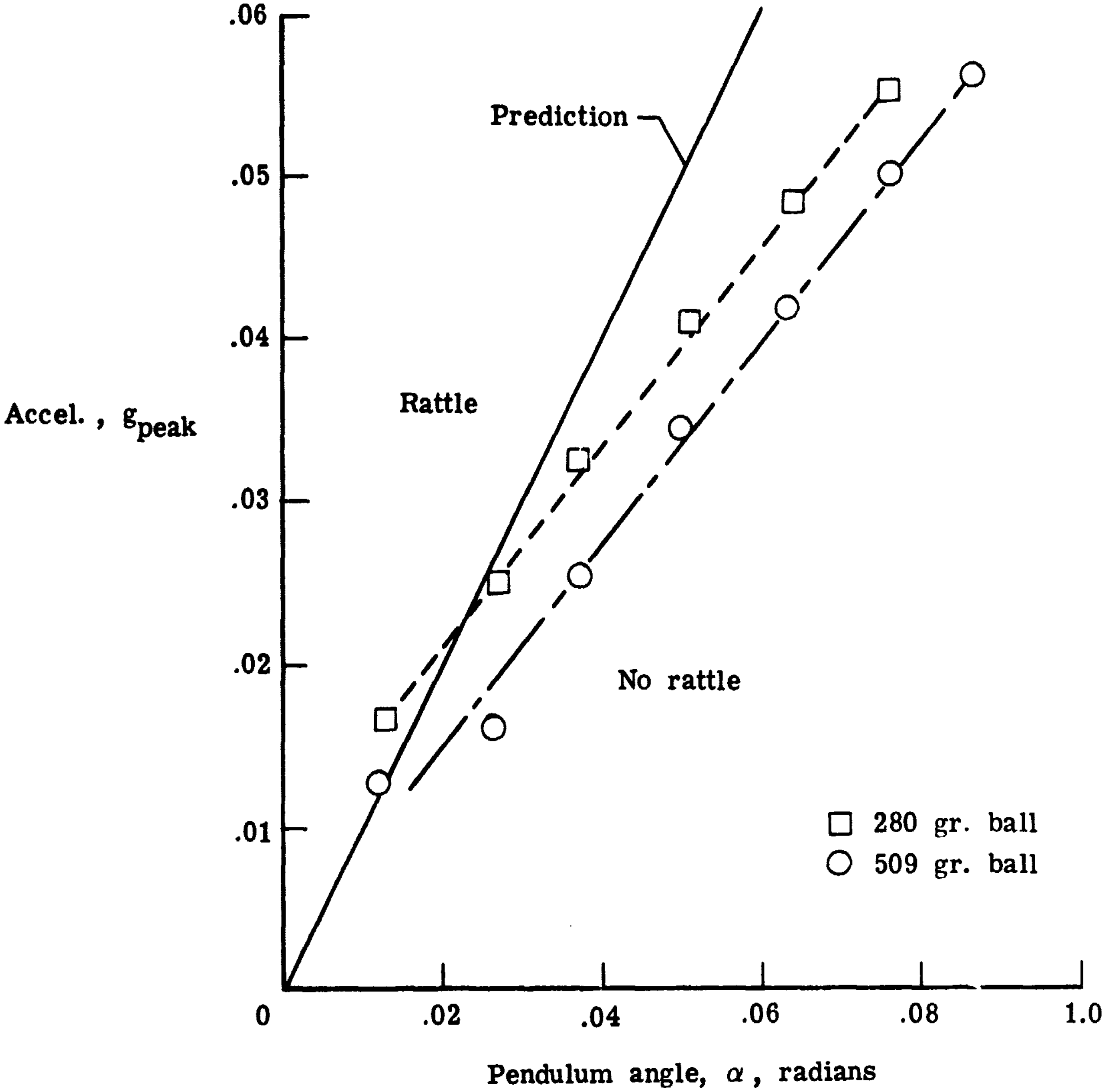


Figure A4.- Rattle boundaries of 2 balls suspended as pendulums with various hang angles (fig. A1e). Excitation Frequency = 20 Hz.