UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
RESEARCH BULLETIN 89

GROWTH AND DEVELOPMENT

With Special Reference to Domestic Animals

II. A New Method for Measuring Surface Area and Its Utilization to Determine the Relation Between Growth in Surface Area and Growth in Weight and Skeletal Growth in Dairy Cattle.

(Publication authorized June 21, 1926)

COLUMBIA, MISSOURI
SEPTEMBER, 1926

UNIVERSITY OF MISSOURI — COLLEGE OF AGRICULTURE

Agricultural Experiment Station

CONTENTS

FOREWORD

Investigations on the subject, "Growth and Development with Special Reference to Domestic Animals," have been in progress for some time at the Missouri Agricultural Experiment Station. Reports on special phases of this general subject will be published as they are completed. The present paper, though numbered second in the series, is the first to be published.

ACKNOWLEDGMENT

A portion of the expenses involved in this investigation was paid from a grant from the Committee on Food and Nutrition of the National Research Council. Grateful acknowledgment is made for this cooperation, which was received through the recommendation of Dr. Graham Lusk, chairman, and Dr. E. B. Forbes, chairman of the Subcommittee on Animal Nutrition.

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II. A New Method for Measuring Surface Area and Its Utilization to Determine the Relation Between Growth in Surface Area and Growth in Weight and Skeletal Growth in Dairy Cattle.*

SAMUEL BRODY AND ERWIN C. ELTING

ABSTRACT.—A device for measuring the surface area of living animals is described. The area of 96 dairy animals was measured with it. Formulae and graphs are presented which give the quantitative relations between area and weight, area and linear dimensions, and area and age of Holstein and Jersey cattle.

INTRODUCTION

The literature relating to surface area and its biological significance has been recently reviewed in great detail by competent observers. These reviews make it unnecessary to discuss here the history and significance of the surface area problem.

By way of introduction it is necessary only to note that there is a theory to the effect that the energy metabolism of animals is directly proportional to their surface area (Rubner's Law). This theory has been widely disputed, and it has never been definitely proven for the reason that while there are accurate and practicable methods for measuring energy metabolism, there is no accurate method for measuring surface area of living animals which is practicable enough to be used on a large scale.

The authors believe that the Missouri Agricultural Experiment Station has developed the needed practicable and accurate method of measuring the surface area of living animals.

*The principal portions of this paper are being published by Mr. Elting in the Journal of Agricultural Research in a paper entitled "A Formula for Estimating Surface Area in Dairy Cattle." The authors are indebted to Professors A. C. Ragsdale and C. W. Turner and to Chester D. Sparrow for assistance in designing and perfecting the surface integrator.

A METHOD OF MEASURING SURFACE AREA OF LIVING ANIMALS

The method consists in passing a revolving metal cylinder of known area, which is attached to a revolution counter, over the entire surface of the animal, and then multiplying the number of revolutions made by the roller by the area of the roller. The resulting product is the surface area of the animal.

The technique involved in measuring surface area is quite simple. In most cases only one-half of the body surface was actually measured, the measurement being made on the right side of the animal and the results multiplied by two. First, the median lines, both dorsal and ventral, were marked with colored crayon. Then, starting at the poll and moving toward the posterior end of the animal along the dorsal median line, the roller was passed over the surface of the body. The roller was equipped with a crayon marker which plainly marked the path of the inside edge of the roller. Then, by keeping the outer edge of the roller along the mark made by the previous trip, it was possible to cover the entire surface without missing or duplicating any portion.

In the work with dairy cattle it was found most convenient to use a milled brass cylinder, five centimeters long and five centimeters in diameter; yet the material used and the size of the roller should be adapted to the need of the animal under investigation.

Similarly, with the marking devices, colored chalk was found most convenient for marking in measuring cattle, but for other animals, or for man, some other marking material, possibly ink, might be more suitable.

The illustrations on pages 7 and 9 (Figs. 1 to 3) will bear out the statement that the method is simple. It is the belief of the authors that this method meets the needs for a surface integrator which has been felt since the appearance of Bergmann's famous paper on "Warmokonomie der Thiere", in 1848.

With this method measurements have been made of the surface area of 96 purebred dairy cattle between birth and ten years of age. Purebred dairy cattle, it should be noted in passing, are very suitable animals for a statistical determination of the relation between surface area and weight, not only because of the homogeneous nature of the population, but also because good dairy animals, unlike most other domestic animals and man, have little tendency to fatten, and thus one of the complicating factors in the formulation of a relation between weight and area is avoided.

THE PRECISION OF THE DATA

One of the simplest methods of estimating the degree of precision of a series of measurements is to "rectify" the data, that is, plot the data in such a way that a straight-line function results. The eye is extremely sensitive to deviations from a straight line, and the degree of closeness of the grouping of the data around the straight line is a simple index of the degree of the reliability of the data, and the precision of the work.

We have found that plotting surface against weight on logarithmic coordinate paper results in a straight-line function. Such a plot is presented in Fig. 4. The data points are seen to group themselves rather closely around the straight line. This close grouping of the data on a straight line indicates that the degree of precision of the data is satisfactory, especially considering the fact that the animals represented different degrees of freshness and were in different stages of lactation and gestation.

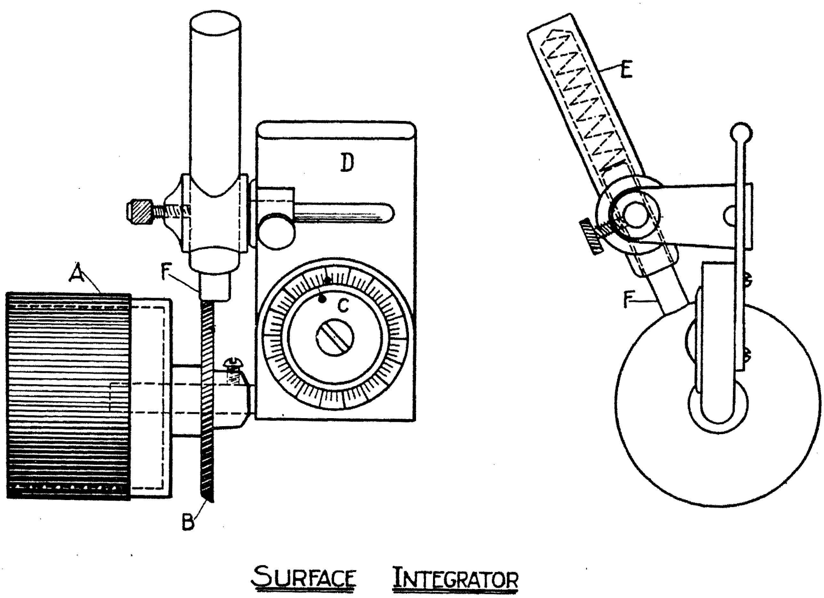

Fig. 1.—The surface integrator. The roller A is mounted on the shaft of an ordinary revolution counter C. A is grooved so as to increase the traction of the roller, and B is beveled so it will leave a sharp mark on the coat of the animal. The milled marker B is grooved so it is easily coated with appropriately colored crayon F. The crayon F is held snugly against the marker by means of a spring in the hollow holder E. The cylinder is made of brass, three-fourths of which is hollow so as to make it of the desired weight. The whole cylinder, including the marker B, is 5 centimeters wide, and 5 centimeters in diameter. D is a brass handle mounted on a Starret revolution counter.

The results of measuring the area of living animals with the integrator were also compared with the results obtained by the direct method. The comparison was carried out as follows: The area of the animal was measured with the integrator, then after slaughtering and removing the hide from the animal, an outline of the hide was made on a smooth concrete floor, the outline was divided into squares and triangles and measured with a meter stick. This comparison was carried out on animals 129 and 27.

Animal 129

Area by integrator----------------------4.2635 sq. meters
Area by direct method------------------4.2883 sq. meters
Percentage difference--------------------0.58

Animal 27

Area by integrator-----------------------1.4821 sq. meters
Area by direct method -------------------1.4701 sq. meters
Percentage difference--------------------0.82

The following measurements were made in order to determine the relative areas of the right and left sides of the body.

Animal 126

Area of left side times 2------------------4.7810 sq. meters
Area of right side times 2----------------4.7161 sq. meters
Percentage difference in favor of the left side, 1.35.

Animal 170

Area of the left side times 2--------------4.4345
Area of the right side times 2-------------4.3544 sq. meters
Percentage difference in favor of the left side, 1.80.

It is appropriate to note, in connection with this difference of area between left and right side, that the paunch lies on the left side of the body.

The results represented in this paper were obtained by measuring the right side and multiplying the results by 2.

It is clear that in order to avoid errors due to bulging to one side the measurements must be made while the animal is standing. Measuring the animal while lying may result in a positive error as high as 25 per cent.

THE NUMERICAL DATA

Tables 1 and 2 give (in the order recounted) the age (as counted from birth), live weight, area, height at withers, length of body (distance from withers to pin bone,) heart girth, width of chest, depth of chest, length from shoulder to pin bone, and length of tail of Jersey and Holstein cattle.

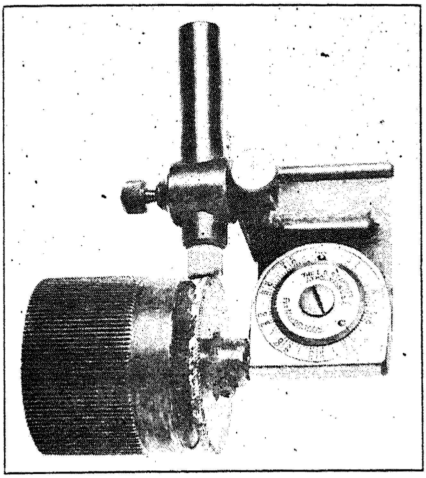

Fig. 2.—A photograph of the surface integrator.

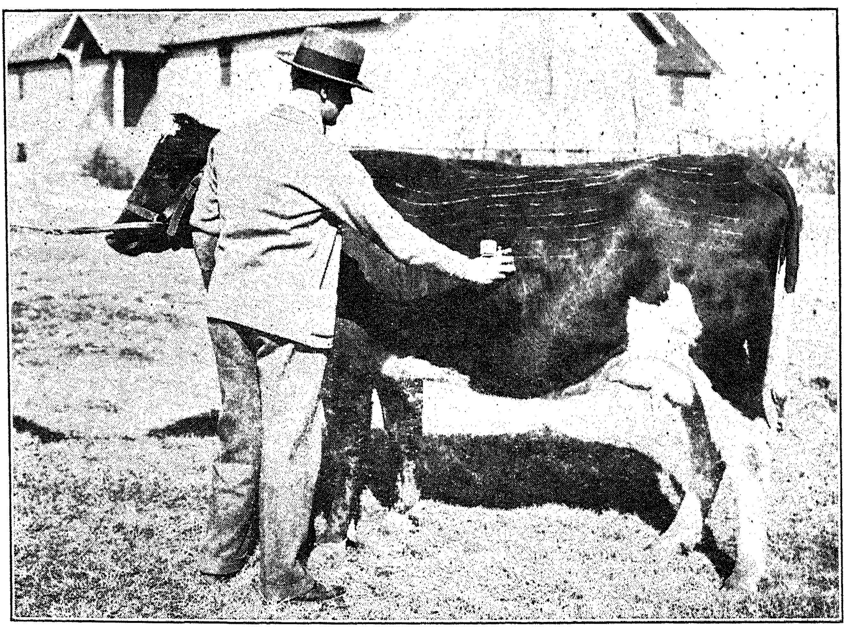

Fig. 3.—The surface integrator in action.

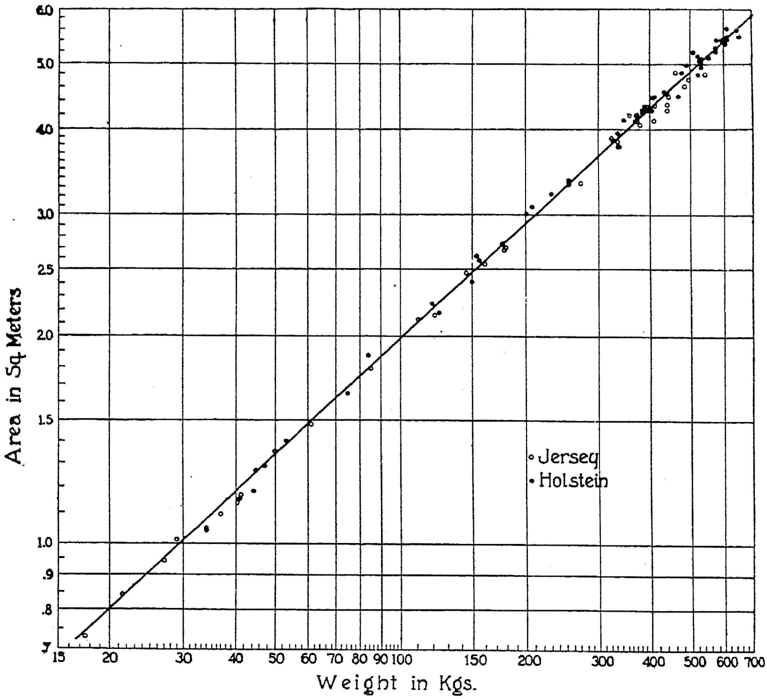

Fig. 4.—The relation between area and weight plotted on a 45 degree angle on logarithmic coordinate paper. The line drawn through the data represents the equation

$$SA = .15\ W^{.56}$$

in which SA is the surface area in square meters, *W* the weight in kilograms.

TABLE 1.—DATA FOR JERSEY CATTLE

Age	Weight	Area	Height at withers	Length of body (withers to pin bone)	Heart girth	Width of chest	Depth of chest	Distance from shoulder to pin bone	Length of tail
Days	Kgs.	sq. cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
.5	17.6	7296	57	46	56	10	22	50	24
2	21.5	8433	66	51	64	11.5	25	59	30
3	27.0	9404	72	54	75	14	28	70	35
16	29.0	10076	69	57	70	14.5	27	69	36
23	34.0	10557	68	60	75	16	28	69	30
35	34.0	10395	70	62	74	14	28	71	30
38	40.5	11368	90	73.5	78	20	36	90	45
40	41.5	11692	92	75	82	20	37	96	45
44	41	11469	75.5	61	82	15.5	31	72	33
50	34	10445	70	61	76	14.5	29	72	35
70	37	10954	72	64	78	15.5	30.5	74	35
80	50	13466	75	67	84	16.5	33	80	42
72	45	12671	76.5	68	82	18	34	81	39
Ms									
3	61	14821	78	69	90	21	35	83	38
4	85	17892	90	81	100	22	40	96	45
5	111	21291	86	84	110	25	42	102	44
6	122	21672	97	93	115	23	44	112	50
6	161	25510	101	95	125	27	47	115	54
6	145	24540	97	92	119	25	45	109	54
7	177	27294	104	103	126	25	50	122	54
8	179	26817	105	103	125	25	49	116	55
9	181	26970	100	98	135	31	51	120	54
Yrs. & Ms.									
1	272	33423	111	118	149	33	58	138	67
1-4	336	37853	117	126	161	36	62	150	68
1-7	324	38964	114	129	160	36	62	148	68
1-7	336	38365	118	122	160	36	61	143	70
1-10	374	41051	123	131	164	38	64	158	77
1-11	395	43094	125	131	170	37	67	150	72
1-11	359	41959	123	127	169	39	64	155	72
2-1	413	43544	127	130	170	38	67	153	75
2-7	374	40750	126	126	174	42	66	148	70
2-7	372	41822	123	132	169	37	65	150	74
2-8	381	40609	122	129	174	38	68	150	68
2-11	338	37773	116	126	170	39	65	150	67
4-1	374	41424	122	132	167	37	67	157	74
4-1	395	42595	123	134	170	35	69	160	77
4-1	463	48263	131	141	180	40	73	162	83
5-3	545	47900	132	140	196	44	75	156	80
7-0	442	42635	124	139	183	41	71	161	80
7-4	495	47161	125	142	183	42	72	157	85
7-7	444	44858	126	141	180	40	73	153	83
7-10	386	42135	125	134	176	39	69	151	80
8-0	442	43430	123	137	179	44	69	154	79
8-1	487	46189	126	142	183	43	71	154	80
8-9	442	45106	123	135	176	40	70	155	77
9-0	410	41112	118	130	178	43	68	150	80

TABLE 2.—DATA FOR HOLSTEIN CATTLE

Age	Weight	Area	Height at withers	Length of body (withers to pin bone)	Heart girth	Width of chest	Depth of chest	Distance from shoulder to pin bone	Length of tail
Days	Kg.	sq. cm.	cm.	cm.	cm.	cm.	cm.	cm.	cm.
1	47.5	12847	77	68	86	15	29	75	41
3	53.5	13982	78	63	87	17	34	77	36
7	41	11600	75	67	83	14	29	72	36
9	44.5	12573	75	67	83	14	28	72	36
49	75	16466	86	76	96	21	36	88	40
Ms.									
3	84	18660	88	81	97	21	36	94	50
3.5	120	22376	96	90	111	24	42	103	46
4	125	21817	91	92	110	24	43	107	46
4.5	150	24061	101	93	120	25	46	118	55
5	154	26159	98	93	119	25	45	116	54
6	156	25820	103	94	122	27	47	119	55
7	202	30081	106	102	130	30	51	120	57
7.5	209	31041	110	110	137	29	52	126	60
8	231	32260	114	111	143	32	56	132	67
10	254	33335	115	111	146	34	55	137	62
Yrs. & Mos.									
1-0	263	33870	117	115	150	34	57	137	66
1-2	336	39591	121	118	165	36	62	148	77
1-4	327	38680	121	122	158	37	61	142	75
1-4	408	44499	124	124	170	41	65	156	72
1-5	389	43194	128	126	174	41	68	154	74
1-6	469	45242	132	129	179	43	69	155	74
1-6	413	45091	125	134	175	40	67	152	76
1-6	406	42604	129	133	172	41	68	154	75
1-7	368	41076	123	130	169	39	63	155	72
1-8	347	41200	121	122	160	39	61	140	79
1-8	386	42495	127	126	179	38	66	158	80
1-10	436	45384	132	132	179	38	66	159	86
2-2	533	50841	129	139	184	44	68	159	80
2-5	553	51165	132	142	187	46	70	159	85
2-11	644	55925	136	139	202	49	73	167	85
3-1	531	50138	132	146	191	46	72	161	90
3-9	601	54044	138	144	198	49	77	166	73
4-0	616	55937	139	145	208	49	76	167	87
4-2	508	51914	135	145	179	41	81	171	83
4-3	576	52737	135	148	188	45	73	166	87
4-3	490	49805	135	146	185	44	74	161	86
4-5	478	48319	136	151	185	39	75	163	84
4-6	574	52012	136	148	194	45	75	169	90
5-0	617	54334	137	150	194	48	76	174	92
6-0	579	54240	131	148	192	41	75	170	87
6-0	653	54818	134	155	196	47	76	172	82
6-0	592	54172	136	152	190	46	71	166	80
6-2	522	47883	131	149	182	40	70	167	85
6-7	526	50521	131	148	188	44	72	164	79
6-8	556	51008	131	151	188	43	72	168	80
7-4	576	52805	136	156	195	44	77	172	80
7-5	608	53710	138	153	197	48	76	171	81
7-5	520	51278	137	153	194	43	78	166	87
8-5	535	49399	131	152	186	42	74	170	80
10-0	617	54830	133	149	198	48	75	173	80

ANALYTIC TREATMENT OF THE DATA

It was already pointed out that when area is plotted against weight on logarithmic coordinate paper a straight-line function results. This fact indicates that the relation between area and weight may be presented by the relation

$$SA = CW^n \qquad \text{(Formula 1)}$$

in which SA is the surface area, W the live weight, n a constant, the numerical value of which is dependent on the shape of the animal and the *change* in the specific gravity of the animal with weight, and C is a constant, the numerical value of which is dependent on the units employed and the specific gravity of the animal.

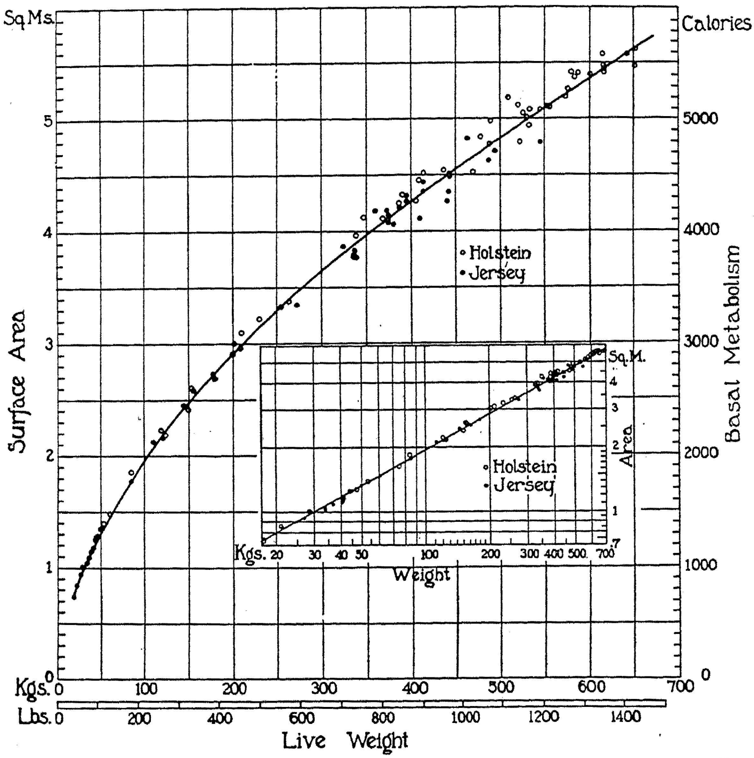

Fig. 5.—The relation between area and weight plotted on coordinate and logarithmic paper. A basal metabolism axis is also given on the assumption that the basal metabolism is one large calorie (or one therm) per square meter.

The numerical value of n is ⅔, or 0.66, when the body is spherical. Meeh and others assumed this value of n also to be true for animals, but, of course, this may not be true since animals are not spherical. In the present study the value of n was found to be .56, which is 85 per cent of the value assumed by Meeh and others. In its final form the equation expressing the relation between weight and area-surface was found to be

$$SA = 0.15\, W^{.56}$$

in which SA is the surface area in square meters, and W the weight in kilograms. The smooth curves passing through the observed values (circles) in Figs. 4 and 5, are based on this equation. The agreement between observed and computed values seems to be satisfactory, and there seems no need of following the example of Du Bois or of Hogan and Skouby, of including a linear measurement in the formula.

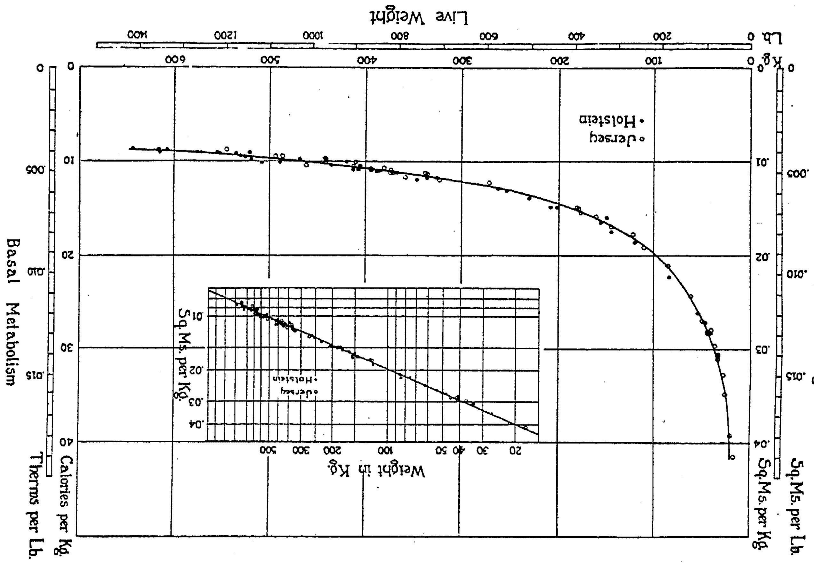

Fig. 6.—The decline in area per unit weight with increasing body weight. The weight as expressed in kilograms and pounds, the area as expressed in terms of square meters per kilogram and square meters per pound, and basal metabolism as expressed in terms of calories per kilogram and therms per pound may be a bit confusing but the arrangement seems convenient.

The smooth curve was drawn according to the equation

$$\frac{SA}{W} = .148\,W^{\cdot 438}$$

in which SA represents area in square meters and W represents weight in kilograms.

Formulae were also fitted, and graphs prepared showing the relation between area and height at withers (Fig. 7), area and circumference of chest (Fig. 8), area and length of body (Fig. 9), and area and age (Fig. 10). With the exception of the area-age curves (Figs. 10 and 11) all these

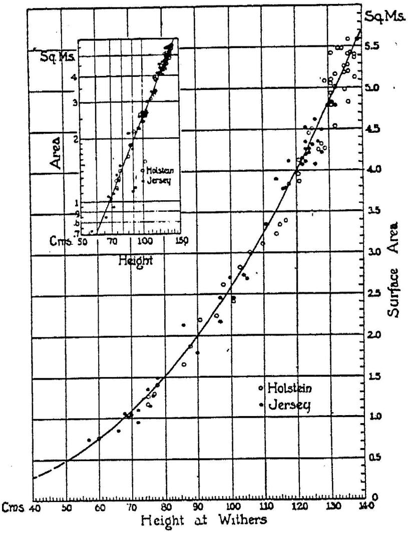

Fig. 7.—The relation between area and height at withers. The relation between the two measurements may be represented by the equation

$$SA = .404H^{2.40}$$

in which SA represents surface area in square centimeters and H height at withers in linear centimeters.

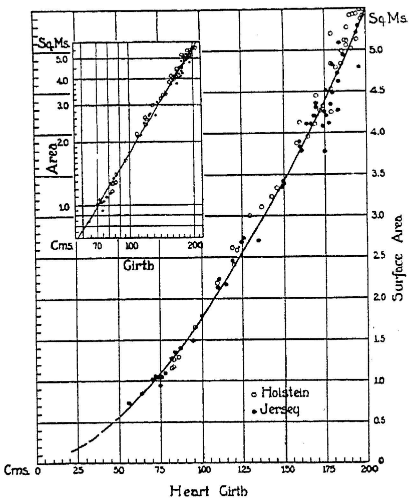

Fig. 8.—The relation between surface area and heart girth. The relation between the two may be expressed by the equation

$$SA = 9.2\ H^{1.64}$$

in which SA represents surface area in square centimeters and H heart girth in linear centimeters.

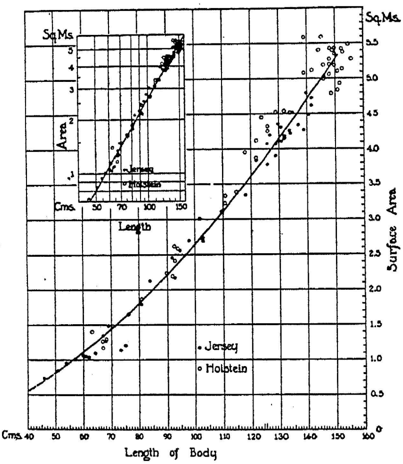

Fig. 9.—The relation between area and body length (length from withers to pin bone). This relation for these measurements in the Holstein cow, may be represented by the equation

$$SA = 10.38\ L^{1.70}$$

for the Jersey cow,

$$SA = 8.76\ L^{1.74}$$

in which SA is surface area in square centimeters and l the body length in linear centimeters.

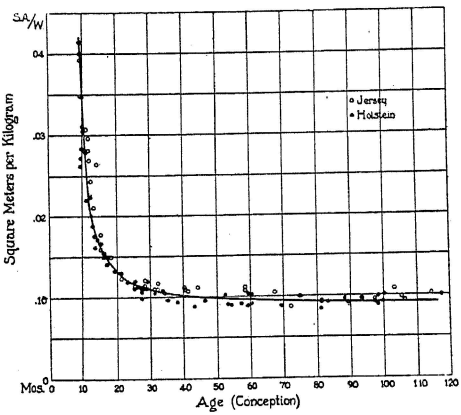

Fig. 10.—The relation between area per unit weight and age (as counted from conception). The relation between area and age may be represented by the equation

$$\frac{SA}{W} = .091\ (t-7)^{-1.18} + .0088$$

in which SA represents area in square centimeters W, weight in kilograms, t, age in months as counted from conception. This equation is empirical and cannot be used for extrapolation purposes.

relations may be represented by Formula 1, using the linear measurements in place of weight, W.

The relation between surface area and height at withers (Fig. 7), is expressed by the equation

$$SA = .404 H^{2.40}$$

The relation between surface area and heart girth (Fig. 8) is expressed by the equation

$$SA = 9.2\ Ht^{1.64}$$

in which SA is the surface area in square centimeters, and $Ht.$, the heart girth in linear centimeters.

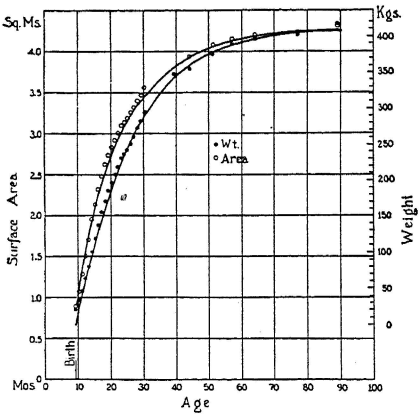

Fig. 11.—An equivalence chart between growth in weight and growth in area constructed on the assumption that weight and area at birth are in the same stage of growth, and 98 per cent of the mature weight and the area of the animal when it reached 98 per cent of the mature weight are in the same stage of growth.

While we have a *rational* equation relating weight with age, our efforts of relating area with age by a *rational* equation have resulted in failure.

The relation between surface area and body length (withers to pin bones, Fig. 9) differs somewhat in Holstein and Jersey animals. This relation in the Jersey breed may be expressed by the equation

$$SA = 10.38 L^{1.76}$$

and in the Holstein breed by the equation

$$SA = 8.76 L^{1.74}$$

in which SA is the surface area in square centimeters and L the body length in linear centimeters. The difference between the two is practically negligible.

The formula relating area to age (Fig. 10) is more complicated, and unlike Formula 1, which is rational in the sense that it may be used for extrapolation purposes, the equation relating area to age cannot be used with safety for extrapolation purposes.

In addition to the charts used on the data obtained with the integrator there has also been prepared a chart including all the data recorded in the literature (Fig. 12).

THE RELATION BETWEEN BASAL METABOLISM AND WEIGHT

Table 3 and Fig. 5, indicating the relation between metabolism and body weight, were prepared on the basis of the relation found between weight and area and on the assumption that metabolism is directly proportional to surface area—which may or may not be true.

TABLE 3.—THERMS PER ANIMAL PER DAY REQUIRED FOR MAINTAINING CATTLE ACCORDING TO ARMSBY, AND AS COMPUTED ON THE BASIS OF THE BODY SURFACE "LAW."

		Computed on the basis of the body surface "law"		
Live Weight Pounds	Armsby's Standard	1 therm per sq. meter (Basal) Therms	1.2 therms per sq. meter (12 hours standing) Therms	1.4 therms per sq. meter (24 hours standing) Therms
50		.84	1.01	1.17
100		1.24	1.49	1.73
150	1.69	1.48	1.78	2.07
200		1.86	2.23	2.60
250	2.38	2.11	2.53	2.95
300		2.35	2.82	3.29
350		2.46	2.95	3.44
400		2.76	3.31	3.86
450		2.94	3.51	4.12
500	3.78	3.12	3.74	4.36
550		3.30	3.95	4.62
600		3.47	4.16	4.85
650		3.62	4.34	5.06
700		3.77	4.51	5.27
750	4.95	3.91	4.70	5.47
800		4.05	4.85	5.66
850		4.19	5.02	5.86
900		4.33	5.19	6.05
950		4.46	5.34	6.24
1000	6.00	4.58	5.49	6.41
1050		4.70	5.62	6.57
1100		4.83	5.79	6.75
1150		4.95	5.93	6.92
1200		5.08	6.09	7.11
1250	6.96	5.20	6.22	7.29
1300		5.32	6.38	7.44
1350		5.44	6.52	7.60
1400		5.56	6.66	7.78
1450		5.68	6.81	6.95
1500	7.86			

REFERENCES TO LITERATURE†

The latest discussion on the surface area problem, including a historical review of the literature, is given by Eugene F. Du Bois in his monograph "*Basal Metabolism in Health and Disease*," Philadelphia and New York 1924 (Lea and Febiger). Graham Lusk discusses this problem in his monograph "*The Science of Nutrition*."

Benedict and his collaborators discussed this problem, especially in its bearing on energy metabolism, in numerous papers. (Note particularly Publication 302 by Benedict and Talbot, and Publication 279 by Harris and Benedict, of the Carnegie Institution of Washington).

C. R. Moulton (Jr. Biol. Chem. 1916, XXIV, 299) and A. G. Hogan together with C. I. Skouby (Jr. Agric. Research, 1923, XXV, 419), discuss the surface area problem and present data on surface area for swine and steers. The data points for swine and steers in Fig. 12 are based on data cited by Hogan and Skouby.

Rubner discusses the surface area problem in several papers and in his monograph "*Die Gesetze des Energieverbrauchs bei der Ernahrung*," Leipzig und Wien 1902. The data points for the mouse, rat, chicken and dog in Fig. 12 were taken from Rubner's papers.

The data on man were taken from the paper by Meeh (Zt. Biol. 1879, XV, 425) and others, as cited by Harris and Benedict *loc. cit.*, and Du Bois (Arch. Int. Med. 1915, XV, 868) and Sawyer, Stone and Du Bois (Arch. Int. Med. 1916, VII, 855).

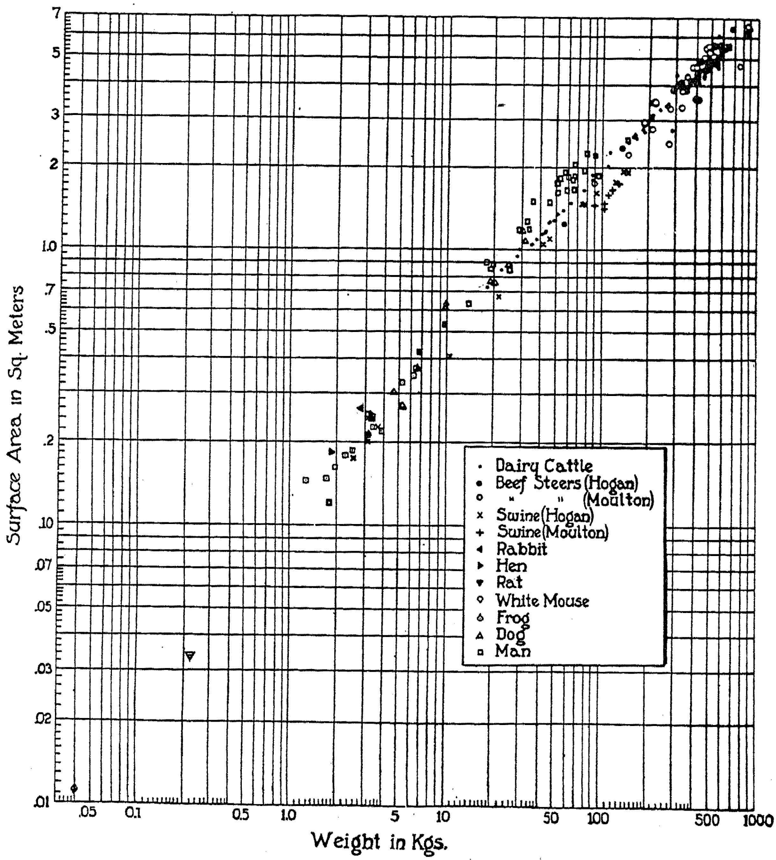

Fig. 12.—The relation between area and weight including all the available data which were, to our knowledge, recorded in the literature, including the data on man.