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Prediction of Eggshell Thickness and Strength By Ultrasonic Measurements

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PREDICTION OF EGGSHELL THICKNESS AND STRENGTH BY ULTRASONIC MEASUREMENTS

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SUMMARY

Ultrasonic measurements were found to be correlated with shell thickness (r = 0.424) and with the force required to fracture the shell under quasi-static compression (r = 0.203) based on readings from 84 eggs. If 6 eggs which were at the extremes were eliminated from the data, the coefficients increased to 0.82 and 0.43 respectively. Thus, it would appear that ultrasonic measurements may have potential for predicting shell thickness and strength non-destructively. It was concluded that additional testing and development is worthwhile when more precise equipment becomes available.

INTRODUCTION

Egg breakage causes considerably losses to the poultry industry. Thus, the measurement of eggshell strength is of interest to poultry breeders and nutritionists as this quality factor must be determined to examine the effect of experimental treatments. Engineering Research Service in co-operation with the Animal Research Institute have performed a number of experiments to examine the relationships between the force required to break the egg (quasi-static and impact) and a number of egg characteristics such as egg specific gravity, shell thickness, shape, size and non-destructive deformation. The extent of this work is indicated in the list of references by the work of Hamilton, Hunt and Voisey spanning 11 years. A primary objective of the work was to find a physical characteristic of the egg that predicted its strength precisely and quickly to handle the many replicates needed in typical experiments.

Ideally any measurement of shell strength for experimental purposes should be non-destructive. Egg specific gravity and non-destructive deformation meet this requirement but although they are correlated with shell strength, their prediction is not very precise. Generally, these measurements account for at best only about 50% of the variation in eggshell strength. Theoretically, a major factor in shell strength is shell thickness but in practice this also appears to account for less than 50% of the strength variation. Shell thickness can be precisely determined breaking the shell and direct measurement with a dial gauge (Voisey and Hunt, 1973, 1974). A nuclear non-destructive technique for this measurement, developed at USDA, Beltsville, was examined and found to be inaccurate (Hunton, 1969; Voisey, Hunt and James, 1969; Voisey and James, 1970; Voisey and Hunt, 1976).

Gould (1972) claimed that an ultrasonic device allowed non-destructive measurement of shell thickness. Because of the importance of this discovery a preliminary experiment was conducted. The results (Voisey and Hamilton, 1976) indicated that the technique was potentially useful. Ultrasonic readings and shell thickness at 4 individual points on the equator of 100 eggs were significantly correlated (r = 0.59). The mean readings for each egg were better correlated (r = 0.74). There was considerable scatter among the mean readings, but a linear relationship between them was evident.

Ultrasonic techniques are widely used for industrial measurments such as the thickness of coatings on metals and have been used for a number of agricultural applications such as back fat determination in hogs, leather quality and milk fat measurement (Finney, 1973). Thus, the needed equipment is readily available in various degrees of sophistication. If the prediction accuracy could be raised sufficiently then the technique could be easily implemented for test work, or even quality selection for production systems.

The purpose of the work here was to test an improved apparatus and develop techniques to obtain better prediction performance and to further examine the relationship between ultrasonic readings and shell thickness using water as the transmission medium for the ultrasonic beam. Also, the relationship between the ultrasonic readings and shell strength was examined.

THE APPARATUS

The apparatus was essentially the same as previously reported (Voisey and Hamilton, 1976). An ultrasonic transducer (C, Fig. 1; Fig. 2A) focused its beam (D) on to the shell surface over a distance of 3.8 cm. The beam was transmitted to and from the egg by water - a common technique for industrial applications. Energy was reflected by both the inner and outer surfaces of the shell. The difference in time between the pulses reflected by the two surfaces was proportional to the distance between the inner and outer surfaces, i.e. shell thickness. The reflected energy was detected by the same transducer. The pulse frequency of the ultrasonic energy was 10 MHz.

The egg (A) was supported by 4 plastic rollers (B, Fig. 1) turned by a hand crank (Fig. 2B), so that the egg could be rotated relative to the transducer while maintaining the shell surface at the focal point of the ultrasonic beam. The transducer, rollers and lower half of the egg were immersed in a water bath (Fig. 1, 2B) containing a wetting agent (household detergent). The method was used on the hypothesis that shell thickness varies over the egg (Voisey and Hunt, 1974). A measurement of mean shell thickness at the weakest part of the shell, the equator, should be more predictive of thickness and strength than the thickness at a single point. Using the arrangement shown it is technically feasible to do this by turning the egg a single revolution, to obtain a continuous ultrasonic reading, and provide a readout of the average shell thickness at the equator by means of electronic circuits. A water transmission medium also facilitates the design of an automatic system to test eggs on a continuous basis.

The transducer was connected to a standard ultrasonic device (Model 303, Krautkramer Branson Inc., Stamford, Connecticut 06904) (Fig. 3) that provided a digital readout. This system is capable of completing measurements at a single point on the shell at the rate of 2000 per sec. Thus, it is theoretically feasible to take several readings around the equator to establish an accurate mean but, still test a number of eggs per second. The complete apparatus is shown in figure 3.

EXPERIMENTAL METHODS

Approximately equal numbers of eggs were collected from three commercial type flocks. Flock A was fed the Ottawa hatching ration containing 3.1% calcium and the birds were 470 days old. The second flock (B) comprised birds that had been in lay for about 180 days and were fed a 3.25% calcium containing diet. Flock C had also been producing eggs for about 180 days but had been fed lower than normal calcium from the time of hatching (0.51% calcium from 1 to 143 days and 2.25% calcium between 143 and 180 days). It was assumed that these selections provided a group of eggs with a wide range of shell quality to properly evaluate the instrumental techniques. The eggs were candled and those with defective shells discarded. The remaining 84 eggs were tested as follows.

Four equally spaced points were marked around the circumference of the equator. An ultrasonic reading was then recorded at each location. A continuous readout of average thickness at the equator was then obtained for each egg by steadily rotating the egg and noting the reading after it had stabilized. The non-destructive deformation of the shell, for an applied force change of 0.1 to 1.1 Kg was then noted. This was accomplished by compressing the egg at 2.0 cm min^{-1} in an Instron testing machine (Voisey and Hunt, 1973, 1974) equipped with a precise digital readout of deformation as described by Voisey (1975), Voisey and Buckley (1974) and Voisey et al. (1974) and previously employed to test eggs by Voisey (1975), Voisey et al. (1973) and Voisey and Hamilton (1976). The quasi-static fracture force when each egg was compressed between parallel ground steel surfaces at 2.0 cm min^{-1} was then determined (Voisey and Hunt, 1973, 1974) using an electronic peak force indicator for the readout (Voisey, 1971). A piece of shell was then removed from the membranes at each of the four marked locations on the equator and their thickness measured by a dial gauge comparitor (Voisey and Hunt, 1973, 1974). The mean ultrasonic reading and shell thickness for each egg was then calculated from the readings taken at the four marked locations.

The ultrasonic apparatus was operated with the following settings.

Range 1.0 Zero 423

Material Cal 414 Double
Delay II 0 Normal mode

Frequency 10 M Hz

Range 5 in.

Coarse delay 2

Fine delay 2 o'clock
4 db in, rest out

Damping off - 0

Coarse gain 60

Fine gain C

As previously mentioned (Voisey and Hamilton, 1976), calibration of the ultrasonic readout in terms of thickness by an independent standard presented problems. The following technique was, therefore, developed. Two sheets of copper (a & b) of different thickness were alternately placed on the plastic rollers above the transducer. The readout controls were adjusted until the readings were 100 times the thickness of the sheets (in English units). These readings were as follows:

Sheet	Thickness		Reading
	in.	mm	
a	0.0215	0.546	21.5
b	0.0300	0.762	30.0

The instrument was thus calibrated to give precise measurements of thickness of copper sheet to within 0.0001 in. (0.00254 mm) and this provided an arbitrary but known consistent instrument standardization technique. The instrument was maintained in a constant operating condition so the readings obtained should, in theory, be repeatable. Readings were taken from the copper sheets prior to testing each egg. To eliminate the drift during warm up the ultrasonic readout was switched on for 1 hr prior to the test.

The calibration of the instrument was thus improved compared to the previous test (Voisey and Hamilton, 1976). Also, the ultrasonic instrumentation settings above were recommended as the optimum for this application by the instrument manufacturer. It was assumed that the ultrasonic technique was evaluated under better conditions than previously.

RESULTS AND OBSERVATIONS

The repeated calibration readings from the copper plates were absolutely consistent throughout the experiment. Thus, it was concluded that the instrument was stable and gave repeatable readings.

The continuous measurement technique of steadily rotating the egg did not give satisfactory results. The readings were not consistent, and it was found difficult to obtain stable readings. Thus, these data were considered suspect. The problem was attributed to movement of the shell surface relative to the focal point of the ultrasonic transducer due to out of roundness of the egg, surface imperfections and the fact that the egg tended to move laterally slightly since it was not a perfect ovoid shape.

A summary of the results (Table 1) indicated that shell thickness of the three flocks (A, B and C) were on the average the same and similarly variable within groups (9, 11 and 8% respectively). The average ultrasonic readings indicated slight differences (less than 3.6%) between groups and the variation within groups was not consistent being 15% for group A compared with 7 and 6% for groups B and C respectively. With the exception of the UR at one location in group A, differences in average shell thickness within groups at the four measurement locations were not indicated by either UR or direct shell thickness measurements. The variation within groups was the same at the four locations as for the pooled readings within groups. Generally the variation for the pooled or individual location readings within groups was similar for both UR and thickness measurements.

The average fracture force for each group indicated a trend of decreasing shell strength from group A to group C. The significantly lower force for group C compared to A and B may reflect the influence of the lower calcium which the flock had been fed. The force readings were paralleled by corresponding increases in the non-destructive deformation readings.

Averages based on the pooled readings from the three groups indicated that variation of fracture force (21%) and deformation (26%) were similar. The variation of shell thickness according to UR or thickness measurements (8 to 11%) was less than half the indicated strength variations. This is a typical result and points out that shell thickness can only account for a part of the strength variations.

The UR gave shell thickness values that were nearly twice the actual shell thickness. This points out that the calibration with copper sheets does not calibrate the instrument in the correct units for testing eggs. It would appear that thinner copper sheets should be used and the calibration based on the regression between shell thickness and UR. Theoretically, it is feasible to adjust the system to indicate shell thickness exactly. This was not attempted for this work. This may be difficult, however, since the slope of the regression line based on individual readings was 0.157 whereas it was 0.260 based on egg means (Table 2).

Regressions and correlation coefficients among all traits (Table 2) indicated that shell thickness and strength (i.e. force) were related (r = 0.48). UR and shell thickness based on individual locations (r = 0.31) or egg means (r = 0.42) were correlated at about the same level. However, UR and shell strength based on egg means (r = 0.20) were correlated at a significantly lower level. On the other hand, non-destructive deformation and shell thickness (r = -0.54) and non-destructive deformation and shell strength (-0.69) showed the strongest relationships within the experiment.

Correlation between continuous ultrasonic readings and the other traits produced coefficients ranging from 0.009 to 0.031 indicating that this means of measurement was not satisfactory (Table 2). Also, the average thickness indicated by the continuous UR as opposed to UR from the four locations was significantly higher (0.600 c.f. 0.536 mm , Table 1). Thus, it was concluded that the continuous reading technique was not worthy of further investigation.

Scatter diagrams of the data indicated that UR readings from 6 of the eggs were far from the average relationship. These were eliminated from the data and the statistical calculations repeated (Table 3). It was assumed that the 6 eggs were due to local shell imperfections (thickness or strength). This showed that the correlation between shell thickness and strength ($r = 0.46$) and shell thickness and deformation ($r = -0.57$) and deformation and strength ($r = -0.61$) were essentially unaltered. However, the relationships between mean UR and mean shell thickness ($r = 0.82$) and mean UR and shell strength ($r = 0.43$) were considerably improved. These effects are illustrated by scatter diagrams (Fig. 4).

DISCUSSION AND CONCLUSIONS

The results obtained support the previous conclusion that ultrasonic techniques have a potential application for measuring shell thickness. They also indicate the possibility of a relationship with shell strength. As previously discussed (Voisey and Hamilton, 1976) shell thickness typically only accounts for 14 to 31% of shell strength variation. Thus, an imprecise indication of shell thickness is not likely to prove a precise index of shell strength. However, ultrasonic readings are affected by both shell thickness and shell density which both affect strength. The technique may thus be useful for predicting strength as well as shell thickness. The results here are encouraging and indicate that the method is worthy of further investigation. If the correlation between ultrasonic readings and shell thickness is consistent and at the level obtained from the data (r = 0.82) or the previous test (r = 0.74) the method already represents a useful non-destructive technique for measuring shell thickness. If strength could also be predicted from the same ultrasonic readings, the technique would indeed be a useful one.

It was concluded that unless some better means can be found to maintain a constant distance between the egg surface and the transducer while the egg rotates , this version of the test method is not satisfactory.

Improvement of the accuracy of the UR method in determining shell thickness is predictably difficult. The narrow range of shell thickness found in experimental eggs (e.g. in this test ± 0.057 mm or±0.0022 in.) and in commercial production dictates the need for an extremely high degree of precision and resolution of measurment to obtain accurate readings. Under practical conditions this may not be possible because of the number of other egg dimensions that vary. The data indicated that the UR were repeatable, but this must not be confused with the establishment of an exact relationship between UR and shell thickness. It is often feasible to obtain repeatable readings that are imprecise in experimental work leading to incorrect conclusions.

An over-all conclusion from the results is that the mean of several readings taken around the equator of the egg predict shell strength and thickness better than individual readings. This is a logical outcome and it remains to determine the optimum number of readings per egg.

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Table 1. Summary of data showing averages based on individual measurement points and means for each egg

Group of birds:	A			B			C			Pooled (individual or means)		
	Mean	S.D.	C.V. %	Mean	S.D.	C.V. %	Mean	S.D.	C.V. %	Mean	S.D.	C.V. %
N of eggs		29			27			28			84	
Trait												
Fracture force Kg	3.03	0.55	18	2.98	0.57	19	2.84	0.72	25	2.95	0.62	21
Non destructive deformation mm	0.071	0.014	20	0.072	0.021	30	0.083	0.020	24	0.075	0.019	26
Individual point shell thickness mm	0.321	0.028	9	0.320	0.034	11	0.320	0.024	8	0.320	0.029	9
Mean shell thickness mm (N = 84)										0.320	0.027	8
Individual point ultrasonic shell thickness mm	0.549	0.082	15	0.533	0.040	7	0.529	0.032	6	0.537	0.057	11
Mean ultrasonic shell thickness mm (N = 84)										0.536	0.044	8
Continuous ultrasonic shell thickness mm (N = 84)										0.600	0.062	10
Position	Thickness reading means of each of 4 positions on egg											
Shell thickness No. 1 (N = 84)	0.322	0.024	7	0.320	0.035	11	0.323	0.025	8			
2	0.319	0.033	10	0.321	0.034	11	0.318	0.024	8			
3	0.321	0.026	8	0.320	0.034	11	0.320	0.025	8			
4	0.321	0.029	9	0.320	0.034	11	0.320	0.023	7			
Ultrasonic thickness No. 1 (N = 84)	0.551	0.074	13	0.537	0.040	7	0.532	0.035	7			
2	0.545	0.075	14	0.530	0.040	8	0.526	0.033	6			
3	0.569	0.106	19	0.533	0.042	8	0.525	0.027	5			
4	0.531	0.064	12	0.531	0.040	8	0.531	0.033	6			

Table 2. Summary of data based on 4 readings on 84 eggs. Force in Kg, deformation and shell thickness in mm giving regression constants for Y = aX + b and correlation coefficients (r).

Traits

y	x	a	b	r
Mean ultrasonic thickness	Deformation	-0.337	0.562	-0.148
Continuous ultrasonic thickness	Deformation	0.058	0.595	0.018
Mean shell thickness	Deformation	-0.746	0.376	-0.535
Deformation	Force	-0.021	0.138	-0.685
Individual point shell thickness	Individual point ultrasonic shell thickness	0.157	0.236	0.313
Mean ultrasonic shell thickness	Continuous ultrasonic shell thickness	-0.007	0.540	-0.009
Mean shell thickness	Mean ultrasonic shell thickness	0.260	0.180	0.424
Mean ultrasonic shell thickness	Force	0.0145	0.494	0.203
Mean shell thickness	Continuous ultrasonic shell thickness	0.013	0.312	0.031
Ultrasonic continuous shell thickness	Force	0.003	0.591	0.028
Mean shell thickness	Force	0.021	0.258	0.481

Table 3. Summary of Results

Eliminating 6 eggs to see effect on results

N = 78 eggs

Summary

Trait	Mean	S.D.	C.V. %
Force Kg	3.01	0.573	19
Mean shell thickness mm	0.321	0.025	8
Mean ultrasonic shell thickness mm	0.533	0.030	6
Shell deformation mm	0.073	0.017	23

Regression equations $Y = aX + b$ and regression coefficients

Y	X	a	b	r
Mean shell thickness	Force	0.020	0.260	0.463
Ultrasonic mean shell thickness	Force	0.023	0.463	0.433
Mean shell thickness	Deformation	-0.857	0.384	-0.573
Ultrasonic mean shell thickness	Deformation	-0.680	0.582	-0.377
Mean shell thickness	Ultrasonic mean shell thickness	0.678	-0.039	0.82
Deformation	Force	-0.018	0.126	-0.609

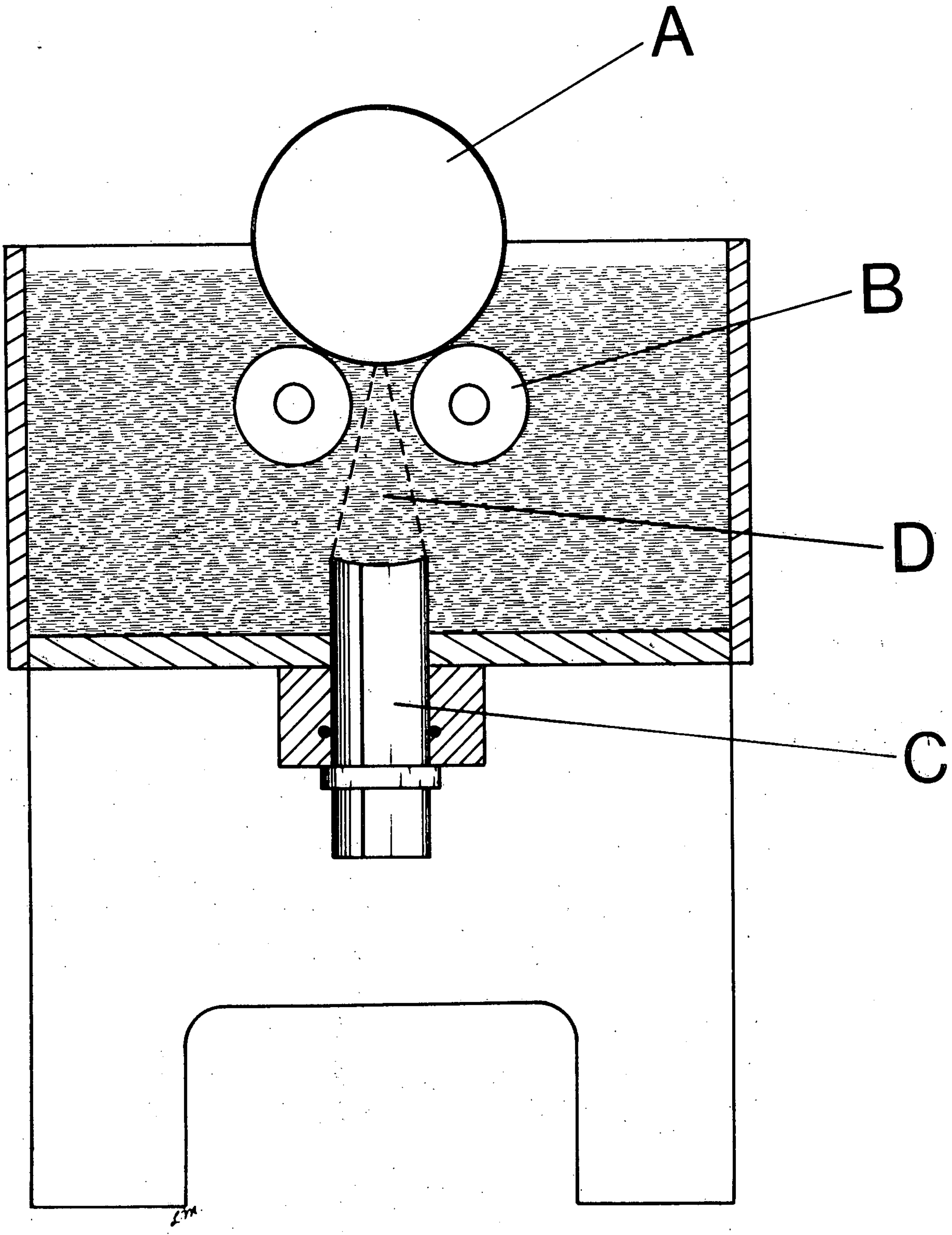

Figure 1. Schematic diagram of apparatus. A. the egg; B. plastic rollers rotated by a hand crank; C. ultrasonic transducer (AeroTechn Inc.); D. ultrasonic beam focussed on to the shell surface. The shaded portion represents water containing household detergent.

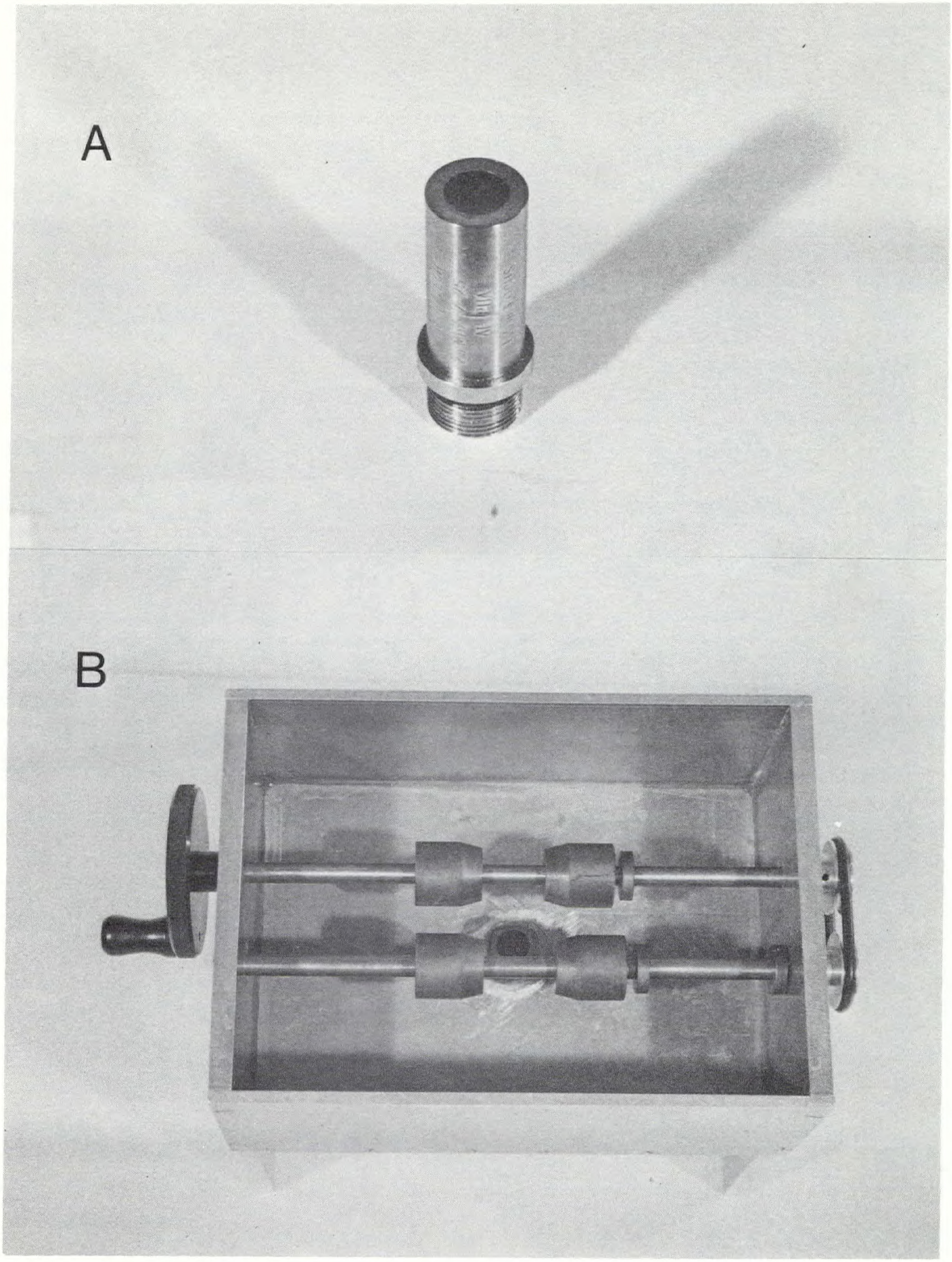

Figure 2. Components of the apparatus. A. the ultrasonic transducer; B. the water bath with hand rotated rollers to support the egg surface above the transducer at the focal point of the ultrasonic beam.

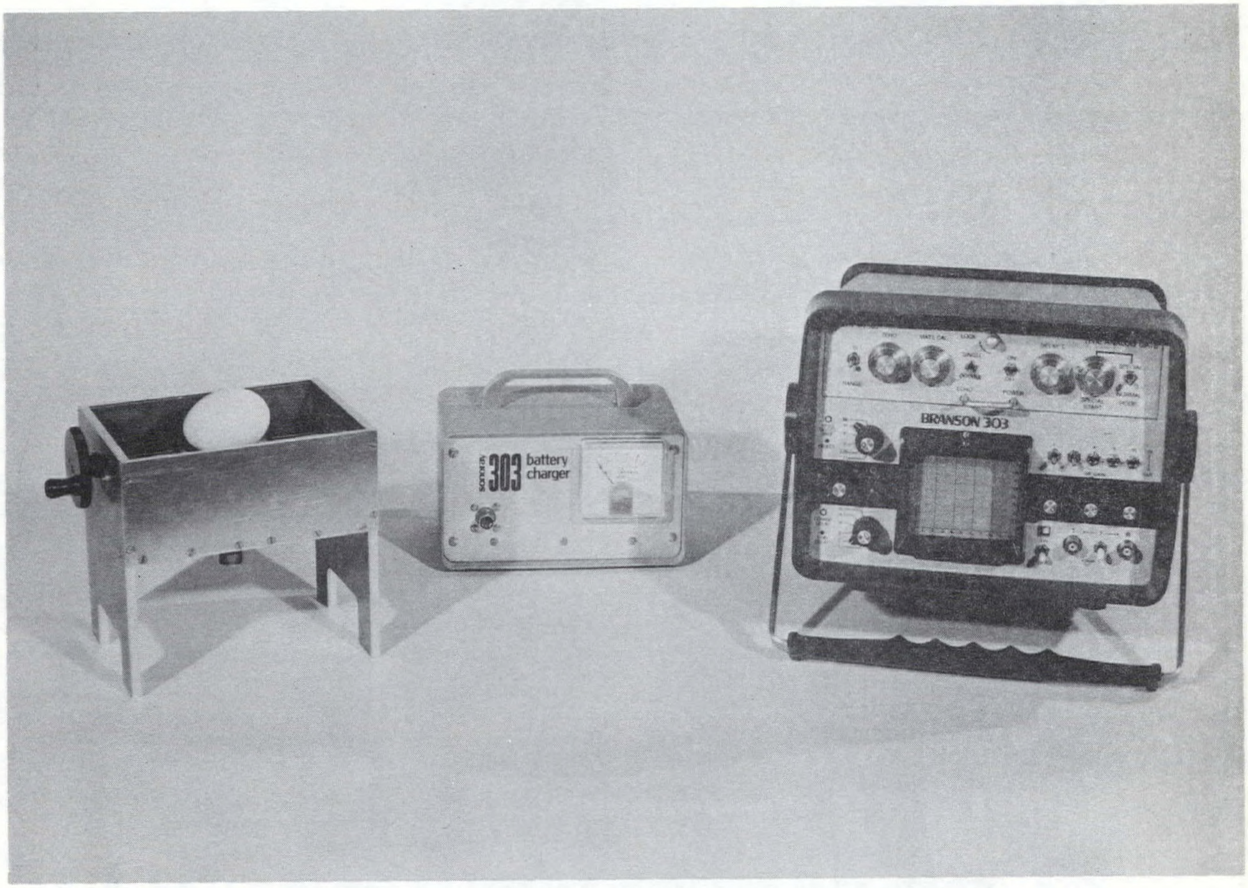

Figure 3. The apparatus in operation - from left to right; the water bath with an egg installed, a charger for the power supply of the readout, electronic control and readout package.

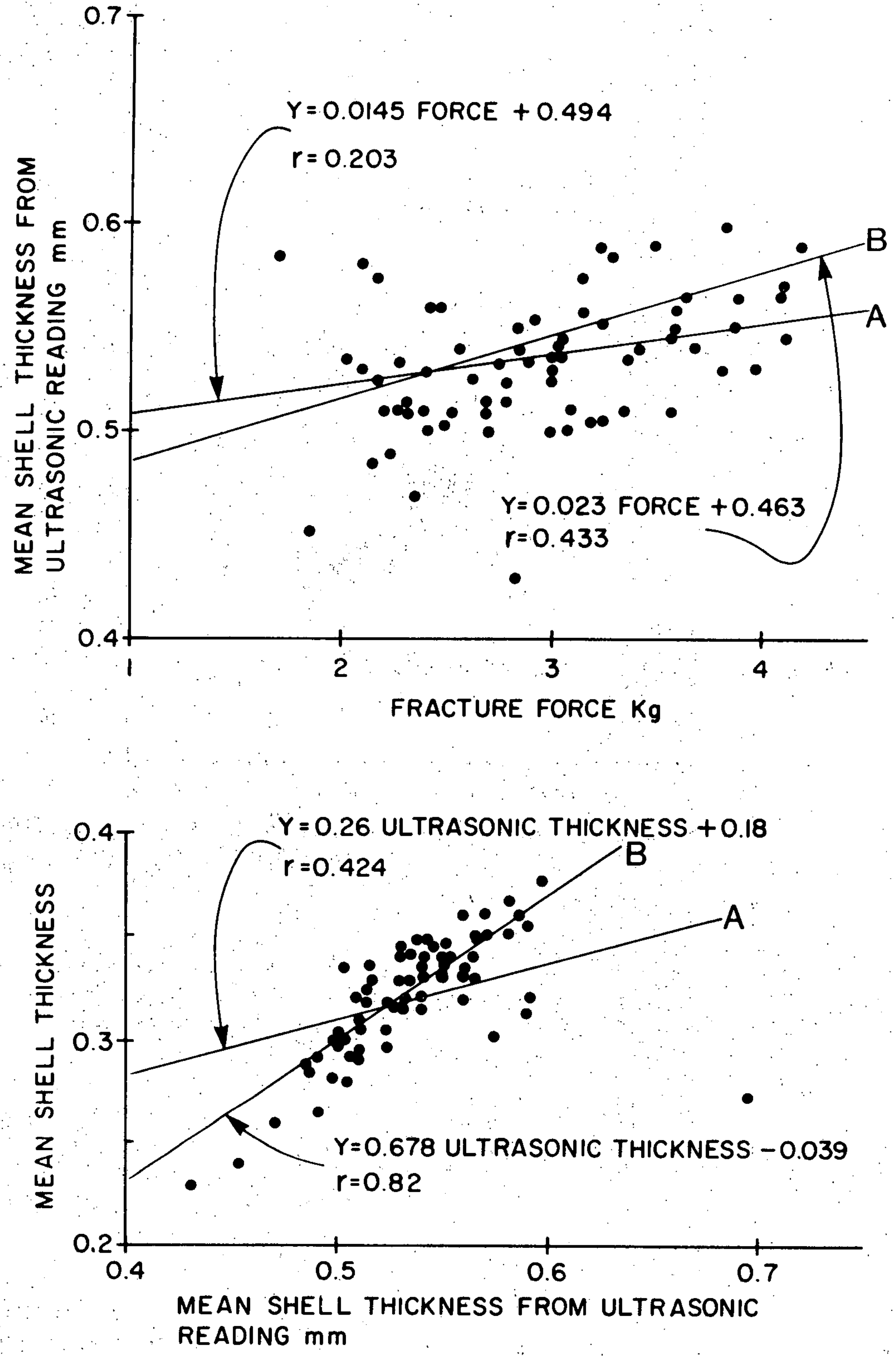

Figure 4. Scatter diagrams. Top, mean ultrasonic shell thickness reading against fracture force; bottom, mean shell thickness against mean ultrasonic shell thickness reading. A. regression line based on all data (84 eggs); B. regression line when 6 eggs are eliminated from the analysis.