DESIGN VALIDATION AND TESTING OF WOLF BITE METER

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ABSTRACT

Caretakers and wolf behavior researchers expressed an interest in obtaining experimental evidence indicating the bite force of a wolf. A request was made by Eckhard H. Hess Institute of Ethology at Wolf Park personnel to design and produce a prototype testing apparatus to obtain bite force data. A literature review showed only the results of laboratory simulation testing to document wolf bite forces. The design of an appropriate wolf bite force test apparatus was undertaken to permit measurement of bite forces directly from wolves. The design of the device needed to allow separation of transverse bite forces from any other loading introduced by the wolves. A prototype steel "tuning fork" type, strain-based load cell was developed and its geometry was chosen based on cantilever beam deflection formulas and centroid and moment of inertia equations. To acquire the true value of the transverse bite force, the effects of any axial loading that the wolves produced when biting the apparatus was subtracted from the total normal strain values, then converted to force. The paper describes the design process used to develop the test apparatus. Successful preliminary testing of a prototype bite force test apparatus was conducted using one female and seven male wolves ranging in age from six to eleven years old at Eckhard H. Hess Institute of Ethology at Wolf Park.

1. TEST DEVICE DEVELOPMENT

1.1 Background

A literature review indicated several standard bite force test device shapes have been used with species ranging from opossums to alligators (Binder, 2000; Dumont, 2003; Ecomorphology, 2004; Erickson, 2003; Lindner, 1995; Martin, 2004; Thomason, 1990; Thomason, 1991). Bite force test device designs used for other species include a force transducer surgically implanted on the mandible of a dog and electrical stimulation of the masticatory muscles of an anesthetized dog, piezoelectric load washers placed between two stainless steel plates for American alligators, and a shark 'gnathodynamometer' where the depth of indentations were correlated to estimated bite pressure. For species with mouth geometries similar to wolves, a "tuning fork" style test device was effective in several cases. Personnel and volunteers at Wolf Park initially developed and tested an aluminum tuning fork-style test device with leather-covered tines. This device was tested via a quick, uncontrolled method to determine if the wolves would cooperate and to see if the device would be able to withstand the largest forces it would be detecting. Because the wolf bites caused the tines to make full contact, the first test device was found to be inadequate for conducting the test, but the basic device design was maintained.

1.2 Design Constraints

The bite force test device must meet a number of sometimes conflicting design constraints. The tuning fork configuration was retained because it is easily modeled as a cantilever beam, and sensing element installation is relatively straightforward. The shape of the test device must be comfortable for the wolf to bite and simple to produce. A rectangular geometry was considered but was rejected due to the possibility of discomfort from the edges and corners. An elliptical shape would be optimal for comfort but was discarded due to difficulty of manufacture. Round bar stock gives the best compromise between comfort and ease of manufacture. The apparatus geometry must be small enough to fit the tine section through a fence hole during testing, in addition to fitting comfortably into the mouth of an adult wolf. The tine section must be sufficiently stiff to prevent full tine closure. Leather tine covers are attached to entice the wolf to bite the test device and provide protection for the wolves' teeth. The handle section must be large enough for the tester to grip it with both hands, and needs to provide a protected path for the sensor wiring. Finally, the cost of the test apparatus must be minimized.

Because real maximum wolf bite force limits are unknown, a combination of laboratory simulation testing and quick prototype testing was used to estimate the bite forces and effectiveness of the first prototype. Previous laboratory simulation testing indicated that peak wolf bite forces are approximately 317 lb_f (1412 N). The original aluminum prototype test device proved to be unable to resist the forces generated by the wolves, deflecting to fully closed upon biting during the simple prototype test at less than 300 lb_f.

1.3 Theoretical Analysis

The test apparatus was modeled as two symmetric, independent cantilever beams, where the tines are the beams and the handle acts as a fixed wall support. Figure 1 shows a diagram of one cantilever beam, as modeled, and the variables used to determine transverse bite force, P, from the tine deflection. Normal flexural stress at the handle end of the tine section was calculated to determine the yield strength needed to prevent permanent deformation of the apparatus material. Stress concentration was assumed to be minimal at the transition from tine to handle since the cross-section is increasing in size. The basic tine cross-section and the corresponding geometric properties are shown in figure 2. Spreadsheet calculations were performed to consider possible tine lengths, tine cross-sections, and the match between material yield strength and design stress. The second prototype was made of 1144 modified stress relieved steel, with a tine length of 7.0 inches, a metal outer tine diameter of 1.375 inches, a tine gap size of 0.25 inches, and a cylindrical handle with an outer diameter of 1.50 inches and an inner diameter of 0.250 inches.

1.4 Laboratory Testing of the Bite Force Apparatus

Strain gages were used for both laboratory simulation testing and experimental testing of the prototype bite force test devices. Strain gages were mounted to the testing device using the conventional method. For the experimental test, two strain gages were mounted on the steel test apparatus to detect total normal and axial strains. The gage used to indicate total strain was located on the top surface of the tine, centered at a fixed distance from the bite point, and axial strain gage was located on the handle of the test device along the neutral axis (line of symmetry).

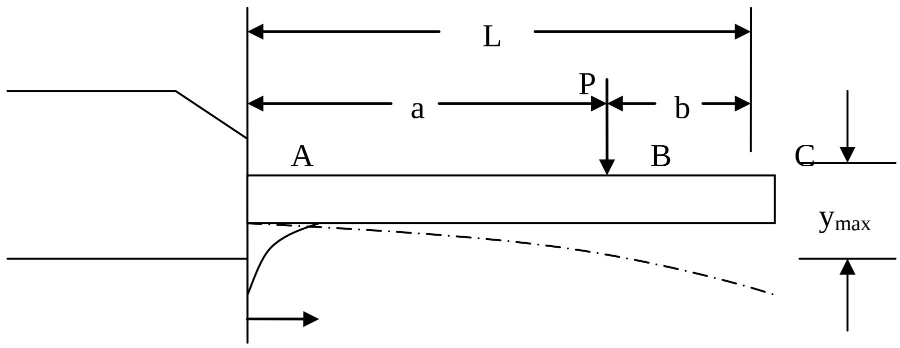


Figure 1: Cantilever beam (Mott, 2002).

Eq.1 $P = -\,y_{max}6EI/a^2\,(3L-a)$

Eq.2 $\sigma_{nom} = Mc/I = (Pa)$

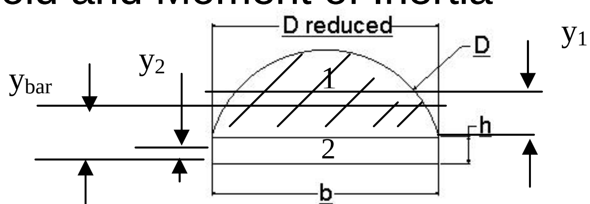
P- load	M- moment (P x a)
E- modulus of elasticity of material	c-centroid location of cross section
σ_{nom}- normal stress due to bending	I- rectangular area moment of inertia

Figure 1: Model of tine section as a cantilever beam.

Centroid and Moment of Inertia

Gap (in)	D (in)	D reduced (in)
0.250	1.375	1.335

b (in)	h (in)	Ybar (in)
1.355	0.125	0.359



Section	Ai (in²)	Yi (in)	AiYi (in³)	di (in)	Aidi² (in⁴)	Ixi (in⁴)
1	0.742	0.292	0.216	0.07	0.00340	0.0245
2	-0.169	0.0625	-0.0106	0.30	-0.0149	-0.000221
Σ Ai =	0.573	Σ AiYi =	0.206	Σ Aidi² =	-0.0115	Σ Ixi = 0.0243

Ix =	0.0128	in⁴
Y =	0.328	in

$d_i = y_{bar} - y_i$ $y_1 = .212D$

$A_1 = \pi D^2/8$ $y_2 = h/2$

$A_2 = h \times [(D+b)/2]$ $ybar = y_1 + y_2/2$

Figure 2: Beam centroid location and area moment of inertia (Mott, 2002)

Laboratory testing began with a wolf bite simulation test on the aluminum prototype device to verify the analytical model's force-deflection values. A comparison of the experimental measurements with the model's force values gives a 9.65 % difference. A universal test machine (UTM), fixtured as shown in figures 3 and 4, was used to compress the tines. Load, strain, and deflection were measured at 0.025 inch UTM position increments. A1000-pound load cell and two Vishay P-3500 strain indicators were used to obtain the load and strain data. To properly simulate the contact of teeth of a wolf on the test device, a dowel pin and a wire were used to make contact with the bite area on the test device, as shown in figure 4.

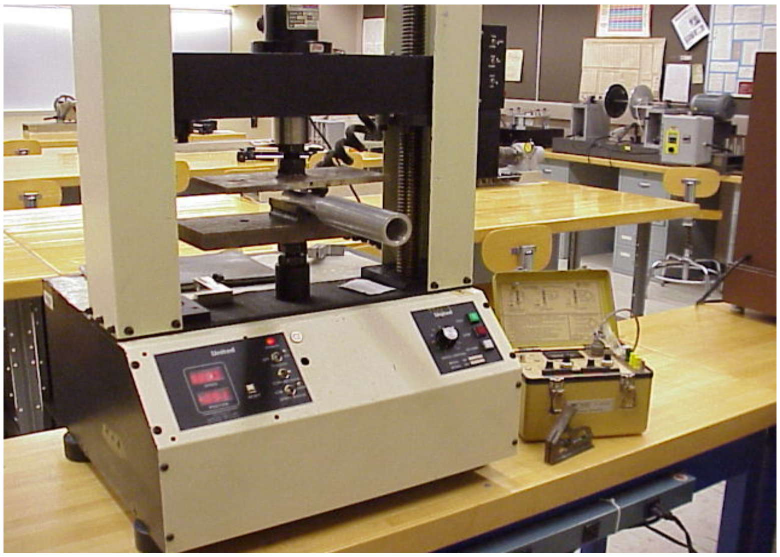


Figure 3: Test setup for wolf bite simulation to confirm analytical solutions.

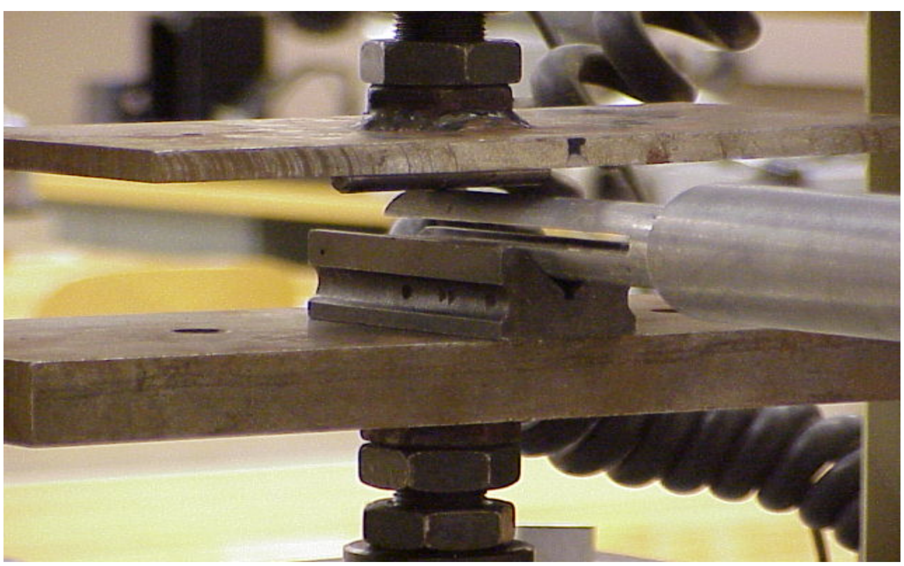


Figure 4: Fixturing to simulate wolf's teeth.

2. INITIAL WOLF BITE TESTING

2.1 Initial Field Testing Procedure

Using the aluminum prototype and food treats, Wolf Park staff worked with the wolves to condition them to bite the test device in a manner that primarily involves transverse force, rather than axial or torsional loading. Figure 5 shows the proper position and bite method. The wolves occasionally pulled or twisted the test apparatus, making it necessary to eliminate data points where extraneous loading was applied and to correct for any remaining axial loading.

Two P-3500 strain indicators were used to detect total normal strain at the fixed end of the tines and axial strain on the handle at the neutral axis. The strain values were recorded by hand for preliminary testing. The synchronization of data recording was done manually, which proved to be difficult and lacked accuracy. Additional testing with a synchronized data acquisition system must be conducted before the measured bite forces can be accepted as valid. Another challenge to the accuracy of the measured forces can be seen on figure 5, which shows a white line was scribed on the test device in helping control where the wolves would bite the stick. The wolves disregarded this purpose and so the moment arm distance that was actually used was the distance from the bite marks on the leather to the center of the strain gage, a method that is reasonable only for a minimal number of test sessions.

Figure.5: Wolf biting for transverse loading.

2.2 Force Calculation Method

The transverse and axial forces can be calculated using equations 3 through 6. The axial force is obtained from the axial strain measurement at the handle and used to calculate axial strain in the tines. The calculated axial strain is then subtracted from the total normal strain. The difference is the flexural strain produced by the transverse bite force, which can be calculated from the deflection equation for a cantilever beam.

Eq. 3 $P_{axial} = \varepsilon_{axial1} A_{handle} E$
Eq.4 $\varepsilon_{Axial2} = P_{axial}/A_{bite}E$
Eq.5 $\varepsilon_{bend} = \varepsilon_{total} - \varepsilon_{axial2}$
Eq.6 $P_{bite} = \varepsilon_{bend} EI/ac$

P_{axial} –axial force	$A_{handle} = [\pi(D_1^2 - D_2^2)]/4 = 1.72\ in^2$
P_{bite}-bite force	$A_{bite} = \pi D^2/8 = 0.742\ in^2$
ε_{axial1}-axial strain on handle	E-modulus of elasticity of material = 30×10^6 psi
ε_{Axial2}-axial strain on bite area	I- area moment of inertia = $0.0128\ in^4$ (see Fig. 2)
ε_{bend}-strain due to bending	a- moment arm = 5.5 in (see Fig.1)
ε_{total}-total strain	c-centroid location of cross section = 0.328 in (see Fig.2)

3. CONCLUSIONS AND REMAINING WORK

The prototype wolf bite force test apparatus is functional, but the bite force data has not been verified. A primary addressable concern is the need to automate data collection for synchronization of strain measurement to ensure that appropriate corrections are made to measured strains. A second addressable concern is to test a similar domesticated and trained species to compare the resulting bite forces to published data. A more challenging, probably ongoing issue is that the test subjects are tamed and inhibited wolves that may not represent the species in the wild. It is speculated that a certain time period such as breeding season could provide increased bite forces due to increased testosterone in both the male and female wolf, which is anticipated to make the wolves more assertive. As the project continues, these three concerns are being addressed.

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