,21

April 5, 1972

To the Graduate Council:

I am submitting herewith a dissertation written by Arthur Laxton Eller, Jr., entitled "The Utility of Measures of Fatness and Skeletal Size in Explaining Weight and Size Differences in Yearling Angus and Hereford Bulls." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

Robert R. Shrode
Major Professor

We have read this dissertation and recommend its acceptance:

J.B. McLaren

Karl M. Barth

Robert L. Dotson

Don O. Richardson

Accepted for the Council:

Hilton A. Smith
Vice Chancellor for
Graduate Studies and Research

THE UTILITY OF MEASURES OF FATNESS AND SKELETAL SIZE IN EXPLAINING WEIGHT AND SIZE DIFFERENCES IN YEARLING ANGUS AND HEREFORD BULLS

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

---

by

Arthur Laxton Eller, Jr.

June 1972

ACKNOWLEDGEMENTS

The author wishes to express his most sincere appreciation to the following:

To Robert R. Shrode, major professor, for his friendship and guidance through the course of the Ph. D. program.

To Will T. Butts, Jr. for his sincere interest, encouragement and council and for reviewing the manuscript.

To William L. Sanders for his willing council in the statistical analysis.

To J. B. McLaren, K. M. Barth, D. O. Richardson and R. S. Dotson for serving on the graduate committee and for reviewing the manuscript.

To the University of Tennessee, Virginia Polytechnic Institute and State University, the Virginia Beef Cattle Improvement Association and the Argicultural Research Service, USDA for making the data available for the study.

To George W. Litton and C. Curtis Mast for encouraging the author to undertake graduate study and to the V.P.I. & S.U. Cooperative Extension Service for granting educational leave.

To the author's parents for unceasing encouragement and the many sacrifices which made higher education possible.

And to his loving wife, Carolyn and children, Amy, Evelyn, John and Karen for their patience, understanding and encouragement throughout the course of graduate study.

ABSTRACT

Records from 669 yearling Angus and 871 yearling Hereford bulls from three central test stations and seven Land Grant University or USDA research herds were utilized in a study which was designed to determine needed refinements in procedures for performance testing young bulls. Generalized least-squares multiple regression analyses were conducted to determine the value of measures of fatness and measures of skeletal size in defining or explaining weight and size differences over and above the effects of age and age of dam, which are in common usage. Principal-component analysis also was employed in an effort to assess its usefulness in evaluating bulls as to size and body shape.

The study indicated that weight alone is not a sufficient measure of size and that selection for conventional adjusted yearling weight alone would tend to favor fatter animals and would produce animals of several different skeletal sizes and body shapes.

A positive but variable association between fatness measures and final weight was found. Ultrasonically measured fat thickness was found to be more accurate as a measure of fatness per se than was subjective condition score, though both were of similar utility in explaining final weight differences. Condition scores tended to measure fatness on a relative basis and were apparently confounded with size and general body type.

Wither height and body length were quite valuable as skeletal-size measures and explained large portions of variance in final weight. Either of these or subjective frame-size scores were valuable in explaining differences in body type and apparent differences in maturity rates. These skeletal-size measures tended to reduce the value of age in explaining weight differences. Shoulder width was highly related to weight differences but was influenced greatly by degree of fatness. Although there are apparently basic relationships among weight, skeletal size and fatness, existent individual-animal variations suggest that the accurate measurement of all three of these is essential in classifying bulls accurately as to potential breeding value. Weight and fatness vary on an individual-animal basis depending on maturity rate. Therefore it seems inappropriate to attempt to develop regression procedures based on group statistics for the adjustment of weight to a fat-constant basis.

The first principal component was found to be useful in ranking bulls on general size. The second component indicates that two basic extremes in body shape apparently exist among all cattle and is useful in ranking animals between these extremes.

It appears that performance testing programs should include measures of fatness and skeletal size in addition to weight and age if potential sires are to be accurately evaluated. This study strongly suggests that post-weaning performance tests for estimation of breeding value should be terminated at a constant physiological age rather than at a constant chronological age. Fatness and skeletal-size measures appear useful in determination of physiological age.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

The use of beef cattle performance records as criteria for selecting breeding stock has become a widely-used practice among seed-stock and commercial producers during the past decade. Research work, largely in North America and Europe, conducted during the past quarter century, has produced useful estimates of genetic parameters pertaining to measures of weight, gain and other economically important traits. These form the scientific basis for currently used performance testing procedures.

Initiation of performance testing programs by Land Grant Universities, state beef improvement associations and breed recording associations and the advent of high speed electronic computers have augmented the widespread use of performance testing as a means of estimating potential breeding value of young beef animals.

Early use of performance records was almost totally confined to selection and culling based on weanling traits such as adjusted weight and conformation score. While such efforts were helpful in the improvement of herd management and cow culling, it is doubtful that appreciable genetic improvement resulted. More recently it has been recognized that because of their higher heritabilities, performance measures beyond the weanling stage must be used in the identification of animals of genetic superiority with respect to growth rate. It has been effectively demonstrated also that maximum improvement in a herd or population must be brought about through the identification and use of sires with superior breeding value. With the knowledge that maximum improvement per unit of time can be attained by mass selection with major selection pressure applied on the basis of the young sires' own performance, it is obvious that individual records must be as reliable as possible.

At present, the most widely-used measure of growth and size is yearling weight adjusted to a standard age and for age of dam. This adjusted weight includes measurement of growth rate in both the weaning and post-weaning phases. Differences in composition of weight have been largely ignored until very recently. Research data are limited in the area of measuring these differences or consideration of them in evaluating individual records.

Conformation is currently assessed visually by a system which attempts to score the total animal from the standpoint of desirability. The conformation scoring system has been of limited usefulness, however, since it is subjective and subject to changes with industry trends and may be influenced by fads, as well as, individual preferences.

Performance testing procedures have traditionally evaluated growth rate and efficiency on a time-constant or age-constant basis. Thus, genetic differences with respect to rate of maturity or physiological age at any point have largely been ignored. Consequently, these age-constant measures compare animals of different maturity rates and thus, different compositions at different points along their individual curves describing growth from a physiological standpoint. Therefore, yearling weight, as presently arrived at, may lack the precision required to accurately predict kind and breeding value.

It is apparent that, with respect to genetic growth and maturity rate, several kinds of bulls within a breed should be classified. Presently used procedures fail to make provision for such classification.

The present study was undertaken as a preliminary effect to determine ways to improve upon weight, adjusted for age and age of dam, as the primary measure of size and growth rate for evaluating the potential breeding value of bulls. A particular concern was that of determining the association between weight and degree of fatness and the possible value of measures of fatness for adjusting weight to a fat-constant basis. Another concern was the assessment of the value of skeletal-size scores and measurements and their association with weight and fatness in describing size and difference in kind of cattle in terms of maturity rate. It was expected that the study might provide some guidance as to the nature of changes which should be made in performance testing procedures in order to more accurately evaluate young bulls as to breeding value.

CHAPTER II

LITERATURE REVIEW

I. DIFFERENCES IN GROWTH AND MATURITY RATE

Considerable data demonstrate that growth curves and rate of maturity vary within breeds and between breeds (Stonaker, Hazaleus and Wheeler, 1952; Fitzburgh and Taylor, 1971; Taylor and Fitzburgh, 1971; Brown, Brown and Butts, 1972b, and Brumgardt, 1972).

Brown, Fitzburgh and Cartwright (1971) reported phenotypic correlations calculated from data on 151 Jersey and 147 beef females. Estimates of mature weight were negatively related to rate of maturing (-.64), age at inflection of the growth curve (-.61) and growth rate at the point of inflection (-.23). Mature weight was positively related to maturing interval (0.67) and to weight at inflection point. The relationships among parameters estimated from these data suggest that rapidly growing animals reach inflection at an older age and, in general, show a larger maturity rate (K) value and, hence, a shorter maturing interval and a smaller mature weight.

Brown *et al*. (1972a) reported rate of maturity (K) values of 0.0568 for Hereford and 0.0605 for Angus females, indicating a definite difference between the two breeds. They found that Hereford females were heavier than Angus females at 40 months of age, but the reverse was true at ages prior to 40 months. Hereford females showed growth until 85 months of age while Angus showed growth until 71 months of age. Effect of age of dam declined much more rapidly in the Angus than in the Herefords. The two breeds differed also in magnitude of sire influence on weights at various ages. In Herefords, sire influence increased from 7.7 percent at 4 months to 16.1 percent at 36 months, while in Angus, sire influence increased from 6.3 percent at 4 months to 9.8 percent at 16 months and then declined to 5.4 percent at 36 months. Sires accounted for a smaller fraction of variance at 8 months than at any other age.

Brown, Brown and Butts (1972c) reported that females of the two breeds at 12 months of age differed in the percentage of mature weight attained at that age (Herefords 45 percent, Angus 53 percent). Angus females reached 95 percent maturity a year before Hereford females reached the same point. These workers reported that the phenotypic correlations among age at a given level of maturity, mature weight and rate of maturing indicated that late-maturing heifers were older and heavier at each level of maturity than were early-maturing individuals. The genetic correlations between level of maturity and mature weight indicated that nearly the same group of genes was involved in development from 40 percent to 80 percent maturity.

These workers suggested that the mean age and weight differences at various levels of maturity in the Hereford and Angus groups indicated that constant age or weight comparisons may not permit accurate evaluation of genotypes if gene action or interaction is related to physiological maturity. In view of this and the fact that genetic correlations between mature weight and rate of maturity were -.95 and -.29 and phenotypic correlations were -.72 and -.62 for Herefords and Angus, respectively, it appeared that the weight of an animal cannot be properly evaluated as to its meaning in terms of projected weight or rate of maturing unless approximate physiological age was known. This was further reinforced by the fact that, in Herefords, heavier yearling weights were associated with heavier mature weights, while in Angus, yearling weight had no relationship to mature weight.

This research pointed out further that there are sufficiently large differences in rate of maturity and mature size, both within and between breeds, to suggest a need for comparisons at similar physiological ages in place of comparisons at constant ages or weights.

In Wisconsin work concerned with differences in Angus, Hereford and Charolais cattle varying in size and growth, Brungardt (1971) reported marked breed differences and within-breed differences. Using Angus as the base, he reported Charolais and Herefords to be 43 percent and 11 percent later maturing, respectively. Significant differences in growth rate, final weight and maturity also were found within each breed when the cattle were divided into five body-size groups. All cattle in this experiment were slaughtered at a composition-constant point, grading choice with fat making up 30 percent of carcass weight. These apparent differences in growth among the three breeds suggest that cattle of all breeds and growth potentials marble after (1) a major portion of thin muscle growth has been completed and (2) when the growth of fat becomes the predominant contribution to the increase in weight. These data suggested further that cattle of varying growth potentials, both within a breed and between breeds, marble when they reach compositional maturity commensurate with the fat deposition required.

Brungardt (1972) stated that appraising cattle of various breeds at constant weights and ages results in comparing cattle at different points on their growth curves. This system failed to recognize differences in composition, quality grade and economic market value.

Since the genetic correlation between 12-month weight and rate of maturing is negative (Brown et al., 1972b), a positive genetic correlation should exist between yearling weight and score, as found by Koch and Clark (1955). If scoring favored shorter kinds, negative genetic correlations should exist between yearling weight and score, as described by Blackwell (1962). The Arkansas results suggest that heifers of early maturity can be differentiated from those of late maturity, to some extent, by genetic factors related to conformation score. Pahnish et al. (1964) found a negative genetic correlation between weaning weight and score of Hereford bulls (scoring favored early maturity) and a positive genetic correlation in heifers (scoring favored later maturing heifers).

In terms of the growth curve, as an upper limit on rate of gain is approached, the only way to increase or decrease rate of maturity is to decrease or increase mature weight (Brown et al., 1972b and Brungardt, 1972). The mean estimated heritabilities (h^2) for weight were not far different in the two breeds in the Arkansas study, but Angus showed a larger range in h^2 and had much smaller estimates of h^2 at 4 and 36 months of age than did Herefords (Brown et al., 1972b).

Joandet and Cartwright (1969), reported that weight and age at which maximum TDN efficiency occurred varied between the different breeding groups in their study.

Cundiff et al. (1969, 1971) reported results of an analysis of data from 503 steers and 75 sires from the Hebraska crossbreeding project which appeared to be consistent with the above noted pattern of relationships between rate of maturity and growth. The findings indicate that selection for growth would be effective and that associated changes in carcass composition and marbling would be greatly influenced by age or weight at slaughter. Estimates of genetic correlation indicated that selection to change proportion of retail product would not be effective. They suggested also that, if slaughter age were standardized across generations, carcass weight, quantity of retail products, fat trim and bone would be increased. Marbling score and percent fat trim would be increased while percent retail product and percent bone would be reduced. On the other hand, if weight were standardized across generations, slaughter would be at younger ages, percent retail product would be improved, percent fat trim and percent bone and marbling score would be reduced. It appeared then that opportunity for genetic improvement by selection would be in more rapid and efficient growth rather than in higher proportion of retail product.

II. ASSESSMENT OF DEGREE OF FATNESS AND ITS ASSOCIATION WITH OTHER VARIABLES

Assessment of the accuracy of estimating degree of fatness in the live animal and assessment of the value of such estimates as they relate to weight and its composition is an important consideration in animal selection and thus, in the present study.

Body fat, as measured by carcass dissection or chemical analysis, is the body component most responsive to varying genetic and nutritional factors (Lohman, 1971). Tulloh (1963) reported that, over a wide range in cattle, sheep and hogs, 88 to 90 percent of the variation in fat was accounted for by the regression of fat content on empty body weight. He concluded that deviations from regression of logarithm of fat on logarithm of empty body weight were great and that variations in carcass composition were primarily due to variation in degrees of fatness.

Callow (1947, 1948, 1949, and 1950) was cited by Hedrick (1968) as showing that the major change in composition of the animal body depended on the level of fatness. Hedrick (1968) cited Andrews (1958) and Callow (1948) in making the statement that fatty deposits appear in younger animals around the viscera and kidney and, with increasing age and adequate, caloric intake, between the muscles, beneath the skin (subcutaneous fat), and lastly, in the form of marbling (intramuscular fat).

The association of fatness and weight has been reported by a number of workers with variable findings. McReynolds and Arthaud (1970a) reported simple correlations between ultrasonically estimated fat thickness and liveweight to range from -.04 to 0.32 (all but one positive) and indicated that heavier animals tend to be fatter. The low correlations were atrributed to variation in fat thickness among cattle of common weights. This work showed a curvilinear relationship between liveweight and fat deposition. Busch, Dinkel and Minyard (1969), from analyses of data from a large number of Hereford steers, reported that visually estimated fat thickness in combination with slaughter weight explained

4 to 5 percent more variation in pounds of edible portion than did slaughter weight alone, indicating that this fatness measure would be useful. Conversely, Swiger (1964) found that additional accuracy in measuring retail product that might be achieved by accurately measuring fat in the live animal was negligible. Cole, Ramsey and Epley (1962) found a 0.53 correlation between fat thickness and weight in carcasses involving six breeds of steers slaughtered at a constant liveweight of 900 pounds.

Table I summarizes the pertinent research results relative to comparison of ultrasonically estimated fat thickness in the live animal with measurement of actual fat thickness in the carcass. While there is general agreement throughout the industry that ultrasonic measurement of fat thickness can be done quite accurately (Stauffer et al., 1961; McReynolds and Arthaud, 1970b and Hedrick et al., 1962) and is a potentially useful method of fat assessment in selection of breeding animals (Meyer et al., 1966), several sources of error and inaccuracy have been pointed out (Watkins, Sherritt and Zieger, 1967 and Temple and Ramsey, 1965).

Research in this area, in general, is in agreement that a single fat thickness estimate at the 12th rib is as valuable as multiple estimates (Ramsey, Cole and Hobbs, 1962; Cole et al., 1962; Temple, 1956; Allen, 1966 and Brungardt and Bray, 1963) and is a very reliable estimator of pounds or percent carcass lean or fat (Ramsey et al., 1962; Cole et al., 1962 and Brungardt and Bray, 1963).

Studies of the accuracy of fat thickness measurement by probing

TABLE I[e]

REPORTED CORRELATIONS OF ULTRASONIC MEASUREMENT OF FAT IN BEEF ANIMALS AND ACTUAL MEASUREMENT TAKEN ON THE CARCASS

Reference	No. of animals	Coefficients of Correlation between ultrasonic and actual measurement of fat thickness
Temple *et al*. (1956)	--	0.63
Stauffer and Wellington (1960)	54	0.35**
and Stauffer *et al*. (1961)	82	0.32**
	16	0.54**
	47	0.42
Davis and Long (1962)	60	0.90**
Hedrick *et al*. (1962)	47	0.53**
	71	0.63**
	57	0.55**
Alsmeyer *et al*. (1963)	204	0.46[a]**
	210	0.61[b]**
	256	0.60[c]**
	183	0.55[d]**
Temple and Ramsey (1963)	--	0.89**
Davis (1963)	69	0.67**
Brown *et al*. (1964)	45	0.46**
Sumption *et al*. (1964)	770 (14 gps.)	0.41 - 0.80**
Davis *et al*. (1965)	51	0.96**
McReynolds *et al*. (1970)	--	0.43 - 0.47**
Watkins *et al*. (1967)	120	0.90**

[a]Measurement taken 2 inches laterial of midline.

[b]Measurement taken 3 inches laterial of midline.

[c]Measurement taken 4 inches laterial of midline.

[d]Measurement taken 5 inches laterial of midline.

[e]Table adapted from Hedrick (1968) **Significant ($P < .01$)

have provided results similar to those with ultrasonic estimates (Bracklesberg, Willham and Walters, 1967 and Bracklesberg and Willham, 1968), though the technique apparently has been used very little.

Research results are limited in the area of subjective appraisal of degree of fatness, though the method has been extensively used with both slaughter and breeding animals. The fact that experience on the part of the estimator is valuable in improving accuracy of fatness and other live animal estimates is fairly well documented (Gregory et al., 1962 and Lewis, Suess and Kaufman, 1969).

Both Gregory et al. (1963) and Stringer et al. (1963) indicated that graders were unable to estimate carcass traits with sufficient accuracy to provide a basis for selecting among breeding animals for differences in these traits. Brungardt (1972) found USDA yield grade estimators were able to account for 52 percent of the variation in percent carcass fat, whereas, visual estimates of carcass fat per se explained only 28 percent of the variation. Lewis et al. (1969) reported experienced estimators to be able to account for three-fourths of the variation in fat thickness.

Little information on the use of condition scores in selection of breeding cattle has been reported. Pahnish et al. (1964), in a study with Hereford cattle, reported mean condition scores and standard deviations for bulls and heifer calves which were reported to be corroborative of those of Synar (1958) in other Arizona work.

Butts (1966) found type score and condition score to be highly correlated (0.70 to 0.73 at pre-weaning and weaning, respectively).

Holding condition score constant removed that fraction of the dam component of variance for pre-weaning and weaning average daily gain and weaning index which had been attributed to differences in maternal ability in an earlier analysis with Angus data.

Limited research is reported in the area of genetic associations of fat measurements and muscling or growth traits. Bracklesberg et al. (1971) reported that genetic correlations among measurements of fatness and measurements of the higher priced cuts were negative and rather large, indicating that this is probably a matter of a basic relationship between fat and muscle, rather than one of real differences in carcass proportions independent of fatness. Data from cattle killed at 623 days of age and grading low choice yielded an estimate of heritability of fat thickness of 0.43. The genetic correlation with carcass value was -.85, whereas the phenotypic correlation was 0.63. Estimates of heritability of fat thickness in this study are in agreement with that of Christians et al. (1962) who reported 0.38.

Brungardt (1972) and Cundiff et al. (1971) indicated agreement that selection of breeding cattle on weight per day of age on a time-constant basis or on an age-constant basis may, in effect, result in favoring fatter cattle and may result in cattle reaching a certain stage of physiological maturity at a younger chronological age, which would have a pronounced effect on the shape of the growth curve.

Nelms et al. (1970) developed several equations to predict weight of retail cuts in bulls. With an accurate estimate of dressing percent, their equation number three could be quite useful in assessing differences in expected breeding values from information on live animals. The equation is:

$$Y = 35.8 + 0.44 \text{ (carcass weight, kg)} - 0.98 \text{ (fat depth, mm)}.$$

III. LINEAR MEASUREMENTS AS ESTIMATORS OF SIZE AND BODY SHAPE

A study of the accuracy of linear body measurements of dairy cattle was reported by Touchberry and Lush (1950). Wither height, chest depth, body length, heart girth and paunch girth were observed at seven ages - six months, one, two, three, four, five and seven years. Relative accuracies at the various ages were not significantly different. In an earlier study by Lush and Copeland (1930), it was reported that little or no correlation existed between the average size of the measurement and the random error in taking the measurement. In both studies there was little improvement in the relative accuracy of obtaining the measurements by taking a second and third observation of the same trait. The repeated observations did serve as a check against gross errors in reading and recording.

Some study has been made comparing linear measurements taken directly from the live animal with measurements taken from photographs. Smith _et al_. (1950) reported slightly higher repeatabilities in general from photographs with differences of greatest magnitude occurring in body length of cows and yearlings. This work indicated that either method is equally accurate but most measurement studies reported have been of measurements taken directly from animals rather than from photographs.

To evaluate body measurements or other traits as selection criteria, it is necessary to have estimates of heritability. Table II summarizes many of the reported estimates of heritability of various body measurements. In general, these characteristics appear to be moderately to highly heritable as compared to weaning performance traits, and the estimates of heritability of skeletal measures are of magnitudes similar to those of values obtained for post-weaning gain and yearling performance traits.

Many studies have been planned to answer questions concerning relationships between various linear measurements and carcass characteristics. Generally, very low associations between linear measurements and percent closely trimmed major cuts or edible portion have been found (Busch et al., 1969; Birkett, Good and Mackintosh, 1965 and Orme et al., 1959). Linear skeletal measurements have generally been found to be negatively correlated with quality factors (Tallis, Klosterman and Cahill, 1959; Black, Knapp and Cook, 1938; Kohli, Cook and Dawson, 1951 and Yao, Dawson and Cook, 1953). This, however, apparently is not true when cattle are fed to a carcass fat constant composition (Brungardt, 1972).

Skeletal length and skeletal height have been shown to be positively and highly correlated with weight and with each other (Orme et al., 1959; Lush, 1932; Brown et al., 1956a; Brown et al., 1956b; Brown and Shrode, 1971; Touchberry, 1951 and Brown et al., 1956c).

The usefulness of linear measures as predictors of post-weaning performance have generally produced positive associations but of generally low magnitude. Early studies by Severson et al. (1917), Hultz (1927), Hultz and Wheeler (1927) and Lush (1928) were concerned primarily with measuring changes in certain body measurements of steers during fattening and, consequently, aging.

TABLE II

SUMMARY OF ESTIMATES OF HERITABILITY OF BODY MEASUREMENTS OF CATTLE

Author	Breed[a]	Kind	Method[b]	No. of animals	Wither height	Hip height	Chest depth	Heart girth	Body length	Hook width
Gowen (1933)	J	cows	rpo	6000+	0.60	--	0.61	0.65	0.68	0.81
Schutte (1935)	X		bod	176	0.76	--	0.20	0.34	0.48	0.62
Touchberry (1951)	Hol.	cows	bod	187	0.73	--	0.80	0.61	0.58	--
Dawson *et al.* (1955)	MS	year.	PHS	58	0.66	--	0.40	--	--	0.01
Brown (1958)	A	calves	PHS	212	0.38	--	0.17	0.06	0.00	0.32
Brown (1958)	H	calves	PHS	255	0.29	--	0.33	0.44	0.10	0.15
Johnson (1958)	Hol.	cows	bod	128	0.76	--	--	--	0.77	0.21
Brown and Franks (1964)	A,H	cows	bod	73 pr.	0.41	0.69	0.71	0.46	0.48	0.11

[a]Breed designations: Angus (A), Hereford (H), Holstein (Hol.), Jersey (J), Milking Shorthorm (MS), Crossbred (X).

[b]Method of estimation: Parent-offspring correlation (rpo), parental half-sib method (PHS), intra-sire regression of offspring on dam (bod).

Lush (1928) found that most useful measurements among those studied to be those which increase at a less rapid rate than weight and seem to be either height at withers or hip height, the former being favored because of general acceptance in other measurement studies. Lush (1932) showed length and height at both withers and hips to be highly correlated with initial weight and with final weight but to a much lesser extent with gain (0.7 compared to 0.3), and concluded that maximum gains were characteristic of animals with a long body, tall at the withers, with a large paunch girth but small flank girth and narrow loin. He stated further that form and function in these respects are not closely enough correlated to permit accurate prediction of future performance of individual steers using measurements as predictors.

Brown and Shrode (1971) made use of weaning fat measurements in addition to weight and age in predicting post-weaning performance. From their data it appeared that body dimension measurements and estimates of fatness could be used effectively to improve the prediction of post-weaning performance and subsequent body composition over conventional methods utilizing only calf weight and age.

Kidwell and associates (1959) concluded that body measurements of feeder cattle are of little practical value as indicators of ability to gain rapidly and economically later in life. Various combinations of wither height, hook height, chest width, hook width, heart girth, round thickness, body length and ratios of these accounted for 16 to 20 percent of the variation of ADG and economy of gain in steers. These beef and dairy steers on two feeding regimes (90 and 150 days) undoubtedly were affected by the varying pre-test environmental effects to which they had been subjected, and these were probably larger than expected within a breed. These sources of variation not accounted for in the regression analysis, would have tended to make R^2 values small.

Kohli et al. (1951), in reporting the findings of a rather extensive study assessing usefulness of linear measures on milking Shorthorn steers, stated that body dimensions of steers tended to vary independently in view of the low correlations among the measurements used.

Yao et al. (1953) reported a low (0.09) correlation between wither height and ADG and negative correlations between wither height and quality traits. However, all cattle were killed at 900 pounds and, thus, were not at the same physiological age when slaughtered. Of all measurements used, wither height was the skeletal measure showing highest correlations with other variables.

The matter of using linear measurements for the purpose of describing type or kind has received considerable attention for a number of years. Most descriptive measures of shape used on an industry-wide basis have been subjective. Brown et al. (1956c) stated that evaluation on the basis of measurement does have the advantages of (1) being independent of human judgment and (2) remaining standard over long periods of time in contrast to subjective conformation and type standards which can and probably do change with time. In a cooperative study to establish relationships between conformation scores and live animal measurements at four state experiment stations in the Southern Region, correlations between chest height and score were negative while wither height and body length were not consistently related to scores. Multiple correlations among all measurements and scores range from 0.38 to 0.76 in various groups, and from 14 to 58 percent of the variation in score was accounted for. Conformation scores in this study apparently favored short-legged, thick cattle. Weight was positively correlated with scores in all cases.

Ternan et al. (1959), in an experiment with Hereford steers, assessed the association among conformation scores, among body measurements and the relations between scores and measurements. He reported wither height and hook height to be closely associated. The correlations between a measure recorded at feeder stage and that recorded at slaughter stage were high for weight, wither height, hook height and heart girth. The only feeder measures importantly related to feeder and slaughter scores were wither height, hook height, chest width and ratios of wither height to heart girth and of chest width to heart girth. Measurements were said not to be correlated with feedlot ADG.

It has been reported that beef animals reach maturity for the dimensions of height, depth, width, length and heart girth at earlier ages than for body weight (Brown et al., 1956a, 1956b). Linear skeletal growth increased faster and was completed earlier than was thickness growth (Guilbert and Gregory, 1952), indicating that much of the fluctuation in body weight of cattle at more mature ages was due to changes in the amount of body fat rather than to changes in true skeletal size.

It was reported by Brown and co-workers (1956a) that Hereford calves at twelve months of age had attained 46 percent of their mature weight and from 71 to 86 percent of their mature size, whereas, Angus calves (Brown et al., 1956b) at the same age had attained 51 percent of their mature weight and from 80 to 89 percent of their mature size with respect to body measurements. This indicates that body measurements may provide a means of more accurately characterizing mature size and shape at earlier ages than is possible using weight or other measures of early gain.

A complete description of conformation apparently cannot be made by a set of measurements. The value of measurements is to detect occurrence of deviations from standards which have been set. Also, they are valuable in a set of research or breeding records as reference points in assessing changes in type or size (Guilbert and Gregory, 1952).

Tallis et al. (1959) suggested that length, height and circumference at the navel are valuable measurements for describing type in cattle and suggested also that weight-height or weight-length ratios may be more satisfactory carcass indexes for use in cattle breeding than is percent edible portion.

A technique recently applied in the objective measurement of size and shape in cattle is that of principal-component analysis, making use of weight and several linear body measures (Carpenter et al., 1971 and Brown et al., 1972d). A principal-component analysis was conducted on data from 267 Hereford and 283 Angus bulls at the Arkansas Station. Nine body measurements, including wither height, hip height, shoulder width, pelvic width, loin width, foregirth body depth, flank depth, heart girth and length from shoulder point to pins as well as weight at 4, 8 and 12 months were used. Five principal components descriptive of various body shapes were constructed. Component one (PC1) is a measure at each age to give an index of size with nearly equal emphasis on all 10 traits. It accounted for 56 to 68 percent of the variance in the total system of variables. Component two (PC2) contrasted tall, narrow bulls with short, wide ones and accounted for 10 percent of total variance. These two major components accounted for about 75 percent of variance in the system. The consistency and importance of shape provided by component two at all ages suggested that tall, narrow-bodied and short, wide-bodied were two basic shapes in cattle at pre-yearling ages. The correlation of PC2 values at successive ages indicated that bulls of these two body shapes remain relatively unchanged over the ages examined. The correlations indicated also that when equal weighting was given to each of the 10 measures of size, as in PC1, bulls selected at one age on this simple composite value could be quite different in shape at later ages. This result emphasized the likelihood that unrestricted selection based on a composite character, such as weight, size or gain, would produce animals of variable dimensions or shape. Approximately 40 percent of the variance in the covariance structure of 10 body measures was explained by contrasting body shapes in which the relationships among body dimensions were not always positive. Thus, extreme length was often offset by decreases in depth and height. Extreme height was counteracted by a decrease in width, and width was frequently attained by sacrificing depth of body. Perhaps such compensations by the developing body are to be expected if there is a size which is optimum for fitness. The study produced heritability estimates as follows:

Breed	Component No.	Component description	Age in Months 4	8	12
Hereford	1	Size	0.40	0.22	1.00
	2	Shape	0.75	0.29	0.65
Angus	1	Size	0.54	0.39	0.42
	2	Shape	0.38	0.45	0.33

In this research no attempt was made to use measures of degree of fatness which might have proven very valuable in view of results of other studies which have included degree of fatness among variables studied.

IV. COMPARISON OF BULLS AND STEERS

When one considers the possibility that breeding value in the young bull may be more accurately estimated by adding consideration of differences in fatness, or composition of weight, it is pertinent to consider also the differences which exist between bulls and steers which are comparable except for sex. Numerous studies have been conducted which yield corroborative results which permit evaluation of bulls on the basis of their slaughter-steer counterparts.

Means for certain production and carcass traits in bulls and steers are summarized in Table III (Field, 1971). The references listed show an average advantage of bulls over steers in feedlog ADG of 17 percent, in feed conversion of 13 percent and in decreased amounts of fat over the longissimus dorsi at the 12th rib (bulls have 65 percent as much fat thickness as do steers). Steers have consistently been found to have greater amounts of intra-muscular fat in the rib (Arthuad, 1970 and Field, 1971), and bulls show superiority of 3.1 to 5.9 in percent separable lean or boneless, closely-trimmed cuts (Field, 1971).

TABLE III

MEANS FOR CERTAIN PRODUCTION AND CARCASS TRAITS OF BULLS (B) AND STEERS (S)[a]

Reference	No. of animals		Avg. daily gain		Feed or TDN/gain		Carcass weight		Dressing percent		Fat thickness	
	B	S	B	S	B	S	B	S	B	S	B	S
			kg				kg		%		mm	
Brown, Bartee and Lewis, 1962	11	11	1.04	0.82	8.5	12.1	191	176	58.0	57.0	--	--
Matsushima and Sprague, 1963	13	14	1.46	1.36	--	--	274	303	60.9	61.8	14.2	17.3
Matsushima et al., 1964	20	20	1.02	0.87	6.6	7.0	291	279	64.9	66.4	9.1	15.5
Field et al., 1964	19	19	1.00	0.89	--	--	267	240	63.7	62.9	8.6	17.0
Anthony and Starling, 1966	6	12	1.35	1.22	9.2	9.6	264	250	57.8	56.0	2.5	5.1
Martin, Douglass and Garwood, 1966	75	82	0.92	0.80	--	--	273	271	62.7	62.1	13.7	20.8
Brannang, 1966	14	14	0.63	0.58	5.4	5.9	257	231	52.0	50.5	--	--
Bailey and Hironaka, 1969	18	18	1.45	1.21	8.0	8.3	250	250	58.4	58.5	16.8	24.5
Watson, 1969	10	10	1.14	1.08	--	--	163	162	55.6	57.4	3.3	8.1
Bailey, Probert and Bohman, 1966	19	19	1.19	1.06	6.5	7.7	258	253	63.0	61.8	--	--
Arthand et al., 1969	77	80	0.94[b]	0.80[b]	5.8	6.5	235	235	--	--	9.0	14.0
Hedrick et al., 1969	18	24	0.88	0.77	5.8	6.2	300	275	60.6	61.6	16.7	21.5

TABLE III. (Cont'd)

Reference	No. of animals		Avg. daily gain		Feed or TDN/gain		Carcass Weight		Dressing percent		Fat thickness	
	B	S	B	S	B	S	B	S	B	S	B	S
			kg				kg		%		mm	
Champagne *et al.*, 1969	20	20	1.23	1.04	6.7	7.8	256	230	61.0	59.3	6.4	10.2
Nichols *et al.*, 1964	30	30	1.00	0.91	6.1	6.6	228	229	58.2	59.1	2.5	3.4
Unadjusted means	--	--	1.16	0.96	6.8	7.8	--	--	59.7	59.6	9.3	14.3

[a] In some cases the values have been calculated from data given in research reports.

[b] For 15 bulls and 20 steers (From Arthand and Adams, 1964).

These findings appear consistent with others reported earlier in this review, with respect to rate of maturity, in that castration apparently alters maturity rate in such a way that bulls and steers of the same chronological age are undoubtedly of different physiological ages.

V. PROCEDURES FOR ADJUSTMENT OF YEARLING WEIGHT

Since the industry is concerned with improvement in the components of yearling weight in addition to post-weaning gains, yearling weight is a simple but effective measure of genetic differences in growth (Gregory, 1965).

The summaries by Clark et al. (1958), Gregory (1961) and Warwick (1958) indicate that yearling weight is more highly heritable than are any of its components. This is reasonable in view of the high genetic correlations among the components of yearling weight.

Brinks et al. (1962), reporting on a study of 1029 performance-tested Hereford bulls at the USDA Range Livestock Experiment Station at Miles City, found that with 60 to 90 day variations, the effect of age on post-weaning performance can be ignored. They reported age-of-dam effect on post-weaning gains also to be negligible. In view of the results of Swiger and Hazel (1961) which showed that calves from younger cows tended to gain faster during the first 28-day period of a 140-day post-weaning test but that the advantage was overcome later and that the trend was reversed near the end of the test, they stated that the net effect of age of dam on post-weaning gain depends on the length of the feeding trial.

The results of Koch and Clark (1955) indicate that partial compensation for age of dam effect occurs in the post-weaning period. This study of 5952 Hereford calves at Miles City (1926-1951) showed that there is actually less difference in yearling weight than in weaning weight as a result of greater age-of-dam effect on performance to weaning.

Swiger et al., (1963) examined the effects of age of calf and age of dam on post-weaning gain. They evaluated post-weaning gain and the effects on it up to 550 days and compared earlier selections with 550-day selections. Calves of the Angus and Hereford breeds (1671 calves in all) were included in the study. Weaning weights were adjusted for age of dam and age of calf (Swiger, 1962). Effects of age of dam on post-weaning ADG and type score were found to be unimportant. Thus, the age-of-dam adjustments of weaning weight were appropriate adjustments for any age from 284 to 550 days. This was in agreement with Brinks et al. (1962) for bulls. The net effect of age at weaning on ADG from 200 to 500 days was found to be very small. The pooled within-group correlation between 550 day weight computed from daily gains adjusted for age and the same weight computed for unadjusted daily gains was 0.98. Pooled estimates for all calves suggested that 200 and 396-day weights would be about 0.52 and 0.81 as efficient, respectively, as 550-day weight in selecting for 550-day weight. Evidence in this study and that of Swiger and Hazel (1961) indicated that increased accuracy should be achieved in predicting genotypes for final weight on the basis of weights taken at an earlier age by measuring gain on a high level of energy intake.

Gregory (1965) raised the question as to whether it can be assumed from results indicating that age-of-dam effect is not compensated for in the post-weaning period that inherent differences in over-all maternal ability behave in the same manner as differences in maternal ability associated with age of dam. If this is the case, selections based on yearling weight obtained by adding post-weaning gains to age-of-dam adjusted weaning weight should place almost as much selection pressure on maternal ability as would selection based on weaning weight. He suggested that additional research is needed to determine the conditions under which age-of-dam effects on post-weaning gains exist, and the possible compensating mechanisms involved, in order to gain a better understanding of the biology involved.

In view of present research, the formula used for calculation of adjusted yearling weight is (Beef Improvement Federation, 1970 and Gregory, 1965):

$$\text{Adjusted 365 day weight} = \left(\frac{\text{Actual final weight - actual weaning weight}}{\text{Days between}}\right) 160$$

$$+ \text{ Weaning weight (205 days) adjusted for age of dam}$$

Breed was found to have a significant effect on all performance measures studied except type score in an analysis of Virginia Test Station bulls (Schalles and Marlowe, 1967). Though breed has been largely ignored in developing adjustment procedures, this and other research offers evidence that breeds do differ significantly and possibly in such a way that a single adjustment procedure may not be appropriate for all breeds.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE AND DESCRIPTION OF DATA

The data for this study are composed of complete records of performance to the yearling stage of Angus and Hereford bulls in central bull testing stations and in Land Grant University or USDA research herds.

From the standpoint of physical test location and/or management regime, the data were classified into ten categories according to source. All bulls, in addition to measures of weight, gain and conformation score, had recorded for them either one or both of two measures of degree of fatness, namely, subcutaneous fat thickness measured ultrasonically with a single reading over the *longissimus dorsi* muscle at the 12th rib and subjective condition score. On bulls from some sources skeletal size scores or measures also were recorded.

The following is a description of the bulls and data from each source. Both Hereford and Polled Hereford bulls are represented in several of these sources of data, but were considered as one breed.

Individual Sources of Data

Source 1, University of Tennessee Test Station (UTTS). The University of Tennessee Test Station at Nashville serves to test bulls consigned by Tennessee breeders who are enrolled in the Tennessee Beef Cattle Improvement Program. Only records for the year 1971 were available for study. These Angus and Hereford bulls were selected for post-weaning testing on the basis of performance to weaning and represented the best performing calves from the consigning breeders' herds. They were gain tested for 140 days following a two-week adjustment period after being delivered to the test station. The bulls were full-fed a 65 percent TDN, 12 percent crude protein ration containing two-thirds concentrate and one-third roughage. The bulls supplying records had an age range of approximately 5 months. Variation due to age and herd differences would, therefore, be prominent in the variation existing in these data which include ultrasonic fat thickness estimates but not condition scores.

Source 2, Culpepper Test Station (CULTS). These records were collected on Angus and Hereford bulls tested at the Virginia Beef Cattle Improvement Association Test Station at Culpeper, Virginia, in the years 1968 through 1971. These bulls consigned to the test by association members throughout the State of Virginia were selected from the best of their respective calf crops on the basis of performance to weaning. After a two-week adjustment period subsequent to delivery to the test station, the bulls were fed 140 days *ad libitum* on a basic ration containing 64 percent concentrates and 37 percent roughage and providing 64 percent TDN and 12 percent crude protein. Management and feeding from year to year were as nearly consistent as possible. Bulls from this source varied over a range of about six months. Thus, variation due to age differences and herd differences would be prominent in the variation observed in these data also. Both fat thickness measured ultrasonically and condition score were recorded for all bulls, and subjective frame-size scores were recorded during the last two years.

Source 3, Dublin Test Station (DUBTS). These records were collected from Angus and Hereford bulls tested at the Virginia Beef Cattle Improvement Association Test Station at Dublin, Virginia, in the years 1969, 1970 and 1971. Criteria of selection for the test, test procedures and rations fed were as nearly like those described for the Source 2 bulls as possible. Management level in this group of bulls was perhaps not quite as high as that attained in Source 2. Variation due to herd differences and age differences would be quite similar to that in Source 2 data. Both ultrasonic fat thickness estimates and condition scores were recorded for all bulls while frame-size scores were recorded only during the last two years.

Source 4, Front Royal (FR). These records were collected at the USDA-Virginia Polytechnic Institute Cooperative Beef Cattle Research Station at Front Royal, Virginia, during the years 1968 through 1971 and included records on both Angus and Hereford bulls. Only a very small percentage of the records were from bulls procured from outside breeders with the majority being produced on the station from the various inbred and selection lines maintained there. The age range was quite narrow. Bulls were weaned at approximately 200 days and went directly on a 168-day post-weaning gain test. Test rations were as nearly uniform as possible from year to year and were composed of about two-thirds concentrates and one-third roughage and provided 63 to 65 percent TDN and 12 percent crude protein. Feeding was ad libitum during the test period. Certain variation associated with the various lines producing the bulls was, of course, present in these data. Condition scores were recorded for all bulls, but ultrasonically measured fat thickness was recorded during the first two years only.

Source 5, University of Tennessee Knoxville (UTKN). These records were collected in 1970 and 1971 from Angus and Hereford bulls produced in the two University of Tennessee herds at Knoxville (Blount and Alcoa Farms) and which were gain tested at the Alcoa Farm. These bulls represented the best of the annual bull-calf crop based on records collected at weaning. The bulls were weaned at approximately seven months of age and were placed immediately on a 140-day post-weaning gain test. Rations for the two years were as nearly identical as possible. Six pounds of shelled corn plus protein supplement and average quality corn silage (*ad libitum*) were fed for the first 100 days. During the last 40 days a full feed of grain plus protein supplement was fed with a small quantity of corn silage as the roughage source. The age range in this group of bulls was quite narrow. Both measures of fatness were recorded.

Source 6, University of Tennessee Tobacco Experiment Station (UTTES). Records of these Hereford bulls were collected at the Tobacco Experiment Station of the University of Tennessee at Greeneville, Tennessee, during the years 1969 and 1970. These bulls were born in January, February and March and were weaned at about seven months of age and were placed immediately on a post-weaning gain test that was terminated when the mean age was 390 days. Post-weaning test rations were as nearly identical as possible during the two years and consisted largely of corn silage with only enough grain and protein to produce modest gains.

These bulls did not deposit as much fat as did the test station bulls. Both measures of fatness were recorded. Body length was the single linear measure used in the analyses, though others were recorded. This measure was taken from the top prominence of the scapula at the point of withers to the posterior edge of the pin bone.

Source 7, Montana (MONT). These records from Hereford bulls were collected at the USDA Range Livestock Experiment Station at Miles City, Montana, from calf crops of 1965 through 1969. These bulls were part of the genotype environment interaction study conducted as a reciprocal transfer of cattle between Miles City, Montana, and Brooksville, Florida (Butts, 1971). These bulls were weaned at six months of age and were placed immediately on post-weaning gain test that varied slightly in length but averaged 196 days. The full-fed ration was quite comparable to those previously described as used at the various test stations and produced moderate gains. Some variation due to differences in origin was, naturally, present in these data. The only measure of fatness included was condition score. Linear measures of body length, wither height and shoulder width were recorded during three of the five years. The sub-group with these measures is referred to as 7A.

Source 8, Florida (FLA). These records from Hereford bulls were collected from the calf crops of 1965 through 1969 at the USDA Beef Cattle Research Station at Brooksville, Florida. The bulls were the counterparts of the Source 7 bulls, being involved in the same study (Butts, 1971). Testing and management of these bulls was quite different, however. They were weaned at 220 days of age and were placed on a 365-day post-weaning development test designed to maximize forage use in the form of stored feed and grazing. Thus, these bulls were moderately thin when weighed, measured and scored as long yearlings. Measures of fatness included condition score during all years and fat thickness during two of the five years. Linear body measures of wither height, shoulder width and body length, were recorded during three of the five years. The subgroup with linear body measures is designated as 8A and the subgroup with linear measures and fat thickness as 8B.

Source 9, University of Tennessee Middle Tennessee (UTMT). Records of these Hereford bulls were collected at the Middle Tennessee Experiment Station of the University of Tennessee at Spring Hill, Tennessee. All bulls were produced in that station's commercial herd. After weaning, all bulls were wintered largely on roughage and then full-fed to attain slaughter finish at about 15 months of age. Records were collected during the years 1967 through 1971. Both measures of fatness were recorded.

Source 10, University of Tennessee Plateau Experiment Station (UTPES). Records of these Angus bulls were collected at the Plateau Experiment Station of the University of Tennessee at Crossville, Tennessee, during the years 1969 and 1970. These bulls were weaned at about seven months of age and were placed immediately on a post-weaning test that was terminated when the mean age was 380 days. Post-weaning rations consisted largely of corn silage, hay and only enough grain to produce modest gains. Thus, the bulls did not deposit large amounts of fat. Both measures of fatness were recorded. The only linear skeletal measure used in the analyses was body length measured dorsally from the prominence of the scapula at point of withers to the posterior edge of the pin bone.

Description of Variables and Variable Names

A description of the variables and variable names (in parentheses) included in the analyses are listed below.

1. Source of data (SOURCE).

2. Year of record (YEAR).

3. Adjusted 205-day weaning weight (ADJ205). Records were adjusted only for age of dam according to the procedure recommended by the Beef Improvement Federation (1970). The weight adjustment factors used on Virginia and Tennessee records deviated slightly from BIF, conforming to those used on all records computed in these states' performance testing programs.

4. Final days of age (FDAYS). The age when final weight, measures and scores were recorded.

5. Post-weaning test average daily gain (ADG) in pounds.

6. Final weight (FINWT) in pounds.

7. Adjusted 365-day weight (ADJ365) in pounds. Age-standard weight adjusted for age of dam according to Beef Improvement Federation (1970) recommendations. Adjusted 550-day weight was calculated for Source 8 (FLA) bulls since they were above the age range appropriate for adjusted 365-day weight calculation.

8. Weight per day of age (WDA) in pounds. This measure of gain was calculated by dividing FINWT by FDAYS.

9. Yearling conformation score (GRADE). Subjective scoring was done on a 17-high system (Beef Improvement Federation, 1970).

10. Yearling condition score (CONDSC). The degree of fatness was subjectively scored using the 17-high scoring system.

11. Fat thickness measured ultrasonically in millimeters (FATTH). All readings were single measures of subcutaneous fat thickness taken over the longissimus dorsi muscle at the 12th rib.

12. Wither height (WHT) in centimeters. This measure was taken from the ground to the top of the withers and taken from a grid-chute photograph.

13. Shoulder width (SHW) in centimeters. This width measure was taken with calipers at the points of the shoulders.

14. Body length (BL). This length measure on MONT and FLA bulls was taken from a grid-chute photograph, measuring the length from point of shoulder to pins in centimeters. In the UTTES and UTPES bulls the measures were taken in inches using a steel tape placed on the dorsal midline from the top prominence of the scapula to a line between the posterior prominences of the pin bones.

15. Frame score (FRAME). This subjective score was assigned on the basis of a 1 to 5 scale where 1 is extremely short and small in all dimensions and 5 is extremely long and large in all dimensions.

16. Age of dam at calving (DAMAGE). Dam ages were discretely classified according to recommendations of the Beef Improvement Federation (1970) into 5 groups as 2 year olds, 3 year olds, 4 year olds, 5 through 10 year olds and 11 year olds and older.

17. Origin (ORIG) of Source 7 and Source 8 bulls.

A description of the data from each source is given in Tables IV (Angus) and V (Herefords) which include numbers of records and means and standard deviations of the variables of interest.

II. METHODS OF ANALYSIS

Because records from the various sources considered in this study did not all include the same variables and because age and some extreme management differences existed, it was necessary to analyze the data in several subgroups. Data from the two breeds were analyzed separately throughout.

Because of unequal subclass numbers, the analyses necessitated use of procedures described by Harvey (1960) for least-squares analysis of data with unequal subclass numbers. A generalized least-squares multiple regression procedure was used in each analysis except the principal-components analyses.

Separate analyses were performed on the data from each source according to the basic model with FINWT as the dependent variable. Subsequently, pooling was done where data measurement, age and management seemed to make logical the pooling of groups for which variances were determined to be homogeneous by means of Bartlett's test, as described in standard text books on statistical methods.

Tables VI and VII give the numbers of records, means and standard deviations of variables of interest for each pooled analysis for Angus and Herefords, respectively.

TABLE IV

NUMBERS, MEANS AND STANDARD DEVIATIONS[a] FOR TRAITS OF INTEREST BY INDIVIDUAL SOURCE FOR ANGUS BULLS

Source	Number of animals	ADJ 205 (lbs)	FDAYS (days)	ADG (lbs)	FINWT (lbs)	ADJ 365 (lbs)	WDA (lbs)	GRADE (unit)	CONDSC (unit)	FATTH (mm)	BL (in)
1 (UTTS)	23	524.6	415.3	2.53	989.8	887.4	2.39	13.17	--	7.22	
		±44.4	±45.4	±0.49	±116.2	±73.0	±0.21	±0.98	--	±1.73	
2 (CULTS)	253	535.2	425.0	2.54	1056.0	923.9	2.49	13.04	12.98	9.87	
		±45.3	±41.3	±0.37	±119.1	±65.2	±0.18	±0.96	±1.40	±3.28	
3 (DUBTS)	94	526.7	416.9	2.52	1023.2	911.0	2.46	13.03	12.48	7.41	
		±47.1	±39.0	±0.42	±115.7	±72.1	±0.19	±1.17	±1.37	±1.82	
4 (FR)	44	477.6	368.6	2.62	898.5	896.3	2.43	12.57	11.46[c]	6.07	
		±53.7	±18.5	±0.45	±122.7	±103.8	±0.28	±0.95	±0.85	±1.70	
5 (TUKN)	51	500.7	380.0	2.49	844.8	883.5	2.33	14.10	9.29	5.33	
		±40.0	±19.6	±0.31	±82.0	±75.1	±0.22	±0.90	±0.99	±1.41	
10 (UTPES)	151	--	383.9	1.23	700.1	--	1.66[b]	12.52	9.10	2.30	41.6
		--	±27.8	±0.28	±86.8	--	±0.16	±1.10	±0.85	±0.77	±1.95

[a]Standard deviation beneath each Mean.

[b]Lifetime ADG.

[c]N = 97.

TABLE V

NUMBERS, MEANS AND STANDARD DEVIATIONS[a] FOR TRAITS OF INTEREST BY INDIVIDUAL SOURCE FOR HEREFORD BULLS

Source	Number of animals	Trait											
		ADJ 205 (lbs)	FDAYS (days)	ADG (lbs)	FINWT (lbs)	ADJ 365 (lbs)	WDA (lbs)	GRADE (unit)	CONDSC (unit)	FATTH (mm)	WHT (cm)	SHW (cm)	BL (cm)
1 (UTTS)	26	534.5	429.6	2.66	1045.4	912.1	2.45	13.38	--	9.85	--	--	--
		±61.4	±46.3	±0.46	±94.4	±73.2	±0.22	±0.85	--	±2.11	--	--	--
2 (CULTS)	135	531.7	445.7	2.72	1125.9	937.3	2.53	13.42	13.09	10.64	--	--	--
		±44.5	±43.1	±0.37	±116.4	±56.5	±0.16	±0.96	±1.30	±3.34	--	--	--
3 (DUBTS)	80	544.4	408.2	2.52	1015.8	927.0	2.49	13.19	12.28	7.34	--	--	--
		±48.8	±39.2	±0.38	±96.6	±65.6	±0.18	±1.02	±1.15	±2.43	--	--	--
4 (FR)	49	477.6	364.4	2.69	905.1	907.8	2.48	12.64	11.35[c]	5.96	--	--	--
		±52.1	±17.2	±0.36	±107.9	±93.9	±0.26	±0.94	±0.94	±2.10	--	--	--
5 (UTKN)	24	516.5	374.8	2.52	899.5	903.8	2.40	13.75	8.88	5.79	--	--	--
		±43.4	±12.5	±0.36	±65.5	±68.7	±0.19	±0.74	±1.03	±2.00	--	--	--
6 (UTTES)	58	--	390.7	1.77	749.7	--	1.74	12.80	9.12	3.30	--	--	42.1[b]
		--	±24.4	±0.26	±85.3	--	±0.17	±1.03	±0.91	±1.07	--	--	1.64
7 (MONT)	207	499.2	394.6	2.67	935.7	856.8	2.37	11.62	10.24	--	--	--	--
		±63.6	±16.8	±0.33	±97.8	±84.0	±0.22	±1.72	±1.32	--	--	--	--
7A (MONT)	165	453.3	393.6	2.63	931.1	854.9	2.36	11.46	10.20	--	112.5	46.5	129.7
		±65.5	±16.7	±0.32	±99.6	±86.4	±0.23	±1.79	±1.32	--	±4.26	±2.49	±6.48

TABLE V (Cont'd)

Source	Number of animals	ADJ 205 (lbs)	FDAYS (days)	ADG (lbs)	FINWT (lbs)	ADJ 365 (lbs)	WDA (lbs)	GRADE (unit)	CONDSC (unit)	FATTH (mm)	WHT (cm)	SHW (cm)	BL (cm)
8 (FLA)	230	408.7	583.1	1.50	967.8	928.9[d]	1.66	11.88	9.09	--	--	--	--
		±59.5	±18.9	±0.21	±115.7	±99.6	±0.18	±1.57	±1.21	--	--	--	--
8A (FLA)	155	402.8	586.8	1.53	974.5	929.9[d]	1.66	12.26	9.23	--	115.0	46.8	132.4
		±65.3	±16.9	±0.17	±114.6	±101.1	±0.18	±1.45	±1.20	--	±3.74	±3.57	±6.45
8β (FLA)	108	403.6	584.8	1.51	967.1	925.4[d]	1.65	12.35	9.36	2.64	115.5	45.6	131.2
		±70.5	±17.1	±0.18	±116.9	±104.8	±0.19	±1.25	±1.13	±0.99	±3.80	±3.06	±6.31
9 (UTMT)	62	427.4	454.7	2.58	929.2	765.3	2.06	--	11.42	5.89	--	--	--
		±61.4	±28.3	±0.35	±101.4	±82.2	±0.21	--	±1.27	±3.31	--	--	--

[a]Standard deviation beneath each Mean.

[b]Measured in inches.

[c]N = 63.

[d]Adjusted 550 day weight.

TABLE VI

NUMBERS, MEANS AND STANDARD DEVIATIONS[a] FOR TRAITS OF INTEREST IN POOLED ANALYSES FOR ANGUS BULLS

Analyses and sources	No.	Trait									
		ADJ 205 (lbs)	FDAYS (days)	ADG (lbs)	FINWT (lbs)	ADJ 365 (lbs)	WDA (lbs)	GRADE (unit)	CONDSC (unit)	FATTH (mm)	FRAME (unit)
POOLED ANALYSES I[b] (1,2,3,4,5)	465	523.7 ±49.3	412.7 ±42.3	2.54 ±0.39	1012.5 ±131.4	912.5 ±73.7	2.45 ±0.20	13.11 ±1.07	-- --	8.38 ±3.18	-- --
POOLED ANALYSIS I A[c] (2,3,4,5)	495	518.6 ±52.4	407.4 ±43.0	2.54 ±0.37	1000.0 ±134.7	911.3 ±75.4	2.45 ±0.21	13.02 ±1.09	12.21 ±1.70	-- --	-- --
POOLED ANALYSIS II (2 & 3)	199	531.0 ±43.5	416.7 ±36.7	2.53 ±0.40	1031.6 ±117.9	918.8 ±67.3	2.48 ±0.19	12.89 ±1.11	12.68 ±1.55	9.40 ±2.72	2.92 ±0.76

[a]Standard deviation beneath each Mean.

[b]Data in these analyses used in assessing the contribution of FATTH.

[c]Data in these analyses used in assessing the contribution of CONDSC.

TABLE VII

NUMBERS, MEANS AND STANDARD DEVIATIONS[a] FOR TRAITS OF INTEREST IN POOLED ANALYSES FOR HEREFORD BULLS

Analyses and sources	Number of animals	Trait									
		ADJ 205 (lbs)	FDAYS (days)	ADG (lbs)	FINWT (lbs)	ADJ 365 (lbs)	WDA (lbs)	GRADE (unit)	CONDSC (unit)	FATTH (mm)	FRAME (unit)
POOLED ANALYSES I[b] (1,2,3,4,5,9)	376	509.4 ±65.3	423.0 ±48.1	2.63 ±0.38	1021.2 ±137.6	899.0 ±92.7	2.42 ±0.26	13.26 ±0.99	-- --	8.18 ±3.54	-- --
POOLED ANALYSIS I A[c] (2,3,4,5,7,9)	571	486.0 ±70.8	411.2 ±41.7	2.65 ±0.36	987.7 ±131.8	884.0 ±93.1	2.41 ±0.25	12.58 ±1.58	11.39 ±1.75	-- --	-- --
POOLED ANALYSIS II (2 & 3)	108	536.9 ±43.4	425.9 ±43.5	2.61 ±0.41	1068.2 ±125.6	930.5 ±62.2	2.51 ±0.17	13.10 ±0.99	12.47 ±1.38	9.72 ±3.31	3.11 ±0.67

[a] Standard deviation beneath each Mean.

[b] Data in these analyses used in assessing the contribution of FATTH.

[c] Data in these analyses used in assessing the contribution of CONDSC.

First General Analysis (I)

The first general analysis conducted was one in which FINWT was regressed on each of the two measures of fatness separately. The models were designed to determine the amount of additional variation in the dependent variable explained by measures of fatness after removal of the influence of other effects which are currently in general use, namely, age (FDAYS) and maternal effect (DAMAGE). The general models employed were as follows:

Analysis of data from each source:

$$Y_{ijk} = \mu + YEAR_i + b_1 (X_1 - \bar{X}_1) + DAMAGE_j + b_2 (X_2 - \bar{X}_2) + b_3 (X_3^2 - \overline{X_3^2}) + e_{ijk},$$

where,

Y_{ijk} = observed FINWT for the k^{th} bull in the j^{th} DAMAGE and the i^{th} YEAR,

μ = population mean,

b_1 = partial regression of Y on FDAYS with YEAR held constant,

$\bar{X}_1$ = the mean of FDAYS in the i^{th} year,

b_2 = partial regression of Y on FATTH or CONDSC, with YEAR and DAMAGE held constant,

$\bar{X}_2$ = the mean of FATTH or CONDSC in the ij^{th} YEAR-DAMAGE subclass,

b_3 = partial regression of Y on the squared FATTH or CONDSC, with YEAR and DAMAGE held constant,

$\overline{X_3^2}$ = the mean of squared FATTH or CONDSC in the ij^{th} YEAR-DAMAGE subclass,

e_{ijk} = random error.

Analysis of data pooled over sources:

$$Y_{ijkl} = \mu + SOURCE_i + YEAR_j/SOURCE_i + b_1 (X_1 - \overline{X}_1) + DAMAGE_k + b_2 (X_2 - \overline{X}_2) + b_3 (X_3^2 - \overline{X_3^2}) + e_{ijkl} ,$$

where,

Y_{ijkl} = observed FINWT for the lth bull in the kth DAMAGE, jth YEAR and ith SOURCE,

μ = population mean,

b_1 = partial regression of Y on FDAYS with SOURCE and YEAR/SOURCE held constant,

$\overline{X}_1$ = the mean of FDAYS in the jth YEAR in the ith SOURCE,

b_2 = partial regression of Y on FATTH or CONDSC, with SOURCE, YEAR/SOURCE and DAMAGE held constant,

$\overline{X}_2$ = the mean FATTH or CONDSC in the kth DAMAGE, jth YEAR and ith SOURCE,

b_3 = partial regression of Y on squared FATTH or CONDSC, with SOURCE, YEAR/SOURCE and DAMAGE held constant,

$\overline{X_3^2}$ = the mean of squared FATTH or CONDSC in the kth DAMAGE, jth YEAR and ith SOURCE,

e_{ijk} = random error.

The quadratic term for fatness measure was removed from the model for further analysis when probability of chance occurrance of the observed effect exceeded 0.05, or if the addition of the quadratic term was responsible for little, if any, increase in the coefficients of multiple determination (R^2).

Second General Analysis (II)

The second general analysis was conducted using data from those sources which had one or more measures of skeletal size in addition to one or both measures of fatness. The objective was to determine the effectiveness of these skeletal measures in accounting for differences in FINWT and also to assess the change in amount of variation in FINWT explained by measures of fatness after the influence of skeletal-size measures was removed. The generalized models with FINWT as the dependent variable used in these analyses were:

Analysis of data from each source which included linear measurements (WHT, BL, SHW):

$$Y_{ijk} = \mu + YEAR_i + b_1\ (X_1-\bar{X}_1) + DAMAGE_j + b_2\ (X_2-\bar{X}_2) + b_3\ (X_3-\bar{X}_3) + b_4\ (X_4-\bar{X}_4) + b_5\ (X_5-\bar{X}_5) + b_6\ (X_6^2-\bar{X}_6^2) + e_{ijk}\ ,$$

where,

Y_{ijk} = observed FINWT for the k^{th} bull in the j^{th} DAMAGE and i^{th} YEAR,

μ = population mean,

b_1 = partial regression of Y on FDAYS with YEAR held constant,

$\bar{X}_1$ = the mean of FDAYS in the i^{th} year,

b_2 = partial regression of Y on WHT, with YEAR and DAMAGE held constant,

$\bar{X}_2$ = the mean of WHT in the ij^{th} YEAR-DAMAGE subclass,

b_3 = partial regression of Y on BL, with YEAR and DAMAGE held constant,

$\overline{X}_3$ = the mean of BL in the ijth YEAR-DAMAGE subclass,

b_4 = partial regression of Y on SHW, with YEAR and DAMAGE held constant,

$\overline{X}_4$ = the mean of SHW in the ijth YEAR-DAMAGE subclass,

b_5 = partial regression of Y on FATTH or CONDSC, with YEAR and DAMAGE held constant,

$\overline{X}_5$ = the mean of FATTH or CONDSC in the ijth YEAR-DAMAGE subclass,

b_6 = partial regression of Y on squared FATTH or CONDSC, with YEAR and DAMAGE held constant,

$\overline{X_6^2}$ = the mean of squared FATTH or CONDSC in the ijth YEAR-DAMAGE subclass,

e_{ijk} = random error.

Analysis of data pooled over sources which include frame scores (FRAME):

$$Y_{ijkl} = \mu + SOURCE_i + YEAR_j/SOURCE_i + b_1\ (X_1-\overline{X}_1) + DAMAGE_k + b_2\ (X_2-\overline{X}_2) + b_3\ (X_3-\overline{X}_3) + b_4\ (X_4-\overline{X_4^2}) + e_{ijkl}\ ,$$

where,

Y_{ijkl} = observed FINWT for the lth bull in the kth DAMAGE, jth YEAR and ith SOURCE,

μ = population mean,

b_1 = partial regression of Y on FDAYS with SOURCE and YEAR/SOURCE held constant,

$\overline{X}_1$ = the mean of FDAYS in the jth YEAR in the ith SOURCE,

b_2 = partial regression of Y on FRAME, with SOURCE, YEAR/SOURCE and DAMAGE held constant,

$\overline{X}_2$ = the mean of FRAME in the k^{th} DAMAGE, j^{th} YEAR and i^{th} SOURCE,

b_3 = partial regression of Y on FATTH or CONDSC, with SOURCE, YEAR/SOURCE and DAMAGE held constant,

$\overline{X}_3$ = the mean of FATTH or CONDSC in the k^{th} DAMAGE, j^{ih} YEAR and i^{th} SOURCE,

b_4 = partial regression of Y on squared FATTH or CONDSC, with SOURCE, YEAR/SOURCE and DAMAGE held constant,

$\overline{X_4^2}$ = the mean of squared FATTH or CONDSC in the k^{th} DAMAGE, j^{th} YEAR and i^{th} SOURCE,

e_{ijkl} = random error.

Again, the quadratic term for fatness measure was removed from an individual model when the probability of chance occurrence of the observed effect exceeded 0.05 or if the addition of the quadratic term was responsible for little, if any, increase in the coefficient of multiple determination, (R^2).

In both of the first two general analyses, partial coefficients of determination were computed from the sequential sum of squares for each independent variable in the respective models.

Third General Analysis (III)

The third general analysis employed the multivariate technique known as principal-component analysis. The objective in this analysis was to determine the usefulness of a multivariate technique which has the capability of utilizing simultaneously several variables measuring size to describe or contrast differences in size and/or shape. Those sources which had measures of skeletal size as well as weight, age and fatness measures were subjected to this analysis. It was believed that such an analysis might prove useful in improving the accuracy of estimating breeding value by taking into account basic differences in kind or shape.

One who has worked with biological data in which a number of correlated independent variables are used to describe or explain a dependent variable appreciates the problem of discerning the usefulness of individual variables. Analytical approaches for such data have historically been those of path coefficients, multiple regression and multiple correlation. However, those approaches have predicted or described variables which themselves are only estimators of the trait in question. For example, weight has been estimated from body dimensions and other measures, when the characteristic of interest was actually size. Principal components offer the possibility of a joint expression of size from a number of variables (measures), each of which is a non-independent measure of size. The concept of principal components has received limited attention in beef cattle research (Carpenter et al., 1971 and Brown et al., 1972d) and undoubtedly is due greater attention in the future.

For a more detailed technical discussion of principal component analysis, the reader is referred to the standard texts of Morrison (1967) and Hope (1968). Basically, the technique provides the user with a method of explaining the variance-covariance structure in a larger system of variables by a smaller number of principal components generated from linear combinations of these same original variables. Principal component analysis is, therefore, a relatively straight-forward method of "breaking down" a covariance or correlation matrix into a set of orthogonal components or axes equal to the number of variables concerned. The user must decide how many of the components are beneficial depending on the data and the desired use.

The first component explains the largest possible portion of variance in the variance-covariance structure, thus minimizing the residual relationship among the variables. Each succeeding component satisfies the same criterion, subject to the restriction that it be orthogonal to all preceeding components. The process continues until the number of principal components equals the number of response variables, eliminating all correlation between variables and accounting for 100 percent of the variance in the system.

There is nothing in the analysis which suggests that some components or synthetic variables are more meaningful or of more biological or economic importance than others, and there is nothing which implies that some are dispensable or negligible. If a dimension exists in the data, it will appear in the analysis. The researcher, upon consideration of the analysis, may choose to eliminate one or more of the original variables because of trivial relationship to each of the components.

A set of synthetic indexes or component scores in standard units are computed for each animal, one per component. These individual animal indexes or component scores are computed by multiplying the component weighting-factor coefficient for each variable by the standardized measure for that variable and summing across variables. The individual-animal component scores will range from large positive to large negative values in each principal component. Thus, ranking of animals within each independent principal component is an obvious use of the method.

With cattle measurement data, such as those in this study, in which all measurements are positively correlated, the first component will generally have all positive weighting-factor coefficients which will rank individual animals on general size and will account for half to two-thirds of the variance in the total system. The second component, being independent of the first, will account for an additional 10 to 30 percent of the variance and will in general contrast animals different in shape or form, independent of weight. Since the first two components account for the largest portions of variance, other components also contrast shapes or kinds of animals but those that are definitely in the minority in most populations of cattle.

Components with positive and negative weighting-factor coefficients are contrasting those variables (measurements) with large positive coefficients against those with large negative coefficients. This differential weighting of various variables provides an objective means of identifying animals of different sizes, shapes and degrees of fatness.

CHAPTER IV

RESULTS AND DISCUSSION

Because the data for this study come from fairly diverse groups of bulls from the standpoint of physical location, management systems and traits measured, it was necessary to analyze various subgroups separately within each of the three main analyses. These differences are clearly pointed out in Tables IV and V, pages 37 and 38, which give numbers, means and standard deviations by SOURCE for Angus and Herefords, respectively, and Tables VI and VII, pages 40 and 41, which give similar statistics in the pooled analyses for Angus and Herefords, respectively.

The results in each of the three major analyses and the discussion of them constitute an attempt to present findings regarding the contribution of measures of fatness, measures of skeletal size and both of these in more accuragely defining size. In addition, inferences are drawn as to the possible usefulness of these measure over and above weight, adjusted for age and age of dam, which is the commonly used measure in performance testing bulls.

I. THE CONTRIBUTION OF MEASURES OF FATNESS

Analyses of Individual Sources

Data from individual sources were analyzed by breed to assess the value of FATTH and CONDSC in explaining differences in FINWT. The effects of YEAR, FDAYS and DAMAGE were removed sequentially with the marginal effect of either fatness measure being assessed by adding it to the model last. Analyses of variance of FINWT with FATTH for all sources are given in Tables VIII and IX for Angus and Herefords, respectively. Likewise, analyses of variance of FINWT with CONDSC for all sources are presented in Tables X and XI.

The most striking finding from these individual-source analyses is the variability of results obtained among the various sources both within and between breeds. Differences between the two breeds are apparent across sources, particularly with respect to the efficiency of the model in explaining variation in FINWT, with respect to the value of fatness measures in explaining variation in FINWT, and to a lesser degree, with respect to the effect of DAMAGE on FINWT.

The model was, in general, more efficient in Herefords than in Angus as indicated by higher coefficients of multiple determination (R^2). Since the total variability in FINWT was generally higher (due to greater age range) in the test station bulls (SOURCES 1, 2 and 3), it was not surprising that R^2 values for these sources were larger than for bulls from sources representing research herds regardless of breed.

The most important effect, as expected, was exerted by FDAYS which was a significant source of variation in all Angus analyses and all Hereford analyses except Source 5 (UTKN). In general coefficients of partial regression for FDAYS tended to be smaller for sources in which FATTH or CONDSC effect was the greatest relative to total variation, which indicates that fatness measures tend to reduce the importance of FDAYS in explaining variation in the dependent variable, FINWT.

Age of dam (DAMAGE) effect was variable but generally of small

TABLE VIII

ANALYSIS OF VARIANCE OF FINWT OF ANGUS BULLS BY INDIVIDUAL SOURCE WITH FATTH IN THE MODEL

Independent variable		Source: 1 UTTS	2 CULTS	3 DUBTS	4 FR	5 UTKN	10 UTPES
Number of Animals		23	253	94	44	51	151
YEAR	df	--	3	2	1	1	1
	MS[a]	--	32711**	28963*	24775	24612*	75976**
	Part. R^2	--	0.0275	0.0523	0.0383	0.0732	0.0672
FDAYS	df	1	1	1	1	1	1
	MS	126820**	2062103**	633680**	220402**	39061**	394752**
	b	1.5089	2.1679	2.0668	4.0614	1.2870	1.8769
	Part. R^2	0.4270	0.5770	0.5092	0.3405	0.1161	0.3492
DAMAGE	df	3	4	4	4	4	4
	MS	13616	6632	6178	6090	7960	3584
	Part. R^2	0.1375	0.0074	0.0199	0.0376	0.0946	0.0127
FATTH	df	1	1	1	1	1	1
	MS	6942	24849*	150	1655	2441	40914**
	b	11.8824	3.3677	-0.7434	3.8256	5.7488	92.2788
	Part. R^2	0.0234	0.0069	0.0001	0.0026	0.0072	0.0362

TABLE VIII (Cont'd)

Independent variable		Source 1 UTTS	2 CULTS	3 DUBTS	4 FR	5 UTKN	10 UTPES
Number of Animals		23	253	94	44	51	151
$FATTH^2$	df	--	--	--	--	--	1
	MS	--	--	--	--	--	20133*
	b	--	--	--	--	--	-13.4327
	Part. R^2	--	--	--	--	--	0.0178
RESIDUAL	df	17	243	85	36	43	142
	MS	7199	5607	6213	10446	5548	4114
R^2		0.5879**	0.6188**	0.5757**	0.4190**	0.2911*	0.4831**

*P < .05.

**P < .01

[a]Partial R^2 is computed as a ratio of a sequential sum of squares due to an independent variable to the total sum of squares.

TABLE IX

ANALYSIS OF VARIANCE OF FINWT WITH HEREFORD BULLS BY INDIVIDUAL SOURCE WITH FATTH IN THE MODEL

Independent variable		Source 1 UTTS	2 CULTS	3 DUBTS	4 FR	5 UTKN	6 UTTES	8B FLA	9 UTMT
Number of Animals		26	135	80	49	24	58	108	62
YEAR	df	--	3	2	1	1	1	1	4
	MS	--	38189**	21894**	979	8030	32790**	216467**	15960
	Part. R^{2a}	--	0.0631	0.0594	0.0018	0.0815	0.0814	0.1479	0.1018
ORIG	df	--	--	--	--	--	--	1	--
	MS	--	--	--	--	--	--	91567**	--
	Part. R^2	--	--	--	--	--	--	0.0626	--
FDAYS	df	1	1	1	1	1	1	1	1
	MS	81522**	1068377**	370395**	148513**	650	113005**	86469**	116052**
	b	1.5678	2.1456	1.8558	2.6628	0.9265	1.5456	0.6928	1.4262
	Part. R^2	0.3660	0.5885	0.5025	0.2660	0.0066	0.2805	0.0591	0.1849
DAMAGE	df	3	4	4	4	3	4	3	4
	MS	1992	17911**	3644	9671	1138	22380**	36683**	7376
	Part. R^2	0.0268	0.0394	0.0198	0.0621	0.0346	0.2223	0.0752	0.0470
FATTH	df	1	1	1	1	1	1	1	1
	MS	203	20118*	31091**	55951**	18199*	16243*	216656**	82691**
	b	-101.2181	29.0281	10.2304	18.4495	17.1672	19.7317	217.9075	19.4523
	Part. R^2	0.0009	0.0111	0.0422	0.1002	0.1846	0.0403	0.1481	0.1318

TABLE IX (Cont'd)

Independent variable		Source: 1 UTTS	2 CULTS	3 DUBTS	4 FR	5 UTKN	6 UTTES	8B FLA	9 UTME
Number of Animals		26	135	80	49	24	58	108	62
$FAITH^2$	df	1	1	--	--	--	--	1	--
	MS	29211*	26785*	--	--	--	--	114777**	--
	b_2	4.6139	-1.0480	--	--	--	--	-26.3741	--
	Part. R^2	0.1312	0.0148	--	--	--	--	0.0784	--
RESIDUAL	df	19	124	71	41	17	50	99	51
	MS	5571	4146	3906	7762	4017	3087	6335	6575
R^2		0.5249*	0.7169**	0.6238**	0.4301**	0.3073	0.6245**	0.5713**	0.4655**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of a sequential sum of squares due to an independent variable to the total sum of squares.

TABLE X

ANALYSIS OF VARIANCE OF FINWT OF ANGUS BULLS BY INDIVIDUAL SOURCE WITH CONDSC IN THE MODEL

Independent variable		Source: 2 CULTS	3 DUBTS	4 FT	5 UTKN	10 UTPES
Number of Animals		253	94	97	51	151
YEAR	df	3	2	3	1	1
	MS	32711**	28963*	11575	24612*	75976**
	Part. R^{2a}	0.0275	0.0465	0.0302	0.0731	0.0672
FDAYS	df	1	1	1	1	1
	MS	2062103**	633680**	295128**	39061**	394752**
	b	2.2317	2.1543	2.2552	1.0945	1.8317
	Part. R^2	0.5770	0.5091	0.2565	0.0731	0.3493
DAMAGE	df	4	4	4	4	4
	MS	6632	6178	5039	7960	3584
	Part. R^2	0.0074	0.0198	0.0175	0.0946	0.0127
CONDSC	df	1	1	1	1	1
	MS	4215	9541	172428**	25072*	36020**
	b	3.2943	-9.0166	57.0079	27.8866	178.1063
	Part. R^2	0.0012	0.0076	0.1499	0.0745	0.0319
$CONDSC^2$	df	--	--	--	--	1
	MS	--	--	--	--	17621*
	b	--	--	--	--	-8.5525
	Part. R^2	--	--	--	--	0.0156

TABLE X (Cont'd)

Independent variable		Source 2 CULTS	3 DUBTS	4 FT	5 UTKN	10 UTPES
Number of Animals		253	94	97	51	151
RESIDUAL	df	243	85	87	43	142
	MS	5692	6103	7618	5022	4167
R^2		0.6130**	0.5832**	0.4541**	0.3583**	0.4766**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of a sequential sum of squares due to an independent variable to the total sum of squares.

TABLE XI

ANALYSIS OF VARIANCE OF FINWT OF HEREFORD BULLS BY INDIVIDUAL SOURCE WITH CONDSC IN THE MODEL

Independent variable		Source 2 CULTS	3 DUBTS	4 FR	5 UTKN	6 UTTES	7 MONT	8 MONT	9 UTMT
Number of Animals		135	80	63	24	58	207	230	62
YEAR	df	3	2	3	1	1	4	4	4
	MS[a]	38189**	21894**	29707**	8030	32790**	33673**	189796**	15962*
	Part. R^2	0.0631	0.0594	0.1192	0.0815	0.0814	0.0683	0.2478	0.1018
ORIG	df	--	--	--	--	--	1	1	--
	MS	--	--	--	--	--	234109**	205654**	--
	Part. R^2	--	--	--	--	--	0.1187	0.0671	--
FDAYS	df	1	1	1	1	1	1	1	1
	MS	1068377**	370395**	142423**	650	113005**	336170**	68197**	116052**
	b	2.0797	1.8180	2.6109	0.6323	1.5171	2.1539	1.3285	1.3040
	Part. R^2	0.5884	0.5025	0.1905	0.0066	0.2805	0.1705	0.0549	0.1850
DAMAGE	df	4	4	4	3	4	2	3	4
	MS	17911**	3644	12369	1138	22380**	27420**	60097**	7376
	Part. R^2	0.0395	0.0198	0.0662	0.0346	0.0222	0.0278	0.0589	0.0470
CONDSC	df	1	1	1	1	1	1	1	1
	MS	38619**	1274	66258**	14774	15811*	389669**	397186**	110505**
	b	14.9557	4.1272	47.5845	27.2529	26.2073	36.2646	43.5276	38.8145
	Part. R^2	0.0213	0.0018	0.0886	0.1498	0.0393	0.1976	0.1297	0.1761

TABLE XI (Cont'd)

Independent variable		Source 2 CULTS	3 DUBTS	4 Fr	5 UTKN	6 UTTES	7 MONT	8 MONT	9 UTMT
Number of Animals		134	80	63	24	58	207	230	62
RESIDUAL	df	125	71	53	17	50	197	219	51
	MS	4179	4326	7556	4219	3096	4175	6176	6030
R^2		0.7123**	0.5834**	0.4644**	0.2725	0.6234**	0.5829**	0.5584**	0.5099**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of a sequential sum of squares due to an independent variable to the total sum of squares.

value and of no statistical significance in Angus bulls from any source. The effect in Herefords was similar in sources which had both breeds of bulls represented except in the instance of Source 2 (CULTS) where DAMAGE exerted a highly significant ($P < .01$) effect. DAMAGE effect in Herefords was statistically significant also in Sources 6, 7 and 8. There is a strong suggestion that breeds do differ with respect to maternal effect on yearling weight. These results are in agreement with those of Brown et al. (1972a) which showed that age of dam effects decline much more rapidly as age increases in Angus than is the case for Herefords. Angus are more mature at any age.

The effect of fatness measure, regardless of whether FATTH or CONDSC was used, appears to be much greater and more consistent across sources in Herefords than in Angus. This is particularly true with respect to FATTH, which explained a considerably larger portion of total variation in Herefords than Angus and was a significant source of variation in all but Source 1 (UTTS) in Herefords but in only two sources in Angus (Sources 2 and 10). The coefficients of partial regression of FINWT on FATTH in Angus sources are quite variable but generally small, except in Sources 1 and 10. Much stronger association between FINWT and FATTH is noted in Herefords as indicated by b values and partial R^2 values.

The individual source analyses for both fatness measures and particularly for FATTH show that there was apparently considerably more individual animal variation as to kind or body type in Angus as a breed than in Herefords, which is in keeping with the impression obtained from observation of the animals. The highest proportion of variation attributable to regression on fatness measure was found in the sources in which the least amount of variation existed in FINWT, FDAYS and, perhaps, body type or maturity rate as was the case in Sources 4, 5, 7, 8, 8B and 9 Herefords.

The smallest partial R^2 values and coefficients of partial regression involving CONDSC were observed in the test station bulls (Sources 2 and 3). This is undoubtedly due in part to the fact that bulls of both breeds in these sources were considerably more variable in weight, size, degree of fatness and, perhaps, type when scored than were the bulls in research herds. This fact may reflect also upon the accuracy of scoring done in the test station bulls. The lower proportion of FINWT differences generally explained by either fatness measure in the more variable test station bulls suggests that in many instances bulls of common weight varied markedly in fat thickness or that bulls of different weights with equal fatness were not scored alike for CONDSC.

The relationship of FATTH and FINWT was found to be curvilinear only in the thin, Source 10 (UTPES) bulls in Angus and in three of eight sources in Herefords (Sources 1, 2 and 8B). Only Source 10 Angus showed curvilinearity in CONDSC Analyses. This suggests that the relationship of fatness measure and weight may not always be linear. Non-linearity is more likely to exist in groups varying widely in age and size (as did the test station bulls) or in groups developed under relatively low energy conditions as was the case in Sources 8B and 10. The eye is apparently not as accurate in determination of fatness *per se* as is the ultrasonic equipment.

It is doubtful that these individual source analyses established the true relationship between fatness measures and FINWT, but they did point out:

(1) That much variation exists between groups of cattle within a breed or between breeds,

(2) That measurement of fatness was perhaps not equally accurate in all groups,

(3) That the relationship between fatness measure and FINWT is stronger and more consistent in Herefords than in Angus, possibly as a result of less individual-animal variation in Herefords,

(4) That FATTH is perhaps a more reliable measure of fatness per se than is CONDSC, which tends to evaluate degree of fatness on a relative basis. Both measures were, however, equally useful in explaining differences in FINWT,

(5) That age of dam effect on FINWT is not the same in the two breeds and is affected by several factors. The commonly used age of dam adjustment factors for yearling weight applied uniformly across all breeds and management systems is perhaps inappropriate.

(6) That development of adjustment factors for adjusting yearling weight to a fatness constant may be difficult to formulate accuractely from data such as these which fail to express the relationship of weight and fat on an individual animal basis.

Analysis of Pooled Groups

Records of bulls from sources in which management and post-weaning energy levels were considered to be similar were pooled by breed after determination that variances were homogeneous. Pooled analysis I for each breed was utilized to assess the value of FATTH in explaining differences in FINWT and included Sources 1, 2, 3, 4, 5 and 9. Pooled analysis IA for each breed was likewise used to assess the value of CONDSC in explaining variation in FINWT and included Sources 2, 3, 4, 5, 7 and 9.

Since there was a large age range because bulls from test stations supplied part of each pooled data set, three separate analyses were made in each breed for each measure of fatness. The analyses of variance are given in Tables XII and XIII for Angus data and in Tables XIV and XV for Hereford data. The first analysis of variance in each table included all ages, the second (Age Group 1) included data from bulls up to 450 days of age and the third analysis (Age Group 2) included bulls over 450 days of age. This age division was made in view of the fact that the industry currently obtains yearling weights of bulls weighed when they are 330 to 450 days of age by adjusting the weights to a 365-day basis, and weights of bulls weighed at ages over 450 days are adjusted to either a 452-day basis or to a 550-day basis as recommended by the Beef Improvement Federation (1970).

SOURCE and YEAR, while of significant magnitude in accounting for FINWT differences in each pooled analysis and for each age group, were more important in Herefords than in Angus.

DAMAGE effects in models containing FATTH were significant ($P < .05$) in Angus when all ages were considered but accounted for less than 1 percent of total variation in FINWT. DAMAGE was slightly more important in

TABLE XII

ANALYSIS OF VARIANCE OF FINWT FOR POOLED ANALYSIS I FOR ANGUS BULLS WITH FATTH IN THE MODEL

Independent variable		All ages	Age Group 1 (≤ 449 days)	Age Group 2 (≥ 450 days)
Number of animals		465	375	90
SOURCE	df	4	4	2
	MS	476456**	238934**	20545
	Part. R^{2} [a]	0.2380	0.2198	0.0427
YEAR/SOURCE (Nested)	df	7	7	5
	MS	29349**	15167	14702
	Part. R^2	0.0257	0.0244	0.0763
FDAYS	df	1	1	1
	MS	3015568**	1128576**	203148**
	b	2.1382	2.2678	2.0386
	Part. R^2	0.3767	0.2595	0.2109
DAMAGE	df	4	4	4
	MS	16075*	18053*	2071
	Part. R^2	0.0080	0.0166	0.0086
FATTH	df	1	1	1
	MS	28726*	25230*	4761
	b	3.2282	3.6122	2.5926
	Part. R^2	0.0036	0.0058	0.0049
RESIDUAL	df	447	357	76
	MS	6232	5773	8420
R^2		0.6520**	0.5261**	0.3435**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of a sequential sum of squares due to an independent variable to the total sum of squares.

TABLE XIII

ANALYSIS OF VARIANCE OF FINWT FOR POOLED ANALYSIS IA FOR ANGUS BULLS WITH CONDSC IN THE MODEL

Independent variable		All ages	Age Group 1 (≤ 449 days)	Age Group 2 (≥ 450 days)
Number of Animals		495	409	86
SOURCE	df	3	3	1
	MS	885510**	439315**	13585
	Part. R^{2a}	0.2965	0.2636	0.0151
YEAR/SOURCE (Nested)	df	9	9	5
	MS	23933**	12902*	14702
	Part. R^2	0.0240	0.0232	0.0818
FDAYS	df	1	1	1
	MS	2997016**	1145104**	179386**
	b	2.1979	2.2094	2.2002
	Part. R^2	0.3344	0.2290	0.1996
DAMAGE	df	4	4	4
	MS	12585	13602	2092
	Part. R^2	0.0056	0.0109	0.0093
CONDSC	df	1	1	1
	MS	29638*	69058**	24499
	b	7.0039	12.0794	-14.5596
	Part. R^2	0.0033	0.0138	0.0272
RESIDUAL	df	476	390	73
	MS	6331	5890	8208
R^2		0.6638**	0.5405**	0.3331**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

TABLE XIV

ANALYSIS OF VARIANCE OF FINWT FOR POOLED ANALYSIS I FOR HEREFORD BULLS WITH FATTH IN THE MODEL

Independent variable		All ages	Age Group 1 (≤ 449 days)	Age Group 2 (≥ 450 days)
Number of Animals		376	251	125
SOURCE	df	5	5	3
	MS	607783**	196781**	465628**
	Part. R^{2a}	0.4281	0.3403	0.5674
YEAR/SOURCE (Nested)	df	11	11	9
	MS	21018**	12071**	15380*
	Part. R^2	0.0326	0.0459	0.0562
FDAYS	df	1	1	1
	MS	1702578**	500026**	153992**
	b	1.9016	2.0131	1.7837
	Part. R^2	0.2399	0.1729	0.0625
DAMAGE	df	4	4	4
	MS	9095	5574	6497
	Part. R^2	0.0051	0.0077	0.0105
FATTH	df	1	1	1
	MS	180366**	116038**	53084**
	b	30.8705	31.1454	36.7751
	Part. R^2	0.0254	0.0401	0.0215
$FATTH^2$	df	1	1	1
	MS	86714**	55405**	34517*
	b	-1.0733	-1.1437	-1.2521
	Part. R^2	0.0122	0.0192	0.0140
RESIDUAL	df	352	227	105
	MS	5178	4763	6119
R^2		0.7433**	0.6261**	0.7323**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

TABLE XV

ANALYSIS OF VARIANCE OF FINWT FOR POOLED ANALYSIS IA FOR HEREFORD BULLS WITH CONDSC IN THE MODEL

Independent variable		All ages	Age Group 1 (≤ 449 days)	Age Group 2 (≥ 450 days)
Number of Animals		571	454	117
SOURCE	df	5	5	2
	MS	782052**	210805**	698168**
	Part. R^{2a}	0.3946	0.2111	0.5752
YEAR/SOURCE (Nested)	df	17	17	9
	MS	26708**	20919**	15380*
	Part. R^2	0.0458	0.0712	0.0570
FDAYS	df	1	1	1
	MS	1952737**	806490**	160709
	b	2.0038	2.0649	1.7771
	Part. R^2	0.1971	0.1615	0.0662
DAMAGE	df	4	4	4
	MS	21380**	21163**	5264
	Part. R^2	0.0086	0.0170	0.0087
CONDSC	df	1	1	1
	MS	495679**	388989**	72552**
	b	26.5046	27.2291	21.7651
	Part. R^2	0.0501	0.0779	0.0299
RESIDUAL	df	542	425	99
	MS	5554	5419	6453
R^2		0.6962**	0.5387**	0.7369**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

Angus bulls 450 days of age or younger, explaining 1.7 percent of variation in the dependent variable, but was diluted by age to an unimportant status in bulls older than 450 days. Though non-significant, the same pattern was observed in Angus with CONDSC as the fatness measure.

In Herefords, DAMAGE was not a significant source of variation in FATTH models and was of similar magnitude in both age groups but was important (P < .01) in models utilizing CONDSC in bulls of all ages and those in Age Group 1 explaining 0.86 percent and 1.7 percent of the variation in FINWT, respectively. DAMAGE significance in the CONDSC analysis was due to Sources 7 and 8 being included, whereas, they were not in the FATTH analysis. In Age Group 2, DAMAGE effect was diluted by age to non-significance, explaining less than 1 percent of the variation in FINWT.

In both Angus and Herefords, FDAYS was the most important source of variation in explaining differences in FINWT, but the magnitude of the effect was greater in Angus bulls than in Hereford bulls, regardless of which measure of fatness was included in the model. FDAYS was considerably less important in explaining variation in FINWT in Hereford bulls older than 450 days as compared to younger bulls but was relatively more important in Angus bulls older than 450 days.

In Angus bulls both FATTH and CONDSC were similar in usefulness but actually of very little value in explaining variation in FINWT when all ages were considered, explaining less than half of one percent of total variation, though both measures were significant at the 0.05 probability level. In Age Group 1 Angus bulls, the b value for FATTH increased slightly as compared to that for all ages.

The b value for CONDSC increased markedly in Age Group 1 Angus as compared to that for all ages and was highly significant ($P < .01$), accounting for 1.38 percent of total variation in FINWT. In Age Group 2 Angus, the b value for CONDSC was strongly negative while the b value for FATTH was reduced compared to Age Group 1, but was positive. Apparently, the older, heavier Angus bulls were fatter, as indicated by FATTH, but were assigned lower condition scores.

In Hereford bulls the regression of FINWT on FATTH was found to be curvilinear, and its total effect was highly significant ($P < .01$), explaining 3.76 percent of total variation in FINWT. FATTH effect in Hereford bulls 450 days of age and younger was at least twice as useful in explaining FINWT variation as was the ease in bulls older than 450 days, though the partial regression coefficients for the linear and quadratic effects were similar in magnitude. CONDSC in Herefords, which was linear, was slightly more useful than FATTH, explaining 5.01 percent of the variation in FINWT. Its effect was far greater in younger bulls than in older bulls.

Both fatness measures were of greater usefulness in Hereford bulls than in Angus bulls, indicating a breed difference in this respect as was noted in the individual source analyses. Angus bulls were apparently far more variable as to body type and maturity level at a given age than were Herefords. The coefficients of determination were approximately equal within breed for models utilizing either measure of fatness but were larger in Herefords, principally due to the greater effect of fatness measure upon FINWT in the Hereford data. Residual mean squares were considerably smaller in the Hereford analyses than in the Angus analyses.

These pooled analyses indicate that both measures of fatness are of approximately equal utility. Neither is of appreciable value in Angus data in increasing the amount of explained variation in FINWT as compared to that attained using FDAYS alone, but either fatness measures would increase the amount of variation in FINWT explained in Herefords by at least 5 percent. Both fatness measures, and particularly CONDSC, are more useful in groups of cattle with less individual animal variation in body type, which was the case in Herefords.

Findings from these analyses indicate also that currently used dam-age adjustments may be inappropriate and certainly should not be the same for all breeds. Age of bull almost completely diluted out DAMAGE effects in bulls older than 450 days and exerted a much smaller influence even in bulls 450 days of age and younger than that found in other studies (Gregory, 1965).

As age increases and bulls approach maturity, FATTH and CONDSC are apparently of less value in explaining differences in FINWT. Certainly bulls varying widely in age should not be considered together as has been pointed out by other workers (Brinks *et al.*, 1962) and also by the Beef Improvement Federation (1970).

Separate pooled analyses of bulls from test stations and bulls from research herds were conducted, but trends and values found were similar to those reported in pooled analysis I and IA. Coefficients of partial regression for both FATTH and CONDSC were of somewhat larger magnitude in analyses of data from research herds than in those of data from test station bulls, possibly reflecting differences in measurement technique, particularly in assigning CONDSC values, as well as greater individual animal variation among test station bulls.

II. THE CONTRIBUTION OF SKELETAL SIZE MEASUREMENTS AND SUBSEQUENT MEASURES OF FATNESS

Due to marked differences in bulls at various locations as to breeding, management, post-weaning energy levels and differences in measurement techniques used, pooling of data was done in only one instance in this portion of the study. Data from Angus and Hereford bulls from Sources 2 (CULTS) and 3 (DUBTS) for two years which had frame scores (FRAME) were pooled across the two sources by breed for analysis (Pooled Analysis II). Other analyses were made of data from individual sources.

In each analysis, models containing one or both measures of fatness were employed to determine the marginal contribution of fatness measure in explaining differences in FINWT. Other models used were those in which various measures of skeletal size were entered in the model ahead of one or the other of the measures of fatness to assess the contribution of skeletal-size measures and the subsequent contribution of either FATTH or CONDSC to the explanation of differences in FINWT.

Pooled Analysis II

Frame score (FRAME) on bulls in this analysis was a subjective measure of overall skeletal size and was influenced by both height and length, by degree of fatness and, to some degree, by apparent stage of physiological maturity. Numbers involved, means and standard deviations of traits of interest are given in Tables VI and VII, pages 40 and 41. Numbers of bulls, and simple statistics for variables of interest by FRAME score are presented for Angus bulls in Table XVI and for Hereford bulls in Table XVII.

As bulls from this analysis were included in pooled Analysis I and IA, SOURCE, YEAR and DAMAGE need not be discussed at this point as sources of variation.

FRAME was a highly significant ($P < .01$) source of variation in explaining differences in FINWT in both Angus and Hereford bulls (Tables XVIII and XIX). R^2 values were increased substantially in both models for each breed. Specifically, the increases were 0.6101 to 0.7553 and 0.6066 to 0.7816 in models containing FATTH and CONDSC, respectively, in Angus data and 0.7523 to 0.8143 and 0.7364 to 0.8225 in models containing FATTH and CONDSC, respectively, in Hereford data.

Sequential sums of squares attributable to FRAME were about twice as large in Angus analyses as in Hereford analyses. Partial R^2 associated with FRAME in Angus was 0.1348 compared to 0.0740 in Hereford. This emphasized the fact that Angus were far more variable in type than were Herefords.

In both breed analyses the value of fatness measures, when frame was not included in the models, was non-significant and quite small. (Partial R^2 values were less than 0.05).

In Angus the addition of FRAME to the model previous to entry of FATTH or CONDSC tended to account for differences in individual variation as to kind and actually allowed the sum of squares associated with fatness

TABLE XVI

MEANS AND STANDARD DEVIATIONS OF VARIABLES BY FRAME SCORE FOR ANGUS BULLS

Variable	Frame Score 1	2	3	4	5
Number of Animals	3	55	97	42	2
ADJ 205	474 ±13.3	512 ±33	536 ±42	547 ±48	558 ±88
FDAYS	423 ±27	415 ±38	412 ±35	428 ±38	447 ±11
ADG	2.15 ±0.08	2.30 ±0.33	2.56 ±0.33	2.79 ±0.45	2.90 ±0.50
FINWT	912 ±28	968 ±104	1029 ±99	1121 ±117	1200 ±106
ADJ 365	808 ±26	865 ±50	925 ±52	969 ±67	987 ±68
WDA	2.16 ±0.08	2.33 ±0.13	2.50 ±0.15	2.62 ±0.18	2.68 ±0.17
GRADE	11.0 ±0.0	11.8 ±0.7	13.1 ±0.8	14.0 ±0.8	13.5 ±0.7
CONDSC	14.3 ±1.5	13.3 ±1.4	12.8 ±1.5	11.7 ±1.4	11.5 ±0.7
FATTH	8.0 ±3.6	9.6 ±2.4	9.4 ±3.0	9.1 ±2.4	11.5 ±0.7

TABLE XVII

MEANS AND STANDARD DEVIATIONS OF VARIABLES BY FRAME SCORE FOR HEREFORD BULLS

Variable	Frame Score 2	3	4	5
Number of Animals	18	61	28	1
ADJ 205	525 ±38	535 ±45	547 ±40	593 --
FDAYS	413 ±44	429 ±45	428 ±39	406 --
ADG	2.29 ±0.34	2.61 ±0.43	2.83 ±0.27	2.50 --
FINWT	972 ±120	1069 ±117	1128 ±115	1080 --
ADJ 365	877 ±38	924 ±58	977 ±50	976 --
WDA	2.35 ±0.11	2.50 ±0.16	2.64 ±0.13	2.66 --
GRADE	11.9 ±0.8	13.1 ±0.7	13.8 ±0.9	15.0 --
CONDSC	12.9 ±1.4	12.6 ±1.3	11.9 ±1.4	11.0 --
FATTH	8.4 ±2.7	10.1 ±3.5	9.9 ±2.9	5.0 --

TABLE XVIII

ANALYSIS OF VARIANCE OF FINWT OF ANGUS BULLS IN POOLED ANALYSIS II WITH FRAME AND FATTH OR CONDSC IN THE MODEL (N = 199)

		FATTH				CONDSC	
Independent variable		Without Frame	With Frame	Independent variable		Without Frame	With Frame
SOURCE	df	1	1	SOURCE	df	1	1
	MS	40361**	40361**		MS	40361**	40361**
	Part. R^2[a]	0.0147	0.0147		Part. R^2	0.0147	0.0147
YEAR/SOURCE (Nested)	df	2	2	YEAR/SOURCE (Nested)	df	2	2
	MS	19474*	19474**		MS	19474**	19474**
	Part. R^2	0.0141	0.0141		Part. R^2	0.0141	0.0141
FDAYS	df	1	1	FDAYS	df	1	1
	MS	1535225**	1535225**		MS	1535225**	1535225**
	b	2.4289	2.2238		b	2.4695	2.1262
	Part. R^2	0.5579	0.5579		Part. R^2	0.5579	0.5579
DAMAGE	df	4	4	DAMAGE	df	4	4
	MS	13590	13590**		MS	13590	13590
	Part. R^2	0.0198	0.0198		Part. R^2	0.0198	0.0198
FRAME	df	--	1	FRAMD	df	--	1
	MS	--	384050**		MS	--	384050**
	b	--	60.2884		b	--	74.8514
	Part. R^2	--	0.1396		Part. R^2	--	0.1396

TABLE XVIII (Cont'd)

Independent variable		FATTH Without Frame	FATTH With Frame	Independent variable		CONDSC Without Frame	CONDSC With Frame
FATTH	df	1	1	CONDSC	df	1	1
	MS	9949	25306**		MS	347	97780**
	b_2	3.1681	5.0754		b_2	-0.9913	18.8935
	Part. R^2	0.0036	0.0092		Part. R^2	0.0001	0.0356
RESIDUAL	df	189	188	RESIDUAL	df	189	188
	MS	5676	3582		MS	5727	3196
R^2		0.6101**	0.7553**	R^2		0.6066**	0.7816**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

TABLE XIX

ANALYSIS OF VARIANCE OF FINWT OF HEREFORD BULLS IN POOLED ANALYSIS II WITH FRAME AND FATTH OR CONDSC IN THE MODEL (N = 108)

Independent variable		FATTH Without Frame	FATTH With Frame	CONDSC Without Frame	CONDSC With Frame
SOURCE	df	1	1	1	1
	MS	439699**	439699**	439699**	439699**
	Part. R^2[a]	0.2606	0.2606	0.2606	0.2606
YEAR/SOURCE (Nested)	df	2	2	2	2
	MS	34678**	34678**	34678**	34678**
	Part. R^2	0.0411	0.0411	0.0411	0.0411
FDAYS	df	1	1	1	1
	MS	695043**	695043**	695043**	695043**
	b	2.1257	2.0381	2.0963	2.0128
	Part. R^2	0.4120	0.4120	0.4119	0.4119
DAMAGE	df	4	4	4	4
	MS	9580	9580*	9580	9580
	Part. R^2	0.0227	0.0227	0.0227	0.0227
FRAME	df	--	1	--	1
	MS	--	124877**	--	124876**
	b	--	54.3641	--	62.5469
	Part. R^2	--	0.0740	--	0.0740

TABLE XIX (Cont'd)

Independent variable		FATTH Without Frame	FATTH With Frame	Independent variable		CONDSC Without Frame	CONDSC With Frame
FATTH	df	1	1	CONDSC	df	1	1
	MS	3775	6629		MS	2	20439*
	b_2	34.0333	3.6087		b_2	-0.1150	12.4975
	Part. R^2	0.0023	0.0039		Part. R^2	0.00	0.0121
$FATTH^2$	df	1	--	---	--	--	--
	MS	23145*	--	---	--	--	--
	b_2	-1.3303	--	---	--	--	--
	Part. R^2	0.0137	--	---	--	--	--
RESIDUAL	df	97	97	RESIDUAL	df	98	97
	MS	4308	3230		MS	4539	3088
R^2		0.7523**	0.8143**	R^2		0.7364**	0.8225**

*P < ..05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

measure to be markedly increased. Effect of FATTH and CONDSC increased to highly significant levels with the addition of FRAME to the model. The b value for FATTH increased from 3.1681 to 5.0754 and that for CONDSC from practically zero (-.9913) to 18.8935. This indicated that FRAME was quite useful in removing individual animal variation regarding kind which allowed fatness differences to exert a stronger positive effect on FINWT.

In the Hereford analyses the inclusion of FRAME in the models prior to the entry of fatness measure exerted a similar effect on the effectiveness of FATTH and CONDSC in explaining variation in FINWT, though not as dramatically as in the Angus analyses. Without FRAME in the model the effect of FATTH was curvilinear. The curvilinearity was removed when individual differences in body type were explained by FRAME, and the value of the linear effect of FATTH was increased slightly but not to the point of significance. In Herefords, as in Angus, CONDSC effect was almost zero without FRAME in the model (b = -.1150). When entered in the model after FRAME, CONDSC explained 1.21 percent of the total variation in FINWT, and the coefficient of partial regression of FINWT on CONDSC was significant ($P < .05$) with a value of 12.4975.

FRAME in both breeds appeared to be independent of FDAYS (Tables XVI and XVII, pages 73 and 74) and as FRAME increased in both breeds, all performance traits increased. Little real variation in mean FATTH was noted in the Angus data, with a tendency for the smaller framed bulls to be just slightly fatter. In Angus and to a lesser extent in Herefords, the smaller framed and lighter bulls were given higher condition scores. In Herefords, mean FATTH increased slightly as FRAME increased.

This analysis indicates that the association between fatness and weight may be very small when animals are considered on a group basis. However, when differences in kind or differences in skeletal size are explained by FRAME, then a more positive and stronger relationship between fatness and weight is observed. This phenomenon is quite logical on a priori grounds since we know that a bull of a given frame size will become fatter as his weight increases.

Source 6 (UTTES)

Data from these Hereford bulls were not poolable with other sources in any analysis due to obvious management and post-weaning energy level differences, and these bulls should be described as bulls which were fed to make moderate gains (mean ADG = 1.77 lbs) and, thus, attained only a moderate degree of fatness (mean FATTH = 3.30 mm).

The only measure of skeletal size included in the analyses was body length (BL). BL was entered into the models after YEAR, FDAYS, and DAMAGE and before the fatness measure. YEAR and DAMAGE were highly significant sources of variation in explaining FINWT differences, as reported earlier. FDAYS was the most important variable in terms of partial R^2 (0.2222). Analyses of variance for models used on these data are given in Table XX.

BL was quite effective in accounting for FINWT differences (partial $R^2 = 0.1823$). The total coefficients of determination for the models with FATTH and those with CONDSC were practically identical and were increased by approximately 0.20 by the addition of BL to the model.

The coefficients of partial regression of FINWT on FATTH were

TABLE XX

ANALYSIS OF VARIANCE OF FINWT OF SOURCE 6 (UTTES) HEREFORD BULLS WITH BODY LENGTH AND FATTH OR CONDSC IN THE MODEL (N = 58)

Independent variable		FATTH Without BL	FATTH With BL	Independent variable		CONDSC Without BL	CONDSC With BL
YEAR	df	1	1	YEAR	df	1	1
	MS	32790**	32790**		MS	32790**	32790**
	Part. R^{2a}	0.0814	0.0814		Part. R^2	0.0814	0.0814
FDAYS	df	1	1	FDAYS	df	1	1
	MS	113005**	113005**		MS	113005**	113005**
	b	1.5456	0.8222		b	1.5171	0.8293
	Part. R^2	0.2805	0.2805		Part. R^2	0.2805	0.2805
DAMAGE	df	4	4	DAMAGE	df	4	4
	MS	22380**	22380**		MS	22380**	22380**
	Part. R^2	0.2223	0.2223		Part. R^2	0.2222	0.2222
BODY LENGTH	df	--	1	BODY LENGTH	df	--	1
	MS	--	73420**		MS	--	73420**
	b	--	28.6852		b	--	27.6557
	Part. R^2	--	0.1823		Part. R^2	--	0.1823

TABLE XX (Cont'd)

Independent variable		FATTH Without BL	FATTH With BL	Independent variable		CONDSC Without BL	CONDSC With BL
FATTH	df	1		CONDSC	df	1	1
	MS	16243*	22566**		MS	15811*	16995*
	b_2	19.7317	23.3363		b_2	26.2073	27.1748
	Part. R^2	0.0403	0.0560		Part. R^2	0.0393	0.0422
RESIDUAL	df	50	49	RESIDUAL	df	50	49
	MS	3087	1490		MS	3096	1606
R^2		0.6245**	0.8225**	R^2		0.6234**	0.8086**

*P < .05

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

increased from 19.7317 to 23.3363 when BL was added to the model. Partial R^2 for FATTH also increased from 0.0403 to 0.0560. Similar but slightly smaller increases in CONDSC b value and partial R^2 were found for the model with CONDSC when BL was added.

These data indicate that considerable individual variation in kind or frame size existed in these Hereford bulls and that BL tended to explain these differences and allowed both measures of fatness to express stronger association with FINWT when differences in BL were removed beforehand.

The coefficient of partial regression of FINWT on FDAYS was almost halved when BL was added to the models, which indicated that an accurate linear measure removes much of the effect of age differences in accounting for variation in FINWT.

Source 10 (UTPES)

Data from this fairly large sample of Angus bulls produced somewhat different results from those expected on the basis of Analysis II Angus data. Whether there was less variability in kind in this group of bulls or whether the effect of such variation was reduced by the low post-weaning energy level and the relatively thin condition of these bulls is not obvious. Results of these analyses are given in Table XXI.

As expected, YEAR effects were important. DAMAGE effects were small and non-significant, as was the case with Angus bulls in Pooled Analysis I and IA, and accounted for only slightly more than 1 percent of the variation in FINWT.

TABLE XXI

ANALYSIS OF VARIANCE OF FINWT OF SOURCE 10 (UTPES) ANGUS BULLS WITH BODY LENGTH AND FATTH OR CONDSC IN THE MODEL (N = 151)

Independent variable		FATTH Without BL	FATTH With BL
YEAR	df	1	1
	MS	75976**	75976**
	Part. R^{2a}	0.0672	0.0672
FDAYS	df	1	1
	MS	394752**	394752**
	b	1.8769	0.8810
	Part. R^2	0.3492	0.3492
DAMAGE	df	4	4
	MS	3584	3584
	Part. R^2	0.0127	0.0127
BODY LENGTH	df	--	1
	MS	--	375961**
	b	--	28.5972
	Part. R^2	--	0.3326

Independent variable		CONDSC Without BL	CONDSC With BL
YEAR	df	1	1
	MS	75976**	75976**
	Part. R^2	0.0672	0.0672
FDAYS	df	1	1
	MS	394752**	394752**
	b	1.8317	0.7875
	Part. R^2	0.3492	0.3492
DAMAGE	df	4	4
	MS	3584	3584
	Part. R^2	0.0127	0.0127
BODY LENGTH	df	--	1
	MS	--	375961**
	b	--	29.0920
	Part. R^2	--	0.3326

TABLE XXI (Cont'd)

Independent variable		FATTH Without BL	FATTH With BL	Independent variable		CONDSC Without BL	CONDSC With BL
FATTH	df	1		CONDSC	df	1	1
	MS	40914**	10570*		MS	36020**	17512**
	b_2	92.2788	60.6514		b_2	178.1063	161.5240
	Part. R^2	0.0362	0.0094		Part. R^2	0.0319	0.0155
$FATTH^2$	df	1	1	$CONDSC^2$	df	1	1
	MS	20133*	9876*		MS	17621*	15516*
	b_2	-13.4327	-9.4426		b_2	-8.5525	-8.0261**
	Part. R^2	0.0178	0.0078		Part. R^2	0.0156	0.0138
RESIDUAL	df	142	141	RESIDUAL	df	142	141
	MS	4114	1765		MS	4167	1676
R^2		0.4831**	0.7798**	R^2		0.4766**	0.7909**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

The usefulness of BL in these Angus bulls was similar to that found in Source 6 Herefords but was more dramatic in terms of partial R^2. Coefficients of determination (R^2) increased in the FATTH analyses from 0.4831 to 0.7798 and in the CONDSC analysis from 0.4766 to 0.7909 when BL was entered into the models prior to the fatness measure.

Partial R^2 for BL was 0.3326, which approach half of the total explanation (more than 42 percent) of variation in FINWT provided by the models which included BL.

Apparently, kind variation was not particularly important in these bulls since the sum of squares associated with FATTH or with CONDSC was smaller after the inclusion of BL. The effects of both FATTH and CONDSC were curvilinear rather than completely linear in these data. Partial R^2 values for both linear and quadratic effects of FATTH combined decreased from 0.0540 to 0.0172 when BL was included in the model. Similarly the partial R^2 value for the combined linear and quadratic effects of CONDSC was reduced from 0.0475 to 0.0293 by the addition of BL to the model.

The data indicated that FATTH or CONDSC are equally important in accounting for differences in FINWT and that BL is extremely useful in describing size and in accounting for difference in FINWT. BL apparently substitutes for FDAYS and measures of fatness as is pointed out by the decrease in coefficients of partial regression of FINWT on FDAYS, FATTH and CONDSC. Apparently, kind differences affect the association of fatness measure and final weight in bulls which have been on lower energy rations producing little variation in degree of fatness.

Source 7A (MONT)

The Montana Hereford bulls provided one of the two data sets in which more than one skeletal size measurement was included, though only one fatness measure, CONDSC, was taken. Six separate analyses were made of this data set, and the analyses of variance are given in Table XXII. In each analysis FINWT was the dependent variable and YEAR, ORIG, FDAYS, DAMAGE and CONDSC were independent variables in the models used. In the first one, no skeletal measurement was included; in the second, WHT was added before CONDSC; in the third, BL was added before CONDSC; in the fourth, SHW was included before CONDSC; in the fifth WHT and BL, as the two strictly skeletal measures, were included in that order before CONDSC and in the final model all three skeletal size measures were entered before CONDSC. Thus, determinations as to the utility of CONDSC alone and when entered after various skeletal measurements in explaining differences in FINWT were made. The contribution of the skeletal measurements alone and in combinations was assessed as to their usefulness in explaining FINWT differences and as to their relationship with FDAYS and CONDSC.

As has already been mentioned, YEAR, ORIG, FDAYS and DAMAGE effects on FINWT were all significant ($P < .05$) or highly significant ($P < .01$), explaining, 7.24, 15.02, 21.50 and 1.67 percent of the variation in FINWT, respectively.

The largest effect of a single measurement was that of SHW (partial $R^2 = 0.2580$). SHW apparently measured degree of fatness to a great extent as it allowed CONDSC to explain a far smaller proportion of total variation

TABLE XXII

ANALYSIS OF VARIANCE OF FINWT FOR SOURCE 7A (MONT) WITH LINEAR MEASUREMENTS AND CONDSC IN THE MODEL (N = 165)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL BL	With WHT, BL and SHW
YEAR	df	3	3	3	3	3	3
	MS[a]	39300**	39300**	39300**	39300**	39300**	39300**
	Part. R^2	0.0724	0.0724	0.0724	0.0724	0.0724	0.0724
ORIG	df	1	1	1	1	1	1
	MS	244420**	244420**	244420**	244420**	244420**	244420**
	Part. R^2	0.1502	0.1502	0.1502	0.1502	0.1502	0.1502
FDAYS	df	1	1	1	1	1	1
	MS	349911**	349911**	349911**	349911**	349911**	349911**
	b	2.4559	1.2327	1.5973	1.7913	0.8475	0.5779
	Part. R^2	0.2150	0.2150	0.2150	0.2150	0.2150	0.2150
DAMAGE	df	2	2	2	2	2	2
	MS	13578**	13578**	13578**	13578**	13578**	13578**
	Part. R^2	0.0167	0.0167	0.0167	0.0167	0.0167	0.0167
WHT	df	--	1	--	--	1	1
	MS	--	302787**	--	--	302787**	302787**
	b	--	14.3574	--	--	11.5849	10.6898
	Part. R^2	--	0.1861	--	--	0.1861	0.1861

TABLE XXII (Cont'd)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL BL	With WHT, BL and SHW
BL	df	--	--	1	--	1	1
	MS	--	--	265215**	--	126604**	126604**
	b_2	--	--	6.8982	--	4.9917	3.9194
	Part. R^2	--	--	0.1630	--	0.0778	0.0778
SHW	df	--	--	--	1	--	1
	MS	--	--	--	419901**	--	213873**
	b_2	--	--	--	17.4850	--	12.6100
	Part. R^2	--	--	--	0.2580	--	0.1314
CONDSC	df	1	1	1	1	1	1
	MS	299098**	216528**	205456**	49576**	171555**	40157**
	b_2	36.1919	31.1905	30.6114	17.7718	28.1181	16.0130
	Part. R^2	0.1838	-.1330	0.1263	0.0305	0.1054	0.0247
RESIDUAL	df	156	155	155	155	154	153
	MS	3775	2379	2693	2700	1864	1337
R^2		0.6381**	0.7735**	0.7436**	0.7428**	0.8236**	0.8743**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

than was the case in analyses in which WHT and BL were inserted separately. Thus SHW is apparently not a true skeletal measure since it is influenced greatly by condition, particularly intra- and inter-muscular fat as well as subcutaneous fat. SHW did not lower the coefficient of partial regression of FINWT on FDAYS to as large a degree as did either of the other two skeletal measures, which supports the above stated hypothesis that SHW is perhaps more a measure of fatness than it is a measure of skeletal size.

WHT explained a larger portion of the variation in FINWT than did BL and was apparently a better indicator of weight or size than BL, as may be observed by the greater decrease of FDAYS b value by the inclusion of WHT in the model than by the inclusion of BL and with no appreciable change in the usefulness of CONDSC. The addition of BL to a model containing WHT explained an additional 7.01 percent of the variation in FINWT, increasing R^2 from 0.7735 to 0.8236. The coefficient of partial regression of FINWT on FDAYS was reduced to 0.8475. All three skeletal measures in the same analysis explained a cumulative total of 39.53 percent of the total variation and decreased the partial regression of FINWT on FDAYS to 0.5779 (non-significant). Similarly, the partial regression of FINWT on CONDSC was reduced to 16.0130, which is similar in magnitude to estimates obtained in other analyses when FATTH and CONDSC were entered after FRAME in Pooled Analysis II.

Certainly, these analyses show that both skeletal measures and CONDSC are significant sources of variation in explaining variance in FINWT. They indicate further that WHT and BL are the most useful measures of skeletal size. It appears that one might accurately predict either FINWT, skeletal size or CONDSC if the other two are known, which emphasizes the fact that these measures should be quite useful in refining the description of size over what can be attained by using only weight, age and other known sources of non-genetic variation.

Sources 8A and 8B (FLA)

Six separate analyses were made of data from the thin, long yearling, Hereford bulls from source 8A, and the analyses of variance are presented in Table XXIII. Included are bulls for which skeletal measures were available but for which the only measure of fatness available was CONDSC. All of the same independent variables as were used in the analyses of Source 7A data were used to assess the utility of CONDSC alone and when entered in a model subsequently to the entry of skeletal size measurements, as well as the effectiveness of these skeletal measures alone and in combination.

In these analyses, as in those for Source 7A, YEAR, ORIG, FDAYS, and DAMAGE all had a highly significant effect on FINWT and explained 11.65, 7.74, 8.42 and 8.50 percent of the total variation in FINWT, respectively. Effect of DAMAGE was even greater than in Source 7, although the bulls were much older. This is contrary to the findings from the Pooled Analysis I and IA. Herefords where increased age tended to dilute out DAMAGE effects.

FDAYS, accounting for 8.42 percent of the total variation in FINWT, is of much less importance than in Source 7A, a finding probably accounted for in part, by the more advanced stage of maturity and possibly also by

TABLE XXIII

ANALYSIS OF VARIANCE OF FINWT FOR SOURCE 8A (FLA) WITH LINEAR MEASUREMENTS AND CONDSC IN THE MODEL (N = 155)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL	With WHT, BL and SHW
YEAR	df	2	2	2	2	2	2
	MS	117960**	117960**	117960**	117960**	117960**	117960**
	Part. R^2 [a]	0.1166	0.1166	0.1166	0.1166	0.1166	0.1166
ORIG	df	1	1	1	1	1	1
	MS	156733**	156733**	156733**	156733**	156733**	156733**
	Part. R^2	0.0774	0.0774	0.0774	0.0774	0.0774	0.0774
FDAYS	df	1	1	1	1	1	1
	MS	170395**	170395**	170395**	170395**	179395**	170395**
	b	1.4320	0.5749	0.8209	0.7611	0.4517	0.3238
	Part. R^2	0.0842	0.0842	0.0842	0.0842	0.0842	0.0842
DAMAGE	df	3	3	3	3	3	3
	MS	57353**	57353**	57353**	57353**	58353**	57353**
	Part. R^2	0.0850	0.0850	0.0850	0.0850	0.0850	0.0850
WHT	df	--	1	--	--	1	1
	MS	--	614331**	--	--	614331**	614331**
	b	--	18.1092	--	--	13.9080	10.8283
	Part. R^2	--	0.3035	--	--	0.3035	0.3035

TABLE XXIII (Cont'd)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL	With WHT, BL and SHW
BL	df	--	--	1	--	1	1
	MS	--	--	559871**	--	157531**	157531**
	b_2	--	--	9.1865	--	4.8413	3.5363
	Part. R^2	--	--	0.2766	--	0.0778	0.0778
SHW	df	--	--	--	1	--	1
	MS	--	--	--	740890**	--	214768**
	b_2	--	--	--	24.1190	--	12.9573
	Part. R^2	--	--	--	0.3660	--	0.1061
CONDSC	df	1	1	1	1	1	1
	MS	300871**	232862**	131494**	14825**	154379**	35583**
	b_2	44.6717	39.4477	30.6349	11.5769	33.2622	18.3653
	Part. R^2	0.1486	0.1151	0.0650	0.0073	0.0763	0.0176
RESIDUAL	df	146	145	145	145	144	143
	MS	6768	3047	4122	3678	2520	1866
R^2		0.5118**	0.7817**	0.7047**	0.7365**	0.8208**	0.8682**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

the lower average fatness and lesser variation in fatness among these bulls than was the case with the Source 7 data.

As was expected in these older, thinner bulls, both WHT and BL separately and in combination were slightly more effective in explaining FINWT differences than they were in Source 7A data. Again, SHW tended, to a great extent, to be a measure of fatness and was not as useful as an indicator of size and weight as was WHT but was similar to BL in this respect. R^2 was increased when both of these skeletal measures were included in the model, but partial regression of FINWT on CONDSC was changed very little. When all three skeletal measures were included in the model simultaneously, the result was almost the same as that observed in Source 7A in that R^2 was increased to 0.8682, the partial regression of FINWT on FDAYS decreased to 0.3238 and that on CONDSC was reduced to 18.3653 which, again, is not very different from that observed in other Hereford analyses which included FATTH and CONDSC.

The Source 8B records came from bulls from the same group but include records from only the last two years, during which time FATTH measures were recorded. The same six analyses as described for Source 7A and 8A data were conducted on these data with the exception that FATTH was the measure of fatness used. The results are presented in Table XXIV. A set of six identical analyses with CONDSC in the models as the measure of fatness were made, but the results were practically identical to those reported for Source 8A and are not given.

In the Source 8B analyses the quadratic term for FATTH was highly significant in each, indicating strong curvilinearity, the same as was noted in Pooled Analysis I of Hereford data.

TABLE XXIV

ANALYSIS OF VARIANCE OF FINWT FOR SOURCE 8B (FLA) WITH LINEAR MEASUREMENTS AND FATTH IN THE MODEL (N = 108)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL	With WHT, BL and SHW
YEAR	df	1	1	1	1	1	1
	MS	216467**	216467**	216467**	216467**	216467**	216467**
	Part. R^{2a}	0.1479	0.1479	0.1479	0.1479	0.1479	0.1479
ORIG	df	1	1	1	1	1	1
	MS	91567**	91567**	91567**	91567**	91567**	91567**
	Part. R^2	0.0626	0.0626	0.0626	0.0626	0.0626	0.0626
FDAYS	df	1	1	1	1	1	1
	MS	86469**	86469**	86469**	86469**	86469**	86469**
	b	0.6928	0.3386	0.1093	0.4089	0.0584	0.0780
	Part. R^2	0.0591	0.0591	0.0591	0.0591	0.0591	0.0591
DAMAGE	df	3	3	3	3	3	3
	MS	36683**	36683**	36683**	36683**	36683**	36683**
	Part. R^2	0.0752	0.0752	0.0752	0.0752	0.0752	0.0752
WHT	df	--	1	--	--	1	1
	MS	--	493278**	--	--	493278**	493278**
	b	--	16.1775	--	--	11.2711	9.0435
	Part. R^2	--	0.3371	--	--	0.3371	0.3371
BL	df	--	--	1	--	1	1
	MS	--	--	496893**	--	152319**	152319**
	b	--	--	9.5334	--	6.3334	4.1817
	Part. R^2	--	--	0.3396	--	0.1041	0.1041

TABLE XXIV (Cont'd)

Independent variable		With no linear measures	With WHT	With BL	With SHW	With WHT and BL	With WHT, BL and SHW
SHW	df	--	--	--	1	--	1
	MS	--	--	--	571863**	--	111168**
	b_2	--	--	--	22.8302	--	12.9436
	Part. R^2	--	--	--	0.3908	--	0.0760
FATTH	df	1	1	1	1	1	1
	MS	216656**	72393**	69893**	32263**	41018**	14933**
	b_2	217.9075	154.7213	138.0592	118.1657	120.8389	91.0123
	Part. R^2	0.1481	0.0495	0.0478	0.0220	0.0280	0.0102
$FATTH^2$	df	1	1	1	1	1	1
	MS	114777**	60426**	43865**	34500**	35609**	21097**
	b_2	-26.3741	-19.3957	-16.7454	-14.9574	-15.1155	-11.7769
	Part. R^2	0.0784	0.0413	0.0300	0.0236	0.0243	0.0144
RESIDUAL	df	99	98	98	98	97	96
	MS	6335	3393	3551	3265	2437	1727
R^2		0.5713**	0.7727**	0.7622**	0.7813**	0.8384**	0.8867**

*P < .05.

**P < .01.

[a]Partial R^2 is computed as a ratio of the sequential sum of squares due to an independent variable to the total sum of squares.

FATTH alone in the model and when entered subsequent to various skeletal measurements and combinations of these tended to account for a slightly larger percentage of the total variation than did CONDSC in Source 8A. conversely, the partial regression of FINWT on FDAYS was smaller than that found in the 8A data. It is interesting to note that the partial regression of FINWT on FDAYS decreased to nearly zero (0.0780) when all three skeletal measures are entered in the model simultaneously and prior to the entry of FATTH, building a more definite case for the reduction of the usefulness of final age in the prediction of FINWT when skeletal size measurements and accurate measures of fatness are used. It certainly seems logical to hypothesize that any one of three measures, (weight, skeletal size or fatness) could be accurately estimated if the other two are known. Apparently, age is less effective as a predictor in bulls of greater maturity and possibly those grown on low energy regimes, which is consistent with the source 10 analysis.

III. PRINCIPAL-COMPONENT ANALYSIS

A principal-component analysis was conducted on all sources in the total data set on which skeletal-size scores or measurements were available. In each of these analyses the variables used were FINWT, either FATTH or CONDSC and all available skeletal-size scores or measurements.

Actually, three stratified sets of data were subjected to principal-component analysis. The first included Angus and Hereford bulls in Pooled Analysis II on which both measures of fatness and frame scores were available. Results are presented in Tables XXV and XXVI.

TABLE XXV

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM ANGUS BULL DATA IN POOLED ANALYSIS II WITH EITHER FATTH OR CONDSC (N = 199)

Measurement	Coefficients for principal component number: 1	2	3	Principal component	Description of bulls having large positive component index values
FINWT	0.7110	0.0290	0.7026	1	Heavy, large-framed and above average fatness.
FATTH	0.2190	0.9402	-0.2605	2	Small-framed and fat (independent of weight).
FRAME	0.6682	-0.3393	-0.6622		
% TOTAL VARIANCE	50	34	16		
FINWT	0.5498	0.6215	0.5580	1	Heavy, large framed and lower condition.
CONDSC	-0.4117	0.7829	-0.4664	2	Heavy, average-framed and high condition.
FRAME	0.7268	-0.0267	-0.6863		
% TOTAL VARIANCE	53	36	11		

TABLE XXVI

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN POOLED ANALYSIS II WITH EITHER FATTH OR CONDSC (N = 108)

Measurement	Coefficients for principal component number: 1	2	3	Principal component	Description of bulls having large positive component index values
FINWT	0.6744	0.1162	0.7292	1	Heavy, large-framed and fat.
FATTH	0.4024	-0.8859	-0.2309		
FRAME	0.6191	0.4492	-0.6442	2	Slightly heavier, larger-framed and thin.
% TOTAL VARIANCE	49	31	20		
FINWT	0.5845	0.5658	0.5815	1	Heavy, large-framed and lower condition.
CONDSC	-0.3429	0.8218	-0.4550		
FRAME	0.7354	-0.0666	-0.6744	2	Heavy, slightly smaller-framed and high condition.
% TOTAL VARIANCE	48	36	16		

The second included separate analyses for Hereford bulls in Source 6 (UTTES) and Angus bulls in Source 10 (UTPES) which had both measures of fatness and only one skeletal size measure (BL). Results for Source 10 are given in Table XXVII and for Source 6 Table XXVIII. The third analysis was on data from Hereford bulls from Source 7A (MONT), Source 8A (FLA), and Source 8B (FLA) on which three skeletal-size measures were available (WHT, SHW and BL) and on which CONDSC was the single measure of fatness available except in Source 8B which had FATTH also. Results are given in Tables XXIX, XXX, XXI and XXXII.

In each of these separate analyses the results for the first two principal components were strikingly similar. The first principal component accounted for the largest percentage of variance in the total dependence structure, this percentage ranging from 48 to 68 percent. This component was, in general, contrasting bulls of different sizes since the coefficients for FINWT, fatness measure and skeletal-size measurements were all positive. The second principal component accounted for the next largest portion of variation in the dependence structure, accounting for from 23 to 36 percent. Thus, the two components combined accounted for from 77 to 94 percent of the total variation. The second principal component, being independent of the first, generally contrasted bulls of different body shapes or forms. It, in general, ranked bulls from those which were fat, wide, and small framed to those which were thinner, narrow and large framed independent of FINWT. The other principal components were felt to be of lesser value but also contrasted bulls of different shapes.

TABLE XXVII

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM ANGUS BULL DATA IN SOURCE 10 (UTPES) WITH EITHER FATTH OR CONDSC (N = 151)

Measurement	Coefficients for principal component number: 1	2	3	Principal component	Description of bulls having large positive component index values
FINWT	0.6615	0.1905	0.7253	1	Heavy, long-bodied and fatter.
FATTH	0.4026	-0.9062	-0.1291	2	Slightly heavier, long-bodied and thin.
BL	0.6327	0.3774	-0.6762		
% TOTAL VARIANCE	67	27	6		
FINWT	0.6858	0.1714	0.7073	1	Heavy, long-bodied and higher condition.
CONDSC	0.2445	-0.9697	-0.0021	2	Slightly heavier, slightly longer and low condition.
BL	0.6855	0.1744	-0.7069		
% TOTAL VARIANCE	62	32	6		

TABLE XXVIII

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN SOURCE 6 (UTTES) WITH EITHER FATTH OR CONDSC (N = 58)

Measurement	Coefficients for principal component number:			Principal component	Description of bulls having large positive component index values
	1	2	3		
FINWT	0.6862	0.1240	0.7167	1	Heavy, long-bodied and fatter.
FATTH	0.3018	-0.9451	-0.1254	2	Slightly-heavier, longer-bodied and thin.
BL	0.6618	0.3024	-0.6860		
% TOTAL VARIANCE	60	31	9		
FINWT	0.6875	0.0964	0.7101	1	Heavy, long-bodied and above average condition.
CONDSC	0.1939	-0.9793	-0.0575	2	Slightly heavier, slightly longer and low condition.
BL	0.6899	0.1777	-0.7018		
% TOTAL VARIANCE	59	32	9		

TABLE XXIX

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN SOURCE 7A (MONT) (N = 165)

Measurement	Coefficients for principal component number:					Principal component	Description of bulls having large positive component index values
	1	2	3	4	5		
FINWT	0.5719	0.0051	0.0075	0.1397	0.8083	1	Heavy, higher condition, tall, wide and long.
CONDSC	0.2459	0.8016	-0.1227	0.4627	-0.2590		
WHT	0.4375	-0.4619	0.4699	0.4734	-0.3909	2	High condition, low, wider and shorter (independent of of weight).
SHW	0.4750	0.2597	0.3697	-0.7252	-0.2146		
BL	0.4421	-0.2768	-0.7921	-0.1280	-0.2841	3	Slightly lower condition, tall, wide and short (independent of weight).
% TOTAL VARIANCE	56	23	11	8	2	4	Slightly heavier, higher condition tall, narrow and shorter.

TABLE XXX

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN SOURCE 8A (FLA) (N = 155)

Measurement	Coefficients for principal component number: 1	2	3	4	5
FINWT	0.5534	-0.0029	-0.1037	-0.1378	-0.8149
CONDSC	0.3534	0.7163	-0.4350	0.3427	0.2350
WHT	0.3894	-0.5758	-0.5828	-0.1941	0.3735
SHW	0.4647	0.2418	0.4959	-0.5966	0.3523
BL	0.4488	-0.3112	0.4631	0.6856	0.1310
% TOTAL VARIANCE	60	17	14	7	2

Principal component	Description of bulls having large positive component index values
1	Heavy, higher condition, taller, wide and long.
2	High condition, low, wider and shorter (independent of of weight).
3	Slightly lighter, low condition, low, wide and long.
4	Slightly lighter, higher condition, lower, narrow and long.

TABLE XXXI

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN SOURCE 8B (FLA) WITH FATTH (N = 108)

Measurement	Coefficients for principal component number: 1	2	3	4	5
FINWT	0.5165	0.0168	0.0926	0.1593	0.8360
FATTH	0.3809	-0.7742	-0.4187	-0.2558	-0.1242
WHT	0.4168	0.5155	-0.6574	0.2575	-0.2454
SHW	0.4643	-0.1646	0.5366	0.5237	-0.4424
BL	0.4458	0.3279	0.3097	-0.7541	-0.1723
% TOTAL VARIANCE	68	14	8	8	2

Principal component	Description of bulls having large positive component index values
1	Heavy, fatter, tall, wide and long.
2	Thin, tall, narrower, longer (independent of weight).
3	Slightly heavier, thin, low, wide and longer.
4	Slightly heavier, thinner, taller, wide and short.

TABLE XXXII

COEFFICIENTS AND INTERPRETATION OF PRINCIPAL COMPONENTS OBTAINED FROM HEREFORD BULL DATA IN SOURCE 8B (FLA) WITH CONDSC (N = 108)

Measurement	Coefficients for principal component number: 1	2	3	4	5	Principal component	Description of bulls having large positive component index values
FINWT	0.5269	0.0142	0.0954	0.0248	0.8441	1	Heavy, higher condition, tall wide and long.
CONDSC	0.3539	-0.7329	0.1058	0.5185	-0.2368		
WHT	0.4158	0.5741	0.5719	0.2669	-0.3328	2	Low condition, tall, narrower and longer (independent of weight).
SHW	0.4848	-0.2197	0.0822	-0.7917	-0.2860		
BL	0.4349	0.2912	-0.8037	0.1802	-0.1970	3	Slightly heavier, slightly higher condition, tall, slightly wider and short.
% TOTAL VARIANCE	67	18	8	5	2	4	Average weight, high condition taller, narrow and slightly longer.

These findings were very similar to those reported by Brown _et al_. (1972d) even though their data included nine measurements of skeletal and body size in addition to FINWT. As compared to their results, in the present study the first principal component accounted for a slightly smaller percentage of the variance and the second principal component accounted for a larger percentage. This may be merely a function of the total number of variables and, thus, the number of principal components. In these data the coefficients for fatness measure were of lower magnitude than those for FINWT or skeletal size measurements in all of the analyses, indicating less relative importance of fatness measure as compared with FINWT or skeletal-size measures in defining size.

It should be noted that little added usefulness is realized from principal components in contrasting types after some 90 percent of the total variance has already been explained by other components. Due to the fact that the procedure of principal-components analyses ultimately explains 100 percent of the variation, the final component is, in general, not descriptive of a conceivable kind or body shape and is thus useless in describing or ranking bulls. Also, it generally explains only a very small percentage of the total variation. In this study, explanation of approximately 90 percent of total variation was believed to be a sufficient attainment. Thus, the practice was to ignore components explaining small percentages of variation after approximately 90 percent had already been explained by other components. The final component was always ignored regardless of the percentage of variation explained by it.

In discussing the findings of the three basic analyses, an abbreviation for principal component (PC) is used followed by the number of the component referred to e.g., PC1 will pertain to the first principal component. PC with no number suffix will be used to refer to all principal components.

First Analysis

The first analysis included 199 Angus and 108 Hereford bulls from Pooled Analysis II. Variables for each of the two analyses by breed are FINWT, FATTH or CONDSC and FRAME (Tables XXV and XXVI, pages 98 and 99, for Angus and Hereford, respectively).

These analyses which contrast measures of fatness in each breed tend to explain further the observations made in earlier analyses using these same data. Where FATTH was used as the measure of fatness, PC1 in both breeds is a measure of general size with large positive coefficients for FINWT and FRAME and smaller positive coefficients for FATTH. The magnitude of the coefficients for FATTH in Herefords was twice as large as that in Angus, which indicates that the association of FATTH with size was stronger in Herefords, as was shown earlier. PC2 contrasted bulls of different type or form in both breeds. Within each breed group, the contrast was between small framed, fat bulls and large framed, thin bulls. The signs of the coefficients were reversed in the Hereford analysis, but this does not affect the contrast. Because a latent vector from which component-weighting factor coefficients are computed is, in geometrical terms, a straight line, the pattern of signs of its elements is arbitrary in the sense that all these signs may be reversed without affecting any of the mathematical properties of the vector of coefficients. Reversing the signs of a component-weighting factor vector is equivalent to looking at the component from its opposite end.

In the analysis in which CONDSC was used as the fatness measure, the sign of the CONDSC coefficients in both breeds in PC1 was negative rather than positive, though PC1 is descriptive of size just as in the analysis with FATTH as the fatness measure. This says simply that CONDSC, while useful as a fatness measure is not indicative of fatness per se but is confounded with FRAME. The small framed, lighter bulls of both breeds, though assigned larger values for CONDSC, were not actually fatter as evidenced by the reversal of sign between the CONDSC and FATTH coefficients. PC2 was also noticably different when CONDSC was the fatness measure as compared to FATTH as the fatness measure. The contrast in PC2 in both breeds was between heavier, fatter bulls of average FRAME and lighter, thin bulls of average FRAME.

It appears from these data that there is a definite breed difference, particularly with respect to the behavior of the fatness measure variable, which substantiates earlier findings in previous analyses in this study. It appears that subjective condition score is not a pure measure of fatness but is influenced by frame size and apparent thickness and, possibly, other dimensions which the eye cannot clearly evaluate independent of fatness. Use of CONDSC, however, does not destroy the possible usefulness of PC1 for ranking as to size, but the bulls in a population might not be ranked exactly the same as when the more accurate fatness measure, FATTH, is used. Also, there may be confounding between the two subjective measures, CONDSC and FRAME, but FRAME definitely appears to be a very useful discrete measure of size, body shape or kind.

In data from Angus bulls in the present study, PC1 explains slightly more variation in the dependence structure than it does in the Hereford data. The same trend is noted for PC2 also. Corroborative findings with respect to this component in the two breeds were reported by Brown et al. (1972d).

Second Analysis

Two sources in which a single skeletal size measurement (BL) was recorded were used in this analysis. Source 6 (UTTES) Hereford bulls and Source 10 (UTPES) Angus bulls were analyzed using the variables FINWT, FATTH and BL and FINWT, CONDSC and BL. The results are presented in Table XXVII (page 101) for the Angus (Source 10) and Table XXVIII (page 102) for the Herefords (Source 6).

In data from both sources PC1 is contrasting bulls of different sizes, regardless of whether FATTH or CONDSC is used as the measure of fatness. In both breeds the coefficients for fatness measure in PC1 were roughly half as large as the coefficients for either FINWT or BL. In PC1 for both breeds where CONDSC was used rather than FATTH, the coefficients, while positive, are much smaller than those for FATTH. This is consistent with the findings from the PC analysis data of Pooled Analysis II.

PC1 explains a higher percentage of total variation in Source 10 Angus than in Source 6 Herefords, indicating a breed difference, though no actual comparison of this sort is appropriate here. PC1 and PC2 combined explained a higher percentage of variance in Source 10 than in Source 6 (94 percent compared to 91 percent).

The second principal component (PC2) in both sources contrasts slightly heavier, thinner, longer bulls with slightly lighter, fatter, shorter bulls, regardless of the fatness measure included. The decreased magnitude of the BL contribution in analyses using CONDSC compared to those using FATTH in both sources indicates that CONDSC in these bulls, as in the bulls in pooled analysis II, is not a true measure of fatness per se and must be measuring, in addition to fatness, other factors which are associated with conformation or aspects of it.

Third Analysis

This analysis was made on the data from Source 7A (MONT) Herefords and the Source 8A (FLA) Herefords in which only CONDSC was recorded as the fatness-measure variable and the sub-sample (8B) of 8A on which FATTH as well as CONDSC was recorded. The results of the Source 7A and 8A analyses are presented in Tables XXIX and XXX, pages 103 and 104, respectively. All animals in these analyses had the skeletal size measurements of WHT, SHW, and BL included in the principal-component analyses.

In Source 7A and 8A, PC1 contrasted animals of different sizes. The animals with high positive indexes in PC1 would be described as heavy, fat, wide, large-framed bulls. The coefficients for all measurements in PC1 were positive, with the most important one being FINWT and the one of least importance being CONDSC. The SHW coefficients in PC1 were larger than were the coefficients for WHT and BL, which are more clearly measures of skeletal size *per se* than is SHW. In both sources the coefficient in PC1 for BL was slightly larger than that for WHT, which is in contrast to the finding reported by Brown *et al.* (1972d). PC1 accounted for 56 and 60 percent of total variation in Sources 7A and 8A, respectively, slightly less than reported by Brown *et al.* (1972d) in their analysis in which more variables were used.

In PC2, the results in both 7A and 8A were almost identical. PC2 contrasted average-weight, fat, wide, small-framed bulls with average-weight, thin, narrow, large-framed bulls. PC2 accounted for 23 percent of the variation in the younger, fatter Montana bulls and 17 percent in the thinner, long-yearling Florida bulls.

PC3 accounts for more than an additional 10 percent of total variation in the dependence structure in both sources, but the contrast of kinds accomplsihed is not identical. Actually, the contrast in types in PC3 of Source 7A is very similar to that of PC4 in Source 8A. This indicates that, beyond PC2, the body type contrasts may not be the same from one population to another due to differences in make-up of the extremes which segregate out in various populations or samples.

In Source 8B the contrast was between measures of fatness, and the results are presented in Tables XXXI and XXXII, pages 105 and 106, for FATTH and CONDSC, respectively.

PC1 accounts for about two-thirds of the variance in the total system which is slightly higher than from the whole Source 8A, of which source 8B was a part. The additional variance explained by PC2, however, is almost identical to that in the Source 8A analysis. Thus, PC1 and PC2 combined accounted for 82 and 85 percent of the variance in the analysis using FATTH and that using CONDSC, respectively.

PC1 in both analyses contrasts animals of various sizes with almost identical coefficients between analyses for each measure-of-fatness variable. PC2 contrasts average-weight, thin, tall, narrower, longer bulls with average-weight fat, low, wider, shorter ones. In both analyses the contrast is the same, though the signs of the larger principal component coefficients are reversed.

From the analyses of 8B it appears that FATTH and CONDSC are of similar utility, which was not the case in comparisons of the two measures of fatness in analyses of data in which there was more variation in FINWT, FDAYS and body type as visually observed. This indicates that in bulls of comparable type and age, CONDSC is more useful as a fatness measure than in more variable groups of animals.

There is striking similarity between analyses of several different data sets with respect to the implications of principal-component analyses, particularly regarding results pertaining to the first two components. PC1 explains one-half to two-thirds of the total variation and contrasts bulls of different sizes. PC2 explains an additional 10 to 30 percent of the variation and contrasts bulls of different shapes, independent of weight. This indicates that a considerable portion of any population consists of cattle which are large-framed, narrow-bodied and thin compared to ones which are small-framed, wide-bodied and fat. This is encouraging, especially in view of the high correlations between PC2 component scores across various pre-yearling ages as reported by Brown et al. (1972d).

It is fairly obvious that FATTH is a more reliable measure of fatness per se than is CONDSC, especially in groups of cattle which vary widely in body type, weight and age.

It appears that more research is needed to determine how best to use principal-component index scores in a selection program. Perhaps some combination of PC1, which ranks bulls with respect to size, and PC2, which ranks bulls with respect to body type or shape would be useful rather than attempting to use indexes derived from each component independently.

No doubt, principal components should be useful in selection programs since selection for one trait, such as weight, is expected to produce heavier cattle but of several shapes and body compositions.

Undoubtedly, a homeostatic system does operate in individual animals and populations, which tends to result in selection against extremes in various dimensions which are involved in fitness.

IV. CONCLUSIONS AND RECOMMENDATIONS

Results of this study lead to several general conclusions which have implications for improvement of performance testing programs purporting to test young bulls.

1. Weight alone adjusted for age and age of dam is not a sufficient measure of size in evaluating young bulls.

2. Both ultrasonically measured fat thickness and subjective condition score are beneficial in explaining weight differences.

3. Ultrasonically measured fat thickness is a much more accurate measure of fatness _per se_ than is condition score. Condition score tends to measure fatness on a relative basis and is apparently confounded with size and general body type.

4. Use of principal-component index scores permits ranking of bulls on size with weight, degree of fatness and skeletal size measures as contributing parts.

5. The second principal component gives strong indication that there are two basic extremes in body shape in cattle populations. One extreme kind of cattle are small-framed, short in stature, short-bodied, wide and fat. The other extreme kind are large-framed, tall, long-bodied, narrow and thin. This component ranks animals between these two extremes.

6. Skeletal-size scores or measurements are highly useful in explaining weight differences and in accounting for body type and growth curve differences.

7. There apparently is a basic relationship between weight, skeletal size and degree of fatness. It appears that if accurate measurements of each are available, any one of the three could be predicted from the other two.

8. Weight and fatness vary together on an individual animal basis depending on the shape of the growth curve. Therefore, it appears inappropriate to attempt to develop regression procedures, based on group statistics, for adjustment of weight to a fat-constant basis. It would,

however, appear feasible to make such adjustment if skeletal-size measurements as well as fatness measures were used.

9. Age-of-dam effect on yearling weight may not be the same for bulls of all breeds or for bulls subjected to different management regimes.

Recommendations that seem appropriate are:

1. Records of performance, to be accurate in classifying the individual as to breeding value, must include methods for defining rate of physiological maturity in addition to weight. Measures of fatness and skeletal size appear to be quite useful for this purpose.

2. Bulls of a breed should be tested to a constant physiological age rather than a constant chronological age. This would entail testing bulls post-weaning under optimum common environment and terminating the gain test when a certain degree of fatness is attained. This degree of fatness should be set so as to be comparable to a 'choice' slaughter steer of the respective breed. Skeletal-size measures should be used as means of classifying body type. Use of performance, thus collected, should lend to accurate classification as to kind and breeding value.

3. Genetic research in the area of bull testing and classification of breeding value in line with the above should be conducted.

4. Age of dam, as it affects yearling weight, should be further studied in each breed under various management regimes.

5. Genetic parameters, testing procedures and any adjustment factors should be developed for each breed separately.

6. Further research is needed to determine the usefulness of principal components in ranking bulls on breeding value, taking into consideration size and body shape.

CHAPTER V

SUMMARY

Records from 669 yearling Angus and 871 yearling Hereford bulls from three central test stations and seven Land Grant University or USDA research herds were utilized in the study. The study was designed to determine needed refinements in procedures for performance testing young bulls. Generalized least-squares multiple regression analyses were conducted to determine the value of measures of fatness and measures of skeletal size in defining or explaining weight and size differences over and above the effects of age and age of dam, which are in common usage. Principal component analysis was also employed in an effort to assess its usefulness in evaluating bulls as to size and body shape.

The study indicated that weight alone was not a sufficient measure of size and that selection for conventional adjusted yearling weight alone would tend to favor fatter animals and would produce animals of several different skeletal sizes and body shapes.

A positive but variable association between fatness measures and final weight was found. Ultrasonically measured fat thickness was found to be a much more accurate measure of fatness _per se_ than was subjective condition score, though both were of similar utility in explaining final weight differences. Both fatness measures were found to be more useful with Herefords than with Angus and also more useful in groups of bulls with less variability in age, fatness and body type. condition scores tended to measure fatness on a relative basis and were apparently confounded with size and general body type.

Wither height and body length were found to be quite valuable as skeletal-size measures and explained large and highly significane proportions of variance in final weight. Either of these or subjective frame-size scores were quite useful in explaining differences in body type and apparent differences in growth curves, particularly in groups of bulls which were highly variable. Skeletal-size measures tended to reduce the value of age in accounting for weight differences. Shoulder width, which was of significant value in explaining weight differences, was shown to be influenced greatly by differences in degree of fatness.

Although there is apparently a basic relationship between weight, skeletal size and fatness, large individual-animal variations exist which suggests that the accurate measurement of all three of these are essential for classifying bulls as to potential breeding value.

The first principal component was found to be useful in ranking bulls on general size. The second component indicates that two basic extremes in body shape exist among all cattle and is useful in ranking animals between these extremes. Some combination of these first two components should be useful in classifying bulls as to breeding value.

Age-of-dam effects were greater in Herefords than in Angus and in groups of bulls of both breeds developed on low energy regimes. Commonly used adjustments of yearling weight for age of dam may not be appropriate across all breeds and management regimes.

Weight and fatness vary on an individual animal basis depending on the shape of the growth curve. Therefore, it seems inappropriate to attempt to develop regression procedures, based on group statistics for the adjustment of weight to a fat-constant basis.

It appears that performance testing programs should include measures of fatness and skeletal size in addition to weight and age if potential sires are to be evaluated accurately. This study suggests that post-weaning performance tests for estimation of breeding value should be terminated at a constant physiological age rather than at a constant chronological age, which is the common practice. Fatness and skeletal-size measures appear useful in determination of physiological age.

LITERATURE CITED

LITERATURE CITED

Allen, D. M., R. A. Merkel and W. T. Magee. 1966. Estimation of beef carcass composition from the physically separable components of some wholesale cuts. J. Anim. Sci. 25:1279. (abstr)

Arthaud, V. W. 1970. Effects of sex and energy levels on beef carcass composition. Proc. 23rd Annual Reciprocal Meat Conf.

Beef Improvement Federation. 1970. Guidelines for uniform beef improvement programs. USDA, Federal Extension Service. Washington, D.C.

Birkett, R. J., D. L. Good and D. MacKintosh. 1965. Relationship of various linear measurements and percent yield of trimmed cuts of beef carcasses. J. Anim. Sci. 24:16.

Black, W. H., B. Knapp and A. C. Cook. 1938. Correlation of body measurements of slaughter steers with rate of gain and with certain carcass characteristics. J. Agr. Res. 56:465.

Blackwell, R. L., J. H. Knox, C. E. Shelby and R. T. Clark. 1962. Genetic analysis of economic characteristics of young Hereford cattle. J. Anim. Sci. 21:101.

Brackelsberg, P. O., R. L. Willham and L. E. Walters. 1967. Probing beef cattle to predict carcass fatness. J. Anim. Sci. 26:713.

Brackelsberg, P. O. and R. L. Willham. 1968. Relationship among some common live and carcass measurements and beef carcass composition. J. Anim. Sci. 27:53.

Brackelsberg, P. O., E. A. Kline, R. L. Willham and L. N. Hazel. 1971. Genetic parameters for selected beef-carcass traits. J. Anim. Sci. 33:13.

Brinks, J. S., R. T. Clark, N. M. Kieffer and J. R. Quesenberry. 1962. Genetic and environmental factors affecting performance traits of Hereford bulls. J. Anim. Sci. 21:777.

Brown, C. J., M. L. Ray, W. Gifford and R. S. Honea. 1956a. Growth and development of Hereford cattle. Ark. Agr. Exp. Sta. Bul. 570.

Brown, C. J., M. L. Ray, W. Gifford and R. S. Honea. 1956b. Growth and development of Aberdeen-Augus cattle. Ark. Agr. Exp. Sta. Bul. 571.

Brown, C. J., E. J. Warwick, H. J. Smith, W. W. Green and H. A. Stewart. 1956c. Relationships between conformation scores and live animal measurements of beef cattle. J. Anim. Sci. 15:911.

Brown, C. J. 1958. Heritability of weight and certain body dimensions of beef calves at weaning. Ark. Agr. Exp. Sta. Bul. 597.

Brown, C. J. and L. Franks. 1964. Factors affecting size of young beef cows. J. Anim. Sci. 23:665.

Brown, J. E., H. A. Fitzhugh, Jr. and T. C. Cartwright. 1971. Relations among lifetime weight-age statistics. J. Anim. Sci. 32:373.

Brown, J. E., C. J. Brown and W. T. Butts. 1972a. A discussion of all genetic aspects of weight, mature weight and rate of maturity in Hereford and Angus cattle. J. Anim. Sci. 34:325.

Brown, J. E., C. J. Brown and W. T. Butts. 1972b. Relationships among weights, gains and rate of maturity in cattle. (Pending publishment)

Brown, J. E., C. J. Brown and W. T. Butts. 1972c. An analysis of body weight and age at fixed levels of maturity. (Pending publishment)

Brown, J. E., C. J. Brown and W. T. Butts. 1972d. Principal components as measures of size and shape in young Hereford and Angus bulls. (Pending publishment)

Brown, W. L. and R. R. Shrode. 1971. Body measurements of beef calves and traits of their dams to predict calf performance and body composition as indicated by fat thickness and condition score. J. Anim. Sci. 33:7.

Brungardt, V. H. and R. W. Bray. 1963. Estimate of retail yield of the four major cuts in the beef carcass. J. Anim. Sci. 22:177.

Brungardt, V. H. 1972. Efficiency and profit differences of Angus, Charolais and Hereford cattle varying in size and growth. Department of Meat and Animal Science Pub. The University of Wisconsin, Madison.

Busch, D. A., C. A. Dinkel and J. A. Minyard. 1969. Body measurements, subjective scores and estimates of certain carcass traits as predictors of edible portion in beef cattle. J. Anim. Sci. 29:557.

Butts, W. T., Jr. 1966. The effects of inbreeding on various performance traits of Angus calves. Unpublsihed Ph.D. Dissertation. University of Tennessee.

Butts, W. T., Jr., M. Koger, O. F. Pahnish, W. C. Burns and E. J. Warwick. 1971. Performance of two lives of Hereford cattle in two environments. J. Anim. Sci. 33:923.

Carpenter, J. A., Jr., H. A. Fitzhugh, T. C. Cartwright, A. A. Melton and R. C. Thomas. 1971. Principal components for size of Hereford cows. J. Anim. Sci. 33:197. (abstract)

Christians, C. J., D. Chambers, L. E. Walters, J. B. Whiteman and D. F. Stephens. 1962. Heritability estimates of beef characteristics. J. Anim. Sci. 21:387. (abstract)

Clark, R. T., J. S. Brinks, R. Bogart, L. A. Holland, C. B. Roubicek, O. F. Pahnish, J. A. Bennet and R. E. Christian. 1963. Beef cattle breeding research in the Western region. Ore. Agr. Exp. Sta. Res. Bul. 73.

Cole, J. W., C. B. Ramsey and R. H. Epley. 1962. Simplified method for predicting pounds of lean in beef carcasses. J. Anim. Sci. 21:355.

Cundiff, L. V., K. E. Gregory, R. M. Kock and G. E. Dickerson. 1969. Genetic variation in total and differential growth of carcass components in beef cattle. J. Anim. Sci. 29:233.

Cundiff, L. V., K. E. Gregory, R. M. Kock and G. E. Dickerson. 1971. Genetic relationships among growth and carcass traits of beef cattle. J. Anim. Sci. 33:550.

Dawson, W. M., T. S. Yao and A. C. Cook. 1955. Heritability of growth, beef characters and body measurements in milking shorthorn steers. J. Anim. Sci. 14:208.

Epley, R. J., H. B. Hedrick. W. C. Stringer and D. P. Hutcheson. 1970. Prediction of weight and percent retail cuts of beef using five carcass measurements. J. Anim. Sci. 30:872.

Field, R. A. 1971. Effect of castration on meat quality and quantity. J. Anim. Sci. 32:849.

Fitzhugh, H. A., Jr., and St. C. S. Taylor. 1971. Genetic analysis of degree of maturity. J. Anim. Sci. 33:717.

Gowen, J. W. 1933. On the genetic constitution of Jersey cattle as influenced by inheritance and environment. Genetics 18:415.

Gregory, K. E. 1961. Improvement of beef cattle through breeding methods. North Central Regional Pub. 120. Neb. Agr. Exp. Sta. Res. Bul. 196.

Gregory, K. E., L. A. Swiger, V. H. Arthaud, R. B. Warren, D. K. Hallet and R. M. Kock. 1962. Relationship among certain live and carcass characteristics of beef cattle. J. Anim. Sci. 21:720.

Gregory, K. E. 1965. Symposium on performance testing in beef cattle: Evaluating post-weaning performance in beef cattle. J. Anim. Sci. 24:248.

Guilbert, H. R. and P. W. Gregory. 1952. Some features of growth and development of Hereford cattle. J. Anim. Sci. 11:3.

Harvey, W. R. 1960. Least squares analysis of data with unequal subclass numbers. USDA-ARS 20:8.

Hedrick, H. B., W. E. Meyer, M. A. Alexander, S. E. Zobrisky and H. D. Naumann. 1962. Estimation of rib-eye area and fat thickness of beef cattle with ultrasonics. J. Anim. Sci. 21:362.

Hedrick, H. B. 1968. Bovine growth and composition. Mo. Agr. Exp. Sta. Res. Bul. 928.

Hope, Keith. 1968. Methods of Multivariate Analysis. University of London Press. Ltd. London.

Hultz, P. S. 1927. Type in beef calves. Wyoming Agr. Exp. Sta. Bul. 153.

Hultz, P. S. and S. S. Wheeler. 1927. Type in two-year old beef steers. Wyoming Agr. Exp. Sta. Bul. 155.

Joandet, G. E. and T. C. Cartwright. 1969. Estimation of efficiency of beef production. J. Anim. Sci. 29:862.

Johnson, J. C., Jr. 1958. Phenotype and genetic relationships between certain body measurements and milk production of first lactation Holsteins. Ph.D. Dissertation. Texas A & M University, College Station, Texas.

Kidwell, J. F., J. E. Hunter, P. R. Terman, J. E. Harper, C. S. Shelly and R. T. Clark. 1959. Relation of production factors to conformation scores and body measurements, association among production factors and the relation of carcass grade and fatness to consumer preferences in yearling steers. J. Anim. Sci. 18:894.

Kock, R. M. and R. T. Clark. 1955. Influences of sex, season of birth and age of dam on economic traits in range beef cattle. J. Anim. Sci. 14:386.

Kohli, M. L., A. C. Cook and W. M. Dawson. 1951. Relation between some body measurements and certain performance characters in Milking Shorthorn steers. J. Anim. Sci. 10:352.

Lewis, R. T., G. G. Suess and R. G. Kauffman. 1969. Estimation of carcass traits by visual appraisal of market livestock. J. Anim. Sci. 28:601.

Lohman, T. G. 1971. Biological variation in body composition. J. Anim. Sci. 32:647.

Lush, J. L. 1928. Changes in body measurements of steers during intensive fattening. Texas Agr. Exp. Sta. Bul. 385.

Lush, J. L. and D. C. Copeland. 1930. A study of the accuracy of measuring dairy cattle. J. Agr. Res. 41:37.

Lush, J. L. 1932. The relation of body shape of feeder steers to rate of gain, to dressing percent and to value of dressed carcass. Texas Agr. Exp. Sta. Bul. 471.

McReynolds, W. E. and V. H. Arthaud. 1970. Estimating fat depth and Longissimus muscle area by use of ultrasonics in beef cattle. J. Anim. Sci. 30:503.

McReynolds, W. E. and V. H. Arthaud. 1970b. Ultrasonic application for estimating fat thickness of beef cattle. J. Anim. Sci. 30:186.

Meyer, W. E., W. G. Moody, G. D. Hunziger, T. P. Ringkole, M. A. Alexander, S. E. Zobrinsky and H. B. Hedrick. 1966. Application of ultrasonic techniques in live animal and carcass evaluation. Mo. Agr. Exp. Sta. Res. Bul. 905.

Morrison, D. F. 1967. Multivariate Statistical Methods. McGraw-Hill Book Co. New York.

Nelms, G. E., R. A. Nimno, M. R. Riley, R. A. Field and G. P. Rochrkasse. 1970. Predicting cutability in bull carcasses. J. Anim. Sci. 31:1078.

Orme, L. E., A. M. Pearson, W. T. Magee and L. J. Bratzler. 1959. Relationship of live animal measurements to various carcase measurements in beef. J. Anim. Sci. 18:991.

Pahnish, O. F., R. L. Roberson, R. L. Taylor, J. S. Brinks, R. T. Clark and C. B. Roubicek. 1964. Genetic analysis of economic traits mreasred in range-raised Herefords at preweaning and weaning ages. J. Anim. Sci. 23:562.

Ramsey, C. B., J. W. cole and C. S. Hobbs. 1962. Relation of beef carcass grades, proposed yield grades and fat thickness to separable lean, fat and bone. J. Anim. Sci. 21:193.

Schalles, R. R. and T. J. Marlowe. 1967. Factors affecting test performance of beef bulls. J. Anim. Sci. 26:21.

Severson, B. O. and P. Gerlaugh. 1917. A statistical study of body weights, gains and measurements of steers during the fattening period. Pa. Agr. Exp. Sta. An. Rept. for 1916-17.

Shutte, D. L. 1935. Factors affecting growth of range cattle in semi-arid regions. Onderstepoart J. Vet. Sci. 5:553. (An. Breeding Abstr. 4:415, 1936).

Smith, H. J., C. S. Hobbs, E. J. Warwick and W. M. Whitaker. 1950. The accuracy and repeatability of live animal and photographic measurements of beef cattle. J. Anim. Sci. 9:639.

Stauffer, J. R., M. V. Wallentine, G. W. Wellington and A. Dickmann. 1961. Development and application of ultrasonic methods for measuring fat thickness and rib-eye area in cattle and hogs. J. Anim. Sci. 20:759.

Stonaker, H. H., M. H. Hazaleus and S. W. Wheeler. 1952. Feedlot and carcass characteristics of individually fed compress and conventional type Hereford steers. J. Anim. Sci. 11:17.

Stringer, W. C., C. L. Cramer, K. O. Zoellner, V. J. Rhodes and H. O. Naumann. 1963. Retail yield estimates of market steers and carcasses. J. Anim. Sci. 22:829 (abstr.)

Swiger, L. A. and L. N. Hazel. 1961. Optimum length of feeding period on selecting for gain of beef cattle. J. Anim. Sci. 20:189.

Swiger, L. A., R. M. Kock, K. E. Gregory, V. H. Arthaud, W. W. Rowden and J. E. Ingalls. 1962. Evaluating pre-weaning growth of beef calves. J. Anim. Sci. 21:781.

Swiger, L. A., K. E. Gregory, R. M. Kock. W. W. Rowden, V. H. Arthaud and J. E. Ingalls. 1963. Evaluating postweaning gain of beef calves. J. Anim. Sci. 22:514.

Swiger, L. A., K. E. Gregory, L. J. Sumption and B. C. Breidenstein. 1964. The importance of measuring cut-out in cattle. J. Anim. Sci. 23:854. (abstr.)

Tallis, G. M., E. W. Klosterman and V. R. Cahill. 1959. Body measurements in relationship to beef type and to certain carcase characteristics. J. Anim. Sci. 18:108.

Taylor, St. C. S. and H. A. Fitzhugh, Jr. 1971. Genetic relationships between mature weight and time taken to mature within a breed. J. Anim. Sci. 33:726.

Temple, R. S., H. H. Stonaker, D. Howry, G. Posakony and M. H. Hazaleus. 1956. Ultrasonic and conductivity methods for estimating fat thickness in live cattle. Proc. West. Sec. Am. Soc. An. Prod. 7:477.

Temple, R. S. and C. B. Ramsey. 1965. Errors in ultrasonic evaluation of beef cattle. J. Anim. Sci. 24:282 (abstr)

Ternan, P. R., J. F. Kidwell, J. E. Hunter, C. E. Shelby and R. T. Clark. 1959. Associations among conformation scores, among body measurements and the relations between scores and measurements in yearling steers. J. Anim. Sci. 18:880.

Touchberry, R. W. and J. L. Lush. 1950. The accuracy of linear body measurements in dairy cattle. J. Dairy Sci. 33:72.

Touchberry, R. W. 1951. Genetic correlations between five body measurements, weight, type and production in the same individual among Holstein cows. J. Dairy Sci. 34:242.

Tulloh, N. M. 1963. The carcass composition of sheep, cattle and pigs as functions of body weight. C. C. A. M. A.

Warwick, E. J. 1958. Fifty years of progress in breeding beef cattle. J. Anim. Sci. 17:922.

Watkins, J. L., G. W. Sheritt and J. H. Zieger. 1967. Predicting body tissue characteristics using ultrasonic techniques. J. Anim. Sci. 26:470.

Yao, T. S., W. M. Dawson and A. C. Cook. 1953. Relationships between meat production characters and body measurements in beef and milking Shorthorn steers. J. Anim. Sci. 12:775.

APPENDIX

TABLE XXXIII

SIMPLE CORRELATIONS BETWEEN VARIABLES OF INTEREST FOR HEREFORD AND ANGUS BULLS IN POOLED ANALYSIS I AND IA

Variable	FDAYS	ADG	FINWT	ADJ 365	WDA	GRADE	FATTH	CONDSC
				ANGUS (N = 465[a])				
ADJ 205	.13	.06	.49	.70	.62	.27	.22	.22
FDAYS		.08	.77	.05	-.02	.04	.38	.41
ADG			.49	.63	.67	.36	.09	.06
FINWT				.65	.62	.27	.41	.44
ADJ 365					.97	.42	.18	.19
WDA						.38	.17	.21
GRADE							-.10	-.10
FATTH								.55
				HEREFORD (N = 376[b])				
ADJ 205	-.13	.03	.49	.81	.74	.33	.29	.36
FDAYS		.11	.63	-.22	-.27	.18	.18	.36
ADG			.46	.43	.47	.22	.25	.24
FINWT				.60	.57	.35	.47	.54
ADJ 365					.98	.38	.39	.38
WDA						.34	.38	.35
GRADE							.08	.52
FATTH								.55

[a]for CONDSC, N = 495.

[b]for CONDSC, N = 571.

TABLE XXXIV

SIMPLE CORRELATIONS BETWEEN VARIABLES OF INTEREST FOR SOURCE 6 (UTTES) HEREFORD AND FOR SOURCE 10 (UTPES) ANGUS BULLS

Variables	FDAYS	ADG	LADG[a]	CONDSC	BL	FATTH
			Source 6 (UTTES) HEREFORDS			
FINWT	.60	.45	.89	.14	.75	.24
FDAYS		.08	.20	-.08	.45	.02
ADG			.52	.11	.36	.05
LADG				.21	.68	.27
CONDSC					.08	.57
BL						.12
			Source 10 (UTPES) ANGUS			
FINWT	.64	.66	.84	.15	.81	.37
FDAYS		.41	.15	-.03	.46	.28
ADG			.57	-.13	.44	.33
LADG				.24	.73	.29
CONDSC					.15	.58
BL						.24

[a]Lifetime average daily gain.

TABLE XXXV

SIMPLE CORRELATIONS BETWEEN VARIABLES OF INTEREST FOR SOURCES 7A (MONT)[a] AND 8A (FLA)[b] HEREFORD BULLS WITH LINEAR BODY MEASUREMENTS

Variable	ADJ 205	FDAYS	ADG	FINWT	ADJ 365[c]	WDA	CONDSC	WHT	SHW	BL
ADJ 205		.25	.16	.71	.83	.69	.12	.50	.37	.66
FDAYS	-.06		.10	.46	.24	.07	.06	.41	.36	.36
ADG	.27	.19		.71	.64	.74	.49	.40	.57	.31
FINWT	.74	.33	.77		.94	.92	.41	.69	.71	.68
ADJ 365[c]	.81	.09	.77	.96		.95	.37	.64	.61	.68
WDA	.79	.09	.76	.97	.99		.43	.60	.63	.61
CONDSC	.45	.13	.40	.59	.59	.59		-.05	.41	.10
WHT	.53	.23	.48	.67	.64	.65	.22		.41	.48
SHW	.52	.29	.62	.74	.71	.71	.45	.31		.40
BL	.44	.28	.60	.69	.65	.66	.26	.48	.59	

[a]Correlations appear in upper half of the table.

[b]Correlations appear in lower half of the table.

[c]Adjusted 550-day weight for Source 8A.

VITA

Arthur Laxton Eller, Jr., son of Arthur Laxton Eller, Sr., and Evelyn (Britton) Eller, was born at Chilhowie, Virginia, November 5, 1933. He was reared on a livestock farm and upon graduation from Chilhowie High School in 1951 entered VPI and received the B.S. Degree in Aminal Husbandry in 1955. He was immediately employed as Assistant County Extension Agent in Tazewell County. He served as County Extension Agent in Russell County from March, 1956 until March, 1960. He was then appointed to the teaching staff of the Virginia Polytechnic Institute Animal Science Department as assistant professor. In August 1961, he was appointed Extension Beef Cattle Specialist in charge of the state beef cattle performance testing program, a post he obtained leave from to pursue graduate study at the University of Tennessee. He served in the U. S. Army in 1958 and 1962, a total of 16 months. He received the Master of Science Degree from Virginia Polytechnic Institute in June, 1966 and the Doctor of Philosophy from the University of Tennessee in June, 1972. The area of major for both degrees was animal breeding and genetics.