Details of Acoustic Substrate Alarm Communication through Head-banging in the Subterranean Termites: *Coptotermes formosanus* Shiraki and *Reticulitermes flavipes* (Kollar)

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Subterranean termites are relatively defenseless insects. Survival depends upon concealment in mudtubes and carton nests. When these are disturbed, termites will often head-bang and tremulate to attract soldiers for defense and workers for breach repair. Head-banging results in the greatest amplitude substrate vibration. High-speed video (Figure 1) reveals a "see-saw" body motion in which movement of the abdomen and head result in a larger effective mass and thus a greater vibrational impact. Soldiers in both species tend to hit the substrate with the mid-ventral portion of the head. However, unlike a see-saw, the fulcrum point varies as the legs not only pivot but also raise the body and head. The soldier can also vary its muscular input. After impact, the head rebounds up, perhaps twice after a single impact. Rf soldiers in nature often head-bang in rapid triplicate in which the time between successive strikes is 30 to 40 milliseconds. Rebounds occur after each head-bang unless the soldier deliberately squelches it. FST generally head-bang at a relatively uniform rate (not showing the diagnostic triplet pattern of most Rf) and the time between their successive head-bangs is often 70 milliseconds or longer. Rf soldier populations are small and most will head-bang in response to perceived colony habitat penetration. Rf soldiers can even be induced to head-bang outside their galleries, whereas FST usually will not. Only a small percentage of FST soldiers head-bang at one time after colony disturbance, thus saving energy. Head-banging in infested trees often subsides within 45 minutes, whereas subsidence takes much longer in very heavily infested trees. Worker termites may head-bang occasionally but more weakly impact the substrate with their mandibular tips.

While the motion of the termite body during head-banging is primarily rotational, some variation occurs, including slight rocking motion. A simplified dynamic model can isolate and predict the body's "see-saw" effect. The proposed model is shown in Figure 2. The body consists of a rigid rod with a lumped mass at either end. Both the head and abdomen are assumed to be an ellipsoidal mass with a constant density. Strictly rotational motion $\theta(t)$ is considered

Model parameters are selected based upon measured data from still and high speed photography. Length, width, and height dimensions were measured and statistically analyzed using five Rf. soldiers. The head mass m_1 and body mass (thorax + abdomen) m_2 were measured on a microgram scale. The mass moments of inertia J_1 and J_2 were estimated using ellipsoidal shapes. At a height h from the ground, a center of rotation, point R, is estimated based upon video evidence.

Dynamic analysis of the model is performed using projectile physics. A given soldier's head-bang is analyzed where the initial deflection angle $\theta_0(t = 0)$ is 30.3˚ and the head contacts the surface at approximately 9 milliseconds from the apex of head motion, which is the initial dynamic rest condition. The measured time to contact provides a comparison point for determination of the head's effective acceleration. The calculations show that termites forces their heads downward in order to increase the impact force. If a Rf. termite were to strictly relax its body and let its head drop naturally, the time to contact would be 12.07 milliseconds. The measured time to contact is approximately 9 milliseconds, so

the termite forces its head downward at a faster rate than gravity. Based upon the difference in the time to contact and the initial body configuration, the vertical acceleration produced by the termite's head is approximately 17.6 m/s^2, or 1.80G. Thus, the termite's head moves downward at an acceleration 80% greater than gravity.

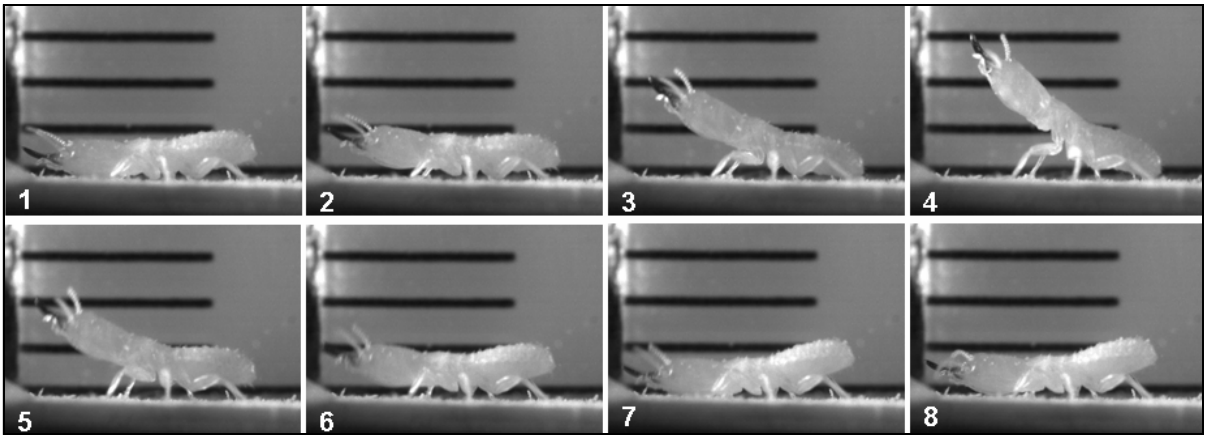

Fig. 1. *Reticulitermes flavipes* head-banging: key frames from high-speed video.

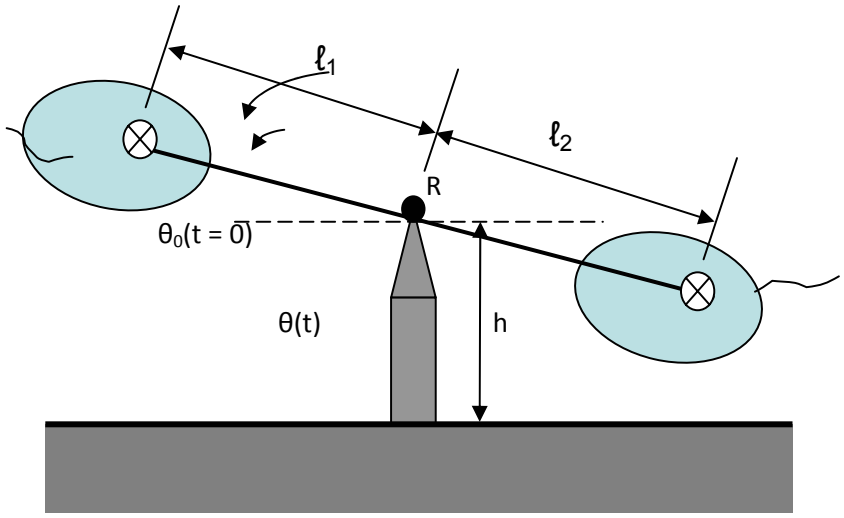

Fig. 2. Simplified termite model.

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